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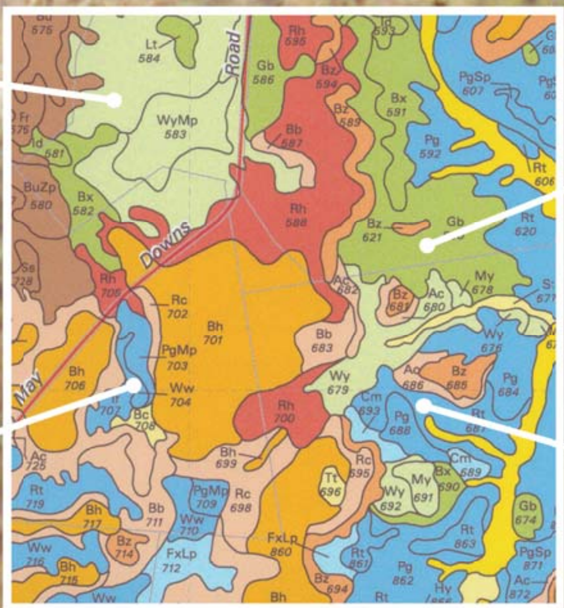
Land Resource Assessment of the Windeyers Hill Area, Isaac - Connors and Mackenzie River Catchments, Central Queensland

J W Burgess



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Land Resource Assessment of the Windeyers Hill Area, Isaac–Connors and Mackenzie River Catchments, Central Queensland

Volume 1

J W Burgess

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SUMMARY

The Windeyers Hill study area covers almost 300 000 ha and lies 250 km south-west of Mackay, near the town of Middlemount. It is centrally located within the Isaac–Connors and Mackenzie River catchments and covers approximately 10% of the total catchment area. The study area is bounded by the standard 1:100 000 Windeyers Hill map sheet (8652) and is located on the gentle watershed that separates the two catchments. It is typical of the major landscapes within the Nebo–Broadsound grazing district, and in particular the range of land types developed during Brigalow Scheme III.

It was selected for detailed land resource assessment because it is representative of:

- landscape diversity within the two catchments;
- soil landscapes of agricultural importance;
- brigalow landscapes developed during Brigalow Scheme III; and
- eucalypt landscapes that have remained largely undeveloped until recently.

The major physiographic unit within the two catchments is a broad, gently undulating valley that is bounded by the coastal ranges in the east and the Cherwell, Harrow and Denham Ranges in the west. In the north, a gentle watershed divides the area from the Burdekin River catchment while in the south the Mackenzie River catchment defines its extent. The study area lies in the centre of this unit.

Drainage within the Isaac–Connors catchment is from north to south, principally through the Isaac, Connors and Funnel Creek systems. The Mackenzie River receives flows from the Nogoa and Comet Rivers to the south as well as local drainage from its immediate catchment. Both catchments lie within the northern section of the Bowen Basin, where distinctive structural geology and lithology have influenced landscape development across much of the region for nearly 300 million years.

The climate of the Isaac–Connors and Mackenzie River catchments is classified as subtropical with moderately dry winters. The area experiences a marked seasonal rainfall distribution with >75% of annual rainfall falling in the summer months between October and March. Both seasonal and annual rainfall are highly variable because of convective activity, and the sporadic incidence of rainfall depressions associated with tropical lows and cyclones. This rainfall variability is a major limitation to agricultural development.

Land use within the two catchments is predominantly grazing although significant areas of dryland cropping (sorghum and wheat) occur in landscapes derived from basalt, calcareous shales or alluvium. In developed scrub country, grazing predominantly targets the production of finished, grassfed bullocks for the export market (i.e. 600 kg animals <3 years of age), while eucalypt country is used for breeding and the production of store cattle.

During the last 30 years, rapid and significant landscape change has occurred in over 70% of both catchments following the implementation of Brigalow Scheme III. Effective monitoring and management of such large scale change in the future, will require the interpretation and modelling of catchment response. A necessary prerequisite to this process is the availability of reliable baseline data at an appropriate scale.

The current study has addressed this issue by:

- providing detailed soil and landscape information that is representative of the catchments;
- linking the new data with existing broad scale CSIRO land system mapping;
- highlighting potential land use hazards and outlining appropriate land management guidelines;
- formatting analytical and spatial data ready for future reinterpretation and modelling; and
- actively promoting the findings of the study to landholders, government and the wider community.

During initial field investigations along a number of representative transects, typical soil landscape relationships within each major geological unit were described. Eight geological landscapes and a further 24 soil landscapes were identified within the study area based on surficial lithology, degree of parent material alteration and landscape position. A total of 56 soil profile classes, 10 soil phases and three soil variants were mapped within these landscapes. Samples from 119 representative profiles and 549 surface fertility samples were analysed in the laboratory.

Detailed morphological and analytical data for each soil are presented in Appendices 2–6 in Volume 2 of this report. The relationships between climate, soils, geology, landscape position and vegetation are discussed in Chapters 4–7, while the most important characteristics of each soil are summarised in Chapter 8. The spatial distribution of soil and vegetation associations is shown on the accompanying maps.

A total of 1515 unique map areas were delineated on the basis of geology, soil type, landscape position and vegetation. The mapping is reliable at a scale of 1:50 000, but is published at 1:100 000 for convenience. Each UMA has been described individually in terms of area, land resource data and soil attributes. The information recorded includes location, geology, landscape position, soil and vegetation associations as well as 15 spatial attributes that describe potential land use limitations and land degradation hazards.

The study provides a comprehensive baseline dataset of representative soil and landscape information that is suitable for future reinterpretation and modelling across the two catchments. In particular, the soil fertility status, effective rooting depth, plant available water capacity, inherent salinity levels and potential salt loads of the major soil landscapes are documented in detail. The data from this study forms an important prerequisite to any future assessments of cropping suitability, grazing productivity, fertility decline and landscape salinity hazard within the Isaac–Connors and Mackenzie River catchments.

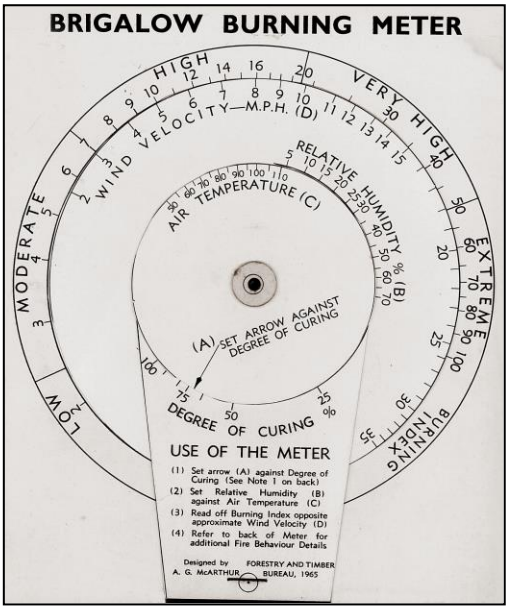
1. INTRODUCTION

This report documents the land resources of the Windeyers Hill 1:100 000 map sheet, covering an area of approximately 300 000 ha near Middlemount, south-west of Mackay. The study area was selected to represent the major landscapes and soils within the Isaac–Connors and Mackenzie River catchments within the Fitzroy Basin in Central Queensland. Together both catchments cover almost 35 500 km^2 and include all the country lying between the coastal ranges and the Central Highlands from Glenden south to Dingo.

Clearing and agricultural development has expanded rapidly in Central Queensland during the last 30–40 years. Shields and Williams (1991) reported that the area being developed to dryland cropping more than doubled between the late 1960s and early 1980s, particularly on the basalt landscapes of the Central Highlands. Equally significant in terms of landscape change has been the broadscale clearing and pasture development that has occurred within the Isaac–Connors and Mackenzie River catchments following the introduction of the Fitzroy Basin Land Development Scheme.

This scheme was better known as the Brigalow Scheme and was initiated by the State and Commonwealth Governments in 1962 to assist in the agricultural development of the central and northern brigalow lands, comprising almost 4.4 million hectares (Turner 1975). The scheme was implemented in three sections known as:

- Brigalow Area I – west of the Dawson River to the Expedition Range;
- Brigalow Area II – from the Expedition Range west to the Comet River; and
- Brigalow Area III – from the Capricorn Highway north to Nebo and Moranbah.



Photograph 1. Brigalow burning meter – a relict from the development heydays of Brigalow Scheme III

Brigalow Area III, which comprised 2.4 million hectares, lies almost entirely within the Isaac–Connors and Mackenzie River catchments. It was the last of the three Brigalow Areas to be developed and nearly all clearing and development has occurred within the last 30 years. The magnitude of the landscape change that followed its introduction is significant, with almost 75% of the inland area between the Capricorn Highway and Nebo, which is represented by the Isaac–Comet Downs Sub-region of Sattler and Williams (1999), cleared and developed up to 1999 (JC McCosker *pers. comm.*). Of most concern are the brigalow communities which have been cleared to endangered levels (≤10% of original extent) since the scheme was implemented. The brigalow–yellowwood (Regional

Ecosystem 11.4.9) and brigalow–blackbutt (Regional Ecosystem 11.4.8) communities demonstrate this point clearly. The original distribution of both communities occurred predominantly in the northern Brigalow Bioregion, and particularly the Isaac–Connors and Mackenzie River catchments. Of the original extent both communities occupied (RE 11.4.9 = 780 294 ha, RE 11.4.8 = 726 134 ha) only 10% and 11% respectively remained by 1999 (JC McCosker *pers. comm.*). In addition, most of the surviving remnants are isolated and lie scattered around the margins of the original core distribution.

Photograph 2. Brigalow–yellowwood scrub (RE 11.4.9) cleared and developed for cropping, east of Dysart

Photograph 3. Brigalow–Dawson gum scrub (RE 11.4.8) cleared and developed to buffel pasture, east of Middlemount

Such large scale changes in land use from lightly grazed, predominantly forested catchments to widespread clearing and subsequent pasture and cropping development have created a need for appropriate soil and land management information for landscape modelling. The availability of a detailed baseline data is crucial to assist in understanding and managing the effects associated with such rapid and complete landscape change.

Turner (1975) identified early in the development phase of Brigalow Scheme III that the broadscale land resource surveys undertaken by CSIRO, while particularly useful for assessing development prospects across large areas, were limited in terms of on-ground detail and impractical for individual property planning. Problems with mapping scale and the lack of detailed landscape and soil data meant development in many areas was a case of trial and error, particularly in the early years. Similarly, any attempt by Government agencies to monitor or model landscape change within the two catchments since development commenced has been limited by the absence of appropriate data.

Shields and Turner (1985) reviewed the availability of detailed land resource data throughout Central Queensland at that time and concluded there was an urgent requirement for soil mapping at a scale of at least 1:100 000 to resolve land use issues and provide a sound basis for land management decisions, development planning and soil conservation purposes.

Because of the sheer size of the region (166 340 km^2), detailed mapping across the entire area was unrealistic. An alternative approach was adopted in which a series of priority areas were chosen to study in detail the landscape characteristics, soils and potential land use within recognised catchments or districts across Central Queensland. The outcomes of these studies were to provide detailed baseline data which could be extrapolated to surrounding catchments where similar landscapes occurred (Shields and Turner 1985).

Three districts were recognised which included the Nebo–Broadsound, the Central Highlands and the Dawson–Callide. Survey areas in each were carefully selected to ensure landscape diversity was adequately represented while also targeting the landscapes of major agricultural importance. The use of 1:100 000 map sheets standardised the shape, size and location of potential study areas, while the mix of land systems previously mapped by CSIRO were used to select and confirm the applicability of each area (Shields and Turner 1985).

The Windeyers Hill 1:100 000 map sheet (8652) was chosen as a priority survey area within the Nebo–Broadsound district because of the significant landscape diversity that occurs within the sheet area. This diversity is typical of and consistent with the range of diversity that occurs across much of the surrounding Isaac–Connors and Mackenzie River catchments. In addition, it provided an even representation of:

- the major cropping soils within the catchments;
- the range of brigalow landscapes intensively developed as part of Brigalow Scheme III; and
- a selection of eucalypt landscapes that have remained largely undeveloped across the catchments until recently.

Shields and Turner (1985) also identified that the map sheet included large areas of marginally suitable cropping lands where development for cropping in the early 1980s was occurring at a very rapid pace.

The broad objectives of the study were to increase the knowledge and understanding of the soils and landscapes within the Isaac–Connors and Mackenzie River catchments amongst landholders, community groups, industry and government, and to facilitate the development of sustainable land use systems. Soil information at the 1:100 000 scale is particularly useful for such purposes as it provides a resource inventory appropriate for evaluating both agricultural potential and the resolution of a wide range of land management and planning issues, such as land degradation, tree clearing, salinity hazard and the preservation of good quality agricultural land.

Specifically, the study has aimed to:

- provide detailed soil and landscape information within the study area;
- provide links between the detailed data and the broadscale CSIRO land system information covering the remainder of the catchments;
- highlight potential land use hazards and provide land management guidelines for the major soils and landscapes;
- provide analytical and spatial data suitable for reinterpretation for a range of land use and modelling scenarios; and
- actively promote the findings of the study to landholders, community groups, industry and government.

2. THE WINDEYERS HILL STUDY AREA

2.1 Location

The Isaac–Connors and Mackenzie River catchments are the major northern sub-catchments of the Fitzroy Basin in Central Queensland and cover an area of about 35 440 km^2 (Isaac–Connors 22 280 km^2, Mackenzie 13 160 km^2). They equate closely with the inland sections of the Nebo and Broadsound Shires (otherwise known as the Nebo–Broadsound district) and include much of the area developed as part of Brigalow Scheme III.

The major physiographic unit within the catchments is a broad, gently undulating valley that is bounded by the coastal ranges in the east and the Cherwell, Harrow and Denham Ranges in the west. In the north, a gentle watershed divides it from the Burdekin catchment while in the south the Mackenzie River catchment defines the extent. Geographically, the catchments lie wedged to the west of the coastal strip between Rockhampton and Mackay and to the east of the Central Highlands between Emerald and Mt Coolon. The extent of the catchments and location of the study area (Windeyers Hill 1:100 000 map sheet) are shown in Figure 1.

Drainage within the Isaac–Connors catchment is from north to south, principally through the Isaac, Connors and Funnel Creek systems. These streams direct drainage southwards from the high yielding coastal ranges in the east and the drier hinterland areas in the north and west, before joining and discharging into the Mackenzie River. The Mackenzie River receives flows from the Nogoa and Comet Rivers to the south as well as local drainage from the immediate catchment between Middlemount and Dingo.

Photograph 4. The lower Isaac–Connors system in flood, September 1998

Both catchments lie within the northern section of the Bowen Basin, where distinctive structural geology and lithology have influenced landscape development across much of the region since Early Permian times, nearly 300 million years ago.

The Windeyers Hill study area is based on the standard 1:100 000 map sheet of the same name. It is located on the watershed between the Isaac–Connors and Mackenzie River catchments and lies roughly in the middle of Brigalow Area III and the Nebo–Broadsound district. The town of Middlemount (approximately 250 km south-west of Mackay) lies in the centre of the study area (Figure 1). The northern and southern boundaries coincide with latitudes 22º 30’ S and 23º S respectively, while the western and eastern boundaries coincide with longitudes 148º 30’ E and 149º E respectively. The map sheet covers an area of approximately 285 000 ha.

Figure 1. Location of the Windeyers Hill study area

2.2 Land use

Land use within the Isaac–Connors and Mackenzie River catchments is predominantly grazing, although significant cropping and mining development has occurred in some areas. Figure 2 illustrates the distribution and extent of the major land uses within the Windeyers Hill study area, and provides an example of the land use patterns to be expected across the wider catchments.

In most areas, clearing and land development have occurred only recently (<30 years ago) compared with other parts of Queensland, and primarily involved clearing brigalow scrubs for the establishment of buffel grass pastures. The dominant land use in developed scrub country is the production of finished grass fed cattle for the export market (i.e. 600 kg animals <3 years of age). Significant areas of eucalypt country also occur which are generally less productive and are used for breeding and growing store cattle to supply the finishing market or live cattle trade.

Dryland cropping development for wheat and sorghum occurred on a wide range of soils during the development years in the late 1970s and through the 1980s. The drought years of the 1990s however demonstrated clearly that only deep (>0.75 m), self-mulching clay soils derived from basalt, calcareous shales or flood plain deposits were viable in the long term. Currently, dryland cropping is restricted to areas at Nebo, Moranbah, Dysart, Barmount and along the Isaac and Mackenzie River flood plains.

Photograph 5. Grassfed export bullocks (>600 kg, <3 years of age) finished on buffel pasture, Middlemount area

Photograph 6. Dryland sorghum crop on the Picardy (Pc) soil, east of Dysart

While a wide range of summer and winter crops can potentially be grown in Central Queensland subject to some agronomic restrictions, summer cropping (particularly sorghum) is the fundamental cropping system. Summer cropping is favoured over winter cropping because >70% of annual rainfall occurs during late spring and in the summer months. Rainfall variability during the summer months however, means cropping systems are mostly opportunistic. Continuous sorghum, continuous wheat and opportunity cropping of sorghum or wheat are the benchmark production systems in Central Queensland (Cox and Chudleigh 2000).

Because the development of dryland cropping in the Isaac–Connors and Mackenzie River catchments is only relatively recent, growers have only just begun to seriously consider the soil fertility status and water holding capacity of the soil in day to day management. Soil nitrogen decline is now recognised in the longer term cropping areas within Central Queensland and is an on-going issue across the region. The rate of nitrogen rundown and the timing of restorative strategies are still largely unquantified (Cox and Chudleigh 2000).

Current issues facing the dryland cropping industry in the region largely involve the adoption and integration of evolving progressive technologies into existing production systems. These include:

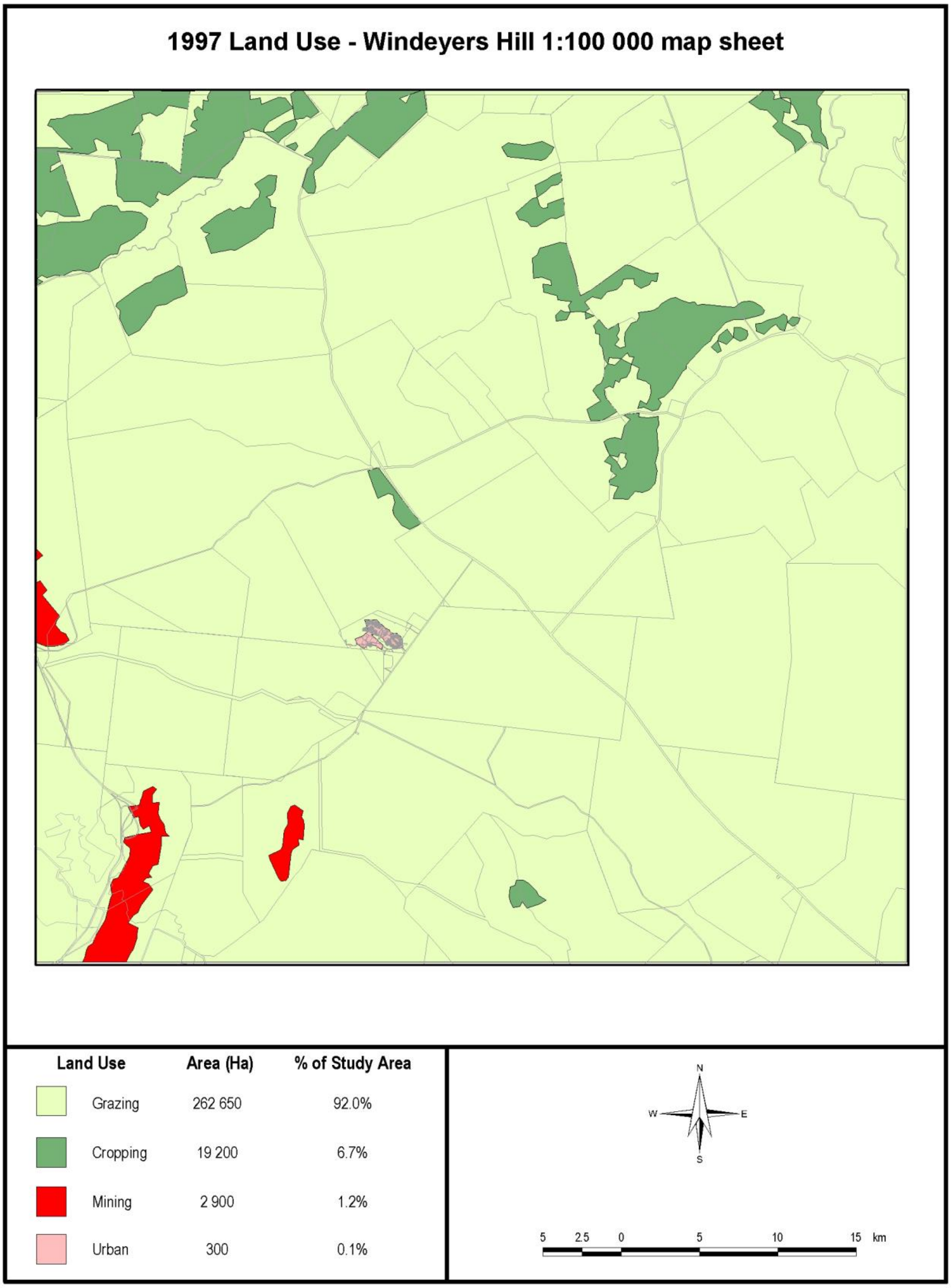


Figure 2. The distribution and extent of the major land uses within the Windeyers Hill study area (Calvert *et al.* 2000)

- controlled-traffic farming;
- the optimum frequency and timing of opportunity cropping;
- zero and minimum tillage systems;
- improved soil water management;
- new ley pasture species;
- nitrogen fertiliser strategies; and
- the incorporation of pulses and ley legumes into farming systems.

2.3 History of land development

Widespread clearing commenced in the early 1970s following the introduction of Brigalow Scheme III. Prior to this, land tenure in the area was predominantly extensive pastoral holdings that were largely undeveloped because of thick brigalow scrubs. These scrubs were widespread within the gently undulating landscapes in the centre of the catchments, which prior to clearing, were difficult to manage and largely unproductive because of low stocking rates.

Broadscale clearing and pasture development proceeded rapidly until the late 1980s by which time most large scale scrub pulling had ceased. A major expansion into dryland cropping occurred during the wetter years of the 1980s. Much of this development utilised soils that were marginal or unsuitable for cropping, and during the drought years of the 1990s much of this country has returned to pasture. During this most recent period, changing land development techniques have seen the rapid and widespread adoption of bladeploughing for regrowth control and pasture rejuvenation in scrub country. At the same time, widespread clearing of low fertility eucalypt country, such as poplar box woodlands, has also occurred.

Development for cropping or pasture establishment has, by necessity, been very rapid on most properties, particularly where lease conditions specified set development schedules. Much of the development has been *ad hoc* and hastily planned compared with other districts and generally without access to appropriate soil and land resource information on which to base sound planning decisions. On most properties, development in the early days was often a case of trial and error.

2.4 Previous investigations

The landscapes and soils of the Isaac–Connors and Mackenzie River catchments have been investigated previously in a number of broad scale surveys reported in:

- Soils and vegetation of the brigalow lands, eastern Australia, CSIRO, Soils and Land Use Series 43, CSIRO (Isbell 1962);
- Lands of the Isaac–Comet area, Queensland, CSIRO, Land Research Series 19 (Story *et al.* 1967);
- Soils, Fitzroy Region, Queensland, Resource Series, Department of National Development (Isbell and Hubble 1967);
- Atlas of Australian Soils, Map plus explanatory data for sheet 4, Brisbane–Charleville–Rockhampton–Clermont area, CSIRO/Melbourne University Press (Isbell *et al.* 1967); and
- Lands of the Dawson–Fitzroy area, Queensland, CSIRO, Land Research Series 21 (Speck *et al.* 1968).

The mapping scales of these studies vary between 1:500 000 and 1:2 000 000, which, while useful for regional and catchment planning, fail to provide sufficient detail to meet the increasing on ground needs of government, industry and the rural community. Most useful of the studies is the broadscale land system mapping of the Isaac–Comet catchments produced by CSIRO at a scale of 1:500 000 (Story *et al.* 1967). The study still provides a useful and reliable spatial coverage across the majority of the Isaac–Connors and Mackenzie River catchments (excluding the coastal ranges) but is limited in terms of the level of detailed soil and analytical information it provides for property planning and catchment modelling.

The land system data was never designed to resolve differences in inherent salinity, sodicity, and fertility status across the catchment and lacks the detail required to resolve practical land management issues such as crop and pasture suitability, moisture availability, erosion potential and landscape salinity hazard at the paddock level. It was used extensively during Brigalow Scheme III to determine the most equitable subdivision of the extensive pastoral holdings being split into 'Brigalow Blocks'. At that stage, the catchment was in pristine condition and almost totally uncleared, and issues now facing the catchments following 25–30 years of development were largely irrelevant.

Other more detailed soil studies that are relevant but mostly lie outside the catchments include:

- Soils of the East Bald Hill Area, Collinsville District, North Queensland, CSIRO, Soils and Land Use Series No. 48 (Isbell 1966);
- Land Suitability Study of the Collinsville–Nebo–Moranbah Region, QB84010, Queensland Department of Primary Industries (Shields 1984);
- Land Resource Survey and Evaluation of the Kilcummin Area, Queensland, QV91001, Queensland Department of Primary Industries (Shields and Williams 1991); and
- Land Resource Assessment of the Banana Area, Central Queensland, Department of Natural Resources and Mines (Muller in prep.).

3. METHODOLOGY

3.1 Soil mapping

The soils and vegetation associations of the Windeyers Hill study area are mapped and described at a scale of 1:50 000 and published at a scale of 1:100 000.

Initial field work commenced in 1991 and involved a reconnaissance inspection of the entire survey area to provide an overview of the main geological landscapes. This was followed by a *reference making phase* (Gunn *et al.* 1988) during the remainder of 1991 and a *mapping phase* (Gunn *et al.* 1988) from 1992 to 1997.

All field observations were recorded according to McDonald *et al.* (1990), Isbell (1996) and Walker and Hopkins (1990). Observations included landform (pattern and element), slope, morphological type, relief/ modal slope class, substrate lithology, site disturbance, erosion, microrelief, surface rock, surface condition, dominant vegetation including tallest stratum (trees), mid-stratum (shrubs) and lowest stratum (grasses), profile morphology, field pH and field profile salinity ($EC_{1:5}$).

A total of 2009 soil profiles were described from undisturbed soil cores to a depth of 1.5 m, or to the depth of hard rock or gravel where present. These included 1890 field mapping sites as well as a further 119 representative profiles which were sampled in detail for laboratory analysis. A vehicle-mounted hydraulic coring rig using 50 mm push tubes was used to retrieve intact cores for examination and sampling. Where vehicle access was difficult or where soils were exceptionally gravelly, samples were retrieved using a Jarrett soil auger.

During the reference making phase, 35 traverses were undertaken to inspect representative landscape catenas within each major geological unit. Soil and landscape data from 357 field sites was used to develop a preliminary hierachical classification of soil profile classes based on parent material, landscape position and profile morphology.

During the subsequent mapping phase, an additional 1533 profiles were described. Map units were delineated on 1962 and 1981 black and white 1:25 000 aerial photography using vegetation photo patterns and stereoscopic landform interpretation. Free survey techniques were used to select sites and confirm map unit boundaries. Site density (ha/site) varied from approximately 50 ha/site in geologically complex areas to less than 200 ha/site in rugged terrain and uniform landscapes. The average site intensity for the entire map sheet is 140 ha/site. Ground observations used to check map unit boundaries (note: these field sites were not recorded) are not included in these calculations; such observations are numerous and mean the actual ground observation density is well within the limits set for 1:50 000 mapping (25 ha/site to 100 ha/site) (Gunn *et al.* 1988). Following the mapping phase, frequency-based descriptions of the soil profile classes were finalised using all available field and laboratory data. All morphological and analytical data are stored in an ACCESS database (SALI_SITE).

The soils were mapped as compound mapping units (termed soil associations) which generally contain 60% or more of one soil profile class. At 1:100 000 scale, minor occurrences of associated soils cannot be separated and mapped individually. As a result, mapping units may contain one or more sub-dominant soil profile class(es). All linework for the mapping units was finalised on 1:25 000 aerial photographs and then scanned, rectified, captured and digitised onto four 1:50 000 cadastral base maps before reduction to the final 1:100 000 map sheet. An area of approximately 13 000 ha in the south-east of the map sheet was excluded from the survey and has not been mapped.

A final map publication scale of 1:100 000 was selected. Where required, the mapping can be reliably enlarged to a scale of 1:50 000 without losing accuracy, because final ground observation densities are within the limits set for this scale (Gunn *et al.* 1988). The mapping may also be useful for property planning and paddock investigations at scales as large as 1:25 000, but map accuracy cannot be guaranteed.

3.2 Soil mapping units

The soils information presented in this report provides a comprehensive assessment of the soil associations covering the Windeyers Hill map sheet at a scale of 1:100 000. Soil information at this scale provides suitable detail for property planning and can also be linked to pre-existing broad scale information to enhance regional and catchment coverages.

In all, 56 soil profile classes, 10 soil phases and three variants are described. A **soil profile class** is defined as a group of similar soils, having soil profile properties in common (Isbell 1988). The variation of selected features such as colour, structure or texture within a particular soil profile class is usually less than the variation between different soil profile classes.

A **soil phase** is a subdivision of a profile class based on attributes that have particular significance for land use (Isbell 1988). For example, the **Indicus** soil profile class is mapped as **Indicus shallow phase** where soil depth is predominantly <0.6 m, and potentially influences its suitability for a particular land use.

By comparison, a **soil variant** is a soil with one or more profile attributes outside the usual range for a defined soil profile class, but because of its restricted distribution (or because the varying properties are not considered to have particular management significance), it is not defined as a separate soil profile class. For example, the **Mayfair** soil profile class is defined as having a loamy surface, but variants with a sandy surface also occur i.e. **Mayfair sandy surface variant**. These may or may not have been mapped depending on the distribution and extent of the variant.

Names for soil profile classes are generally based on localities or natural features in the survey area. However, the use of a particular name for a soil profile class does not necessarily imply that it is the dominant soil at the locality from which its name is derived. Often it is simply the location where the soil was first mapped. In the discussion that follows, the names are abbreviated. For example, the **Foxleigh soil profile class** is referred to as the **Foxleigh soil** or simply **Foxleigh**.

Two or four letter codes, that represent abbreviations of the soil profile class name, are used on the accompanying soil maps. For example, **Foxleigh** is recorded as **Fx** while **Mayfair sandy surface variant** becomes **MfSv**. These codes are also used in tables and appendices throughout both volumes of this report.

3.3 Unique map area data

Each occurrence of a mapping unit (i.e. separate polygon on a map) is termed a unique mapping area (UMA). It is coded with a unique number and described individually in terms of area, land resource attributes and soil attributes. The information recorded for each of the 1515 UMAs delineated on or adjacent to the map sheet is stored in an ACCESS database (SALI_UMA).

Land resource information recorded includes photo location, geological formation, substrate, dominant soil profile class, associated soil profile classes, landform, slope and vegetation associations. The proportion of each dominant and sub-dominant soil profile class and vegetation association in the UMA is estimated as a percentage.

Soil attribute data describing frost susceptibility (Cf), erosion potential (E), flooding (F), moisture availability (M), fertility (Nd), workability (Pm), surface condition for plant establishment (Ps), rockiness (R), profile salinity (Sa), landscape salinity hazard (intake (Si) and outflow (Ss)), microrelief (Tm), wetness (W) and soil complexity (Xs) are also recorded.

Mapping unit names on the soil association map are derived from the dominant soil profile class (including phases and variants) present within each UMA. A soil profile class is defined as dominant if it occupies at least 60% of the spatial area of an individual polygon. Many UMAs are recorded as consisting entirely (100%) of a dominant soil or vegetation association. It is unlikely these UMAs are completely pure however, and with more intense mapping other soil profile classes or vegetation associations may be delineated.

In UMAs where two soil profile classes or vegetation associations are regarded as co-dominant, each of the co-dominant units must have a spatial extent <60%, and a difference in spatial extent of 20% or less between each co-dominant. In each case, a combined name incorporating both co-dominant soil profile classes or vegetation associations is recorded. For example, **Rt–Ww** would be recorded for a UMA in which a 40%–40% combination of the **Racetrack** and **Warwick** soil profile classes occurred.

Where more than two soil profile classes or vegetation associations are deemed co-dominant, each of the co-dominant units must have a spatial extent >20% and ≤50%, and a difference in spatial extent of 25% or less between each co-dominant. A combined name incorporating each of the relevant co-dominant soil profile classes or vegetation associations is recorded. For example, **Rt–Ww–Tr** would be recorded for a UMA in which a 40%–30%–30% combination of the **Racetrack, Warwick** and **Turon** soil profile classes occurred.

3.4 Soil analyses

A total of 119 soil profiles were sampled for detailed laboratory analysis. Sampling locations were carefully selected to represent typical examples of the major soil profile classes described within the study area. Location of the sampling sites are shown on the enclosed soil map, while Australian Map Grid (AMG) coordinates for each site are detailed in Appendix 3. Samples from representative profile 9003 were never submitted for analysis.

Representative profiles were sampled in 0.1 m increments to a maximum depth of 1.5 m where possible, and analysed for a range of standard analyses every 0.3 m down the profile. The sampling intervals were altered, where necessary, to allow for thin surface horizons and to avoid sampling across horizon boundaries (Baker and Eldershaw 1993). At each site, a bulk (0–0.1 m) surface sample (composed of 8 to 10 subsamples) was collected for surface fertility assessment. The specific analyses performed at each of the standard depths are shown in Table 1. In addition $pH_{1:5}$, pH_{CaCl_2}, electrical conductivity ($EC_{1:5}$) and soluble chloride (ppm) were determined on all intermediate depths down the profile to a depth of 1.5 m. The drying status (air dry or oven dry) associated with each of the analyses is also shown.

Full profile morphology, landscape characteristics, vegetation and analytical data for each of the representative profiles are presented in Appendix 3. The laboratory methods used are listed in Appendix 7 while assessment criteria are recorded in Appendix 8. Detailed descriptions of the analytical methods are presented in Rayment and Higginson (1992) while further information on interpreting data is available from Baker and Eldershaw (1993), Bruce and Rayment (1982), Landon (1991) and Peverill *et al.* (1999).

In addition to the standard analyses described in Table 1, a number of ratios have been calculated. These include:

- organic carbon/total nitrogen ratio (C/N);
- calcium/magnesium ratio (Ca/Mg);
- CEC/clay % ratio (CCR); and
- exchangeable sodium percentage (ESP).

Table 1. Standard laboratory analyses undertaken for surface soil samples and representative profiles

1. Surface soil fertility analyses – bulk surface sample

Sample depth(s) – 0–0.1 m

Macronutrients	• Organic carbon (C)	Air dry @ 40ºC
	• Total nitrogen (N)	Air dry @ 40ºC
	• Acid-extractable phosphorus (P), Bicarb.-extractable phosphorus (P)	Air dry @ 40ºC
	• Acid-extractable potassium (K)	Air dry @ 40ºC
	• Water soluble nitrate nitrogen (N)	Air dry @ 40ºC
	• Calcium phosphate-extractable sulfur (S)	Air dry @ 40ºC
Micronutrients	• DTPA-extractable Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn)	Air dry @ 40ºC

2. Profile analyses – sample depths every 0.3 m

Sample depth(s) – 0–0.1 m, 0.2–0.3 m, 0.5–0.6 m, 0.8–0.9 m, 1.1–1.2 m, 1.4–1.5 m

Analyses	• CEC[1] or ECEC[2] and exchangeable cations (Ca, Mg, Na, K)[1,2]	Oven dry @ 105ºC
	• Particle size analysis (coarse sand %, fine sand %, silt % and clay %)	Oven dry @ 105ºC
	• Dispersion ratio (R1)	
	• Moisture measurements (% air dry, % 15 KPa)	Oven dry @ 105ºC
	• Total phosphorus (P), Total potassium (K), Total sulfur (S)	Oven dry @ 60ºC

3. pH and salinity analyses – sample depths every 0.1 m

Sample depth(s) – 0–0.1 m, 0.1–0.2 m, 0.2–0.3 m, 0.3–0.4 m, 0.4–0.5 m, 0.5–0.6 m, 0.6–0.7 m, 0.7–0.8 m, 0.8–0.9 m, 0.9–1.0 m, 1.0–1.1 m, 1.1–1.2 m, 1.2–1.3 m, 1.3–1.4 m, 1.4–1.5 m

Analyses	• Soil pH $_{1:5}$, soil pH $_{CaCl_2}$	Air dry @ 40ºC
	• Electrical conductivity (EC $_{1:5}$)	Air dry @ 40ºC
	• Soluble chloride (Cl)	Air dry @ 40ºC

Notes 1. CEC/alcoholic cations @ pH 8.5 [Methods 15I3, 15C1 – Rayment and Higginson (1992)]
2. ECEC/aqueous cations @ pH 7 [Methods 15J1, 15A1 – Rayment and Higginson (1992)]

Calculation of these ratios follows the methodology of Rayment and Higginson (1992). Interpretation of the ratios is described in Appendix 8.

Adjustment of exchangeable sodium (Na) values (measured using method 15A1) has been necessary for samples from profiles that are both saline (>0.3 dS/m) and acidic (pH $_{1:5}$ ≤7), due to excess soluble sodium (Na) in the soil solution. The problem arises because prewashing to remove soluble salts is not undertaken with neutral to acidic samples where method 15A1 is used, and soluble Na in the soil solution is incorrectly measured as part of the total exchangeable value. To correct this problem, the level of soluble Na is estimated from the chloride (Cl) content and subtracted from the measured exchangeable value. Summed values (ECEC) and ratios (CEC/Clay%, ESP) are then calculated as normal. Further detail can be found in Rayment and Higginson (1992) (method 15A3).

In addition to the 119 representative profiles, a further 549 surface soil samples (0–0.1 m Bulk) were taken from typical sites across the study area to establish the surface fertility status of the major soil profile classes, and to investigate relationships between soil fertility, parent material, landscape position and vegetation. Approximately 5–10 samples from each soil profile class have been analysed for a range of organic and inorganic nutrients. For most soils at least seven samples were collected to ensure the geometric mean (geomean) and minimum–maximum range values (geomean ± SD) are statistically valid (CR Ahern *pers. comm.*). The specific analyses performed are listed in Table 1, while the methods and assessment criteria used are listed in Appendices 7 and 8 respectively. Individual analyses for a particular site are available from the site database (SALI_SITE), while statistically summarised data is presented for each soil in Appendix 4.

3.5 Interpretation of analytical data

Detailed assessment criteria, ratings, methodology and explanatory notes for all of the analytical or modelled data in Appendices 3, 4, 5 and 6 are described in Appendix 8. The published data in this report follows the formatting recommendations of Rayment and Higginson (1992) and has been adjusted where applicable for accuracy (number of decimal places) and drying status (air dry (AD) or oven dry (OD)) following measurement. Further detail on drying status and accuracy is presented in Appendix 7.

Interpretation of the analytical data collected during the study has mainly involved grouping various data sets [fertility data, profile salinity data ($EC_{1:5}$, soluble Cl), sodicity data (ESP), pH data, effective rooting depth (ERD) and plant available water capacity (PAWC) data] on a soil and landscape basis to allow comparison and discussion.

The large quantity of data in each data set (e.g. 6830 field $EC_{1:5}$ values) was simplified by grouping data on an SPC basis and calculating a geometric mean (geomean) and standard deviation (SD) for each sample depth. The geometric mean was selected as the most appropriate statistic for this process because it is more reliable than an arithmetic mean, particularly where variability in the data associated with random high values is a possibility.

Geometric means were calculated using the formula:

Geometric mean = $\sqrt[n]{y_1, y_2, y_3 \ldots\ldots y_n}$
where y_1 to y_n are the individual data values in the sample population

The minimum and maximum range in expected values associated with the calculated geometric means was determined as 1 standard deviation either side of the mean value ($\pm$ SD). This range encompasses approximately 70% of the variation expected in the sample population.

3.5.1 Surface soil fertility data

Each of the individual analytes in the surface soil fertility data set (i.e. 17 analytes for each 0–0.1 m bulk sample from 549 typical sites) were grouped by soil type and gilgai component (non-gilgaied, mound, shelf or depression) prior to interpretation. Because significant variation in fertility levels was thought to occur between gilgai components, each component was evaluated separately. Geometric mean, standard deviation and the minimum and maximum range (mean $\pm$ SD) were calculated for each component (where applicable) for each SPC. The means are grouped by landscape and vegetation type in the summary table in Appendix 4. An alphabetical listing for each SPC with statistics and the number of samples analysed is also presented.

Mean and range values are representative where calculations are based on data from five or more samples (CR Ahern *pers. comm.*). While statistical theory suggests sample populations should be much larger, the high cost required to achieve statistical validity across a wide range of soils becomes prohibitive. In practice, some soils may need only a few samples to achieve a representative mean, while in others significant natural variation means even large sample numbers may not produce a reliable estimate. In most soil–land based systems however, a sample population of at least five to seven analytical values for a particular soil is usually sufficient to provide a representative mean (CR Ahern *pers. comm.*).

The majority of soils that are either agronomically important or spatially significant within the study area have sample populations of between 8–12 samples. Sampling outside the study area for field days and property planning workshops (JW Burgess unpublished data) suggests mean values for these soils are both reliable and predictive. Some minor soils however have sample populations of <5 samples. Mean values for these soils, whilst indicative, are less reliable and may require further sampling if robust predictive values are required.

3.5.2 Profile salinity data – $EC_{1:5}$

Electrical conductivity (EC) is a measure of the strength of an electric current passing through the soil solution. Salts in solution conduct the current and the strength of the current is proportional to the concentration of salt (i.e. EC reading). Most commonly EC is measured as $EC_{1:5}$ which provides a measure of the soluble salt content in a 1:5 soil:water suspension (i.e. one part soil to five parts water). Field $EC_{1:5}$ and laboratory $EC_{1:5}$ measurements effectively use the same methodology, but field $EC_{1:5}$ values are less reliable because sample preparation and testing conditions in the field may vary. Differences between field and laboratory results occur mainly because drying, shaking and settling times used in the laboratory are not appropriate for the field (*Salinity Management Handbook* DNR 1997). $EC_{1:5}$ values were measured in the field for sites 1–2171 and in the laboratory for representative profiles 9001–9119 (less 9003).

EC_{SE} which estimates the electrical conductivity of the actual soil solution without dilution is calculated from $EC_{1:5}$ values following adjustment for clay %. As such, it provides a realistic estimate for predicting plant response to salinity in the soil. While it can be measured, it is most commonly calculated from laboratory data (DNR 1997). As such, EC_{SE} values are available for the representative profiles 9001–9119 (less 9003) only.

Field $EC_{1:5}$ measurements were recorded routinely at 0.3 m intervals down the profile as well as major horizon changes. Measured values were grouped by SPC and sample depth then geometrically meaned. Mean values for each standard depth (0–0.1, 0.2–0.3, 0.5–0.6, 0.8–0.9, 1.1–1.2 and 1.4–1.5 m) were plotted against depth to give a statistically valid profile salinity curve for each soil. These curves are presented in Chapter 8. Laboratory measured $EC_{1:5}$ values were also graphed for each of the representative profiles 9001–9119 but have not been presented. Full profile data is however available in Appendix 3.

Soil salinity is defined for the purpose of this report as the presence (or concentration) of soluble salts in the soil profile (DNR 1997). Plant response to high levels of soluble salts in the soil solution occurs either as an osmotic effect in plant tissues or as a toxicity effect related to specific ions, particularly sodium (Na) or chloride (Cl). When excess soluble salts are present in the soil solution it often becomes difficult for plants to extract enough water for normal growth because osmotic effects restrict water uptake in the root cells. As a result, plants growing in saline conditions often show water stress even when there appears to be adequate water for plant uptake. Inherently high levels of subsoil salinity in many inland soils, such as brigalow clays, effectively limit the rooting depth and restrict plant growth to species with some degree of salt tolerance. In a soil profile, the depth of soil above the subsoil salt bulge is referred to as the effective rooting depth (ERD). This depth is important when calculating the plant available water capacity (PAWC) of a soil, because water stored below the effective rooting depth is not considered available to the plant.

The mean profile salinity curves in Chapter 8 provide a reliable means of estimating effective rooting depth (ERD) for each soil. Interpretation of ERD from geomeaned field data has used either:

- the depth where salinity values ($EC_{1:5}$) reach a critical level >0.8 dS/m; or
- the depth where the subsoil salinity bulge reaches a maximum and profile salinity goes into equilibrium (i.e. becomes constant).

The critical $EC_{1:5}$ value of 0.8 dS/m was adopted following a comparison of field and laboratory $EC_{1:5}$ data for representative profiles 9001–9119. ERD values estimated using an EC_{SE} values associated with a 10% reduction in wheat and sorghum yield (DNR 1997) was compared against the mean field $EC_{1:5}$ values at the same depth. A yield reduction of at least 10% was selected to represent the point at which root development in the subsoil begins to be significantly affected. In the majority of cases an $EC_{1:5}$ value close to 0.8 dS/m was involved. The similarities in predicted ERD for the representative profiles 9001–9119 using both approaches suggests 0.8 dS/m is a reliable and robust threshold for evaluating ERD from field EC data in the Isaac–Connors and Mackenzie River catchments.

The shape of the profile salinity curve ($EC_{1:5}$ plotted against depth) is often termed a 'salt bulge'. Salt bulges characteristically show a sudden and significant increase in subsoil salinity at a particular depth, below which levels stay constant or even decrease. The shape of the curve is best explained by the interaction of profile drainage and long-term water uptake by plants. In general, a greater volume of water passes through the upper part of the profile because root concentration and plant water extraction are higher. As a result, the concentration of salts in the soil solution is much lower. As water uptake decreases with depth, a much lower volume of water passes through the soil (i.e. deep drainage only) and salt concentrations in the soil solution increase. In simple terms, soluble salts in the upper part of the profile are leached downwards where they accumulate because of drainage restrictions, creating an apparent 'salt bulge'.

The long-term wetting front of a soil, which in many cases determines the ERD, can be estimated from the shape of the profile salinity curves. The point at which the curve first becomes constant after the sudden increase associated with the salt bulge is usually considered the point at which profile salinity is in equilibrium. In theory, long-term water uptake by plants has not commonly occurred below this point. The shape of a profile salinity curve is less reliable as a predictor of ERD than the critical levels discussed above however, and has only been used for soils in which $EC_{1:5}$ levels were <0.8 dS/m throughout (e.g. Carlo (Cc) soil – see Chapter 8).

3.5.3 Profile salinity data – soluble chloride (Cl)

Laboratory measured soluble Cl values (ppm) have been graphed against depth for each of the representative profiles 9001–9119. In general, the shape and interpretation of the Cl graphs closely follows that described for the $EC_{1:5}$ graphs. A critical value of 1000 ppm Cl was adopted as the limit for effective rooting depth (Littleboy *et al.* in prep.), and good correlation was observed between predicted ERD from Cl data and predicted ERD from $EC_{1:5}$ data. Chloride profile graphs have not been presented but full profile data is available in Appendix 3.

3.5.4 Profile sodicity data – ESP

Sodicity is primarily a function of sodium dominance on the soil exchange complex and is defined as the relative abundance of exchangeable sodium (Na) compared with the other exchangeable cations, calcium (Ca), magnesium (Mg) and potassium (K). It is normally assessed as the exchangeable sodium percentage (ESP) which compares the amount of exchangeable Na against the cation exchange capacity of the soil (either CEC or ECEC depending on pH).

$$\mathbf{ESP} = \frac{\mathbf{Ex.Na}}{\mathbf{CEC\ or\ ECEC}} \times \mathbf{100}$$

A critical ESP level of 20% was adopted for assessing ERD (Littleboy *et al.* in prep.). Subsoil materials (>25% clay) with ESP levels >20% exhibit adverse physical characteristics such as severe dispersion and slaking, high soil density and coarse columnar structure. Such features limit root penetration and water extraction from the subsoil and restrict ERD.

Calculated ESP values have been graphed against depth for each of the representative profiles 9001–9119, and examples of the ESP profile graphs are presented in Chapter 8. The ESP curves show similar trends to the EC $_{1:5}$ and Cl graphs, but only in soils where significant inherent salinity also occurs in the subsoil. In such cases, the predicted ERDs from all three graphs were well correlated, although predicted ERDs from ESP graphs were mostly 0.1–0.2 m lower down the profile.

In soils where significant subsoil salinity or acidity does not occur, such as sandy surfaced texture contrast soils with eucalypt vegetation, the only reliable predictor for assessing ERD is the presence or absence of physical characteristics that limit root penetration. In most cases, critical ESP levels >20% were well correlated with columnar structure in morphological descriptions and high dispersion ratios measured in the upper subsoil. Horizon changes associated with sodic clay layers in the lower subsoil of some soil profile classes were also predicted.

In general, the shape of the ESP curve has not been used for assessing ERD. ESP data reflect complex exchangeable cation processes in the clay fraction of the soil and the shape of the profile curve is dependent on a number factors other than just profile drainage and water extraction.

3.5.5 Assessment criteria for effective rooting depth (ERD)

Effective rooting depth is defined as the depth to which approximately 90% of plant roots will extract water. It is normally limited either by the presence of underlying rock or other hard materials or by chemical or physical attributes within the subsoil that restrict root growth (QDPI 1990). Assessment of ERD in the Windeyers Hill study has used criteria adapted from those of Littleboy *et al.* (in prep.). Criteria for assessing representative profiles 9001–9119 where all necessary analytical data are available differ from those used for field sites 1–2171 where only field based attributes were recorded.

ERD criteria for representative profiles (9001–9119) include:

1. Lab EC $_{1:5}$ > 90% yield reduction EC $_{SE}$ threshold for wheat/sorghum.
2. Cl $_{1:5}$ > 1000 ppm.
3. ESP > 20% (where clay content >25%).
4. Lab pH < 5.5.
5. Depth to C or R horizons (or other hard materials).

ERD criteria for field sites (1–2171) include:

1. Field EC $_{1:5}$ > 0.8 dS/m.
2. Depth to moderate or strong columnar structure.
3. Field pH < 5.5.
4. Depth to C or R horizons (or other hard materials).

3.5.6 Assessment methodology for plant available water capacity (PAWC)

Estimation of PAWC for the soils described in the Windeyers Hill study has used the PAWCER (Plant Available Water Capacity Estimation Routine) methodology of Littleboy (1997) and Littleboy *et al.* (in prep.).

For representative profiles (9001–9119), where all necessary analytical data are available, the PAWCER model calculates the upper and lower soil moisture storage limits (USL, LSL) based on particle size analyses (particularly clay content) and 15 bar moisture measurements (wilting point). Allowance for the proportion of coarse fragments in the soil is included. The difference between the USL and LSL is summed down the profile to the ERD and calculated as a final PAWC in mm.

For field sites (1–2171) where analytical data is not available field attributes have been used to estimate the input parameters required by the PAWCER model (D Brough *pers. comm.*). Field texture has been used to generate estimates of the particle size and 15 bar inputs. Whilst potential errors and reduced accuracy are recognised in this approach, the size of the dataset allows statistical analysis of the results and provides for more predictive and robust data interpretation. Comparison of both approaches for representative profiles 9001–9119 shows reasonable agreement and validates the use of field data for estimating mean PAWC values on a soil profile class basis.

Geometrically meaned PAWC values and the expected range (mean $\pm$ SD) estimated from field data for each soil profile class are presented in Appendix 5. Individual PAWC values for representative profiles 9001–9119 are presented in Appendix 6.

4. CLIMATE

The climate of the Isaac–Connors and Mackenzie River catchments is classified as subtropical with moderately dry winters, according to the modified Koeppen classification system of Stern *et al.* (2001). By definition, this means the catchment has a mean annual temperature >18 °C and receives >3 but <10 times the rainfall of the driest winter month over the winter period (June to August). The catchments lie at the northern end of this climatic zone, which covers large parts of central and to a lesser extent southern inland Queensland.

The nearest climate station to the Windeyers Hill study area that experiences similar conditions is the Clermont Post Office, while the nearest long term (>85 years) rainfall station is 'Bombandy', lying just north of the map sheet. While anecdotal evidence suggests slight variations in geographical rainfall distribution may occur across the study area, it is difficult to ascertain the accuracy of this information. As a result, a uniform coverage using the 'Bombandy' data has been assumed.

4.1 Rainfall

Mean monthly and annual rainfall figures are presented in Table 2 for Nebo, Collaroy, 'Bombandy' and Dingo rainfall stations in the north, east, middle and south of the Isaac–Connors and Mackenzie River catchments respectively. All four stations have >85 years of records. Total rainfall increases significantly in the east of the catchment and also marginally in the north of the catchment compared with the south. All four locations also experience marked seasonal distribution with approximately >75% of annual rainfall falling in the six month period from October to March. The dominance of 'wet season' rainfall is highlighted by the fact that for most of the catchment areas >60% of annual rainfall falls in the four months between December and March. This dominance gradually decreases from north to south across the 2 catchments.

Table 2. Mean and median monthly and annual rainfall for selected stations in the Isaac–Connors and Mackenzie River catchments

Station	**Statistic**	**Rainfall (mm)**												
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Nebo	Mean	143	137	110	45	36	38	26	22	20	32	55	98	762
	Median	103	107	84	26	22	29	11	10	8	18	43	89	728
Collaroy	Mean	165	152	103	42	35	38	22	20	17	33	59	100	788
	Median	110	106	66	25	22	25	8	8	7	20	42	77	717
'Bombandy'	Mean	124	114	73	32	28	34	24	16	19	33	64	85	646
	Median	115	88	49	22	17	22	9	7	8	22	51	71	613
Dingo	Mean	114	109	74	38	36	34	28	22	26	48	64	100	694
	Median	91	84	53	22	20	26	14	16	11	32	55	94	664

Source: Clewett *et al.* (1999) (Australian Rainman)

Station	**Seasonal rainfall as a % of mean annual** #		
	Apr.–Sep. (6 months)	**Oct.–Mar. (6 months)**	**Dec.–Mar. (4 months)**
Nebo	25	75	63
Collaroy	24	76	64
'Bombandy'	24	76	61
Dingo	27	73	57

Seasonal % were calculated individually for each year in the record and then meaned.

Both seasonal and annual rainfall are highly variable due to the convective origin of much of the rainfall, and the sporadic incidence of rainfall depressions associated with tropical cyclones. In addition, climatic patterns such as the El Nino–Southern Oscillation (ENSO) significantly affect rainfall variability from year to year. Seasonal variability within the study area is clearly illustrated in Figure 3.

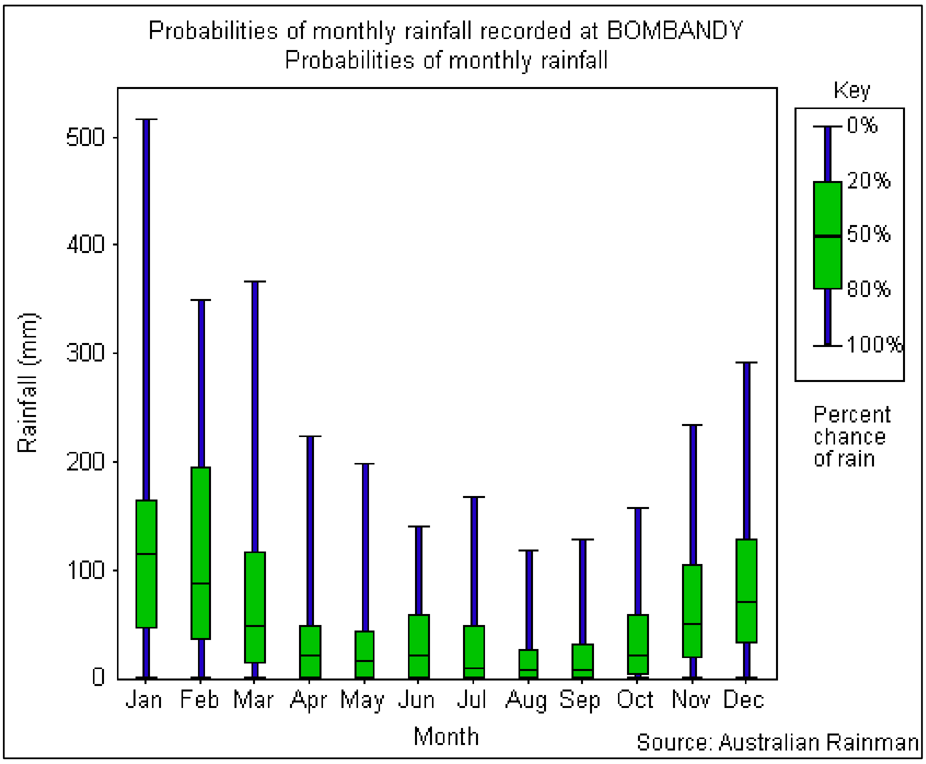


Figure 3. Monthly and annual rainfall variability for 'Bombandy' (based on probabilities of monthly rainfall) (Clewett *et al.* 1999)

4.2 Rainfall intensity

High intensity rainfall increases the potential for soil loss from exposed soil surfaces. The erosivity of rainfall may be quantified using the erosion index (EI_{30}) which is derived from the product of total storm rainfall and the maximum 30-minute intensity of the storm. This index has proved to be highly correlated with soil loss (Rosenthal and White 1980). A comparison of EI_{30} data, mean monthly rainfall and mean number of rain days is presented in Table 3, for stations at Collinsville, Blair Athol, Dingo, Emerald and 'Bombandy'.

Table 3. Mean monthly rainfall [1], average number of rain days (>0.1 mm)[1] and average EI_{30} [2] for Collinsville, Blair Athol, 'Bombandy', Dingo and Emerald

Station	Statistic #	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Collinsville	rainfall	163	133	97	41	27	29	20	15	15	26	50	110	728
	rain days	8	7	6	2	2	2	1	1	1	2	3	6	41
	EI_{30}	130	48	39	6	0	8	5	3	2	16	52	61	370
Blair Athol	rainfall	108	112	68	34	30	28	26	20	15	35	57	94	629
	rain days	8	7	5	3	3	3	2	2	2	3	5	7	50
	EI_{30}	80	70	26	7	11	10	5	14	9	11	29	93	365
'Bombandy'	rainfall	124	114	73	32	28	34	24	16	19	33	64	85	646
	rain days	7	6	5	3	2	3	2	1	2	3	4	5	43
	EI_{30}	131	70	49	8	3	3	2	3	4	12	21	69	375
Dingo	rainfall	114	109	74	38	36	34	28	22	26	48	64	100	694
	rain days	7	6	5	3	3	3	2	2	2	4	5	6	48
	EI_{30}	84	45	27	14	18	5	7	7	5	23	40	77	352
Emerald	rainfall	102	97	69	36	34	33	27	22	24	40	59	89	634
	rain days	8	7	6	4	4	3	3	3	3	4	6	7	58
	EI_{30}	102	37	33	13	2	1	3	4	3	5	35	66	304

mean monthly values for rainfall (mm), number of rain days and EI_{30} index

Sources: 1. Clewett *et al.* (1999) (Australian Rainman)

2. Rosenthal and White (1980)

These data show for all stations that the summer months are critical for potential soil loss, because rainfall is both higher and also significantly more intense than in the winter months. The annual EI_{30} expected in the Isaac–Connors and Mackenzie River catchments (350–375) is higher than for cropping areas further south in Queensland (Biloela 245) and in northern New South Wales (Gunnedah 146), but is similar to other Central Queensland cropping areas such as the Central Highlands (Emerald 304) and the Kilcummin district (Blair Athol 365).

4.3 Evaporation and humidity

The effectiveness of rainfall for plant growth is most limited when evaporation rates are high. Monthly pan evaporation data for Clermont are compared with monthly rainfall and relative humidity data in Table 4.

Table 4. Mean monthly rainfall, pan evaporation and relative humidity data for Clermont

Statistic #	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall (mm/mth)	119	114	77	40	36	34	26	20	20	35	57	93	671
Evaporation (mm/mth)	279	216	205	165	130	117	127	158	207	260	291	307	2462
Evaporation (mm/day)	9.0	7.7	6.6	5.5	4.2	3.9	4.1	5.1	6.9	8.4	9.7	9.9	6.7
Rel. humidity 9 am	64	66	70	70	73	71	68	62	55	55	56	60	64
3 pm	39	42	42	39	42	39	36	32	26	27	28	34	36

mean monthly values for rainfall (mm/month), pan evaporation (mm/month and mm/day) and relative humidity (%)
Source: Clewett *et al.* (1999) (Australian Rainman)

Evaporation rates for the Isaac–Connors and Mackenzie River catchments are highest from September to March, while relative humidity is lowest during the August to December period. The combination of high temperatures, low relative humidity and high evaporation rates in the spring and early summer months mean rainfall effectiveness is at its lowest during this period. Mean pan evaporation exceeds mean rainfall in all months throughout the year, while annual pan evaporation is more than three times annual rainfall.

4.4 Temperature

Temperature data for Clermont are given in Table 5. The three hottest months are November, December and January which have daily mean maximum temperatures around 34 °C. High summer temperatures are recognised as an impediment to crop performance in the Isaac–Connors and Mackenzie River catchments, particularly for sorghum crops which may flower during this period. Heat wave conditions, defined as three consecutive days with temperatures >38.7 °C (Shields and Williams 1991), are possible from October to March, although the most likely period is November to January (i.e. months with at least one day >40 °C).

The three coldest months are June, July and August which all have an average daily minimum temperature <9.0 °C. The average number of days with a minimum temperature <2.2 °C indicates the period which has the greatest potential for frost. The likelihood of heavy frosts within this period is estimated from the average number of days with minimum temperatures <0 °C. The frost period at Clermont extends from June to August with heavy frosts most likely in June or July (Table 5). Within the study area and surrounding catchments, frosts are generally more regular and more severe on low lying alluvial landscapes, compared with adjacent elevated or sloping areas (P Quinn *pers. comm.*).

Table 5. Mean monthly temperature data for Clermont

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean monthly max. (°C)	34.0	32.9	31.7	29.2	25.7	22.8	22.6	24.9	28.3	31.4	33.5	34.3	29.3
Average days >35 (°C)	14	8	4	0	0	0	0	0	1	4	10	14	55
Average days >40 (°C)	1	0	0	0	0	0	0	0	0	0	1	1	3
Mean monthly min. (°C)	21.6	21.2	19.7	16.2	12.3	8.1	6.9	8.7	12.3	16.4	19.1	20.9	15.3
Average days <2.2 (°C)	0	0	0	0	0	3	6	2	0	0	0	0	11
Average days <0 (°C)	0	0	0	0	0	1	1	0	0	0	0	0	2

Source: Clewett *et al.* (1999) (Australian Rainman)

4.5 Drought

Droughts, defined as a severe rainfall deficit over a period of at least 12 months, are a regular occurrence in the catchments. Seventeen droughts (where annual rainfall is less than the driest 10% of years) have been recorded at ‘Bombandy’ between 1905 and 1990 (86 years). Droughts can be expected to occur approximately one year in every five. The occurrence of drought at ‘Bombandy’ is shown in Table 6. The percentage of time in severe drought (where rainfall is less than that received in the driest 5% of years) is also shown for each event.

Table 6. The occurrence of drought events at ‘Bombandy’, 1905–1990

Drought event	Period	Duration (months)	Total rainfall (mm)	% of time in severe drought
1	Mar 1911 to May 1912	15	508	75
2	Apr 1914 to Feb 1916	23	668	75
3	Mar 1918 to Jul 1920	29	851	17
4	Jan 1923 to Jan 1924	13	395	50
5	Mar 1925 to Jan 1927	23	768	58
6	Jun 1930 to Oct 1931	17	514	83
7	Dec 1947 to Dec 1948	13	406	50
8	Feb 1951 to Mar 1952	14	427	67
9	Apr 1963 to Aug 1964	17	472	33
10	Nov 1964 to Nov 1965	13	395	0
11	Feb 1966 to Jan 1967	12	379	0
12	Mar 1968 to Dec 1969	22	679	91
13	Feb 1970 to Jan 1971	12	402	0
14	Feb 1972 to Jan 1973	12	365	0
15	Apr 1979 to Nov 1980	20	447	11
16	Mar 1981 to Mar 1983	25	851	14
17	Jun 1983 to Jan 1985	20	644	22

Source: Clewett *et al.* (1999) (Australian Rainman)

Because rainfall records for ‘Bombandy’ ceased after 1990, data for drought events during the decade from 1990–2000 are unavailable. Analysis of drought records for Nebo (1991–1995, 1999), Dingo (1992–1995) and Clermont (1992–1993, 1996) indicate drought events were widespread throughout both catchments for much of the 1990s.

4.6 Climate and agriculture

Agricultural production is dependent on adequate moisture, nutrient supply, radiation and temperature. In inland Central Queensland, the availability of adequate moisture often limits crop and pasture productivity, and is dependent on the interaction of:

- rainfall amount and seasonal distribution;
- evapotranspiration;
- evaporation from the soil surface;

- runoff;
- plant available water capacity (PAWC) of the soil; and
- deep drainage.

Clearly, climatic conditions are responsible for the level of rainfall inputs and evaporation losses across the catchment, while the remaining factors are largely controlled by soil and landscape processes.

Although total rainfall across the two catchments decreases significantly from east to west and also marginally from north to south, seasonal rainfall distribution and rainfall variability follow similar trends throughout. The distinct seasonality of the rainfall at 'Bombandy' is typical of much of the catchment, and is best illustrated by the median monthly rainfall figures in Table 7. In 50% of years, the period from April to October receives <25 mm of rainfall per month. Of particular concern are the months between July and September which receive a median monthly rainfall of <10 mm.

Table 7. Probabilities of monthly rainfall recorded at 'Bombandy', 1905–1990 (amounts of rain (mm) received or exceeded in 100%, 90% … 0% of years)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Lowest on record	0	0	0	0	0	0	0	0	0	0	0	0	260
90% years at least	25	13	5	0	0	0	0	0	0	0	8	13	396
80% years at least	47	37	15	0	0	1	0	0	0	4	20	33	474
70% years at least	59	62	26	4	2	7	0	0	0	9	23	42	509
60% years at least	95	75	39	14	4	15	6	1	2	16	38	61	564
median, 50% years	**115**	**88**	**49**	**22**	**17**	**22**	**9**	**7**	**8**	**22**	**51**	**71**	**613**
40% years at least	138	118	71	30	25	34	15	10	16	29	69	87	689
30% years at least	153	137	83	36	36	42	36	17	23	42	87	109	769
20% years at least	165	194	116	49	43	59	49	27	32	58	105	128	845
10% years at least	213	245	194	80	64	95	63	47	62	85	131	187	919
Highest on record	517	350	367	224	199	141	167	119	128	158	234	292	1187
Mean	124	114	73	32	28	34	24	16	19	33	64	85	646
Standard deviation	93	87	73	40	38	35	34	24	27	34	52	61	204

Source: Clewett *et al.* (1999) (Australian Rainman)

The average number of rain days also shows similar trends (see Table 3). The summer period (November to March) averages between 5 and 7 rain days per month, but this drops markedly to <3 per month over the autumn and winter months (April to October). Effectively, this means there are significantly less rainfall opportunities during winter, and significantly less rainfall with each event.

This has implications for dryland cropping. While regular planting opportunities and significant in-crop rainfall occur over the summer growing period, planting opportunities for winter cropping are limited and significant in-crop rainfall is rare. In addition, winter planting rains are usually isolated events and the likelihood of well timed follow-up rain is very low in most years. This can be a particular problem for the successful development of secondary roots in wheat and often dramatically reduces final yield. In contrast, follow-up rainfall is unnecessary for root development in sorghum, provided a full profile of moisture is present at planting (G Lambert *pers. comm.*).

The interaction between rainfall variability and crop establishment is well illustrated by the crop modelling of Cox and Chudleigh (2000) for wheat and sorghum at Capella. Under similar climatic conditions and on similar soils to those used at Dysart in the Windeyers Hill study area, wheat crops only established and grew a harvestable yield in 67–71% of the last 100 years, irrespective of the level of soil PAWC. The modelling used typical planting windows (sorghum – 15 Nov. to 30 Jan., wheat – 2 Apr. to 8 Jul.), stored moisture requirements (80 mm) and planting rainfall events (sorghum – 25 mm over 4 days, wheat – 20 mm over 4 days) for sorghum and wheat monoculture cropping systems at Capella.

In contrast, cropping success for sorghum under the same conditions was consistently 90–100%. This comparison highlights the effect climatic conditions have had on opportunities for planting, establishment and crop growth to harvest over the last 109 years at Capella. It is fair to assume that the significant difference between wheat and sorghum response at Capella probably relates to the reduced probability of follow-up winter rainfall after planting and the subsequent establishment problems wheat crops would experience.

As a result, early planting in March/April is preferred for winter crops in the Isaac–Connors and Mackenzie River catchments to maximise chances of follow-up rain in May and June. A strategy of early planting however, increases the likelihood of frost damage during flowering. This is a particular problem on low-lying alluvial areas such as the Isaac and Mackenzie River flood plains. These areas are more frost prone than surrounding elevated landscapes and are generally planted later to avoid frost damage, thereby reducing the chances of receiving well timed planting and follow-up rains (G Lambert *pers. comm.*).

Cox and Chudleigh (2000) have shown at Capella (with a similar climate and on similar soils to the Windeyers Hill study area) that, at almost all potential yield levels, the predicted yield from high-PAWC soils exceeds the yield from soils with lower soil water-holding capacities. It is only when extreme conditions result in either very low (or very high) soil water at planting and/or very low (or very high) in-crop rainfall that the curves converge. This effect is illustrated in Figure 4.

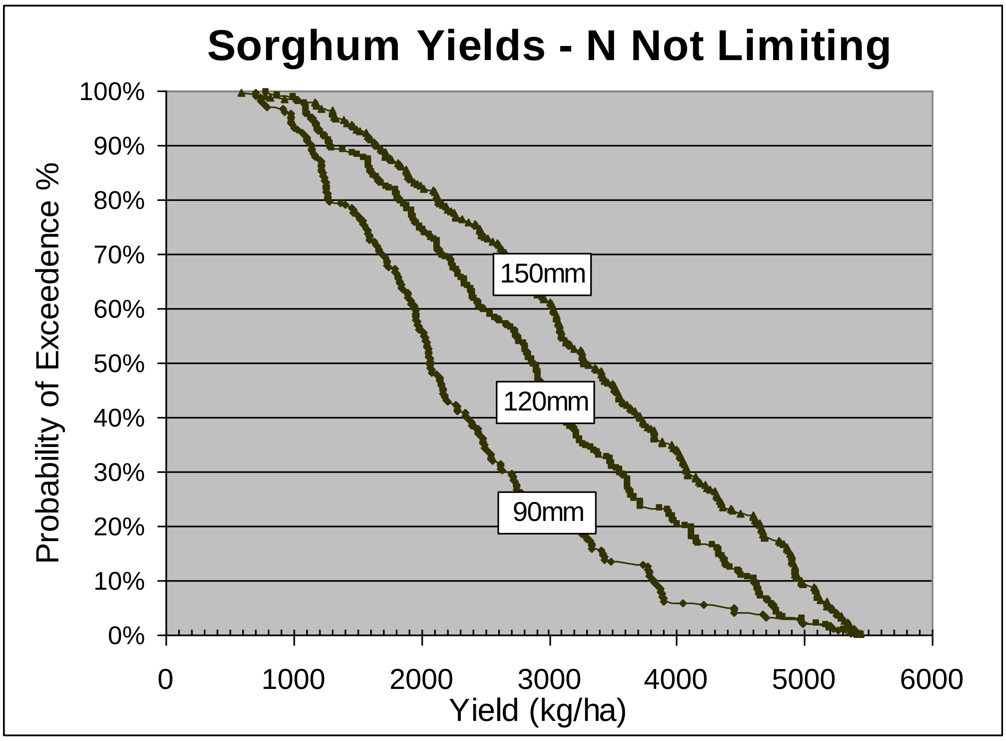


Figure 4. Probability of exceedence curves for 90, 120 and 150 mm PAWC for sorghum yields for the years 1890–1999 at Capella (Cox and Chudleigh 2000)

It is useful therefore to separate the role of soil water-holding capacity (PAWC) in cropping success, from climatic effects that also affect crop yield. The PAWC of a soil is a major factor (along with soil fertility) affecting potential crop yield, because it determines for any particular season not only the level of soil water available at planting but also how effectively in-crop rainfall is captured and utilised by the crop. Evidence for this comes from Dalal *et al*. (1997) who reported a correlation of only 0.43 between soil water at planting and crop yield. This indicates that while PAWC is a significant determinant of final crop yield (i.e. PAWC explains 45% of the variation in final yield in any particular season) other factors such as in-crop rainfall are just as important. In addition to determining the moisture available at planting, PAWC can impact significantly on the ability of the soil-crop system to make the most effective use of in-crop rainfall. Soils with good infiltration characteristics and a large PAWC (e.g. deep, well structured, strongly self-mulching, calcareous clay soils) maximise the storage of in-crop rainfall, further enhancing yield potential. Conversely, shallow soils with poor infiltration characteristics experience higher runoff losses and fail to utilise rainfall of the same duration and intensity as effectively.

In summary, the PAWC of a soil together with the actual stored soil water at planting and the amount and effectiveness of in-crop rainfall received in any particular season are the major determinates of yield potential (where fertility is not limiting) for sorghum and wheat, both at Capella and in the Windeyers Hill study area.

5. GEOLOGY AND LANDSCAPE DEVELOPMENT

The Isaac–Connors and Mackenzie River catchments occupy the central part of the Bowen Basin, one of the major geological structural units in Queensland. While previous investigations within the Bowen Basin are numerous, the only contiguous coverage across both catchments is still the regional 1:250 000 mapping undertaken by the Bureau of Mineral Resources (BMR) and Geological Survey of Queensland (GSQ) in the 1960s. Mapping across the two catchments includes areas from the following 1:250 000 map sheets:

- Mt Coolon – Malone *et al.* (1964)
- Mackay – Jensen AR (1965)
- Clermont – Olgers F (1969)
- St Lawrence – Malone EJ (1970)
- Emerald – Olgers F (1984)
- Duaringa – Malone *et al.* (1969)

More recently Balfe *et al.* (1988) produced a solid geology map of the Bowen Basin, which also shows the distribution of surficial deposits of Tertiary age or younger. Many of the original 1:250 000 formation names were reviewed by these authors and the revised names have been used in this report. Recent mapping and investigation in parts of the map sheets listed includes Hutton *et al.* (1998) – Mt Coolon, Withnall *et al.* (1995) – Clermont and Emerald, and Hutton *et al.* (1999 a) – Mackay, St Lawrence and Duaringa.

Information in the following sections on structural geology, geological formations, lithology and geological history within the two catchments comes largely from the 1:250 000 reports as well as Dickens and Malone (1973) and Henderson and Stephenson (1980). Detail on landscape development since the beginning of the Tertiary Period draws heavily on the conclusions of Galloway (1967 a, b), Wright (1968 a, b), Grimes (1980) and Stephenson *et al.* (1980).

5.1 Structural geology

Landscape development within the Isaac–Connors and Mackenzie River catchments has been controlled largely by geological events within the structurally complex Bowen Basin since pre-Permian times. Six structural zones are recognised within the northern part of the Bowen Basin (Staines and Koppe 1980) which include:

- the Connors Arch;
- the Comet Platform (or Comet Ridge);
- the Collinsville Shelf;
- the Nebo Synclinorium and Folded Zone;
- the Duaringa Basin; and
- the Gogango Overfolded Zone.

Geomorphic processes within each of these zones have shaped the landscapes that can be seen within the two catchments today. The location of each of the six zones is shown in Figure 5.

The coastal ranges in the eastern part of the two catchments are associated with igneous rocks that form a structural high known as the **Connors Arch**. The arch is a broad simple ridge structure that existed prior to the formation of the Bowen Basin and has been subject to considerable uplift since Permian times (251 million years ago). In the north, it occurs as an uplifted granitic core associated with the Urannah Igneous Complex (CKg) while in the south it consists mainly of the Connors

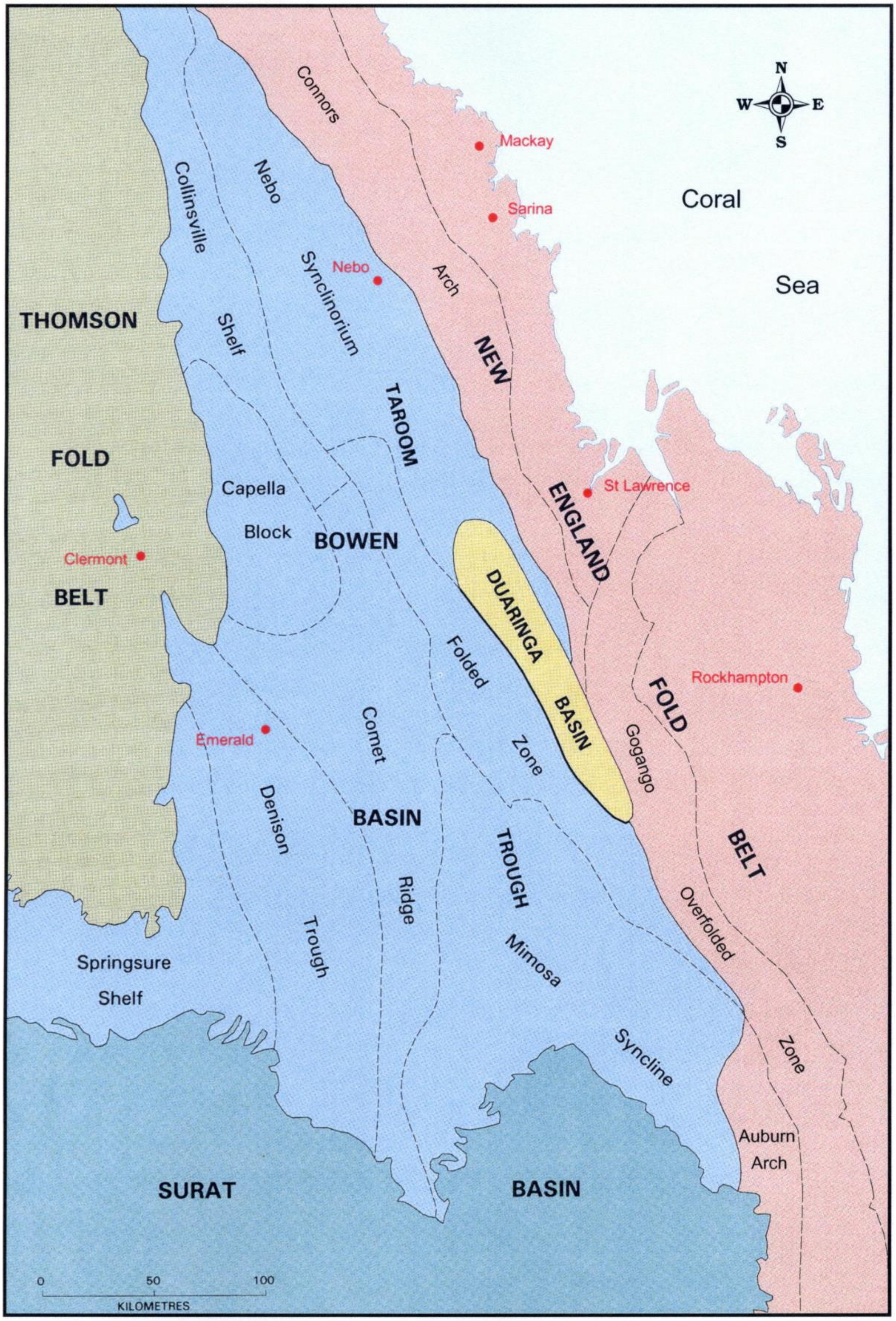


Figure 5. Geological structures within the Bowen Basin (Balfe *et al.* 1988)

Volcanics (DCo) and isolated intrusives. There appears to have been more uplift at the northern end, west of Sarina and Mackay (Staines and Koppe 1980). The Bowen Basin lies both to the east and west of these structures, but only areas west of the ranges are relevant to the Isaac–Connors and Mackenzie River catchments.

The Bowen Basin is a very large depositional structure comprising four main elements, namely the Nebo Synclinorium and Folded Zone, the Comet Platform and the Collinsville Shelf. The Nebo Synclinorium is the most significant and occupies the central and northern parts of the catchments, while the Comet Platform and Collinsville Shelf are located in the south-west and north-west of the catchments respectively (Hutton *et al.* 1998). Deposition within the Bowen Basin first began in the Early Permian nearly 300 million years ago.

The **Nebo Synclinorium** (geological depression) is the major structural unit within both catchments and occupies the majority of the catchment north from about 'Bombandy', near the Isaac River. It has undergone significant subsidence since formation and has a sedimentary sequence up to 6000 m thick. The sedimentary rocks in the Nebo Synclinorium are broadly folded due to tectonic activity, but have not been subject to the tight and complex folding associated with the adjacent Folded Zone. There is no evidence of widespread post depositional uplift within the structure, although local uplift, folding and metamorphism occurred following the emplacement of igneous intrusions in the Cretaceous and Tertiary Periods (Dickens and Malone 1973).

The adjacent **Folded Zone** is relatively narrow and lies along the western side of the Nebo Synclinorium, from the Valkyrie area south-east to Dingo. The Permian sedimentary rocks within this province are generally tightly folded about a north-westerly axis. The intensity of folding generally decreases from south to north and east to west and terminates at the boundary with the Comet Platform and Collinsville Shelf. This boundary occurs along the western edge of the folded zone and corresponds roughly with a line from 'Bombandy' to Bluff (on the Capricorn Highway). Tectonic activity associated with the Hunter–Bowen Orogeny (i.e. uplift of the Connors Arch) is most probably responsible for the folding (Staines and Koppe 1980).

Folded Permian sedimentary rocks are well exposed along the length of the Folded Zone, particularly in the Barwon Park area and further south towards Dingo. Folding is aligned in a general south-east to north-west direction and is responsible for rapid changes in surficial lithology and the development of complex soil and vegetation patterns. Vegetation patterns are often aligned in strips or swirls and form characteristic signatures on aerial photography and satellite imagery. Across large areas of both catchments however, unconsolidated Tertiary–Quaternary deposits cover the folded rocks and mask these effects.

The **Comet Platform** is a broad anticlinorium (geological ridge) lying along south-western parts of the two catchments between Comet and Dysart. It is separated from the folded zone by faulting. The Comet Platform merges into a similar structure termed the **Collinsville Shelf**, further north in the Isaac–Connors catchment between Dysart and Glenden. Sedimentary rocks in both structures dip gently to the east and are only very gently folded in comparison with the Nebo Synclinorium and Folded Zone.

By the end of the Triassic Period (205 million years ago), the main phases of sedimentation and deformation within the northern Bowen Basin were complete. The only depositional feature to have formed since Permian–Triassic times is the **Duaringa Basin**. This basin extends northwards through the Mackenzie River catchment and into the south-eastern end of the Isaac–Connors catchment, in the vicinity of the Junee tablelands. It has a sedimentary sequence over 1000 m thick, that has been superimposed within the Bowen Basin, as a result of faulting and subsidence. Deposition within the Duaringa Basin began approximately 60–70 million years ago at the beginning of the Tertiary Period.

The eastern edge of the Duaringa Basin lies adjacent to the Connors Arch in the north and the **Gogango Overfolded Zone** in the south. The distribution and extent of the Gogango Overfolded Zone is restricted to a small area of the Boomer Range that enters the south-eastern corner of the Mackenzie River catchment. It is associated predominantly with outcropping folded strata of the Back

Creek Group (Pb) and represents only a minor structural component within the Isaac–Connors and Mackenzie River catchments.

5.2 Geological history

5.2.1 Pre-Permian–Cretaceous history (>300–65 million years)

Devonian–Carboniferous volcanics

The oldest rocks in the two catchments are the **Connors Volcanics (DCo)** which are widespread in the Broadsound Range west of St Lawrence and to a lesser extent in the Connors and Boomer Ranges to the north and south. The Connors Volcanics (DCo) were the original structural unit within the Connors Arch and are older than 300 million years as they have been intruded by igneous bodies of at least this age. They span the Carboniferous Period (354–298 million years) and consist mainly of terrestrial volcanics (mostly massive acid to intermediate flows) which are silcified, jointed and intruded. They were extruded before the development of the Bowen Basin and higher parts were probably exposed as islands in the Early Permian sea. As the Bowen Basin formed, they provided the basement on which Early Permian volcanics and sediments were first laid down. Their present day structurally high position as resistant and moderately dissected rugged highlands within the Connors Arch is largely the result of uplift during Late Permian (270 million years ago) to Early Cretaceous (98 million years ago) times. Further detail is available in a recent paper by Hutton *et al.* (1999 b).

Carboniferous–Cretaceous intrusives

The Connors Volcanics (DCo) were extensively intruded in the northern end of the Connors Arch by the **Urannah Igneous Complex (CKg)**. This occurred over a long period of time from mid-Carboniferous (325 million years ago) to Early Cretaceous (125 million years ago) times. While the intrusive history of the Urannah Igneous Complex (CKg) is complicated, the majority of the intrusive activity occurred prior to the formation of the Bowen Basin (298 million years ago). As a result, the basal units of the Bowen Basin, the Lizzie Creek Volcanics (Pvl) and Carmila Beds (Pm) tend to overlie the Urannah Igneous Complex (CKg) along the western and eastern margins of the coastal ranges respectively. Rock types in the complex are mainly granitic, although localised dykes of intermediate rocks such as andesite and diorite also occur. The Urannah Igneous Complex (CKg) is widespread within the northern end of the coastal ranges and includes the Clarke, Pisgah and northern Connors Ranges, as well as the Whitehorse, Balaclava and Blue Mountains.

Further south in the Connors and Broadsound Ranges a number of smaller, more isolated **Carboniferous–Mesozoic (mostly pre-Permian) intrusions (CMzg)** intrude the Connors Volcanics (DCo). They are similar in lithology to the Urannah Igneous Complex (CKg) and may be related. Some intrusions are older than the Lizzie Creek Volcanics (Pvl) and Carmila Beds (Pm) and most were probably intruded prior to the formation of the Bowen Basin (298 million years ago). Others appear to be younger however, and may have been emplaced since the Permian (<251 million years ago). In general, these intrusions have been more easily weathered and stripped, relative to the surrounding Connors Volcanics (DCo), and form areas of gentle terrain within the rugged ranges. Rock types are predominantly granitic, although some intermediate (granodiorite) and basic (gabbro) intrusions also occur.

Permian volcanics

By Early Permian times (298 million years ago) deposition within the newly formed Bowen Basin had commenced. The **Lizzie Creek Volcanics (Pvl)** and **Collaroy Volcanics (Pvc)** which are predominantly mafic (i.e. andesitic to basaltic) and the **Carmila Beds (Pm)** which comprise acid volcanics and interbedded sediments accumulated to the west and east of the Connors Arch respectively. Initial deposition consisted mostly of terrestrial volcanics, which was followed by freshwater sedimentation, further volcanism and finally by marine sedimentation. The final stage occurred when the sea, which had apparently been east of the Connors Arch, transgressed (sea levels rose and flooded inland areas) westward into the Bowen Basin during the end of the volcanic cycle in the Early Permian (298–270 million years ago).

Permian sedimentary rocks

Deposition of sedimentary rocks within the Bowen Basin began with the predominantly marine **Back Creek Group (Pb)**, which commenced during the Early Permian (298–270 million years ago) and continued into the Late Permian (270–251 million years ago). Initially, thick sequences of predominantly marine mudstones and siltstones were deposited throughout most of the northern Bowen Basin, becoming thinner on the Comet Platform and Collinsville Shelf in the west. Throughout the Mid–Permian, a prolonged period of shallow marine deposition continued which produced predominantly quartzose sandstones and siltstones. This phase of sedimentation was initiated by accelerated sediment supply from the western and north-western hinterland of the basin. Where sediment supply exceeded subsidence around the margins of the basin occasional coal forming deltas developed, while in the rapidly subsiding central areas a shallow sea still existed.

Folding of the sedimentary rocks in some areas (e.g. Folded Zone, Gogango Overfolded Zone) has resulted in low grade metamorphism of the original mudstones and sandstones and produced rocks such as foliated mudstone and sandstone, slate, phyllite, schist and quartzite. These rocks were formerly mapped as the Rannes Beds (Pr) and are restricted to the Boomer Range, east of the lower Mackenzie River. They are now considered part of the Back Creek Group (Pb) (Withnall *et al.* 1998).

Shallow marine environments prevailed until the Late Permian (270–251 million years ago) when regression (sea level fall) of the shallow sea within the Bowen Basin commenced. Uplift and associated volcanic activity in the northern part of the Connors Arch at this time introduced an abundant supply of fresh volcanic sediment to the northern end of the basin. Sediment supply greatly exceeded subsidence rates and there was a rapid southward expansion of non-marine fluvial–deltaic (river delta) systems throughout the basin. The withdrawal of the sea to the south accompanied this change and, across the whole of the northern and central Bowen Basin, freshwater volcaniclastic sediments from the north were deposited. These formed the **Blackwater Group (Pw)**, which is the uppermost group within the Permian aged Bowen Basin deposits.

The sedimentary rocks of the Blackwater Group (Pw) were deposited in a changing system of deltas, river channels, braided streams, flood plains, lakes and swamps. Fluviatile (river), lacustrine (lake) and paludal (swampy) environments were widespread and a range of labile, lithic sandstones, calcareous sediments, siltstones and mudstones were laid down, as well as coal and abundant fossil wood. Deposition was greatest in the centre of the basin in the Nebo Synclinorium and Folded Zone where the sedimentary sequence is over 2000 m deep. Towards the margins of the basin on the Comet Platform and Collinsville Shelf thicknesses of only 300–600 m are recorded.

The climate in the Late Permian (270–251 million years ago) was cool and moist and high watertables were thought to be common in the fluvial and deltaic systems across the basin. These conditions favoured coal formation, particularly in the broad interfluve swamps (low lying areas between rivers) that occurred. During the final phase of Permian sedimentation, volcanolithic sandstones were being widely deposited by the south flowing streams and almost the entire Bowen Basin was occupied by coal forming environments. As a result, extensive coal seams accumulated during this period.

Calcite is abundant in the sedimentary rocks of the Blackwater Group (Pw) where it occurs either as a matrix or cement in calcareous sandstones and siltstones, or as a sandy or silty limestone. Dickens and Malone (1973) suggest the abundance of calcite in this environment is unusual. The sedimentary rocks of the Blackwater Group (Pw), particularly in the northern Bowen Basin, where calcite is most abundant, consist mainly of plagioclase grains and fragments of volcanic rock derived from a Late Permian volcanic provenance, probably within the Connors Arch. The calcite may have been derived from the same volcanic source, and was probably formed during diagenesis (consolidation and lithification) of the volcanic derived sediments. Some of the calcite may also have been derived from the Early Permian (298–270 million years ago) Lizzie Creek Volcanics, although the majority appears to have come from contemporaneous volcanism during the Late Permian (270–251 million years ago). Further detail on the history and stratigraphy of Permian sedimentation can be found in recent papers by Fielding *et al.* (1997) and Holcombe *et al.* (1997).

Triassic sedimentary rocks

Following the end of Permian sedimentation approximately 250 million years ago, the non-marine Triassic sedimentary rocks of the Rewan (Rr) and Clematis (Re) Groups were laid down. The Triassic sediments conformably overlie those of the Late Permian Blackwater Group (Pw). Both Triassic groups appear to have been deposited in meandering, mixed load river systems which flowed in much the same manner and direction as the streams that deposited the underlying Permian strata. They are however, devoid of the coal seams that characterise the underlying Blackwater Group (Pw). In the Rewan Group (Rr), which is the lowest Triassic sequence, very little fossil plant material of any description is preserved. Significant climate change from cool wet conditions in the Late Permian (270–251 million years ago) to markedly seasonal rainfall early in the Triassic Period (251–241 million years ago) is thought to have lowered watertables and increased oxidation. Slower subsidence rates relative to sediment supply following tectonic stabilisation of the basin at this time may have also contributed to the absence of plant fossils.

The **Rewan Group (Rr)** consists of red and green mudstones, siltstones and labile sandstones that were deposited in a predominantly fluvio-lacustrine (river and lake) environment. The red sediments are the most abundant with beds up to 30 m thick. They were apparently derived from the erosion of lateritic profiles that developed during post-Permian climatic changes.

The **Clematis Group (Re)** consists predominantly of mature quartzose sandstones that were deposited in shallow fluviatile (river) environments during a period when the intensity of tectonic activity associated with the Late Permian and Early Triassic (270–241 million years ago) was temporarily reduced. They contrast sharply with the underlying red brown mudstones and labile sandstones of the Rewan Group (Rr) and are responsible for familiar landmarks such as the Carborough, Kerlong and Burton Ranges in the north, and the Blackdown Tableland and Expedition and Shotover Ranges further south.

During the Middle to Late Triassic (241–205 million years ago) renewed tectonic activity took place, although probably not as vigorously as during the deposition of the Rewan Beds (Rr) in the Early Triassic (251–241 million years ago). As a result, the quartzose sandstones of the Clematis Group (Re) were succeeded by the fine grained, labile sediments of the **Moolayember Formation (Rm)**. The Moolayember Formation (Rm) was laid down in a predominantly fluvio–lacustrine (river/lake) environment although occasional incursions by the sea probably occurred. The reappearance of calcite as a matrix within the sandstones of the Moolayember Formation (Rm) separates them from those of the preceding Clematis Group (Re). The distribution of the Moolayember Formation (Rm) follows a similar pattern to that of the older Rewan Beds (Rr) suggesting conditions during deposition in the Late Triassic (230–205 million years ago) may have been similar to those in the Early Triassic (251–241 million years ago), albeit not as extreme. During the Late Triassic (230–205 million years ago) deposition within the Bowen Basin effectively ceased.

Cretaceous–Tertiary intrusives and volcanics

By the end of the Triassic Period (205 million years ago) the main phases of sedimentation and deformation within the northern Bowen Basin were complete. The principal post-Triassic events involved the emplacement of igneous intrusions both early and late in the Cretaceous Period (125 and 70 million years ago) and widespread volcanic activity during the Tertiary Period (mainly 35–20 million years ago). Generally thin but extensive non-marine sedimentation also occurred through much of the Tertiary Period and was at least partly contemporaneous with the volcanism. The events of the Tertiary Period are discussed in more detail in section 5.2.2.

Triassic deformation and folding (205 million years ago) was confined to the Early Cretaceous (125 million years ago) when local deformation associated with the emplacement of felsic (granite) to mafic (gabbro) igneous intrusions occurred. There is no evidence to suggest tectonic activity was involved in this process, as folding and metamorphism is not evident except in sediments immediately adjacent to larger intrusions such as the **Bundarra (Kgb) and Gotthardt (Kgg) Granodiorites** (Staines and Koppe 1980). The resistant hills and associated meta-sediments around Mt Flora–Mt Orange and Mt Gotthardt formed in this way and provide evidence of the localised nature of the intrusive activity during this phase.

More recent **undifferentiated Cretaceous–Tertiary intrusions and/or volcanics (Ki, K–Tv, Tp)** (<70 million years old) are mostly smaller and have had little effect on surrounding sediments. One of the most obvious examples is Middlemount and the associated series of minor trachyte dykes and sills that intrude the folded Permian sediments immediately to the west and north. Other examples occur at various locations along the eastern edge of the Bowen Basin from Clarke Creek to Collinsville, particularly around 'Barmount', Nebo, 'Homevale', 'Blenheim' and in the 'Havilah' area. These include well known landmarks such as Mt Fort Cooper, Mt Landsborough, Pine Mountain, Bar Mountain and Mt Bluffkin.

5.2.2 Tertiary–Quaternary history (65 million years to present day)

The following discussion outlines the Tertiary–Quaternary geomorphic history of the area and draws heavily on the conclusions of Galloway (1967b), Wright (1968b), Grimes (1980) and Stephenson *et al.* (1980). It begins when the majority of sedimentation, folding, uplift and igneous intrusive activity in the northern Bowen Basin ceased in the Late Cretaceous (approximately 70 million years ago). During the Tertiary and Quaternary Periods that followed (65 million years ago to present day) a number of distinct phases of landscape development are recognised.

Late Cretaceous–Early Tertiary erosion

Between the Late Cretaceous (98–65 million years ago) and Early Tertiary (65–55 million years ago) immense quantities of rock and sediment were removed from the catchments by erosion and some of the present day landforms first became apparent. Undulating lowlands formed on the relatively soft Permian sedimentary rocks (Blackwater Group (Pw)) in the east and centre of the catchments while low hills with strike ridges, escarpments and transverse valleys developed in western areas on the more resistant Permian quartzose sandstones (Back Creek Group (Pb)) of what is now the Cherwell Range. Areas of highly resistant Triassic quartz sandstone (Clematis Group (Re)) already formed upstanding hill masses which, in modified form, survive today as the Carborough, Kerlong and Burton Ranges. The drainage pattern was significantly different to that of present day however, with the Isaac River catchment apparently directed to the south-west rather than the south-east. Recent work in Hutton *et al.* (1998) in the Mt Coolon area provides further detail on drainage patterns in the Tertiary Period.

Early to Mid-Tertiary basalt

In the Early to Mid-Tertiary Period (55–24 million years ago) extensive basalt flows spread across the landscape, possibly covering almost the entire area. The majority of the basalt flows and associated acid differentiates (mostly volcanic plugs) were probably laid down during a number of phases between 30 and 20 million years ago (Dickens and Malone 1973), with intervening periods of erosion and deposition. The Tertiary aged intrusive rocks such as the volcanic plugs in the Peak Range were also emplaced during this period.

In the north-west (e.g. near 'Highland Plains'), the Early Tertiary land surface closely resembled that of today. Evidence for this comes from the presence of Early Tertiary basalt flows on low ground near the foot of the western escarpments of the Cherwell Range, indicating the escarpments existed prior to the flows and no more than one or two kilometres of scarp retreat has occurred since.

Post-basalt erosion

Following the extrusion of the basalts there was a period of severe and prolonged erosion during which much of the basaltic cover was removed from the catchment. Only occasional residuals, such as Anvil Peak and Lords Table Mountain which are protected by caps of resistant lava, give an indication of the original thickness of the basalt. Generally the basalt was either entirely removed or was reduced to an average thickness of <5–15 m. Erosion in many places during this stage exposed the Permian sediments underlying the basalt flows. The dominant structural features of the present landscape were apparent by the end of this phase with dissected plateaus and ranges on resistant Permian and Triassic quartz sandstones overlooking lowlands and plains on softer shales and basalts.

Mid-Tertiary deposition

A major period of deposition and sediment accumulation then commenced. While landscape erosion continued at similar levels to the previous stage, the resulting products were not removed from the catchments, but accumulated to form a uniform depositional cover across most of the area. The Tertiary sediments were deposited in rivers, flood plains and temporary lakes on a gently undulating, stable land surface similar in many respects to the present topography. Some of the lakes were formed after rivers and streams were dammed by basalt flows. The majority of the Tertiary sediments in the northern Bowen Basin are <100 m thick, although much greater thicknesses have accumulated in small faulted basins, such as the Duaringa Basin. Sediments in this basin are at least 1000 m thick and have been mapped separately as the **Duaringa Formation (Td)**.

With the exception of this formation, the remainder of the Tertiary sediments in the northern Bowen Basin have not been sub-divided and are mapped as an **undifferentiated Tertiary cover (Ta)**. For the purposes of this study, which is concerned primarily with the relationship between soil development and surficial geology, the Duaringa Formation (Td) has been lumped for convenience with the undifferentiated Tertiary cover (Ta).

While significant differences in stratigraphy are recognised between the deposits inside and outside the Duaringa Basin, these stratigraphic differences are not expressed in surficial geology and have had little influence on soil and landscape development. One of the main reasons for this is the intense weathering and alteration (i.e. Tertiary deep weathering) to which all deposits were subjected during the Mid-Tertiary. The thick laterite profiles that developed as a result of this weathering are very uniform and similar soils and landscapes have developed irrespective of location or stratigraphy.

The Tertiary sediments range from conglomerate and quartz sandstone through to sandy claystone, siltstone and clay. Variations in lithology reflect variations in source rock, position in the landscape and changes in weathering and erosion. Sandstone sources such as the Carborough Range tended to supply sandy sediments, while basalts and shales produced predominantly argillaceous (clayey) sediments. Gravelly deposits formed in the vicinity of the major rivers which already occupied approximately their present positions, while poorly sorted rubbles accumulated around scarps and ranges. Variations in the nature of weathering and erosion in the supply areas, presumably caused by climatic changes, are reflected in a commonly occurring sequence that grades upwards through the Tertiary sediments from argillaceous to sandy material. Exposed, elevated remnants of the Tertiary sediments reach a maximum thickness of about 80–100 m in the Junee Tablelands. Local elevations of 5–50 m are more common however. Frequently, the Tertiary sediments were laid down over earlier basalt flows, protecting them from further weathering and erosion (e.g. ‘May Downs’ area). They also underlie the basalt flows in many areas and interbedded sediments and basalt flows are common, indicating basalt extrusion and sediment deposition were contemporaneous during the Mid-Tertiary. Although the age of the Tertiary sediments is not known precisely, their stratigraphic relationship with the Tertiary basalts (particularly in the northern Bowen Basin) suggests they are at least as old as the basalts and often much younger. They range from Oligocene (34 million years ago) to as young as Miocene (5 million years ago) in age.

Although the Tertiary sediments have now been extensively dissected and stripped, intact remnants still survive as elevated plateaus in many areas. Examples occur north of Moranbah and around ‘Rookwood’, ‘Junee’ and ‘Kauiroo’.

Mid-Tertiary deep weathering

The term ‘deep weathering’ is used in this report to describe the intense weathering and extensive alteration that occurred in sediments and volcanics exposed during the Mid-Tertiary Period (34–24 million years ago). It is used in place of the recently defined term ‘intensely weathered’ described in Eggleton (2001), because of its established usage in the literature for Central Queensland and its widespread local acceptance. The two terms are synonymous within the Central Queensland context and the ‘intensely weathered’ definition of Eggleton (2001) is used to define the term ‘deeply weathered’ in the context of this study.

The intensity and prolonged nature of the weathering has meant significant changes in the chemical or mineralogical composition of the original rock have occurred (Bates and Jackson 1987). This alteration is often so complete it may be difficult or impossible to determine the original nature (mineralogy and rock fabric) of the deeply weathered substrate. Eggleton (2001) suggests only major parent rock features such as lithological changes or resistant veins (if present at all) are discernable in intensely weathered substrates (= ‘deeply weathered’ substrates). Typical mineralogy includes $\pm$ goethite/hematite/maghemite $\pm$ quartz $\pm$ kaolinite $\pm$ gibbsite, while high levels (>50%) of sesquioxides and negligible alkalis are present.

In the Isaac–Connors and Mackenzie River catchments, deep weathering has occurred extensively within the exposed Tertiary sediments and Tertiary basalts. The intensity and widespread uniformity of this weathering is evidenced today by the presence of similar laterite profiles on all Tertiary remnants across the northern Bowen Basin. The intact laterite profiles are typically thick with well developed mottled and pallid zones capped by indurated petroreticulite and to a lesser extent ferricrete or silcrete.

Layers within the ‘laterite profile’ may be either enriched or depleted (McDonald *et al.* 1990) and typically include:

- ferruginised or silicified zones where ferricrete or silcrete cappings are preserved;
- partially ferruginised or kaolinised zones where mottled zone materials such as petroreticulite or reticulite (Isbell 1996) are developed; and
- completely kaolinised zones that lack features associated with enrichment and occur as a thick pale or white kaolinitic clay layer usually at the base of the profile (i.e. pallid zone).

At the southern end of the Junee Tablelands, where very thick profiles are exposed in scarps (50–100 m high), partially altered, fine grained sandstones and siltstones outcrop around the base of the scarps and can be traced upwards as they grade into the pallid zone above. Where surficial deposits were only thin, the deep weathering process often penetrated through the Tertiary deposits into the underlying older rocks. While much of the deep weathering seems to have taken place after deposition of the Tertiary rocks, it is probable that intense weathering also preceded and accompanied their formation. Galloway (1967b) suggests the argillaceous nature of the Tertiary rocks implies at least some deep weathering of the source areas occurred prior to erosion and subsequent deposition.

The depth of the deep weathering profile varies widely from >25 m on deeply weathered sediments on the Junee Tablelands and deeply weathered basalt at ‘Red Hill’ in the north-west to <1–3 m on quartzose sandstone at the southern end of the Cherwell Range. Weathering resulted in leaching of elements such as phosphorus, calcium and magnesium from the rocks. Where deep weathering of basalts occurred, the leached material was often redeposited at depth and resulted in relatively enriched layers. Where these have been subsequently exposed and redistributed following stripping of the weathered profile, calcareous substrates and minor deposits of secondary carbonate or gypsum may occur. The redistribution of this calcareous material provides a possible explanation for the development of alkaline clays with free carbonates in the profile, on areas where acid clays within the basal layers of the Tertiary land surface would have initially been exposed following dissection and stripping.

Around 'Annandale', 'Saltbush Park' and Roper Creek, deep weathering has been associated with the development of a quartzose silcrete or 'billy' horizon within the deeply weathered profile, but across most of the catchments, silcrete formation appears mostly restricted to the base of Tertiary basalt flows (Galloway 1967b).

The combination of Tertiary erosion on higher areas, subsequent deposition on lowlands and deep weathering across the whole region resulted in the formation of a very gently undulating, stable landscape across the two catchments. Galloway (1967b) referred to this as the Tertiary Land Surface. Major valleys existed in much the same areas as those of today, but the drainage pattern was much more open. This land surface was erosional in higher parts, depositional in lower parts and was interrupted only by low ranges associated with the resistant Triassic and Permian quartz sandstones of the Carborough–Kerlong Ranges.

Late Tertiary erosion

During the Late Tertiary (24–1.8 million years ago), the gently undulating land surface and associated deeply weathered zone formed during the Mid-Tertiary were dissected by erosion. Significant remnants of the Tertiary Land Surface still remain across the two catchments. These remnants range from scarp bounded, elevated, intact plateaus through to dissected residuals, pediments and plains where the middle or lower parts of the intensely weathered zone are now exposed. Often stripping and erosion have cut right through the deeply weathered Tertiary sediments exposing older unweathered rocks lying below.

Where the surface is almost intact, it forms level to gently undulating, elevated plateaus (or tablelands) that rise 5 to 130 m above the adjacent valley floors. Typical examples include the Junee Tablelands and mesas to the north and west of 'Annandale'.

Where only the middle or lower parts of the deeply weathered profile remain, a very different level to gently undulating landscape of pediments, plains and low rises has developed, either from unconsolidated and reworked Tertiary material or from the exposed basal layers of the intensely weathered, remnant Tertiary surface. In erosional areas, where the Tertiary cover was relatively thin, complete stripping has often occurred and landscape development on the underlying older rocks has progressed. In depositional areas, unconsolidated sediments have covered and masked the underlying rocks (including stripped and dissected Tertiary sediments), and broad gentle landscapes with relatively uniform soils and vegetation have developed and currently occupy significant areas within the two catchments. The gently undulating plains north-east of Middlemount and between 'Bombandy' and 'Valkyrie' are good examples. Soil landscapes associated with these Late Tertiary unconsolidated sediments include the majority of brigalow and eucalypt land types developed during or since Brigalow Scheme III.

In erosional areas, where the Tertiary land surface has been removed entirely and unconsolidated sediments have not accumulated, little-weathered Permian sedimentary rocks and basalt (or andesite along the western edge of the Connors Arch) have been exposed. In these areas, lithologic variations in the exposed rock generally control soil development. It appears erosion during the Late Tertiary has only lightly stripped areas where fresh rocks were exposed, suggesting the present land surface is not dissimilar to the surface that existed prior to the deposition of the Tertiary sediments. In effect, there has been little overall movement of the area relative to the original erosional base level since that time.

The dissection of the deeply weathered land surface has been associated with considerable readjustment of the major drainage systems within the catchments. In the north, it appears there was an overall shift of drainage to the east. Headwaters of the Connors system (e.g. Bee Creek, Nebo Creek, etc.) appear to have encroached on the former Isaac drainage, which in turn has captured and diverted streams originally flowing west as part of the Suttor drainage. Dissection and downcutting within the Tertiary Land Surface during this period formed the precursors to the major modern drainage systems (i.e. the Isaac, Mackenzie and lower Connors Rivers).

Late Tertiary deposition

Renewed deposition is thought to have occurred in the Late Tertiary (5–1.8 million years ago), though it is difficult to distinguish the later sediments from the earlier sediments. The later deposits generally form fans and colluvial aprons around uplands or terraces along the major streams. The nature of the material in these deposits is generally related to that of the adjacent or upstream source areas. For example, streams sourcing sediments from sandstone ranges laid down extensive sandy fans during this period. Examples occur along Cherwell Creek west of its junction with the Isaac River and also within areas fringing the Carborough–Kerlong Ranges north of Coppabella and near ‘Burton Downs’. The Late Tertiary deposits were, in turn, subject to weathering and dissection though these processes were far less intense or prolonged than those which operated earlier in the Tertiary.

Quaternary alluviation

During the Quaternary Period (1.8 million years ago to present day), extensive alluviation occurred along the major streams that exist today and a complex landscape of levees, alluvial plains, flood plains, channels and back swamps developed. The higher parts of the alluvial plains are now stable with well-developed soil profiles and are generally above regular flood levels (>1:50 year flood). The lower parts are still subject to regular scouring, deposition and flooding. Two definite terraces are developed along the Mackenzie River and Upper Isaac River where the higher level may be as much as 10–20 m above the present river bed.

5.3 Modern geological landscapes

The **Isaac–Connors catchment** is elongated in a north-westerly direction and is clearly bounded in the east, north and south-west by mountains or hills. In the east, the catchment follows a distinct watershed along the summit of the coastal ranges from west of Mackay south to Marlborough. In the north-west between Moranbah and ‘Homevale’ the border is lower and less distinct and follows the crest of part of the Denham Range. Around ‘Homevale’, it consists of hills rising 50–100 m above the surrounding country which drop away to undulating plains and low tablelands on weathered basalt and Tertiary sediments north-west of Moranbah. The south-western border of the Isaac basin follows the watershed along the Peak Range. This range is characterised by a number of steep hills associated with Tertiary intrusions and volcanic plugs which rise 150–500 m above the surrounding undulating basalt plains and rises. The higher structures within the Peak Range have summits up to 900 m above sea level.

The **Mackenzie River catchment** is bounded in the east by similar coastal ranges to the Isaac–Connors catchment and in the south by dissected Tertiary landscapes south of Duaringa and Dingo and the Blackdown Tableland south of Bluff (on the Capricorn Highway). In the south-west, a gentle watershed associated with outcropping Permian sedimentary rocks divides it from the Nogoa and Comet catchments, north and south of Blackwater.

Within both catchments, the modern landscape consists mainly of plains and undulating lowlands from which rise a number of isolated ranges and hills. The plains and lowlands are between 130 and 330 m above sea level and are developed mainly on unconsolidated Tertiary–Quaternary sediments, Tertiary basalt and Permian sedimentary rocks.

A number of distinct ranges that are geographically separate and of different origins occur within the two catchments. These include;

- the coastal ranges and foothills (Clarke, Connors, Pisgah, Broadsound and Boomer Ranges and the Whitehorse, Balaclava, Blue and Pine Mountains) on resistant volcanics, (DCo, Pvl, Pvc, K–Tv), intrusives (Ckg, CMzg) and steeply dipping, folded and interbedded sedimentary rocks (Pm, Pb) in the east;
- the Cherwell, Harrow and Denham Ranges and foothills on resistant Permian sandstones (Pb) in the west and north-west;
- the Carborough, Kerlong and Burton Ranges, Mt Coxendean, Iffley Mountain, Coxens Peak (and the Redcliffe Tableland just north of the catchments) on resistant Triassic sandstones (Re) in the north;
- the Blackdown Tableland and Expedition and Shotover Ranges on resistant Triassic sandstones (Re) in the south.

Within the broad gentle valleys defined by these ranges (i.e. lowlands within the Isaac–Connors and Mackenzie River catchments) a number of gently undulating landscapes are developed on labile rocks and sediments. These include:

- intact and dissected remnants of the Tertiary Land Surface (Td, Ta)—including elevated intact plateaus, scarps, footslopes, pediments and dissected residuals;
- level to gently undulating plains and rises overlying labile rocks which include Permian andesites (Pvl), Permian and Triassic sedimentary rocks (Pw, Rr) and Tertiary basalts (Tb);
- level to gently undulating plains on unconsolidated Tertiary–Quaternary sediments (TQa, TQa_b); and
- Quaternary alluvial landscapes (Qa) associated with current drainage systems.

Scattered Cretaceous–Tertiary intrusive or volcanic structures (Kgb, Kgg, Ki, K–Tv, Tp) provide the only significant relief within the gentle lowlands that dominate the centre of the two catchments. Typical examples include Middlemount, Mt Bluffkin, Bar Mountain, Mt Flora–Mt Orange, Mt Fort Cooper and Mt Gotthardt, as well as a number of smaller structures in eastern areas between ‘Homevale’ and Clarke Creek, south-west of Middlemount and also in the Peak Range.

In all, nine modern geological landscapes are recognised within the Isaac–Connors and Mackenzie River catchments. The geology, landform and distribution of each landscape is discussed below, while the geological formations, codes and lithology associated with each is summarised in Table 8. In addition, the relationships between the geological formations in each landscape and the broadscale land systems mapped by CSIRO and QDPI within the two catchments are summarised in Table 9. The range of land systems that occur within each geological unit are listed, however the Capricornia Coast, Dawson–Fitzroy and Nogoa–Belyando studies are listed only where land systems not described in the Isaac–Comet study are mapped within the catchments.

Table 8. The geological formations, codes and lithology associated with each of the modern geological landscapes

Modern geological landscape	Formation name [1]	Code [1]	Lithology [1]	Examples/distribution
Devonian–Carboniferous volcanics	Connors Volcanics	DCo	Rhyolite, dacite, trachyte and andesite volcanics, dacitic and andesitic tuff and agglomerate, volcanic breccia and conglomerate, tuffaceous sandstone; extensively silicified, jointed, quartz veined.	Major unit within the coastal ranges, particularly the western side of the Broadsound Range from the Connors River south to Apis Creek. Outliers also occur west of Carmila and west of Eungella.
Carboniferous–Cretaceous intrusives	Urannah Igneous Complex	CKg	Granite–granodiorite–diorite complex with abundant acid, intermediate, and basic dykes. Includes hornblende–biotite adamellite and granodiorite, tonalite, hornblende diorite, quartz diorite, biotite granite, hornblende gabbro, hornblende microdiorite.	Major unit occupying the centre of the coastal ranges, north of Carmila. Includes the Clarke and Pisgah Ranges, Whitehorse Mountains, Balaclava Mountains, Blue Mountains and the northern end of the Connors Range.
	Undifferentiated Carboniferous–Mesozoic intrusions	CMzg	Adamellite, granite, granodiorite, gabbro	Relatively minor unit associated with occasional intrusions within the Connors and Broadsound Range, south of Carmila. Largest examples occur at 'Dacey', 'Burwood' and west of 'Tooloombah'.
Permian volcanics	Lizzie Creek Volcanics	Pvl	Andesite flows, sills, crystal and lithic tuffs, agglomerate, minor basalt and sediments.	Long sinuous unit that bounds the western flank of the coastal ranges, north of the Connors River. Generally only 10–15 km wide.
	Collaroy Volcanics	Pvc	Mafic volcanics (basalt), minor labile sandstone, volcanic breccia and fossiliferous limestone.	Extensive in the upper catchment of the Connors River.
Permian sedimentary rocks	Carmila Beds	Pm	Conglomerate, sandstone, siltstone, shale, rhyolitic, dacitic and andesitic volcanics, crystal and lithic tuff.	Extensive unit along the eastern side of the coastal ranges but mostly outside the catchments. Restricted to minor occurrences west of St Lawrence and around Apis Creek further south.
	Back Creek Group	Pb	Quartzose and sub-labile sandstone, quartz pebble conglomerate, micaceous siltstone, carbonaceous mudstone, calcareous sandstone and sandy coquinite. Minor deformed sedimentary rocks (slate, phyllite, interbedded volcanics) in the Boomer Range.	Major unit associated with the Denham, Cherwell and Harrow Ranges along the western catchment boundary between Tieri and Moranbah. Exposures also occur along the Marlborough–Sarina Road and around Apis Creek at the southern end of the coastal ranges.
	Blackwater Group	Pw	Volcanolithic and feldspathic sandstone, calcareous in places, siltstone, carbonaceous mudstone, coal, ashstone with plant remains, tuffaceous conglomerate.	Major unit within the Folded Zone between Dingo and the Isaac River. Extensive exposures also occur between 'Mt Stuart' and Comet in the south and between Nebo and Collinsville in the north.
Triassic sedimentary rocks	Rewan Group	Rr	Lithic sandstone, red and green mudstone, siltstone, conglomerate.	Widespread in the north of the Isaac–Connors catchment in areas surrounding the Carborough, Kerlong and Burton Ranges and further north to the Redcliffe Tableland. Examples are exposed on the Peak Downs Highway near 'Moorvale'.

Notes:

1. Formation names, codes and lithology descriptions follow those of the Bowen Basin Solid Geology 1:500 000 series geological map (1988). Exceptions are described in notes 2, 3 and 4.
2. Lithology description for the Moolayember Formation (Rm) comes from the Mt Coolon 1:250 000 series geological map (1964).
3. Codes and lithology descriptions for Cretaceous–Tertiary volcanics (K–Tv), Tertiary basalt (Tb) and Tertiary sediments (Td, Ta) follow those of the St Lawrence 1:250 000 series geological map (1970).
4. Codes and lithology descriptions for the remainder of the Tertiary–Quaternary cover have been adapated specifically for the Windeyers Hill study area and follow current naming conventions (L. Hutton *pers. comm.*, Exploration Promotion and Geological Survey, NR&M).

Table 8 (cont). The geological formations, codes and lithology associated with each of the modern geological landscapes

Modern geological landscape	Formation name [1]	Code [1]	Lithology [1]	Examples/distribution
Triassic sedimentary rocks (continued)	Clematis Group	Re	Quartz sandstone, feldspathic in places, conglomerate, mudstone, siltstone.	Major unit associated with the Carborough, Kerlong and Burton Ranges, Mt Coxendean, Coxens Peak and Iffly Mountain in the Isaac–Connors catchment, and the Expedition and Shotover Ranges in the Mackenzie River catchment.
	Moolayember Formation	Rm[2]	Micaceous lithic sandstone, calcareous in places and micaceous siltstone.	Minor unit restricted to valleys and lowlands within the Carborough and Shotover Ranges.
Cretaceous–Tertiary intrusives and volcanics	Bundarra Granodiorite	Kgb	Leucocratic biotite granodiorite, alkali granite, hornblende syenite.	Restricted to the granodiorite core within the ring of metamorphic hills located near 'Bundarra', at the northern end of the Fitzroy Developmental Road. Hills such as Mt Flora, Mt Orange and Mt Marion form part of the metamorphic aureole that surrounds the intrusive structure.
	Gotthardt Granodiorite	Kgg	Biotite–hornblende granodiorite, porphyritic microgranite.	Restricted to the Gotthardt Range immediately north-east of Lake Elphinstone. Represents a similar intrusive structure and associated metamorphosed hills to those described for the Bundarra Granodiorite.
	Undifferentiated intrusives	Ki	Trachyte, pyroclastics, quartz porphyry, rhyolite aplite, granite, syenite, granodiorite, diorite, gabbro.	Small to medium sized laccoliths, sills and dykes associated with folding along the north-eastern boundary of the Nebo Synclinorium between Nebo and Collinsville and along the western boundary of the Folded Zone near Middlemount. Examples include Mt Fort Cooper and Middlemount.
	Undifferentiated volcanics	K–Tv[3]	Trachyte, rhyolite, dacite and andesite flows and pyroclastics, plugs and dykes	Relatively minor scattered flows, plugs and dykes within and immediately west of the Connors, Broadsound, Pisgah and Clarke Ranges from Marlborough north to Eungella. Examples include Mt Bluffkin, Bar Mountain, Pine Mountain, Mt Landsborough, Mt Britton and the Diamond Cliffs.
	Peak Range Volcanics	Tp	Alkaline trachyte and rhyolite plugs, domes and flows	Distinctive plugs, domes and flows associated with the Peak Range along the western catchment boundary. Structures occur in two main locations to the east and north-east of Clermont. Examples include Scotts Peak, Mt McArthur, Wolfang Peak, Fletchers Awl and Mt Saddleback.

Notes:

1. Formation names, codes and lithology descriptions follow those of the Bowen Basin Solid Geology 1:500 000 series geological map (1988). Exceptions are described in notes 2, 3 and 4.
2. Lithology description for the Moolayember Formation (Rm) comes from the Mt Coolon 1:250 000 series geological map (1964).
3. Codes and lithology descriptions for Cretaceous–Tertiary volcanics (K–Tv), Tertiary basalt (Tb) and Tertiary sediments (Td, Ta) follow those of the St Lawrence 1:250 000 series geological map (1970).
4. Codes and lithology descriptions for the remainder of the Tertiary–Quaternary cover have been adapated specifically for the Windeyers Hill study area and follow current naming conventions (L. Hutton *pers. comm.*, Exploration Promotion and Geological Survey, NR&M).

Table 8 (cont). The geological formations, codes and lithology associated with each of the modern geological landscapes

Modern geological landscape	Formation name [1]	Code [1]	Lithology [1]	Examples/distribution
Deeply weathered Tertiary sediments	Duaringa Formation, undifferentiated Tertiary sediments	Td, Ta[3]	Tertiary sediments (Td, Ta) fully exposed to Tertiary deep weathering; includes petroreticulite, reticulite, ferricrete, silcrete, ferruginised and kaolinised zones. Underlying sediments include sandstone, claystone, siltstone, conglomerate, oil shale, brown coal, sandstone breccia and minor basalt.	Deeply weathered plateaus and dissected residuals occur extensively throughout both catchments. Typical examples include areas around Dingo and Duaringa, 'Kaiuroo', the Junee Tablelands, 'Rookwood' and areas around Coppabella and north-east of Moranbah.
Deeply weathered Tertiary basalt		Tb_d[4]	Tertiary basalt (Tb) fully exposed to Tertiary deep weathering; includes petroreticulite, reticulite, ferruginised and kaolinised zones.	Restricted to residuals and dissected plateau remnants associated with deeply weathered Tertiary basalt flows. Examples include Windeyers Hill in the 'May Downs' area, Red Hill Bluff north of Moranbah and unnamed rises in the Barmount area.
Fresh or partially altered Tertiary basalt		Tb[3], Tb_a[4]	Fresh or partially altered basalt and/or olivine basalt flows and plugs, collapsed basalt sheets, minor trachyte, rhyolite or gabbro flows, plugs and dykes, minor pyroclastics, minor sediments. Partially altered basalts occur where flows were only partially exposed to Tertiary deep weathering.	Mostly gently undulating plains and rises. Locations within the catchments include 'May Downs', 'Barmount', 'Grosvenor Downs', 'Broadlea', 'Red Hill'–'Dabin' area, 'Oxford Downs' and minor occurrences along the eastern side of the Peak Range. Basalt flows are also widespread to the north and west of the catchments.
Unconsolidated Tertiary–Quaternary sediments	(Sedimentary origins)	TQa[4]	Sand, soil, reworked Tertiary clay, gravel, scree, 'billy' and/or lateritic gravel, duricrust, reworked duricrust.	Widespread. Level to gently undulating plains and low rises associated with relict alluvium or stripped and reworked Tertiary sediments.
	(Basaltic/andesitic origins)	TQa_b[4]	Clay, marl, fine sandy basaltic/andesitic sediments, calcareous sediments, sand lenses, gravel beds, calcrete.	Mostly relict alluvial fans and lacustrine (lake) or fluvial (stream) deposits derived from basaltic or andesitic provenance areas. Significant deposits occur east of Dysart (along the Golden Mile Road) and also north, south and immediately west of Nebo.
Quaternary alluvium		Qa	Alluvial sand, silt, mud, clay, gravel.	Widespread along all current depositional drainage systems (including upper tributaries, lower tributaries and flood plains) within both catchments.

Notes:

1. Formation names, codes and lithology descriptions follow those of the Bowen Basin Solid Geology 1:500 000 series geological map (1988). Exceptions are described in notes 2, 3 and 4.
2. Lithology description for the Moolayember Formation (Rm) comes from the Mt Coolon 1:250 000 series geological map (1964).
3. Codes and lithology descriptions for Cretaceous–Tertiary volcanics (K–Tv), Tertiary basalt (Tb) and Tertiary sediments (Td, Ta) follow those of the St Lawrence 1:250 000 series geological map (1970).
4. Codes and lithology descriptions for the remainder of the Tertiary–Quaternary cover have been adapated specifically for the Windeyers Hill study area and follow current naming conventions (L. Hutton *pers. comm.*, Exploration Promotion and Geological Survey, NR&M).

Table 9. Land systems associated with each of the modern geological landscapes

Modern geological landscape	Formation name	Code	Land system study[1]	Associated land system(s)
Devonian–Carboniferous volcanics	Connors Volcanics	DCo	Capricornia Coast	Croydon (Cd); minor Berserker (Bk), Chalmers (Ch), Macksford (Mc), Wheeler (Wh)
			Dawson–Fitzroy	Hillmore (Hm)
Carboniferous–Cretaceous intrusives	Urannah Igneous Complex	CKg	Nebo[2]	Blue Mountain (BM), Glensfield (GI), Murray (Mu), Strathdee (Sd)
	Undifferentiated intrusives	CMzg	Capricornia Coast	Glassford (north) (Gf)
Permian volcanics	Lizzie Creek Volcanics	Pvl	Isaac–Comet	Britton (Br), Nebo (N)
			Capricornia Coast	Croydon (Cd), Macksford (Mc); minor Artillery (Ar)
	Collaroy Volcanics	Pvc	Capricornia Coast	Artillery (Ar), Macksford (Mc)
Permian sedimentary rocks	Carmila beds	Pm	Capricornia Coast	Croydon (Cd), Killarney (Kl); minor Belmont (Bt), Macksford (Mc)
			Nebo	Bolingbroke (BK), Jordan (Jo)
	Back Creek Group	Pb	Isaac–Comet	Carborough (Ca), Cotherstone (Cr), Daunia (Da) in eastern areas, Durrandella (Du), Hillalong (Hi); minor Percy (P) on metamorphic aureoles
			Dawson–Fitzroy	Boomer (Bm), Irving (I), Malakoff (Mf), Mourangie (Me), Rosewood (Rd)
			Capricornia Coast	Kooltandra (Kt), Rosewood (Rd); minor Moore (Mo)
	Blackwater Group	Pw	Isaac–Comet	Barwon (Bw), Daunia (Da), Girrah (Gi)
Triassic sedimentary rocks	Rewan Group	Rr	Isaac–Comet	Cotherstone (Cr), Daunia (Da), Hillalong (Hi)
	Clematis Group	Re	Isaac–Comet	Carborough (Ca); minor Planet (Pt)
	Moolayember Formation	Rm	Isaac–Comet	Planet (Pt)
Cretaceous–Tertiary intrusives and volcanics	Bundarra Granodiorite	Kgb	Isaac–Comet	Monteagle (Mo) on the stripped and weathered core, Percy (P) on metamorphic aureole
	Gotthardt Granodiorite	Kgg	Isaac–Comet	Percy (P)
	Undifferentiated intrusives	Ki	Isaac–Comet	Percy (P)
	Undifferentiated volcanics	K–Tv	Isaac–Comet	Britton (Br), Percy (P)
	Peak Range Volcanics	Tp	Isaac–Comet	Percy (P)
Deeply weathered Tertiary sediments	Duaringa Formation	Td	Isaac–Comet	Durrandella (Du), Junee (J)
			Dawson–Fitzroy	Duaringa (Du), Kaiuroo (Ko), Melbadale (Mb), Perch (P), Wooroonah (Wo)
	Undifferentiated Tertiary sediments	Ta	Isaac–Comet	Durrandella (Du), Junee (J)
Deeply weathered Tertiary basalt		Tb_d	Isaac–Comet	Bedourie (Be), Durrandella (Du)
Fresh or partially altered Tertiary basalt		Tb	Isaac–Comet	Oxford (O), Racecourse (R), Waterford (Wa)
		Tb_a	Isaac–Comet	Oxford (O), Racecourse (R)
Unconsolidated Tertiary–Quaternary sediments	(Sedimentary origins)	TQa	Isaac–Comet	Blackwater (Bl), Humboldt (Hu), Monteagle (Mo), Somerby (So)
			Dawson–Fitzroy	Highworth (H), Thomby (T)
	(Basaltic/andesitic origins)	TQa_b	Isaac–Comet	Blackwater (Bl), Girrah (Gi), Nebo (N)
Quaternary alluvium		Qa	Isaac–Comet	Comet (Ct), Connors (Co), Funnel (Fu)
			Dawson–Fitzroy	Coolibah (C), Coreen (Ce), Dingo (Dn)
			Capricornia Coast	Coolibah (C), Coreen (Ce)

Notes: 1. The Capricornia Coast, Dawson–Fitzroy and Nogoa–Belyando studies are listed only when land systems not described in the Isaac–Comet study are mapped within the catchments.
2. Unpublished information from the report *Land Systems of the Nebo Area, Central Queensland* (Shields 2002).

5.3.1 Ranges and foothills associated with resistant Devonian–Cretaceous volcanics, intrusives and interbedded sedimentary rocks (DCo, Ckg, CMzg, Pvl, Pvc, Pm, Pb, K–Tv)

The eastern watershed of the Isaac–Connors and Mackenzie River catchments is bounded by a continuous line of predominantly igneous ranges (volcanic and intrusive) that divide coastal areas to the east from the inland sections of the Fitzroy Basin to the west. The ranges form part of the structural province known as the Connors Arch and are known locally as the coastal ranges. The arch forms a structural high that has been subject to significant uplift and intrusion between Early Permian and Early Cretaceous times (290–125 million years ago). The ranges are geologically diverse and encompass a number of geological units of different ages and origins, which include:

- Connors Volcanics (DCo);
- Urannah Igneous Complex (CKg);
- Undifferentiated Carboniferous–Mezozoic intrusions (CMzg);
- Lizzie Creek Volcanics (Pvl) and Collaroy Volcanics (Pvc);
- Carmila Beds (Pm); and
- Back Creek Group (Pb).

The **Connors Volcanics (DCo)** are Late Devonian–Carboniferous (350–298 million years ago) in age, and represent the oldest unit within the coastal ranges. They are a major spatial and structural unit within the ranges and occupy a significant area along the western side of the Broadsound Range from the Connors River south to Apis Creek. Isolated blocks also occur in the northern end of the Boomer Range, the Connors Range west of Carmila and the Clarke Range west of Eungella. Recent mapping has resulted in the sub-division of the Connors Volcanics (DCo) and the recognition of several phases of volcanism (Hutton *et al.* 1999a). Lithology is predominantly massive, acid to intermediate volcanics as well as associated agglomerate, breccia, tuff and minor sediments. Basic flows are locally abundant in places. Most of the volcanics are extremely altered and resistant to erosion and develop moderately dissected, rugged hills and mountains.

The **Urannah Igneous Complex (Ckg)** intruded the Connors Volcanics (DCo) in a number of phases from the Mid–Carboniferous through to the Early Cretaceous (325–125 million years ago). It is the dominant unit through the centre of the coastal ranges, north of Carmila and includes the Clarke, Pisgah and northern Connors Ranges as well as the Whitehorse Mountains, Balaclava Mountains and Blue Mountains. It is predominantly a granite–granodiorite–diorite complex with abundant acid, intermediate and basic dykes. Steep hills and rugged mountains (e.g. Blue Mountain area) are developed on resistant lithologies within the complex, while extensive areas of undulating to rolling rises and low hills have formed where less resistant intrusives have been weathered and dissected.

Undifferentiated Carboniferous–Mesozoic intrusions (CMzg) occur irregularly within the Connors and Broadsound Ranges south of Carmila and also in the Urannah Igneous Complex (Ckg) to the north. The intrusions have generally been stripped and deflated and occupy less rugged lowlands relative to the adjacent resistant volcanics. Lithology may be complex or simple (i.e. consists of just one rock type), and includes adamellite, granite, granodiorite or gabbro, with trachyte and dolerite dykes. Examples occur in the vicinity of ‘Dacey’ (e.g. Dacey Granite) (Hutton *et al.* 1999a) in the upper catchment of the Connors River, and also near ‘Burwood’ and ‘Tooloombah’ further south in the Broadsound Range. Further detail can be found in recent work by Hutton *et al.* (1999a).

The **Lizzie Creek Volcanics (Pvl)** occupy a narrow continuous belt trending north-northwest along the western flank of the coastal ranges, from the Broadsound Range north to Collinsville. The unit is generally only 10–15 km wide. Areas that were formerly mapped as the Lizzie Creek unit in the upper catchment of the Connors River are now mapped as the slightly younger **Collaroy Volcanics (Pvc)**. The Collaroy unit occupies a raised basin which is floored by mafic volcanics and flanked by hills of the Connors Volcanics (DCo) (Hutton *et al.* 1999a), from ‘Undercliff’ south to ‘Dacey’. Lithology in both units is predominantly mafic (i.e. andesitic to basaltic) although minor acid volcanics and sediments also occur. The Lizzie Creek and Collaroy Volcanics (Pvl, Pvc) and the Carmila Beds (Pm) are probably lateral equivalents, but differ significantly in terms of dominant lithology. The Lizzie Creek and Collaroy units are mostly mafic, while the Carmila Beds (Pm) are predominantly acid volcanics and interbedded sediments. Landforms associated with the Lizzie Creek Volcanics (Pvl) include undulating to rolling rises and low hills within the foothills along the western boundary of the ranges to steep hills and rugged mountains in the main ranges to the east. Topography within the Collaroy Volcanics (Pvc) is generally more subdued. Further detail on changes to the volcanic units in the Connors Arch can be found in Hutton *et al.* (1999a).

The **Carmila Beds (Pm)** occupy large areas along the eastern side of the coastal ranges. They are however associated mainly with coastal catchments. The distribution of this unit within the Isaac–Connors and Mackenzie River catchments is restricted to minor occurrences west of St Lawrence and surrounding of the southern end of the Broadsound Range, between the Sarina–Marlborough Road and Leura. Lithology consists predominantly of acid volcanics and interbedded sediments which may vary enormously depending on location. Topography often reflects the varied lithology and structure within the beds and landforms range from undulating depositional basins within the centre of the Connors Range, west of St Lawrence, through to prominent cuestas (asymmetric ridge) and strike ridges on steeply dipping beds along the eastern edge of the coastal ranges (particularly the Connors and northern Broadsound Ranges). In areas surrounding the southern end of the Broadsound Range topography is more subdued and undulating to rolling low hills are developed. These lie adjacent to the rugged hills and mountains on Connors Volcanics (DCo) that form the main range in that area.

Sedimentary rocks of the **Back Creek Group (Pb)** (formerly Rannes Beds (Pr)) are restricted to the Boomer Range, immediately east of the lower Mackenzie River, and represent only a minor unit within the coastal ranges (Withnall *et al.* 1998). The formation has been strongly folded and metamorphosed and lithology ranges from mudstone, slate, phyllite, siltstone, sandstone, conglomerate and limestone through to acid to intermediate volcanics and tuff. Landforms developed on this unit are predominantly rugged and include rolling to steep hills and mountains associated with the main Boomer Range. Around the base of the range and in areas that have been more dissected however, gently undulating to undulating rises and low hills are developed.

5.3.2 Ranges and foothills associated with resistant Permian–Triassic sedimentary rocks (Pb, Re, Rm)

The ranges that bound the northern, western and southern watersheds of the two catchments are developed predominantly on resistant sandstones of Permian or Triassic age (298–205 million years ago). Lithology within the ranges is relatively uniform irrespective of age or location. Geological units within this landscape include:

- Back Creek Group (Pb);
- Clematis Group (Re); and
- Moolayember Formation (Rm).

Along the western boundary of the catchments, the **Denham, Cherwell** and **Harrow Ranges** which occur as a north-westerly trending, elongated range of rugged hills, plateaus and dissected valleys are developed on the resistant Permian sandstones of the **Back Creek Group (Pb)**. The majority of the ranges are formed from flat lying or gently folded quartzose sandstones, although fine grained micaceous sandstones and shales are also associated in less rugged areas. Many of the softer sedimentary rocks within the ranges have been deeply weathered and altered to some extent while the quartzose sandstones are less affected. The relief and amount of dissection decrease at the southern end of the ranges where less resistant rocks are more common and undulating to rolling hills have developed around the headwaters of German Creek, south-west of Middlemount.

Distinct foothills that lie at the base of these ranges are developed on lithic and micaceous sandstones from the same group. The foothills run up the eastern and western flanks of the Cherwell Range from Tieri in the south to Moranbah in the north. They occur mostly as gently undulating to rolling rises and low hills. Slopes range from 1 to 20%, while local relief is commonly 10–50 m above the plains and rises that lie adjacent. Similar foothills are also developed around the base of the Carborough Range and across the northern watershed of the catchment to 'Homevale'.

In the north of the catchments the rugged and dissected **Carborough, Kerlong** and **Burton Ranges** are developed on resistant Triassic quartzose sandstones of the **Clematis Group (Re)**. Similar ranges are also developed at the southern end of the Mackenzie River catchment and include the **Expedition** and **Shotover Ranges** and the **Blackdown Tableland**. In all cases the ranges are similar to those of the Denham, Cherwell and Harrow Ranges which are developed on resistant Back Creek sandstones (Pb). Other examples that now occur as outliers away from the main ranges include Iffly Mountain, Mount Coxendean and Coxens Peak in the centre of the Isaac–Connors catchment and the Redcliffe Tableland which lies to the north.

Surficial exposures of the Triassic sedimentary rocks of the **Moolayember Formation (Rm)** are mostly associated with areas of subdued topography within the rugged sandstone ranges of the Clematis Group (Re). Within the Isaac–Connors and Mackenzie River catchments it occurs only in the valley that separates the Carborough and Kerlong Ranges, north of 'Annandale'. Because the sandstones associated with the Moolayember Formation (Rm) are less resistant than those of the adjacent Clematis Group (Re), preferential dissection has produced sandy lowlands in the area between the two ranges. Other examples outside the catchments occur within the Redcliffe Tableland in the north and the Expedition and Shotover Ranges in the south. Lithology includes micaceous or lithic sandstone and micaceous siltstone, which may be calcareous in places. Landforms within the valley range from gently undulating to rolling rises and low hills with slopes <15%.

5.3.3 Hills and rises associated with resistant Cretaceous–Tertiary intrusives and volcanics (Kgb, Kgg, Ki, K–Tv, Tp)

This landscape comprises a range of intrusive and extrusive (i.e. volcanic) structures and flows of Cretaceous–Tertiary age. While a significant number of individual structures are recognised within the two catchments the distribution and spatial extent of the landscape as a whole is very limited. Most occur in isolation and form striking features that rise above the surrounding gently undulating lowlands. Five geological units are recognised which include:

- Bundarra Granodiorite (Kgb);
- Gotthardt Granodiorite (Kgg);
- Undifferentiated intrusives (Ki);
- Undifferentiated volcanics (K–Tv); and
- Peak Range Volcanics (Tp).

The intrusives are predominantly granite, granodiorite, syenite, diorite or gabbro, while the volcanics range from rhyolite, dacite and trachyte through to andesite. Lithology specific to each unit as well as examples and distribution are detailed in Table 8.

Landforms are mostly rugged and range from undulating to precipitous rises, low hills, hills or mountains depending on size and elevation of the igneous structure. Most extensive are the hills and ranges developed on resistant metamorphic aureoles surrounding the Bundarra (Kgb) and Gotthardt (Kgg) Granodiorites, which rise 50–300 m above the adjacent plains. The Bundarra Granodiorite (Kgb) lies at the northern end of the Fitzroy Developmental Road and is surrounded by a ring of steep hills (e.g. Mt Orange, Mt Flora, Mt Marion etc.), while the rugged Gotthardt Range, east of Lake Elphinstone, surrounds the Gotthardt Granodiorite (Kgg).

Undifferentiated Cretaceous intrusives (Ki) occur in the north-east of the Isaac–Connors catchment between Nebo and ‘Exevale’ (e.g. Mt Fort Cooper), and also west of ‘Daunia’ and south-west of Middlemount. The size and elevation of these intrusive structures is variable and ranges from undulating low rises with local relief <20 m near German Creek to steep mountains such as Middlemount (local relief 100 m) and Mt Fort Cooper (local relief 300 m).

Along the inland side of the coastal ranges a series of isolated, undifferentiated volcanic flows, plugs and dykes are developed. These lie within and immediately west of the Connors, Broadsound, Pisgah and Clarke Ranges, from Marlborough north to Eungella. Landforms associated with these volcanic structures are similar to those of the intrusives and range from undulating or rolling rises and low hills (e.g. Mt Bluffkin with local relief 60 m) to steep hills and mountains (e.g. Bar Mountain with local relief of 150 m or Pine Mountain with local relief 400 m).

Similar structures also occur along the western watershed of the Isaac–Connors catchment where the distinctive volcanic plugs, domes and flows associated with the Peak Range Volcanics (Tp) are developed. These structures occur predominantly as individual volcanic plugs with steep to precipitous slopes (>30%) and local relief 200–450 m. Examples within the catchment occur mainly at the south-eastern end of the Peak Range and include Scotts Peak, Roper Peak and other unnamed hills. Similar structures are also developed on Tertiary basalts (Tb) in the area. Examples of basaltic structures within the catchments include Lords Table Mountain, the Hodgson Range, Gilberts Dome, Browns Peak, Eastern Peak and Mt Demipique.

5.3.4 Plateaus and dissected residuals associated with deeply weathered Tertiary sediments or basalt (Td, Ta, Tb_d)

Tertiary sediments were originally widespread as a gently undulating uniform land surface across almost the entire catchment, but occur now only as dissected residuals (gentle to steep rises and low hills) or scarp bounded tablelands. The sediments were originally laid down as fluviatile (streambed) and lacustrine (lake and swamp) deposits and the distribution of the **Tertiary Land Surface** during deposition appears to have been controlled by the ranges in the east (coastal ranges), west (Denham, Cherwell and Harrow Ranges) and south (Expedition and Shotover Ranges) of the basin.

Maximum development of the Tertiary sediments occurs in the Duaringa Basin which has been mapped as a separate formation, the **Duaringa Formation (Td)**, which has a sedimentary sequence over 1000 m deep. Outside the Duaringa Basin the thickness of the **undifferentiated Tertiary sediments (Ta)** is mostly <100–200 m. Basalt sheets are interbedded with the sediments in places and probably dammed the drainage at the time, producing lakes in which the sediments were deposited. Elsewhere, the basalt overlies the sediments. Extensive deep weathering and lateritisation took place during the Tertiary Period and thick laterite profiles developed on the flat-lying, weakly consolidated Tertiary sediments. The laterite profiles are often capped by resistant, indurated petroreticulite, which has helped to preserve the Tertiary landforms from stripping and dissection. Unlateritised Tertiary sediments are generally poorly exposed and consist of sandy gravel, pebbly quartz sandstone, argillaceous sandstone, siltstone, claystone and conglomerate.

Dissection and erosion of the **Tertiary Land Surface** during the late Tertiary period has resulted in a number of different landscapes depending on the degree of stripping and the lithology and degree of alteration of the sediments exposed. Remnants of the original Tertiary surface are preserved only on intact plateaus that rise up 5–100 m above the surrounding plains. Examples include extensive plateaus near ‘Kauiroo’ and ‘Junee’ and smaller plateaus near ‘Bombandy’, ‘Rookwood’, ‘Iffley’, ‘Annandale’ and north of Moranbah.

Dissected Tertiary residuals are widespread throughout both catchments and vary enormously depending on the degree of stripping that has occurred. The most significant examples occur immediately north and south of Dingo–Duaringa area where shallow dissection of the Tertiary surface has resulted in the formation of an undulating landscape of lateritic plains and rises. Further north around Middlemount, residuals are scattered widely across the landscape and range from completely dissected remnants with almost no elevation to steep rocky rises and low hills with similar elevations to the intact plateaus but without a distinct plateau surface. Similar residuals also occur around the upper reaches of the Mackenzie River north of Comet, in the area around 'Saltbush Park' and to the north and east of Moranbah.

Where basalt flows were surficial during Tertiary deep weathering, alteration of the exposed basalts resulted in the formation of deeply weathered substrates similar to those developed on Tertiary sediments (e.g. reticulite, petroreticulite, ferruginised and pallid zones). The degree of alteration was not constant in the basalts however, and was dependent on the length of exposure and the depth and thickness of the flow relative to the deep weathering front. Late Tertiary dissection and stripping has exposed a range of basaltic substrates which grade from deeply weathered to partially altered to fresh basalts. Landscape development on the deeply weathered basalts (reticulite, petroreticulite) is very similar to that on deeply weathered sediments and is included in this section. Landscape development on partially altered or fresh basalts differs significantly however and is described in section 5.3.7.

Exposures of **deeply weathered basalts (Tb_d)** are relatively minor within the two catchments and are restricted to dissected residuals such as Windeyers Hill in the 'May Downs' area, Red Hill Bluff north of Moranbah and unnamed rises in the 'Barmount' area. All exposures represent dissected plateau remnants which may or may not be scarp bounded, depending on the degree of dissection. Most remnants have stripped surfaces that are gently undulating to undulating (mostly <5%). Scarps, where developed, are rolling to precipitous (10–>100%) and local relief is normally <30 m.

5.3.5 Lowlands associated with labile Permian volcanics (Pvl)

While the majority of exposures of **Lizzie Creek Volcanics (Pvl)** are associated with rugged hills and mountains along the western flank of the coastal ranges, an undulating landscape of foothills and lowlands with more subdued topography also occurs. Landforms are predominantly gently undulating to undulating plains and rises or occasional low hills at the base of the ranges. The landscape is developed *in situ* on andesitic volcanics which tend to interfinger with Permian sedimentary rocks (Pb) and unconsolidated sediments (TQa, TQa_b, Qa) along the edge of the Lizzie Creek unit. Slopes are mostly 1–5%, with local relief 10–30 m, or occasionally up to 50 m in the steeper foothills. Lithology is predominantly fine to coarse grained, andesitic volcanics, which may grade to basic volcanics, such as basalt, in some areas. Deposits of secondary carbonate (e.g. marl or calcrete beds) also occur and are probably sourced from the weathering and breakdown of andesites in the catchment. The distribution of the andesitic lowlands is restricted to a narrow zone immediately west of the coastal ranges, from 'Macksford' north to Collinsville.

5.3.6 Lowlands associated with labile Permian–Triassic sedimentary rocks (Pw, Rr)

In the centre of both catchments large expanses of gently undulating plains and low rises dominate the landscape. Surficial deposits of Tertiary–Quaternary sediments cover large areas of these lowlands and obscure the underlying Permian sedimentary rocks. In areas where significant folding has occurred however, the tilted and folded strata of the Late Permian **Blackwater Group (Pw)** are often exposed. Because of the labile nature of these rocks, planation and stripping during the Late Tertiary has reduced the folded surface to a gently undulating landscape of plains and low rises. Slopes are mostly 1–3% and local relief is <30 m.

Outcropping strata in these areas are often strike aligned and form distinctive groved or striped soil landscapes characterised by rapidly changing lithology, soils and vegetation. Typical examples occur along the Fitzroy Developmental Road between Dingo and the Isaac River, and also in the 'Mt Stuart'–'Girrah' area and between 'Barwon Park' and Middlemount. Folding in north-eastern areas of the Isaac–Connors catchment has produced similar landscapes near 'Homevale' and 'Blenheim', and immediately west of Mt Orange near 'Daunia'.

The **Rewan Group (Rr)** are the oldest unit in the Triassic sedimentary sequence and unconformably overlie the sedimentary rocks of the Permian Blackwater Group (Pw). The largest exposures surround the Carborough, Kerlong and Burton Ranges at the northern end of the Isaac–Connors catchment. These continue outside the catchment and are widespread around the Redcliffe Tableland, which lies to the north. Lesser exposures within the catchments occur in the Hail Creek area north of Nebo and around the Blackdown Tableland at the southern end of the Mackenzie River catchment. Typical examples of the 'red beds' associated with this unit can be seen in road cuttings on the Peak Downs Highway near the Carborough Range. Lithology is predominantly red-brown and green mudstones which are both characteristic and abundant, with beds up to 30 m thick. Interbeds of green or grey-green siltstone, lithic or feldspathic sandstone and calcareous sediments also occur. The 'red beds' are most likely non-marine, shallow water deposits that were subject to intermittent exposure. They appear to have accumulated under strongly oxidising conditions associated with significant global climate change at the end of the Permian (251 million years ago) (Malone *et al.* 1969). The labile nature of the mudstones and shales of the Rewan Beds (Rr) mean soils and landscapes are similar to those developed on the Blackwater Group (Pw), namely level to gently undulating plains and low rises with slopes <5% and local relief <30 m.

5.3.7 Lowlands associated with fresh or partially altered Tertiary basalt (Tb, Tb_a)

Landscapes developed on partially altered or fresh basalts (exposed following Late Tertiary dissection and stripping) occur in a number of distinct locations across the two catchments. These include 'May Downs', 'Barmount', 'Grosvenor Downs', 'Broadlea', 'Red Hill', 'Dabin', 'Oxford Downs' (north to Mt Landsborough) and areas on the eastern side of the Peak Range that lie within the Isaac–Connors catchment. Basalt flows are also widespread immediately north of the catchments, between 'Homevale' and 'Exevale' and from 'Wards Well' north to 'Weetalaba'.

Geographical variation in the degree of alteration and dissection at each location means the proportion of partially altered basalt versus fresh basalt is not constant. Some locations such as 'Oxford Downs' are developed predominantly on fresh basalts, while in others such as the 'May Downs' area at the northern end of the Junee Tablelands, a complex landscape on deeply weathered, partially altered and fresh basalts is developed.

In general, landscapes on partially altered or fresh basalts occupy gently undulating to undulating pediments, plains and rises. Field evidence suggests the partially altered basalts are probably basal layers within the deeply weathered profile and lie in between the deeply weathered basalt above and the fresh basalt below. Partially altered basalts usually occupy positions mid-way in the catenary sequence and occur on footslopes and pediments below mesas, or on remnant crests and rises within gently undulating fresh basalt landscapes. In contrast, fresh basalts are usually lower in the catenary sequence and are normally devoid of features associated with deeply weathered or partially altered basalts. Landforms on fresh basalts are normally gently undulating plains and rises. In both cases, slopes are <1–5% and local relief is <10–30 m.

5.3.8 Lowlands associated with unconsolidated Tertiary–Quaternary sediments (TQa, TQa_b)

Undifferentiated, unconsolidated sediments of Tertiary–Quaternary age mantle much of the gently undulating lowlands across the centre of the two catchments. These sediments vary in thickness from only 1 or 2 m on colluvial slopes to depths >100 m in older valleys. On average, deposits are 10–60 m thick. The sediments represent depositional material that has been transported at some stage either as alluvium or colluvium. The deposits bear no relationship with current streams or underlying rocks and include relict alluvial deposits, reworked alluvium/colluvium and reworked basal layers of the Tertiary Land Surface.

The sediments are derived predominantly from stripping and dissection of Late Tertiary landscapes. The nature of the material at any particular location is dependent on the provenance areas from which it was sourced. Two main groups of unconsolidated Tertiary–Quaternary sediments are recognised, namely:

- those derived from the stripping and dissection of the predominantly sedimentary Tertiary Land Surface (TQa); or
- those derived from the stripping and dissection of basaltic or andesitic landscapes exposed during the Late Tertiary (TQa_b).

The sedimentary derived TQa sediments are widespread and are associated with level to gently undulating landscapes (slopes <3% and local relief <30 m) throughout the centre of both catchments. Typical examples include the poplar box and brigalow landscapes in areas around Coppabella, 'Valkyrie', Middlemount and north of Blackwater. Lithology within the TQa sediments includes sand, soil, reworked Tertiary clay, gravel, scree, 'billy' and/or lateritic gravel and reworked duricrust.

The basaltic or andesitic TQa_b sediments are restricted to depositional areas downstream from basaltic or andesitic provenance areas. Similar level to gently undulating landscapes are developed but the distribution and spatial extent is more restricted. Lithology is also very different and includes clay, marl, fine sandy basaltic or andesitic sediments, calcareous sediments, sand lenses, gravel beds and calcrete.

Drilling logs from BHP in the vicinity of the Golden Mile Road confirm there is 10–40 m (mostly 25–35 m) of Tertiary–Quaternary cover overlying consolidated Permian sandstones and siltstones. The logs indicate significant layering is present within the unconsolidated sediments. A general sequence is described which includes soil material for the first 1–2 m overlying fine grained, basaltic derived, powdery sandy clay sediments up to 5 m thick. These in turn overlie varying thicknesses of sand or clay lenses, marl beds, secondary carbonate deposits, gravel beds and stone layers.

In nearly all locations, soils are directly underlain by powdery basaltic sediments. The basaltic sediments are mostly labile and weather readily to predominantly montmorillonitic or mixed mineralogy clays. Clay activity ratios vary, being 0.5–0.8 in texture contrast soils, 0.6–0.9 in clay soils that are not strongly self-mulching, 1.1–1.3 in strongly self-mulching clays and >1.3 in most of the powdery, unweathered, fine sandy clay substrates. Ratios >1.0 are normally associated with weathered basaltic material (R Shaw *pers. comm.*). In most cases, ratios in the subsoil are similar to those in the underlying substrate, indicating profiles are both basaltic in origin and have developed *in situ*. The unconsolidated sediments are distinctly layered and exhibit well developed local cross bedding. They are indicative of a deltaic environment where stream channels were migrating rapidly both north and south about a predominantly east or north-easterly axis. Channel migration left a series of graded sediments (coarse to fine) across the flood plains that were subsequently buried and preserved as cross-bedded deposits.

There is a strong geomorphic relationship between the lithology of the deposited sediments and the basaltic provenance areas in the upper catchments of these creeks. The basaltic landscape lies at the eastern edge of the Central Highlands, along the watershed of the Peak Range. Lying between these basalts and the unconsolidated deposits are resistant quartzose sandstones of the Cherwell Range. These ranges are only partially dissected and largely unstripped and have contributed relatively little to the unconsolidated deposits compared with the more easily weathered and erodible basalt landscapes. While the majority of the depositional sequence comprises either basaltic derived fine grained sediments or clay and calcareous deposits, the presence of cross-bedded coarse sand lenses and gravel beds containing both sandstone and basaltic coarse fragments provides an insight into the nature of the depositional environment.

Waterworn surface gravels including subrounded to rounded basalt, quartzose sandstone and quartz pebbles are indicative of the basaltic derived, TQa_b sediments between Phillips Creek in the north and Scott Creek in the south. They provide a useful field marker to identify the sediments of basaltic origins and differentiate them from the adjacent, widespread sedimentary derived TQa deposits. These gravels were particularly useful in identifying the margins of the TQa_b landscape where the two landscapes intermix. The most extensive examples occur in the cropping areas east of Dysart and in areas to the north and west of Nebo. Localised deposits are also developed along the western footslopes of the coastal ranges (i.e. along the Sarina–Marlborough Road from 'Tierawoomba' to Clarke Creek) and in the 'Barmount' area.

5.3.9 Alluvial landscapes (Qa)

Quaternary alluvium is defined for the purpose of this study as alluvial deposits associated with current streams. During the Quaternary Period (1.8 million years ago to present day) extensive alluviation (deposition of alluvial sediments) occurred along all streams within the catchments, creating a complex landscape of channels, levees, alluvial plains, flood plains, scroll plains, backplains, back swamps, sand ridges and occasional terraces, depending on the size, location and flood regime of the stream. Along the Isaac, Mackenzie and lower Connor Rivers and their tributaries, Quaternary alluvial systems often lie adjacent to older gently undulating plains on unconsolidated Tertiary–Quaternary sediments. In many areas the two landscapes appear to merge, but subtle elevation differences (1–5 m) normally exist because of dissection associated with modern streams.

Local relief is generally <9 m and landforms are classified as level to gently undulating plains (slopes 0–3%). Higher parts of many alluvial plains, such as elevated levees and sand ridges, are now stable and generally above regular flood levels (>1 in 50 years average recurrence interval (ARI)). Lower parts, particularly along the Isaac and Mackenzie Rivers and major tributaries are still subject to scouring, deposition and regular flooding (>1 in 1 to 1 in 10 years ARI). Lithology includes alluvial sand, silt, mud, clay and gravel. The thickness of the alluvial deposits is variable and is dependent largely on stream size, age and position in the catchment. Malone *et al.* (1969) suggest most alluvium is 10–30 m thick.

6. SOIL LANDSCAPES

Soil complexity in any landscape can be simplified by grouping soil profile classes according to geology and landform. Soils grouped in this way are referred to as soil landscapes. In general, soil landscapes are lithologically based and soil development shares common origins from a defined set of similar or related underlying substrates. The development of individual soil profile classes within such landscapes is a function of local variation in substrate lithology, substrate alteration, substrate age, position in the landscape and drainage. Soil landscapes are a useful concept because they simplify landscape complexity and provide a convenient structure for the logical presentation of soil and vegetation information.

Of the nine modern geological landscapes (sections 5.3.1–5.3.9) identified within the Isaac–Connors and Mackenzie River catchments in Chapter 5, seven are recognised within the Windeyers Hill study area according to geological formation, surficial lithology and degree of alteration. The surficial distribution and extent of these landscapes within the study area is illustrated in Figure 6.

Landscapes from sections 5.3.4 and 5.3.8 have been further sub-divided to separate deeply weathered Tertiary sediments (Td, Ta) from deeply weathered Tertiary basalts (Tb_d), and unconsolidated Tertiary–Quaternary sediments of sedimentary origins (TQa) from those of basaltic origins (TQa_b) respectively. The only other change has involved recombining landscapes from section 5.3.2 (Ranges and foothills associated with resistant Permian sandstones of the Back Creek Group (Pb)) and section 5.3.6 (Lowlands developed on labile Permian sedimentary rocks of the Blackwater Group (Pw)). Both units have been lumped into one geological landscape within the study area because of lithologic–soil overlap between the two groups. The combined unit provides greater flexibility by allowing soils from either landscape to be mapped on a lithological basis first and then by landform. Differences in landform effectively separate the units at the next level on the map reference (see also Table 11). The final geological landscapes identified within the study area include:

- **Permian sedimentary rocks (Pb, Pw) – Sections 5.3.2, 5.3.6**
- **Coarse grained, acid to intermediate, Cretaceous igneous rocks (Ki) – Section 5.3.3**
- **Deeply weathered Tertiary sediments (Td, Ta) – Section 5.3.4**
- **Deeply weathered Tertiary basalt (Tb_d) – Section 5.3.4**
- **Fresh or partially altered Tertiary basalt (Tb, Tb_a) – Section 5.3.7**
- **Unconsolidated Tertiary–Quaternary sediments sourced from sedimentary landscapes (TQa) – Section 5.3.8**
- **Unconsolidated Tertiary–Quaternary sediments sourced from basaltic landscapes (TQa_b) – Section 5.3.8**
- **Quaternary alluvium (Qa) – Section 5.3.9**

The group or formation name(s), code(s) and lithology of each of the geological landscapes within the study area are summarised in Table 10. Landscapes described in sections 5.3.1 and 5.3.5 are not represented as they do not occur within the study area.

Within the eight geological landscapes recognised within the study area, 24 soil landscapes were described. These group the soils according to lithology and landscape position. By definition, the soil profile classes in each soil landscape share similarities in parent material, substrate age, degree of alteration and landscape position. Most soil landscapes have been further sub-divided on the basis of dominant vegetation, either eucalypt, brigalow or *Acacia* (other than brigalow). The discussion that follows provides an overview of these groups and the factors controlling soil formation and soil distribution in each case. In particular, the relationships that exist between individual soil profile classes and the lithology, landscape position and vegetation with which they are associated in each geological landscape is explored.

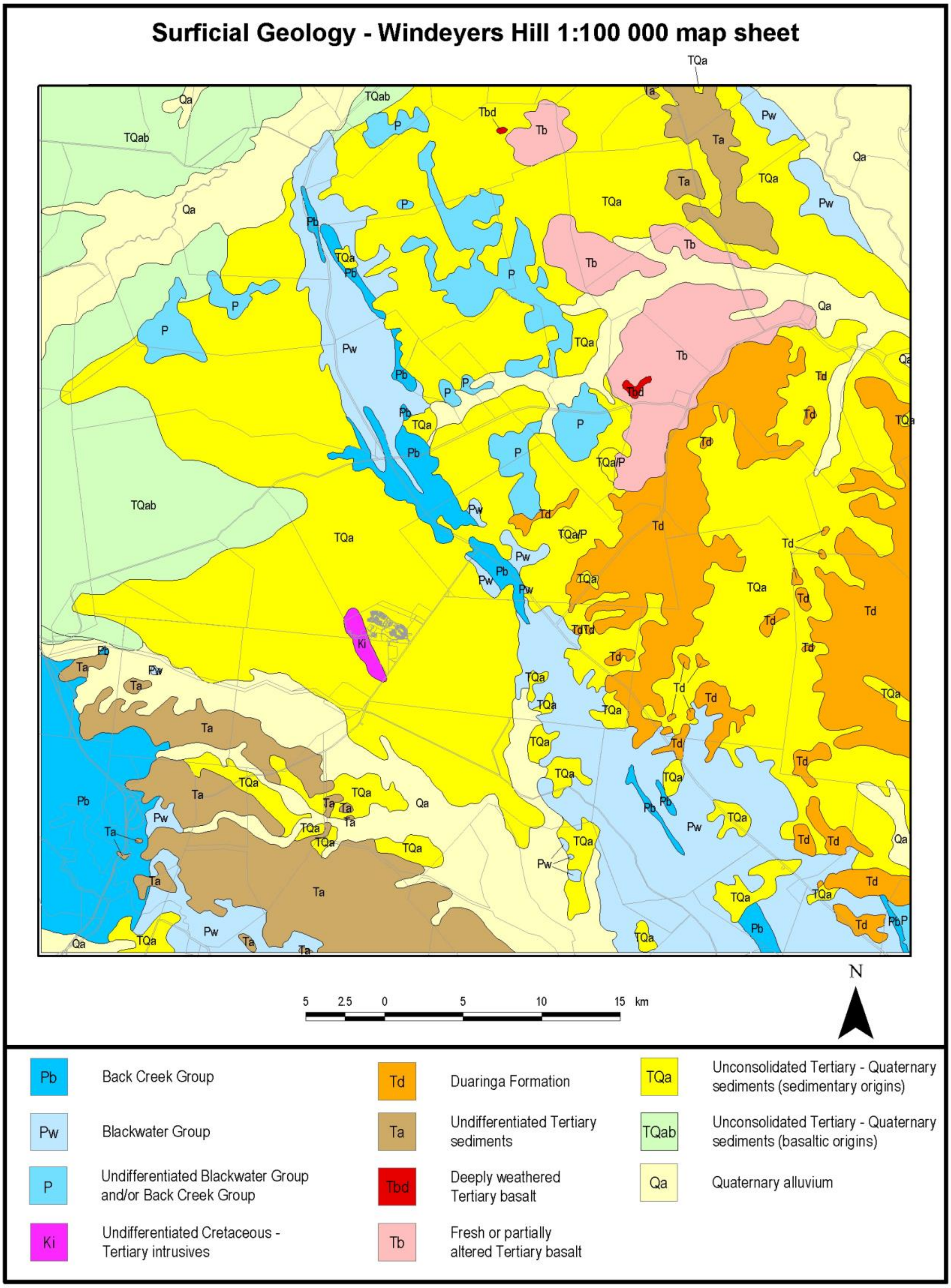


Figure 6. Surficial geology of the Windeyers Hill study area (adapted from the 1:250 000 Geological Series mapping, Saint Lawrence Sheet SF 55–12, Malone (1970))

Table 10. Surficial geology of the Windeyers Hill study area (after Balfe *et al.* 1988, Malone *et al.* 1964, Malone 1970)

Modern geological landscape/ map code	Formation name	Lithology
Permian sedimentary rocks		
Pb	Back Creek Group	Quartzose and sub-labile sandstone, quartz pebble conglomerate, micaceous siltstone, carbonaceous mudstone, calcareous sandstone, sandy coquinite.
Pw	Blackwater Group	Volcanolithic and feldspathic sandstone, calcareous in places, siltstone, carbonaceous mudstone, coal, ashstone with plant remains, tuffaceous conglomerate.
P	Undifferentiated Blackwater Group and/or Back Creek Group	Folded and interbedded lithologies from both groups.
Cretaceous–Tertiary intrusives and volcanics		
Ki	Undifferentiated intrusives	Trachyte, trachy–syenite, syenite.
Deeply weathered Tertiary sediments		
Td Ta	Duaringa Formation, undifferentiated Tertiary sediments	Tertiary sediments (Td, Ta) fully exposed to Tertiary deep weathering; includes petroreticulite, reticulite, ferricrete, silcrete, ferruginised and kaolinised zones. Underlying sediments include sandstone, claystone, siltstone, conglomerate, minor basalt.
Deeply weathered Tertiary basalt		
Tb_d	Undescribed	Tertiary basalt (Tb) fully exposed to Tertiary deep weathering; includes petroreticulite, reticulite, ferruginised and kaolinised zones.
Fresh or partially altered Tertiary basalt		
Tb Tb_a	Undescribed	Fresh or partially altered olivine basalt flows, minor plugs, minor pyroclastics, minor sediments. Partially altered basalts occur where flows were only partially exposed to Tertiary deep weathering.
Unconsolidated Tertiary–Quaternary sediments		
TQa	(Sedimentary origins)	Sand, soil, reworked Tertiary clay, gravel, scree, 'billy' and/or lateritic gravel, duricrust, reworked duricrust.
TQa_b	(Basaltic origins)	Clay, marl, fine sandy basaltic/andesitic sediments, calcareous sediments, sand lenses, gravel beds, calcrete.
Quaternary alluvium		
Qa	Undescribed	Alluvial sand, silt, mud, clay, gravel.

The soil landscapes identified within the study area (in order of substrate age from oldest to youngest), the soil profile classes (including concept and classification) and the dominant vegetation associations that occur in each landscape are listed in Table 11. The spatial extent of each geological landscape, soil landscape and individual soil profile class within the study area, both in terms of absolute area (ha) and as a percentage of the total study, is presented in Table 12. Discussion of the parent material, landscape position, distinguishing profile features, important physical and chemical characteristics (e.g. salinity, sodicity, acidity) and associated vegetation for each of the 69 soils follows in the text below. Correlation of the soil profile classes at a scale of 1:100 000 with the equivalent conceptual land system units from the broad scale CSIRO Isaac–Comet land system (1:500 000) mapping is presented in Table 13.

(DNR 1997) defines the term salinity simply as the presence (or concentration) of salts in solution. Throughout this report and particularly in the discussion that follows (Chapters 6 and 8), it refers specifically to the concentration of soluble salts in the soil profile (i.e. in the soil solution). Soluble salts in the soil are sourced either from additions of cyclic salt from the atmosphere (i.e. ocean salts in rainfall) or from salts released during weathering of underlying substrates. Whether or not inherent salt loads have accumulated in a soil is a function of the long term hydrologic equilibrium that has operated. The size and shape of a soil salinity profile (i.e. soluble salt concentration with depth) reflects this equilibrium and provides valuable information about the hydrologic characteristics in a particular soil landscape.

Further detail on landscape characteristics, vegetation, profile morphology and analytical data for each soil profile class is presented in Appendices 2, 3, 4, 5 and 6 and is summarised in Chapter 8 of this report.

6.1 Soil landscapes on Permian sedimentary rocks (Pb, Pw)

6.1.1 Landscape development

Permian age sandstones, siltstones, mudstones and shales of the Back Creek (Pb) and Blackwater (Pw) Groups outcrop across much of the study area. The Back Creek Group (Pb) consists of Early Permian (298–270 million years ago) sedimentary rocks, predominantly marine, quartzose, lithic or micaceous sandstones, which are associated with undulating to rolling rises and low hills on the Comet Platform in the south-west of the study area. In contrast, the sedimentary rocks of the Blackwater Group (Pw) are Late Permian (270–251 million years ago) in age, and consist predominantly of freshwater, feldspathic and volcanolithic labile sandstones, siltstones, mudstones and shales. The freshwater sedimentary rocks are often calcareous and the presence of fossil wood is characteristic of some beds. Within the study area, they are predominantly folded and outcrop extensively where the Folded Zone crosses the area from the south-east to the north-west. They are less resistant than the Back Creek (Pb) sandstones and are associated with gently undulating plains and rises that form a local highpoint along which the Dingo–Mt Flora Beef Road was surveyed.

The extent and distribution of soils within the Permian landscape is controlled by the lithology and pattern of exposure of the outcropping sedimentary beds. Soils are developed *in situ* from fresh sedimentary rocks that have been exposed and in turn stripped following the dissection and removal of the Tertiary Land Surface during the Late Tertiary Period (1.8–24 million years ago). The pattern of outcrop and exposure within the Permian sedimentary rocks is directly related to the dip and strike of the individual beds and whether or not they are folded. Sedimentary rocks exposed in the centre of the study area lie within the Folded Zone. Typically, they are tightly folded with fold axes that either lie parallel or occur as elongate domes and basins. Following initial exposure, the folded surface was significantly stripped and planed back to a gently undulating surface. This process removed the upper sections of the folds so that outcropping sedimentary beds follow parallel lines or occur as a series of elongate swirls or loops. Folded sediments also occur in eastern areas but are rarely exposed because of Tertiary or Quaternary cover.

Table 11. The concept and classification of the soil profile classes and associated vegetation in each geological landscape

	Soil name	Soil concept [1]	Australian Soil Classification [2]	Dominant vegetation association(s) [3]
SOILS DERIVED FROM PERMIAN SEDIMENTARY ROCKS (Pb, Pw)				
Eucalypt [3] or *Acacia* [3] Vegetation				
	Undulating rises to steep hills and dissected plateaus			
Cw	**Cherwell**	A shallow to moderately deep, stony, loose, acid, black or brown, uniform coarse sand over quartzose sandstone from 0.05–1.0 m.	Leptic Rudosol	Queensland peppermint (VA25), Lemon-scented gum (VA31), Lancewood (VA3) or Rosewood (VA2) in steeper areas; Long-fruited bloodwood (VA15) or Eucalypts with shrubby teatree (VA13) on gentler slopes.
Mw	**Maywin**	A shallow, sporadically bleached, acid, sand to clay loam (0.25–0.5 m) on steeper slopes grading to a moderately deep, sandy to clay loamy surfaced, conspicuously or sporadically bleached, acid, mottled, grey texture contrast soil on gentler slopes over partially altered quartzose or micaceous sandstone, siltstone or shale from 0.5–1.1 m.	Grey Kurosol Leptic Tenosol	Eucalypts with shrubby teatree (VA13), Narrow-leaved ironbark (VA12), Lemon-scented gum (VA31) or Queensland peppermint (VA25).
Eucalypt Vegetation				
	Gently undulating rises to undulating low hills			
Hf	**Heyford**	A sandy surfaced, conspicuously bleached, gravelly, alkaline, mottled, brown, sodic texture contrast soil with coarse columnar structure over micaceous or lithic sandstone from 0.6–1.1 m.	Brown Sodosol	Poplar box (VA20) or Eucalypts with bull oak (VA32); occasionally Poplar box–ironbark (VA34) or Narrow-leaved ironbark (VA12).
	Gently undulating plains and rises			
Ad	**Adeline**	A hard setting, loamy or clay loamy surfaced, sporadically or conspicuously bleached, alkaline, brown or black, sodic texture contrast soil over labile sandstone, siltstone or shale from 0.6–1.2 m.	Brown or Black Sodosol	Poplar box (VA20) or Poplar box–ironbark (VA34); occasionally Narrow-leaved ironbark (VA12) or Silver-leaved ironbark (VA17).
Cc	**Carlo**	A hard setting or firm pedal, alkaline, black, brown or red non-cracking clay over marl or labile, fine grained calcareous sedimentary rocks from 0.3–1.2 m.	Black, Brown or Red Dermosol	Ironbark–bloodwood–ghost gum (VA43); occasionally Mountain coolibah (VA19), Silver-leaved ironbark (VA17), Poplar box–ironbark (VA34) or Poplar box (VA20).
Em	**Emoh**	A firm or hard setting, sandy surfaced, conspicuously bleached, alkaline, mottled, brown or grey, sodic texture contrast soil with coarse columnar structure over lithic sandstone from 0.5–1.3 m.	Brown or Grey Sodosol	Shrubby poplar box (VA7) or Poplar box (VA20); occasionally Poplar box–ironbark (VA34).
Ms	**Mt Stuart**	A strongly self-mulching, alkaline, black cracking clay with linear or lattice gilgai (VI 0.05–0.15 m) over marl or labile, fine grained calcareous sedimentary rocks or feldspathic sandstone from 0.7–1.3 m.	*Mound* - Black Vertosol *Depression* - Black Vertosol	Ironbark–bloodwood–ghost gum (VA43), Mountain coolibah (VA19), *Bothriochloa* grassland (VA27) or Queensland bluegrass downs (VA28).
Rn	**Red-one**	A hard setting, loamy or clay loamy surfaced, alkaline, red, non-sodic texture contrast soil over lithic, feldspathic or calcareous sandstone, siltstone or shale from 0.4–0.8 m.	Red Chromosol	Silver-leaved ironbark (VA17), Narrow-leaved ironbark (VA12) or Ironbark–bloodwood–ghost gum (VA43); occasionally Poplar box–ironbark (VA34) or Poplar box (VA20).

Table 11 (cont). The concept and classification of the soil profile classes and associated vegetation in each geological landscape

	Soil name	Soil concept [1]	Australian Soil Classification [2]	Dominant vegetation association(s) [3]
Brigalow [3] Vegetation				
	Gently undulating plains and rises			
Bu	**Burradoo**	A hard setting or firm pedal, alkaline, brown or black non-cracking to cracking clay over labile sandstone, siltstone or shale from 0.6–1.2 m.	Brown or Black Dermosol Brown or Black Vertosol	Brigalow (VA1) or Brigalow with shrubs (VA8); occasionally Brigalow–Dawson gum (VA5).
BuZp	**Burradoo sodic phase**	A very hard setting, saline, sodic version of the Burradoo (Bu) soil over acid clay or fine grained marine sedimentary rocks from 0.7–>1.5 m.	Grey, Brown or Black Vertosol Grey, Brown or Black Dermosol	Brigalow (VA1); occasionally Blackwood (VA37) or Brigalow–blackwood (VA4).
Fr	**Farlane**	A strongly developed melonhole gilgai complex (VI 0.5–1.2 m) with: • a firm pedal or weakly to moderately self-mulching, alkaline, grey or brown, sodic cracking clay on mounds; and • a weakly self-mulching, acid, grey, sodic cracking clay in depressions; over strongly structured, acid clay or fine grained marine sedimentary rocks from 0.8–>1.5 m.	*Mound* - Grey or Brown Vertosol *Depression* - Grey Vertosol	Brigalow with shrubs (VA8) or Brigalow (VA1).
Ss	**Stateschool**	A hard setting, clay loamy surfaced, sporadically bleached, alkaline, brown or black, sodic texture contrast soil over labile sandstone, siltstone or shale from 0.5–1.2 m.	Brown or Black Sodosol	Brigalow–Dawson gum (VA5) or Brigalow (VA1); occasionally Dawson gum (VA10), Shrubby poplar box (VA7), Brigalow with shrubs (VA8) or Belah (VA9).
Tn	**Ternallum**	A strongly self-mulching, alkaline, black cracking clay over marl or labile, fine grained calcareous sedimentary rocks or feldspathic sandstone from 0.7–1.3 m.	Black Vertosol	Brigalow with shrubs (VA8) or Brigalow (VA1); occasionally Belah (VA9).
Ty	**Tiny**	A firm pedal or weakly to strongly self-mulching, alkaline, black or grey cracking clay, frequently with normal gilgai (VI 0.1–0.3 m), over strongly structured, acid clay or labile sandstone, siltstone or shale from 0.5–1.1 m.	Black or Grey Vertosol	Brigalow (VA1) or Brigalow with shrubs (VA8).
SOILS DERIVED FROM COARSE GRAINED, ACID TO INTERMEDIATE, CRETACEOUS IGNEOUS ROCKS (Ki)				
Eucalypt Vegetation				
	Gently undulating rises to steep hills			
Mi	**Middlemount**	A shallow, rocky, hard setting, acid, loam to clay loam (0.05–0.15 m) on steeper slopes grading to a moderately deep, loamy or clay loamy surfaced, neutral, brown or red, non-sodic gradational or texture contrast soil on gentler slopes over syenite (or equivalent) from 0.4 m.	Leptic Rudosol Orthic Tenosol Brown or Red Dermosol Brown or Red Chromosol	Ironbark–bloodwood–ghost gum (VA43), Silver-leaved ironbark (VA17) or Narrow-leaved ironbark (VA12).
	Pediments and colluvial footslopes			
MiCv	**Middlemount colluvial variant**	A shallow, stony, conspicuously bleached, acid, sand to clay loam (<0.4 m) on steeper slopes grading to a moderately deep, sandy to clay loamy surfaced, conspicuously bleached, alkaline, grey or brown, sodic texture contrast soil or gradational soil on gentler slopes. Developed on colluvial material over syenite (or equivalent) from 0.4–1.1 m.	Leptic Rudosol Orthic Tenosol Grey or Brown Sodosol	Eucalypts with shrubby teatree (VA13) or Narrow-leaved ironbark (VA12).

Table 11 (cont). The concept and classification of the soil profile classes and associated vegetation in each geological landscape

Soil name		Soil concept [1]	Australian Soil Classification [2]	Dominant vegetation association(s) [3]
SOILS DERIVED FROM DEEPLY WEATHERED TERTIARY SEDIMENTS (Td, Ta)				
Eucalypt Vegetation				
	Level to gently undulating, intact plateau surfaces			
Bh	**Bills Hut**	A hard setting, uniform or gradational, clay loamy surfaced, acid, red massive earth over deeply weathered sediments below 1.5 m.	Red Kandosol	Ironbark–bloodwood–ghost gum (VA50), Narrow-leaved ironbark (VA12) or Budgeroo (VA26); occasionally Narrow-leaved white mahogany (VA41).
Wm	**Wyndham**	A deep, soft or loose, acid, brown or yellow uniform sand (>1.1 m) grading to a thick (0.4–1.1 m), sandy surfaced, conspicuously bleached, acid to alkaline, mottled, grey, sodic texture contrast soil with coarse columnar structure over ferricrete or deeply weathered sediments below 0.8–>1.5 m.	Orthic Tenosol Grey Sodosol	Eucalypts with shrubby teatree (VA13), Narrow-leaved ironbark (VA12), Ironbark–bloodwood–ghost gum (VA50) or Long-fruited bloodwood (VA15); occasionally Queensland peppermint (VA25).
	Gently undulating to undulating plateau margins and dissected plateau remnants			
Bb	**Bul Bul**	A hard setting, uniform or gradational, loamy or clay loamy surfaced, acid, brown massive earth over ferricrete or deeply weathered sediments from 0.4–1.0 m.	Brown Kandosol	Narrow-leaved ironbark (VA12) or Eucalypts with shrubby heath myrtle (VA14); occasionally Poplar box (VA20) or Poplar box–ironbark (VA34).
Bd	**Bundoora**	A hard setting, sandy surfaced, conspicuously bleached, alkaline, mottled, grey or brown, sodic texture contrast soil with coarse columnar structure over deeply weathered sediments from 0.7–>1.5 m.	Grey or Brown Sodosol	Eucalypts with bull oak (VA32) or Bull oak (VA35).
BhSv	**Bills Hut sandy variant**	A thick (0.4–0.9 m), firm, sandy or loamy surfaced, acid or neutral, gradational variant of the Bills Hut (Bh) soil over ferricrete or deeply weathered sediments below 1.2–>1.5 m.	Red Kandosol	Narrow-leaved ironbark (VA12); occasionally Ironbark–bloodwood–ghost gum (VA50).
Rc	**Red Cliff**	A shallow, hard setting, uniform, clay loamy surfaced, acid, red massive earth (<0.5 m) grading to a moderately deep, clay loamy surfaced, acid, red, structured gradational soil over deeply weathered sediments from 0.5–1.1 m.	Red Kandosol Red Dermosol	Narrow-leaved ironbark (VA12) or Ironbark–bloodwood–ghost gum (VA50); occasionally Bendee (VA30), Eucalypts with shrubby heath myrtle (VA14), Queensland peppermint (VA25) or Lancewood (VA3).
Wt	**Wieta**	A hard setting, clay loamy surfaced, acid to alkaline, brown, structured gradational soil to non–cracking clay over deeply weathered sediments from 0.6–1.0 m.	Brown Dermosol	Poplar box (VA20), Poplar box–ironbark (VA34), Narrow-leaved ironbark (VA12) or Silver-leaved ironbark (VA17).
	Gently undulating to undulating footslopes, pediments and dissected residuals below intact plateaus			
Ac	**Anncrouye**	A hard setting, loamy or clay loamy surfaced, sporadically bleached, acid, mottled, red texture contrast soil over deeply weathered sediments from 0.3–0.8 m.	Red Kurosol Red Chromosol	Narrow-leaved ironbark (VA12), Rosewood (VA2) or Yapunyah (VA24).
Mr	**Merion**	A hard setting, firm pedal or weakly self-mulching, acid, black, saline, sodic cracking clay over reticulite or partially altered, fine grained sandstone or siltstone below 0.9–>1.5 m.	Black Vertosol	Yapunyah (VA24); occasionally Gum-topped box (VA18) or Poplar box–ironbark (VA34).
***Acacia* Vegetation**				
	Undulating to precipitous plateau scarps			
Bz	**Bellarine**	A shallow, stony, firm or hard setting, acid, black or brown loam or clay loam over deeply weathered sediments from 0.05–0.4 m.	Leptic Rudosol	Lancewood (VA3), Rosewood (VA2) or Bendee (VA30); occasionally Yapunyah (VA24), Narrow-leaved ironbark (VA12) or Queensland peppermint (VA25).

Table 11 (cont). The concept and classification of the soil profile classes and associated vegetation in each geological landscape

Soil name		Soil concept [1]	Australian Soil Classification [2]	Dominant vegetation association(s) [3]
SOILS DERIVED FROM DEEPLY WEATHERED TERTIARY BASALT (Tb_d)				
Eucalypt Vegetation				
	Gently undulating to undulating dissected plateau remnants			
Rh	**Red Hill**	A hard setting, clay loamy surfaced, acid or neutral, red, structured gradational soil or non–cracking clay grading to a uniform or gradational, clay loamy surfaced, acid, red massive earth over deeply weathered basalt from 0.6–1.1 m.	Red Dermosol Red Kandosol	Narrow-leaved ironbark (VA12); occasionally Bendee (VA30), Ironbark–bloodwood–ghost gum (VA43) or Ironbark–bloodwood–ghost gum (VA50).
SOILS DERIVED FROM FRESH OR PARTIALLY ALTERED TERTIARY BASALT (Tb, Tb_a)				
Eucalypt Vegetation				
	Gently undulating pediments and colluvial footslopes below Tertiary plateaus			
Wy	**Windeyers Hill**	A hard setting, alkaline, brown or red non-cracking clay grading to a clay loamy surfaced, alkaline, brown or red, non–sodic texture contrast soil over partially altered basalt or strongly structured, basaltic clay from 0.5–>1.5m.	Brown or Red Dermosol Brown or Red Chromosol	Ironbark–bloodwood–ghost gum (VA43); occasionally Narrow-leaved ironbark (VA12), Silver-leaved ironbark (VA17), Poplar box–ironbark (VA34) or Poplar box (VA20).
WyMp	**Windeyers Hill melonhole phase**	A lattice or shallow melonhole gilgai complex (VI 0.3–0.5 m) with: • a hard setting, firm pedal or weakly self-mulching, alkaline, brown non-cracking to cracking clay on mounds and shelves; and • a hard setting, firm pedal or weakly self-mulching, acid, grey cracking clay in depressions; over acid, basaltic clay from 0.6–1.1 m.	*Mound/shelf* - Brown Dermosol or Vertosol *Depression* - Grey Vertosol	Narrow-leaved ironbark (VA12) or Ironbark–bloodwood–ghost gum (VA43); locally in depressions Sedges (VA29).
	Gently undulating plains and rises			
My	**May**	A strongly self-mulching, alkaline, black cracking clay over fresh basalt from 0.65–1.0 m.	Black Vertosol	Gum-topped bloodwood (VA16) or Queensland bluegrass downs (VA28); occasionally Mountain coolibah (VA19) or Coolibah (VA11) on lower footslopes adjacent to alluvium.
MySp	**May shallow phase**	A shallow, stony version of the May (My) soil over fresh basalt from 0.15–0.4 m.	Black Vertosol	Gum-topped bloodwood (VA16); occasionally Queensland bluegrass downs (VA28) or Ironbark–bloodwood–ghost gum (VA43).
Nm	**Ninemile**	A weakly to strongly self-mulching, alkaline, red or brown cracking clay over partially altered basalt from 0.4–0.9 m.	Red or Brown Vertosol	Silver-leaved ironbark (VA17) or Ironbark–bloodwood–ghost gum (VA43).
Brigalow Vegetation				
	Gently undulating pediments and colluvial footslopes below Tertiary plateaus			
Bx	**Battery**	A weakly to strongly self-mulching, alkaline, brown cracking clay over partially altered basalt or acid, basaltic clay from 0.5–1.0 m.	Brown Vertosol	Brigalow with shrubs (VA8) or Brigalow (VA1).
Gb	**Gordons Bore**	A hard setting, firm pedal or weakly self-mulching, alkaline, brown non–cracking to cracking clay over partially altered basalt or strongly structured, basaltic clay from 0.7–1.3 m.	Brown Dermosol Brown Vertosol	Brigalow with shrubs (VA8), Brigalow (VA1) or Brigalow–Dawson gum (VA5).

Table 11 (cont). The concept and classification of the soil profile classes and associated vegetation in each geological landscape

	Soil name	Soil concept [1]	Australian Soil Classification [2]	Dominant vegetation association(s) [3]
	Gently undulating plains and rises			
Id	**Indicus**	A strongly self-mulching, alkaline, black cracking clay over fresh basalt from 0.7–1.2 m.	Black Vertosol	Brigalow with shrubs (VA8) or Brigalow (VA1).
IdMp	**Indicus melonhole phase**	A weakly to strongly developed melonhole gilgai complex (VI 0.3–1.0 m) with: • a firm pedal or weakly to strongly self-mulching, alkaline, grey, brown or black, sodic cracking clay on mounds; and • a hard setting or weakly to strongly self-mulching, acid or alkaline, grey, sodic cracking clay in depressions; over partially altered basalt or acid, basaltic clay from 0.5–>1.5 m.	*Mound* - Grey, Brown or Black Vertosol *Depression* - Grey Vertosol	Brigalow (VA1) or Brigalow with shrubs (VA8).
IdSp	**Indicus shallow phase**	A shallow, stony version of the Indicus (Id) soil over fresh basalt from 0.3–0.55 m.	Black Vertosol	Brigalow with shrubs (VA8) or Brigalow (VA1).
Lt	**Leitrim**	A strongly self-mulching, alkaline, red or brown cracking clay over partially altered basalt from 0.5–0.9 m.	Red or Brown Vertosol	Brigalow with shrubs (VA8) or Brigalow (VA1).
SOILS DERIVED FROM UNCONSOLIDATED TERTIARY–QUATERNARY SEDIMENTS				
(i) SEDIMENTS SOURCED FROM SEDIMENTARY LANDSCAPES (TQa)				
Eucalypt Vegetation				
	Level to gently undulating plains and low rises			
Cm	**Collawmar**	A sandy surfaced, conspicuously or sporadically bleached, alkaline, mottled, grey, sodic texture contrast soil with coarse columnar structure.	Grey Sodosol	Shrubby poplar box (VA7) or Poplar box (VA20); occasionally Dawson gum (VA10) or Brigalow–Dawson gum (VA5).
Fx	**Foxleigh**	A sandy surfaced, conspicuously bleached, alkaline, mottled, brown or grey, sodic texture contrast soil with coarse columnar structure.	Brown or Grey Sodosol	Poplar box (VA20) or Poplar box–bloodwood–Moreton Bay ash (VA33); occasionally Poplar box–ironbark (VA34) or Eucalypts with bull oak (VA32).
FxLp	**Foxleigh clay loamy phase**	A hard setting, loamy or clay loamy surfaced, conspicuously or sporadically bleached, alkaline, brown, sodic texture contrast soil with coarse columnar structure. (Loamy surfaced version of the Foxleigh (Fx) soil).	Brown Sodosol	Poplar box (VA20); occasionally Shrubby poplar box (VA7), Poplar box–ironbark (VA34), Gum-topped box (VA18) or Yapunyah (VA24).
Brigalow Vegetation				
	Level to gently undulating plains, pediments and footslopes below Tertiary plateaus			
Pg	**Pomegranate**	A hard setting, gravelly, alkaline, brown, sodic cracking to non-cracking clay, frequently with normal or shallow melonhole gilgai (VI 0.2–0.5 m), on valley floors and pediments.	Brown Vertosol Brown Dermosol	Brigalow (VA1); occasionally Brigalow–Dawson gum (VA5).

Table 11 (cont). The concept and classification of the soil profile classes and associated vegetation in each geological landscape

Soil name		Soil concept [1]	Australian Soil Classification [2]	Dominant vegetation association(s) [3]
PgMp	**Pomegranate melonhole phase**	A strongly developed melonhole gilgai complex (VI 0.6–1.5 m) with: • a firm pedal, gravelly, alkaline, brown, sodic cracking clay on mounds; and • a hard setting, firm pedal or weakly self-mulching, gravelly, acid, brown or grey, sodic cracking clay in depressions; frequently over reworked, acid Tertiary clay from 0.7–>1.5 m on valley floors and pediments.	*Mound* - Brown Vertosol *Depression* - Brown or Grey Vertosol	Brigalow (VA1); occasionally Brigalow with shrubs (VA8).
PgSp	**Pomegranate shallow phase**	A moderately deep, very hard setting, gravelly, acid to alkaline, strongly sodic version of the Pomegranate (Pg) soil, developed on colluvium over deeply weathered sediments from 0.6–1.1 m, on pediments and footslopes.	Brown Dermosol Brown Vertosol	Brigalow–yapunyah (VA40); occasionally Brigalow (VA1).
RtSp	**Racetrack shallow phase**	A moderately deep, sporadically bleached, gravelly, neutral or alkaline version of the Racetrack (Rt) soil with blocky structure, developed on colluvium over deeply weathered sediments from 0.5–1.1 m, on pediments and footslopes.	Brown Sodosol	Brigalow–Dawson gum (VA5); occasionally Dawson gum (VA10) or Brigalow–yapunyah (VA40).
	Level to gently undulating plains			
Rt	**Racetrack**	A hard setting, clay loamy surfaced, conspicuously or sporadically bleached, alkaline, brown, sodic texture contrast soil with coarse columnar structure.	Brown Sodosol	Brigalow–Dawson gum (VA5); occasionally Brigalow (VA1), Dawson gum (VA10) or Brigalow–yapunyah (VA40).
Tr	**Turon**	A strongly developed melonhole gilgai complex (VI 0.7–1.5 m) with: • a hard setting, firm pedal or weakly self-mulching, alkaline, grey or brown, sodic cracking clay on mounds; and • a firm pedal or weakly self-mulching, acid, grey, sodic cracking clay in depressions; over reworked, acid Tertiary clay from 0.6–>1.5 m.	*Mound* - Grey or Brown Vertosol *Depression* - Grey Vertosol	Brigalow (VA1), Blackwood (VA37) or Brigalow–blackwood (VA4); occasionally Brigalow with shrubs (VA8) or Belah (VA9).
Ww	**Warwick**	A normal or shallow melonhole gilgai complex (VI 0.25–0.5 m) with: • a hard setting, firm pedal or weakly self-mulching, alkaline, grey or brown, sodic cracking clay on mounds and shelves; and • a hard setting, firm pedal or weakly to moderately self-mulching, acid, grey, sodic cracking clay in depressions; over reworked, acid Tertiary clay from 0.5–>1.5 m.	*Mound* - Grey or Brown Vertosol *Depression* - Grey Vertosol	Brigalow (VA1), Blackwood (VA37) or Brigalow–blackwood (VA4); occasionally Brigalow–Dawson gum (VA5).
(ii) SEDIMENTS SOURCED FROM BASALTIC LANDSCAPES (TQa_b)				
Eucalypt Vegetation				
	Gently undulating plains and low rises			
Cx	**Carfax**	A strongly self-mulching, alkaline, black cracking clay with strongly developed, linear gilgai (VI 0.1–0.4 m) over unconsolidated, calcareous sediments below 0.8–1.3 m.	*Mound* - Black Vertosol *Depression* - Black Vertosol	Mountain coolibah (VA19) or Queensland bluegrass downs (VA28); occasionally Ironbark–bloodwood–ghost gum (VA43).
Kc	**Kirkcaldy**	A hard setting, firm pedal or weakly to strongly self-mulching, alkaline, black or brown non–cracking to cracking clay over unconsolidated, calcareous sediments from 0.3–1.1 m.	Black or Brown Dermosol Black or Brown Vertosol	Mountain coolibah (VA19), Silver-leaved ironbark (VA17) or Ironbark–bloodwood–ghost gum (VA43).

Table 11 (cont). The concept and classification of the soil profile classes and associated vegetation in each geological landscape

	Soil name	Soil concept [1]	Australian Soil Classification [2]	Dominant vegetation association(s) [3]
Mf	**Mayfair**	A hard setting, loamy or clay loamy surfaced, sporadically bleached, alkaline, brown or red, non-sodic texture contrast soil over unconsolidated, calcareous sediments from 0.6–1.1 m.	Brown or Red Chromosol	Silver-leaved ironbark (VA17) or Poplar box (VA20); occasionally Narrow-leaved ironbark (VA12), Poplar box–ironbark (VA34) or Mountain coolibah (VA19).
MfSv	**Mayfair sandy surface variant**	A sandy surfaced, sporadically bleached, alkaline, mottled, brown or grey, sodic texture contrast soil with coarse columnar structure over unconsolidated, calcareous sediments below 0.9–>1.5 m. (Sandy surfaced, sodic version of the Mayfair (Mf) soil).	Brown or Grey Sodosol	Poplar box (VA20) or Poplar box–ironbark (VA34); occasionally Ironbark–bloodwood–ghost gum (VA43).
Brigalow Vegetation				
	Level to gently undulating plains and low rises			
Hb	**Hazelbrae**	A hard setting, clay loamy surfaced, sporadically bleached, alkaline, brown or grey, non-sodic texture contrast soil over unconsolidated, calcareous sediments below 1.0–>1.5 m.	Brown or Grey Chromosol	Brigalow–Dawson gum (VA5) or Belah (VA9); occasionally Brigalow (VA1).
Kk	**Knockane**	A hard setting, firm pedal or weakly self-mulching, alkaline, grey non–cracking to cracking clay, frequently with normal gilgai (VI 0.1–0.3 m), over unconsolidated, calcareous sediments below 1.1–>1.5 m.	Grey Dermosol Grey Vertosol	Brigalow (VA1) or Brigalow–Dawson gum (VA5); occasionally Brigalow with shrubs (VA8).
Nw	**Norwich**	A weakly to strongly self-mulching, alkaline, grey or black cracking clay with normal (VI 0.1–0.3 m) or melonhole (VI 0.3–0.8 m) gilgai over unconsolidated, calcareous sediments below 1.1–>1.5 m.	Grey or Black Vertosol	Brigalow (VA1) or Brigalow with shrubs (VA8).
Pc	**Picardy**	A strongly self-mulching, alkaline, black cracking clay, frequently with weakly developed linear, lattice or normal gilgai (VI 0.05–0.1 m), over unconsolidated, calcareous sediments below 0.8–>1.5 m.	Black Vertosol	Brigalow with shrubs (VA8) or Brigalow (VA1); occasionally Belah (VA9).
PcXp	**Picardy surface seal phase**	A strongly self-mulching, cracking clay similar to the Picardy (Pc) soil but with a lower clay content, increased sand fraction, less basaltic influence and normal or lattice gilgai (VI 0.1–0.3 m). A weak surface seal and thin sandy veneer form after rain.	Black Vertosol	Brigalow with shrubs (VA8); occasionally Brigalow (VA1).
SOILS DERIVED FROM QUATERNARY ALLUVIUM (Qa)				
Eucalypt Vegetation				
	Channel benches and narrow alluvial plains on upper tributaries			
Gm	**German**	A moderately deep to deep, soft or loose, acid or neutral, brown uniform sand over buried alluvial layers (sand to sandy medium clay) from 0.5–>1.5 m.	Stratic Rudosol	Blue gum–mixed eucalypts (VA22) or Moreton Bay ash (VA23).
	Scroll plains, channel benches and active levees on flood plains			
Is	**Isaac**	A hard setting or firm pedal, silty surfaced, neutral or alkaline, black non-cracking to cracking clay.	Black Dermosol Black Vertosol	Coolibah–mixed eucalypts (VA38), Blue gum–mixed eucalypts (VA22) or Coolibah (VA11).
	Levees and sand ridges			
Bn	**Booroondarra**	A deep, soft or loose, neutral, red uniform sand (>1.5 m) grading to a thick (0.4–1.0 m), sandy surfaced, sporadically bleached, neutral or alkaline, red, non-sodic texture contrast soil.	Orthic Tenosol Red Chromosol	Moreton Bay ash (VA23); occasionally Poplar box–bloodwood–Moreton Bay ash (VA33) or Blue-gum–mixed eucalypts (VA22).

Table 11 (cont). The concept and classification of the soil profile classes and associated vegetation in each geological landscape

	Soil name	Soil concept [1]	Australian Soil Classification [2]	Dominant vegetation association(s) [3]
	Alluvial plains and levees			
Pr	**Parrot**	A thick (0.5–1.0 m), sandy surfaced, conspicuously or sporadically bleached, acid to alkaline, mottled, brown texture contrast soil.	Brown Chromosol Brown Sodosol	Poplar box (VA20) or Poplar box–bloodwood–Moreton Bay ash (VA33).
Rp	**Roper**	A hard setting, sandy to clay loamy surfaced, sporadically or conspicuously bleached, alkaline, brown or black texture contrast soil.	Brown or Black Chromosol Brown or Black Sodosol	Poplar box (VA20); occasionally Poplar box–bloodwood–Moreton Bay ash (VA33), Blue gum–mixed eucalypts (VA22) or Coolibah–mixed eucalypts (VA38).
St	**Stephens**	A hard setting, alkaline, black non–cracking clay grading to a thin (0.04–0.1 m), clay loamy surfaced, alkaline, black texture contrast soil.	Black Dermosol Black Chromosol or Sodosol	Poplar box (VA20); occasionally Blue gum–mixed eucalypts (VA22) or Coolibah–mixed eucalypts (VA38).
	Seasonal swamps and backplains			
Bc	**Bluchers**	A hard setting, firm pedal or weakly self-mulching, alkaline, black or grey cracking clay, frequently with normal gilgai (VI 0.1–0.3 m).	Black or Grey Vertosol	Coolibah (VA11), *Bothriochloa* grassland (VA27) or Sedges (VA29).
Tt	**Thirteenmile**	A hard setting, silty surfaced, conspicuously or sporadically bleached, acid to alkaline, mottled, grey or brown, sodic texture contrast soil to non–cracking clay.	Grey or Brown Sodosol Grey or Brown Dermosol	Blue gum (VA21); occasionally Poplar box (VA20), Blue gum–mixed eucalypts (VA22), Swamp mahogany (VA49) or Sedges (VA29).
	Level flood plains			
Ld	**Lindsay**	A strongly self-mulching, alkaline, black cracking clay.	Black Vertosol	Coolibah (VA11); occasionally Queensland bluegrass downs (VA28).
Brigalow Vegetation				
	Alluvial plains and levees			
Hy	**Honeycomb**	A hard setting, clay loamy surfaced, sporadically or conspicuously bleached, alkaline, black, sodic texture contrast soil with columnar or blocky structure.	Black Sodosol	Brigalow–Dawson gum (VA5) or Shrubby poplar box (VA7); occasionally Brigalow (VA1).
Tl	**Tralee**	A hard setting, firm pedal or weakly to moderately self-mulching, alkaline, black, grey or brown cracking to non-cracking clay, frequently with normal (VI 0.1–0.3 m) or melonhole (VI 0.3–0.8 m) gilgai.	*Non-gilgaied/mound* - Black, Grey or Brown Vertosol or Dermosol *Depression* - Black or Grey Vertosol	Brigalow (VA1); occasionally Brigalow–coolibah (VA6) or Brigalow with shrubs (VA8).
	Level flood plains			
Lg	**Langley**	A strongly self-mulching, alkaline, black cracking clay.	Black Vertosol	Brigalow–coolibah (VA6), Brigalow (VA1) or Brigalow with shrubs (VA8).

Notes: 1. Geological, landform and soil profile terms and conventions follow those of McDonald *et al.* (1990), Isbell (1996) or as otherwise defined in Appendix 2.
2. Australian Soil Classification from Isbell (1996). Most frequent classifications are listed first.
3. Vegetation terms and conventions follow those of Walker and Hopkins (1990) or as otherwise defined in Chapter 7 and/or Appendix 11.

Table 12. Spatial extent of the geological landscapes, soil landscapes and individual soil profile classes within the study area

Modern geological landscape	Dominant vegetation	Soil profile class	Area (ha)	% of study area
Permian sedimentary rocks (Pb, Pw)				
• Rises, low hills, hills and dissected plateaus	Eucalypt or *Acacia*	Cherwell (Cw)	1797	0.65
		Maywin (Mw)	1688	0.60
• Rises and low hills	Eucalypt	Heyford (Hf)	3164	1.2
• Plains and rises	Eucalypt	Adeline (Ad)	4906	1.8
		Carlo (Cc)	426	0.15
		Emoh (Em)	658	0.25
		Mt Stuart (Ms)	696	0.25
		Red–one (Rn)	2841	1.0
	Brigalow	Burradoo (Bu)	8602	3.2
		Burradoo sodic phase (BuZp)	2541	0.95
		Farlane (Fr)	2812	1.0
		Stateschool (Ss)	15687	5.8
		Ternallum (Tn)	618	0.25
		Tiny (Ty)	3733	1.4
Coarse grained, acid to intermediate Cretaceous igneous rocks (Ki)				
• Rises, low hills or hills	Eucalypt	Middlemount (Mi)	430	0.15
• Pediments and colluvial footslopes	Eucalypt	Middlemount colluvial variant (MiCv)	207	0.10
Deeply weathered Tertiary sediments (Td, Ta)				
• Intact plateau surfaces	Eucalypt	Bills Hut (Bh)	8095	3.0
		Wyndham (Wm)	1923	0.70
• Plateau margins and dissected plateau remnants	Eucalypt	Bul Bul (Bb)	3678	1.4
		Bundoora (Bd)	7832	2.9
		Bills Hut sandy variant (BhSv)	248	0.10
		Red Cliff (Rc)	2850	1.0
		Wieta (Wt)	1013	0.40
• Footslopes, pediments and dissected residuals	Eucalypt	Anncrouye (Ac)	4043	1.5
		Merion (Mr)	130	0.05
• Plateau scarps	*Acacia*	Bellarine (Bz)	6570	2.4
Deeply weathered Tertiary basalt (Tb_d)				
• Dissected plateau remnants	Eucalypt	Red Hill (Rh)	1097	0.40
Fresh or partially altered Tertiary basalt (Tb, Tb_a)				
• Pediments and colluvial footslopes	Eucalypt	Windeyers Hill (Wy)	2116	0.80
		Windeyers Hill melonhole phase (WyMp)	232	0.10
	Brigalow	Battery (Bx)	485	0.20
		Gordons Bore (Gb)	1505	0.55
• Plains and rises	Eucalypt	May (My)	6513	2.4
		May shallow phase (MySp)	817	0.30
		Ninemile (Nm)	53	0.02
	Brigalow	Indicus (Id)	2013	0.75
		Indicus melonhole phase (IdMp)	806	0.30
		Indicus shallow phase (IdSp)	62	0.02
		Leitrim (Lt)	39	0.01

Table 12 (cont). Spatial extent of the geological landscapes, soil landscapes and individual soil profile classes within the study area

Modern geological landscape	Dominant vegetation	Soil profile class	Area (ha)	% of study area
Unconsolidated Tertiary–Quaternary sediments sourced from sedimentary landscapes (TQa)				
• Plains and low rises	Eucalypt	Collawmar (Cm)	3418	1.3
		Foxleigh (Fx)	13579	5.0
		Foxleigh clay loamy phase (FxLp)	5567	2.0
• Plains, pediments and footslopes below Tertiary plateaus	Brigalow	Pomegranate (Pg)	10390	3.8
		Pomegranate melonhole phase (PgMp)	2323	0.85
		Pomegranate shallow phase (PgSp)	1195	0.45
		Racetrack shallow phase (RtSp)	1251	0.45
• Plains	Brigalow	Racetrack (Rt)	21323	7.8
		Turon (Tr)	10010	3.7
		Warwick (Ww)	24450	9.0
Unconsolidated Tertiary–Quaternary sediments sourced from basaltic landscapes (TQa_b)				
• Plains and low rises	Eucalypt	Carfax (Cx)	2825	1.0
		Kirkcaldy (Kc)	1478	0.55
		Mayfair (Mf)	1161	0.45
		Mayfair sandy surface variant (MfSv)	445	0.15
	Brigalow	Hazelbrae (Hb)	2086	0.75
		Knockane (Kk)	4059	1.5
		Norwich (Nw)	1912	0.70
		Picardy (Pc)	7193	2.6
		Picardy surface seal phase (PcXp)	2783	1.0
Quaternary alluvium (Qa)				
• Channel benches and narrow alluvial plains on upper tributaries	Eucalypt	German (Gm)	2132	0.80
• Scroll plains, channel benches and active levees on flood plains	Eucalypt	Isaac (Is)	2177	0.80
• Levees and sand ridges	Eucalypt	Booroondarra (Bn)	1607	0.60
• Alluvial plains and levees	Eucalypt	Parrot (Pr)	3002	1.1
		Roper (Rp)	7465	2.7
		Stephens (St)	1966	0.7
	Brigalow	Honeycomb (Hy)	9322	3.4
		Tralee (Tl)	9321	3.4
• Seasonal swamps and backplains	Eucalypt	Bluchers (Bc)	525	0.20
		Thirteenmile (Tt)	543	0.20
• Flood plains	Eucalypt	Lindsay (Ld)	2399	0.90
	Brigalow	Langley (Lg)	10998	4.1

Table 13. Correlation of soil profile classes and conceptual units of the Isaac–Comet land systems within the Windeyers Hill study area

Modern geological landscape	Dominant vegetation	Soil profile class	Conceptual land system unit(s) [1]
Permian sedimentary rocks (Pb, Pw)			
• Rises, low hills, hills and dissected plateaus	Eucalypt or *Acacia*	Cherwell (Cw)	Carborough (Ca) unit 1, unit 2; Durrandella (Du) unit 2
		Maywin (Mw)	Durrandella (Du) unit 2
• Rises and low hills	Eucalypt	Heyford (Hf)	Cotherstone (Cr) unit 3, unit 4
• Plains and rises	Eucalypt	Adeline (Ad)	Barwon (Bw) unit 3
		Carlo (Cc)	Girrah (Gi) unit 1
		Emoh (Em)	Barwon (Bw) unit 1; Daunia (Da) unit 2
		Mt Stuart (Ms)	Girrah (Gi) unit 2
		Red–one (Rn)	Barwon (Bw) unit 3
	Brigalow	Burradoo (Bu)	Barwon (Bw) unit 2; Daunia (Da) unit 4, unit 5
		Burradoo sodic phase (BuZp)	Daunia (Da) unit 4
		Farlane (Fr)	Daunia (Da) unit 6
		Stateschool (Ss)	Barwon (Bw) unit 1, unit 2
		Ternallum (Tn)	Barwon (Bw) unit 2; Daunia (Da) unit 5
		Tiny (Ty)	Barwon (Bw) unit 2; Daunia (Da) unit 5
Coarse grained, acid to intermediate Cretaceous igneous rocks (Ki)			
• Rises, low hills or hills	Eucalypt	Middlemount (Mi)	Percy (P) unit 3
• Pediments and colluvial footslopes	Eucalypt	Middlemount colluvial variant (MiCv)	Minor unit – Percy (P) unit 3
Deeply weathered Tertiary sediments (Td, Ta)			
• Intact plateau surfaces	Eucalypt	Bills Hut (Bh)	Durrandella (Du) unit 1; Junee (J) unit 1, unit 3
		Wyndham (Wm)	Durrandella (Du) unit 1; Junee (J) unit 3
• Plateau margins and dissected plateau remnants	Eucalypt	Bul Bul (Bb)	Durrandella (Du) unit 1
		Bundoora (Bd)	Durrandella (Du) unit 4; Junee (J) unit 4
		Bills Hut sandy variant (BhSv)	Junee (J) unit 3
		Red Cliff (Rc)	Durrandella (Du) unit 1
		Wieta (Wt)	Durrandella (Du) unit 4; Junee (J) unit 4
• Footslopes, pediments and dissected residuals	Eucalypt	Anncrouye (Ac)	Durrandella (Du) unit 4; Junee (J) unit 4
		Merion (Mr)	Durrandella (Du) unit 5; Junee (J) unit 4
• Plateau scarps	*Acacia*	Bellarine (Bz)	Durrandella (Du) unit 3; Junee (J) unit 2
Deeply weathered Tertiary basalt (Tb_d)			
• Dissected plateau remnants	Eucalypt	Red Hill (Rh)	Bedourie (Be) unit 1; Durrandella (Du) unit 1
Fresh or partially altered Tertiary basalt (Tb, Tb_a)			
• Pediments and colluvial footslopes	Eucalypt	Windeyers Hill (Wy)	Oxford (O) unit 1
		Windeyers Hill melonhole phase (WyMp)	Minor unit – Oxford (O) unit 3
	Brigalow	Battery (Bx)	Racecourse (R) unit 2
		Gordons Bore (Gb)	Racecourse (R) unit 2
• Plains and rises	Eucalypt	May (My)	Oxford (O) unit 2, unit 3
		May shallow phase (MySp)	Oxford (O) unit 1; Waterford (Wa) unit 1, unit 2
		Ninemile (Nm)	Minor unit – Oxford (O) unit 2
	Brigalow	Indicus (Id)	Racecourse (R) unit 2
		Indicus melonhole phase (IdMp)	Minor unit – Racecourse (R) unit 2

Table 13 (cont). Correlation of soil profile classes and conceptual units of the Isaac–Comet land systems within the Windeyers Hill study area

Modern geological landscape	Dominant vegetation	Soil profile class	Conceptual land system unit(s) [1]
		Indicus shallow phase (IdSp)	Racecourse (R) unit 2
		Leitrim (Lt)	Racecourse (R) unit 1, unit 2
Unconsolidated Tertiary–Quaternary sediments sourced from sedimentary landscapes (TQa)			
• Plains and low rises	Eucalypt	Collawmar (Cm)	Humboldt (Hu) unit 2; Monteagle (Mo) unit 3, unit 4
		Foxleigh (Fx)	Monteagle (Mo) unit 3
		Foxleigh clay loamy phase (FxLp)	Humboldt (Hu) unit 2; Monteagle (Mo) unit 4
• Plains, pediments and footslopes below Tertiary plateaus	Brigalow	Pomegranate (Pg)	Blackwater (Bl) unit 3, unit 4; Humboldt (Hu) unit 4
		Pomegranate melonhole phase (PgMp)	Somerby (So) unit 5
		Pomegranate shallow phase (PgSp)	Durrandella (Du) unit 5
		Racetrack shallow phase (RtSp)	Durrandella (Du) unit 5; Humboldt (Hu) unit 2
• Plains	Brigalow	Racetrack (Rt)	Humboldt (Hu) unit 3
		Turon (Tr)	Somerby (So) unit 5
		Warwick (Ww)	Blackwater (Bl) unit 3, unit 4; Humboldt (Hu) unit 4
Unconsolidated Tertiary–Quaternary sediments sourced from basaltic landscapes (TQa_b)			
• Plains and low rises	Eucalypt	Carfax (Cx)	Girrah (Gi) unit 2; Nebo (N) unit 1
		Kirkcaldy (Kc)	Girrah (Gi) unit 1; Nebo (N) unit 1
		Mayfair (Mf)	Nebo (N) unit 1; minor unit – Girrah (Gi) unit 1
		Mayfair sandy surface variant (MfSv)	Minor units – Monteagle (Mo) unit 3; Nebo (N) unit 1
	Brigalow	Hazelbrae (Hb)	Humboldt (Hu) unit 3
		Knockane (Kk)	Blackwater (Bl) unit 3, unit 4; Humboldt (Hu) unit 4
		Norwich (Nw)	Blackwater (Bl) unit 3, unit 4; Humboldt (Hu) unit 4
		Picardy (Pc)	Blackwater (Bl) unit 3, unit 4; Humboldt (Hu) unit 4
		Picardy surface seal phase (PcXp)	Blackwater (Bl) unit 3, unit 4; Humboldt (Hu) unit 4
Quaternary alluvium (Qa)			
• Channel benches and narrow alluvial plains on upper tributaries	Eucalypt	German (Gm)	Carborough (Ca) unit 4; Comet (Ct) unit 6; Connors (Co) unit 7; Cotherstone (Cr) unit 5; Durrandella (Du) unit 6; Funnel (Fu) unit 5; Monteagle (Mo) unit 6
• Scroll plains, channel benches and active levees on flood plains	Eucalypt	Isaac (Is)	Comet (Ct) unit 1, unit 2, unit 4; Funnel (Fu) unit 1
• Levees and sand ridges	Eucalypt	Booroondarra (Bn)	Connors (Co) unit 2
• Alluvial plains and levees	Eucalypt	Parrot (Pr)	Connors (Co) unit 2, unit 3
		Roper (Rp)	Connors (Co) unit 3, unit 4
		Stephens (St)	Comet (Ct) unit 1; Connors (Co) unit 1, unit 4; Funnel (Fu) unit 1
	Brigalow	Honeycomb (Hy)	Comet (Ct) unit 1; Connors (Co) unit 4; Funnel (Fu) unit 1
		Tralee (Tl)	Connors (Co) unit 6
• Seasonal swamps and backplains	Eucalypt	Bluchers (Bc)	Minor units – Comet (Ct) unit 3; Connors (Co) unit 3, unit 6; Funnel (Fu) unit 3, unit 4
		Thirteenmile (Tt)	Minor units – Connors (Co) unit 3; Junee (J) unit 1, unit 3; Monteagle (Mo) unit 3
• Flood plains	Eucalypt	Lindsay (Ld)	Funnel (Fu) unit 2, unit 4
	Brigalow	Langley (Lg)	Comet (Ct) unit 3

Note: 1. A conceptual land system unit is defined as the dominant and/or most representative unit or units that best describe the landscape concept being mapped in each land system (e.g. Somerby (So) land system – Unit 5 (50%) = gilgaied clay plains with brigalow). All land systems listed are from the Isaac–Comet study (Story *et al.* 1967).

In western parts of the study area, Permian sedimentary rocks lie within the Comet Platform on the western margins of the Bowen Basin. The sedimentary rocks in this area dip gently to the east and do not exhibit the rapid changes in lithology that occur with the folded sediments. As a result, the same lithological unit may outcrop over much larger areas providing more uniform soil development and less complexity. Similar areas also occur in the north-east of the study area at the southern end of the Nebo Synclinorium, where fine grained sandstones and siltstones have weathered to yield a soft, yellow fine sandy clay matrix of considerable depth.

Whilst the pattern, distribution and extent of soil development depends largely on whether the sedimentary rocks are folded or not, profile development is lithologically controlled. The lithologic complexity described in the Bowen Basin is enormous, not only in terms of the number of formations but also the number of strata described in each formation. To simplify this complexity from a soil development perspective Permian substrates have been grouped in two simple categories, these being the **marine sedimentary rocks of the Back Creek Group (Pb)** and the **freshwater sedimentary rocks of the Blackwater Group (Pw).**

It is important to recognise that there is a degree of lithologic overlap between these two groups and the spatial distribution of some soils (e.g. Red-one (Rn), Heyford (Hf), etc.) may actually place them in both groups. In general, however, the soils in question are associated predominantly with one group and occur only as occasional outliers in the other. The landform categories used to split the Permian landscape on the map reference largely overcomes this problem by separating the soils on a landform basis. Soil landscapes developed on the rugged, more resistant Back Creek (Pb) sandstones are grouped separately on the reference from those developed on the gently undulating, labile sedimentary rocks of the Blackwater Group (Pw).

6.1.2 Soil development on resistant sedimentary rocks of the Back Creek Group (Pb)

Substrates within the Back Creek Group (Pb) mostly outcrop in western parts of the study area associated with the Comet Platform. The sedimentary rocks in this area are relatively flat lying or dip gently to the east. In contrast, landscape development, particularly around the Cherwell Range, has been subject to long periods of dissection that have shaped the undulating to steep rises, hills and ranges currently associated with these sediments. Small relatively isolated exposures also occur within the folded zone in the centre of the study area, where the older marine and younger freshwater sediments have become mixed because of the intense folding. Substrate lithologies within the Back Creek Group (Pb) are predominantly quartzose sandstone, micaecous sandstone, lithic sandstone and marine shales. Minor exposures of freshwater sedimentary rocks also occur and include lithic, feldspathic and calcareous sandstones as well as siltstone, mudstone and shale. Soil development on these relatively minor substrates resembles that seen in areas developed on the younger freshwater sedimentary rocks of the Blackwater Group (Pw).

Photograph 7. Undulating to rolling terrain on fine grained sandstones of the Back Creek Group (Pb), at the southern end of the Cherwell Range

Photograph 8. Aerial image of the rugged, dissected plateaus and valleys on resistant quartzose sandstones of the Back Creek Group (Pb), west of Dysart

While relatively few soils are described on the predominantly flat lying marine sedimentary rocks of the Back Creek Group (Pb), the resistant nature of these rocks has meant landform complexity following dissection is often greater. Landforms range from gently undulating to undulating rises in the foothills around the Cherwell Range through to steep hills and rugged sandstone plateaus within the main range. Only three soils are described within this landscape, namely the **Cherwell (Cw), Maywin (Mw)** and **Heyford (Hf)** soils. Typical landform–soil–vegetation relationships for this landscape are illustrated diagrammatically in Figure 7.

The **Cherwell (Cw)** and **Maywin (Mw)** soils occur predominantly on the rises, hills and plateaus within the Cherwell Range. The **Cherwell (Cw)** soil is a shallow to moderately deep, stony, loose, acid, black or brown, uniform coarse sand over hard, fresh quartzose sandstone from 0.05–1.0 m. Because of the resistant nature of the sandstones, deep weathering in the Mid-Tertiary Period produced little or no alteration (<3 m). Profiles range from imperfectly drained in lower areas to rapidly drained on steeper slopes and have very low levels of salinity throughout. Frequently 10–>90% stone or rock outcrop is present. In steeper areas typical vegetation includes Queensland peppermint (VA25), Lemon-scented gum (VA31), Lancewood (VA3) or Rosewood (VA2). Long-fruited bloodwood (VA15) or Eucalypts with shrubby teatree (VA13) are normally present on gentler slopes.

The **Maywin (Mw)** soil occupies similar landscape positions to the **Cherwell (Cw)** soil. It is developed on a variety of marine sedimentary rocks including quartzose sandstone, micaecous sandstone, siltstone and shale. Substrates have normally been deeply weathered to some extent and are at least partially altered. Because the lithology and degree of alteration of the substrate is not constant, profile development within the **Maywin (Mw)** soil encompasses significant variation. Typically, it ranges from a shallow, sporadically bleached, acid sand to clay loam (0.25–0.5 m deep) on steeper slopes through to a moderately deep, sandy to clay loamy surfaced, conspicuously or sporadically bleached, acid, mottled, grey texture contrast soil on gentler slopes over partially altered quartzose or micaceous sandstone, siltstone or shale from a depth of 0.5–1.1 m. Profiles are imperfectly to moderately well drained, non-sodic and have low levels of subsoil salinity. Associated vegetation includes Eucalypts with shrubby teatree (VA13), Narrow-leaved ironbark (VA12), Lemon-scented gum (VA31) or Queensland peppermint (VA25).

The gently undulating to undulating foothills that lie adjacent to the Cherwell Range were stripped and exposed after Tertiary deep weathering had ceased. Substrates are predominantly fresh, fine grained marine sandstones, such as lithic or micaecous sandstone, that show little evidence of alteration. The dominant soil developed within the foothills is the **Heyford (Hf)** soil. It has been correlated with a soil of the same name on similar sediments in foothills at the northern end of the Cherwell Range in the Kilcummin area (Shields and Williams 1991). Typically, it is a sandy surfaced, conspicuously bleached, gravelly, alkaline, mottled, brown, sodic texture contrast soil with coarse columnar structure over micaceous or lithic sandstone from a depth of 0.6–1.1 m. Profiles are imperfectly to moderately well drained (depending on landscape position), with strongly to extremely sodic subsoils and low levels of subsoil salinity. Bleached subsurface horizons are characteristically gravelly and produce a lag gravel layer following disturbance and erosion. Typical vegetation includes Poplar box (VA20) or Eucalypts with bull oak (VA32). Less commonly Poplar box–ironbark (VA34) or Narrow-leaved ironbark (VA12) may be associated with this soil.

6.1.3 Soil development on labile sedimentary rocks of the Blackwater Group (Pw)

The **Blackwater Group (Pw)** represents the youngest of the Permian strata deposited in the Bowen Basin. They are derived from wholly freshwater sediments deposited in mostly fluvial or deltaic environments in the Late Permian (251–270 million years ago). The largest exposures occur within the Folded Zone which runs through the centre of the study area from the south-east to the north-west. The distribution of outcropping substrates within this geological structure is very complex. Rapidly changing substrate lithologies over short distances (20–500 m) are common and complex patterns of *in situ* soil development are normally associated with this group.

Substrate lithologies include feldspathic and lithic labile sandstones, calcareous sandstone and mudstone, dark siltstone, grey-green or dark mudstone and fossil wood. The entire range of freshwater sedimentary rocks in the Blackwater Group (Pw) are colloquially referred to as 'shales' by locals to differentiate them from the more resistant marine sandstones of the Back Creek Group (Pb). In practice, only some of the finer grained siltstones and mudstones are fissile and actually qualify as shales in the strict geological sense. The mineral calcite is abundant in the sedimentary rocks where it occurs either as a matrix or cement in calcareous sandstones and siltstones, or as a sandy or silty limestone in its own right. Lithologies within the group are predominantly labile and calcareous as a result.

Photograph 9. Gully exposure showing outcropping folded sedimentary rocks of the Blackwater Group (Pw), 'Carlo Creek'

Photograph 10. Aerial image of strike aligned, groves and strips associated with outcropping sedimentary rocks of the Blackwater Group (Pw) in the folded zone, south of Middlemout

Photograph 11. Alternating strips of Brigalow with shrubs (VA8) and *Bothriochloa* grassland (VA27), 'Carlo Creek'

Photograph 12. Alternating strips and swirls of Mountain coolibah (VA19) and Brigalow (VA1), 'Mt Stuart'

A far greater variety of soils have been described within the predominantly calcareous, freshwater sedimentary rocks of the Blackwater Group (Pw) when compared with the Back Creek (Pb) sandstones, due largely to the significant lithologic variation exposed within the Folded Zone in the centre of the study area. Because the sediments are mostly labile and easily weathered, planation of the land surface following stripping and exposure has formed a gently undulating landscape of plains and low rises that follows the north-westerly axis of the outcropping folded rocks. The only significant dissection within the landscape occurs where easterly flowing streams have been incised.

A total of ten soils and one phase are developed on the freshwater sedimentary rocks of the Permian landscape. All occur on gently undulating plains or rises and are developed *in situ* from the underlying substrate. The extent and distribution of each soil is strongly controlled by substrate lithology. Landscape position plays very little part in soil development in this landscape. Five of the soils are associated with eucalypt woodland while the remainder are brigalow soils. Typical landform–soil–vegetation relationships for the eucalypt soils in this landscape are illustrated diagrammatically in Figure 8. The eucalypt soils include **Adeline (Ad), Carlo (Cc), Emoh (Em), Mt Stuart (Ms)** and **Red-one (Rn)**.

The **Adeline (Ad)** soil is a hard setting, loamy or clay loamy surfaced, sporadically or conspicuously bleached, alkaline, brown or black, sodic texture contrast soil over labile sandstone, siltstone or shale from a depth of 0.6–1.2 m. It occurs on gently undulating plains and rises and its distribution often follows folded patterns. It is moderately well drained with moderate levels of subsoil salinity. Subsoil sodicity is variable and probably substrate dependent. Typical vegetation includes Poplar box (VA20) or Poplar box–ironbark (VA34), although occasionally Narrow-leaved ironbark (VA12) or Silver-leaved ironbark (VA17) may be associated with this soil.

Relatively minor occurrences of coarser grained, lithic or quartzose sandstones are sometimes exposed within the folded sedimentary rocks. The **Emoh (Em)** soil, which is a firm or hard setting, sandy surfaced, conspicuously bleached, alkaline, mottled, brown or grey, sodic texture contrast soil with coarse columnar structure is developed *in situ* on these rocks. It generally occurs on upper slopes, crests and low rises within the folded Permian landscape. It is imperfectly to moderately well drained and overlies sandstone from a depth of 0.5–1.3 m. Subsoils are mostly strongly to extremely sodic, although this varies with substrate. Levels of subsoil salinity are low throughout. Typical vegetation includes Shrubby poplar box (VA7), Poplar box (VA20) or occasionally Poplar box–ironbark (VA34).

The **Red-one (Rn), Carlo (Cc)** and **Mt Stuart (Ms)** soils are non-sodic and are developed largely from calcareous sedimentary rocks or feldspathic sandstones. The **Red-one (Rn)** soil is a hard setting, loamy or clay loamy surfaced, alkaline, red, non-sodic texture contrast soil with strong blocky structure. In some profiles a thin sporadic bleach may be developed at the boundary between the surface soil and subsoil. Subsoils are light medium to heavy clays that are moderately well drained, non-sodic throughout and have very low levels of salinity. Profiles are developed *in situ* and overlie lithic, feldspathic or calcareous sandstone, siltstone or shale from a depth of 0.4–0.8 m. Typical vegetation includes Silver-leaved ironbark (VA17), Narrow-leaved ironbark (VA12) or Ironbark–bloodwood–ghost gum (VA43). Occasionally Poplar box–ironbark (VA34) or Poplar box (VA20) may also be associated with this soil.

The **Carlo (Cc)** soil is a clay soil developed from similar substrates and with similar vegetation to the **Red-one (Rn)** soil. Typically, it is a hard setting or firm pedal, alkaline, black, brown or red non-cracking clay over marl or labile, fine grained calcareous sedimentary rocks such as calcareous mudstone. The calcareous beds are mostly relatively thin and are often underlain by non-calcareous sandstone or siltstone. Profiles are mostly moderately well drained (well drained if highly calcareous), non-sodic and have low levels of subsoil salinity. They are developed *in situ* and overlie weathering substrate from a depth of 0.3–1.2 m. Ironbark–bloodwood–ghost gum (VA43) is normally associated with this soil. Occasionally Mountain coolibah (VA19), Silver-leaved ironbark (VA17), Poplar box–ironbark (VA34) or Poplar box (VA20) may also be present.

The **Mt Stuart (Ms)** soil often occurs in association with the **Carlo (Cc)** soil. It is a much heavier clay however, and large pure units are normally associated with areas of open downs. Typically, it is a strongly self-mulching, alkaline, black cracking clay with linear or lattice gilgai (VI 0.05–0.15 m), over marl or labile, fine grained calcareous sedimentary rocks (such as calcareous mudstone) or feldspathic sandstone from a depth of 0.7–1.3 m. Mound and depression profiles are similar, except depressions have a coarser self-mulch, less surface carbonate, darker colours and lower surface pH. The soil is moderately well drained with low to moderate levels of subsoil salinity, probably sourced from the weathering substrate. Upper profiles are generally non-sodic and sodicity at depth, where it occurs, is dependent on variations in the underlying substrate. Typical vegetation includes Ironbark–

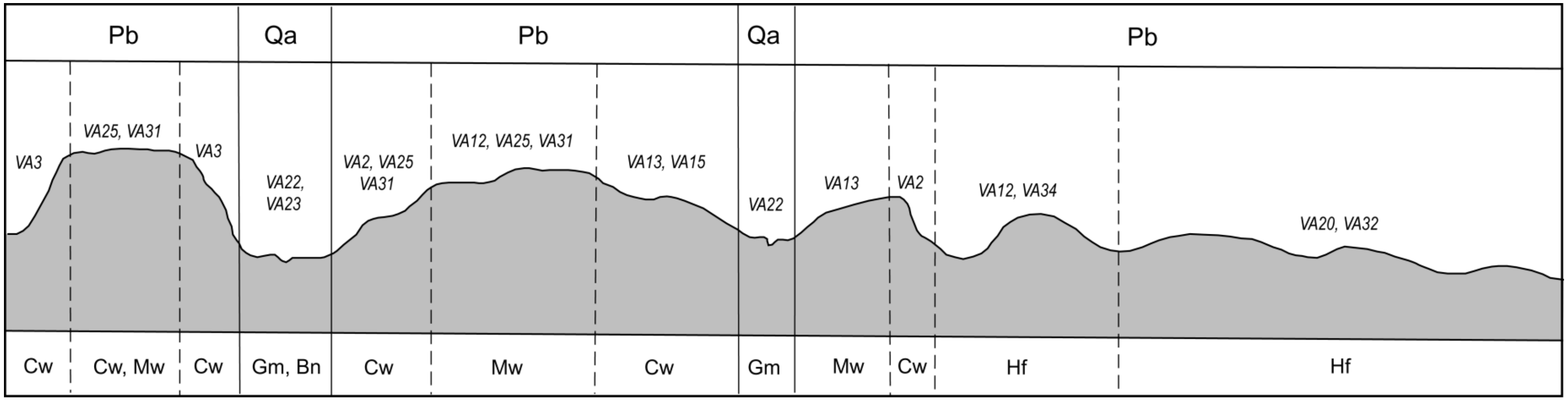


Figure 7. Typical landform, soil and vegetation relationships for soil landscapes developed on the resistant sedimentary rocks of the Back Creek Group (Pb)

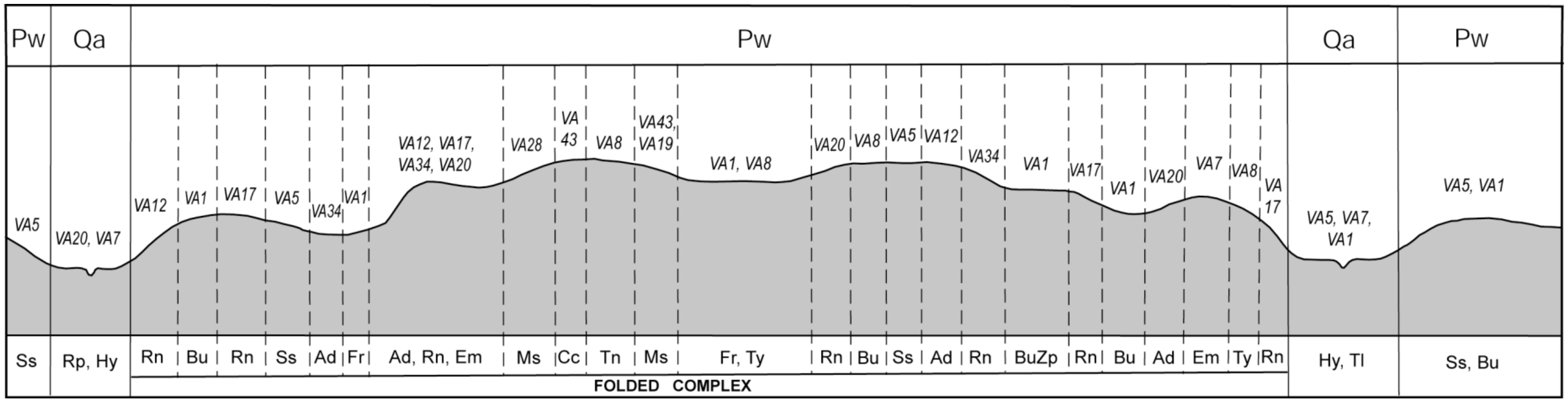


Figure 8. Typical landform, soil and vegetation relationships for soil landscapes developed on the labile, folded sedimentary rocks of the Blackwater Group (Pw)

bloodwood–ghost gum (VA43), Mountain coolibah (VA19), *Bothriochloa* grassland (VA27) or Queensland bluegrass downs (VA28).

In addition to the five eucalypt soils described, six scrub soils are developed on the Permian sedimentary rocks of the Blackwater Group (Pw). They include the **Burradoo (Bu), Burradoo sodic phase (BuZp), Farlane (Fr), Stateschool (Ss), Ternallum (Tn)** and **Tiny (Ty)** soils. Typical landform–soil–vegetation relationships for the brigalow soils in this landscape are illustrated diagrammatically in Figure 8.

The **Stateschool (Ss)** soil is the only texture contrast soil in this group. Typically, it is a hard setting, clay loamy surfaced, sporadically bleached, alkaline, brown or black, sodic texture contrast soil over labile sandstone, siltstone or shale. The soil is a major unit within the outcropping strongly folded sedimentary rocks in the centre of the study area where it occurs in well defined strips. It also occurs in large uniform tracts in the north-east which are associated with relatively flat lying, fine grained sandstones and siltstones. In these areas the sediments have weathered to considerable depths (2–>5 m) yielding a characteristic, soft, yellow fine sandy clay matrix known colloquially as 'yellow baked clay' (P Quinn *pers. comm.*). In both areas profiles are developed *in situ* and overlie weathering substrate (including lithic, feldspathic, micaceous or calcareous sedimentary rocks) from a depth of 0.5–1.2 m. Soils are moderately well drained with sodic upper subsoils and strongly to extremely sodic lower subsoils. Salinity levels in the subsoil are moderate to high. Typical vegetation includes Brigalow–Dawson gum (VA5) or Brigalow (VA1). Occasionally Dawson gum (VA10), Shrubby poplar box (VA7), Brigalow with shrubs (VA8) or Belah (VA9) may also be present.

The **Burradoo (Bu)** soil is a clay soil developed from similar substrates and with similar vegetation to the **Stateschool (Ss)** soil. Typically, it is a hard setting or firm pedal, alkaline, brown or black non-cracking to cracking clay over labile sandstone, siltstone or shale. It is often associated with the **Stateschool (Ss)** soil and has a similar distribution and extent. Occasionally normal gilgai (VI 0.05–0.4 m) with a prominent shelf are present on the heavier clays. Profiles are developed *in situ* and overlie weathering substrate (including lithic, feldspathic or calcareous sedimentary rocks) from a depth of 0.6–1.2 m. Soils are moderately well drained, with upper subsoils that range from non-sodic to sodic and lower subsoils that are strongly to extremely sodic. Salinity levels in the subsoil are normally high below a depth of about 0.6 m. Typical vegetation includes Brigalow (VA1) or Brigalow with shrubs (VA8). Occasionally Brigalow–Dawson gum (VA5) may be present, particularly where the **Stateschool (Ss)** soil is associated.

A very hard setting, saline, sodic version of the **Burradoo (Bu)** soil occurs where marine sedimentary rocks of the Back Creek Group (Pb) are exposed amongst outcropping folded freshwater beds of the Blackwater Group (Pw). The extent and distribution of the **Burradoo sodic phase (BuZp)** soil is relatively minor and is largely confined to exposures within the Folded Zone in the centre of the study area. Typically, it is a very hard setting, gravelly, alkaline, grey, brown or black, sodic cracking to non-cracking clay over acid clay substrate or fine grained sandstone, siltstone or shale of marine origins. Occasionally, normal or shallow melonhole gilgai (VI 0.1–0.4 m) are present. Profiles are developed *in situ* and overlie weathering substrate from 0.7–>1.5 m. Soils are imperfectly to moderately well drained and strongly to extremely sodic throughout, except for thin surface horizons. Salinity levels are high to very high from a depth of about 0.3 m and some profiles are underlain by strongly acid clay substrate at depth. Brigalow (VA1) is normally associated with this soil, although occasionally Brigalow–blackwood (VA4) or Blackwood (VA37) may be present.

The **Farlane (Fr)** soil has a similar distribution and extent to the **Burradoo sodic phase (BuZp)** soil. It occurs mainly on elevated, level plains within the gently undulating folded Permian landscape. Field evidence indicates it is developed from fissile marine shales of the Back Creek Group (Pb) that are similar to the substrates underlying the **Burradoo sodic phase (BuZp)** soil, but significantly more labile. Typically, it occurs as a strongly developed melonhole gilgai complex (VI 0.5–1.2 m) with:

- a firm pedal or weakly to moderately self-mulching, alkaline, grey or brown, sodic cracking clay on mounds; and
- a weakly self-mulching, acid, grey, sodic cracking clay in depressions.

The profiles are developed *in situ* and overlie strongly structured, acid clay substrate or weathering fine grained marine sedimentary rocks from a depth of 0.8–>1.5 m. The upper subsoil is sodic, both on mounds and in depressions, and increases to strongly sodic levels with depth, particularly under mound profiles. Salinity levels in the subsoil are high from a depth of about 0.2 m on mounds and 0.8 m in depressions. This difference is probably due to leaching associated with ponding in depressions. Mound profiles are mostly moderately well drained, while depressions are poorly to imperfectly drained and may be ponded for 2–3 months or more. Typical vegetation includes Brigalow with shrubs (VA8) or Brigalow (VA1).

The **Tiny (Ty)** soil occurs throughout the gently undulating plains and rises of the folded Permian landscape, both in narrow strips and larger more uniform units. Typically, it occurs as a firm pedal or weakly to strongly self-mulching, alkaline, black or grey cracking clay, frequently with normal gilgai (VI 0.1–0.3 m). It overlies a range of freshwater substrates from lithic and feldspathic sandstones to fine grained, calcareous sedimentary rocks and marl. Often interbedded with these sediments as a result of folding are fine grained marine sedimentary rocks or strongly structured acid clays similar to those underlying the **Burradoo sodic phase (BuZp)** and **Farlane (Fr)** soils. Where these occur, the upper part of the **Tiny (Ty)** profile has probably formed from labile calcareous sedimentary rocks lying above these layers. Profiles are developed *in situ* and overlie acid clay or weathering substrate from a depth of 0.5–1.1 m. Soils are moderately well drained with sodic upper subsoils and strongly sodic lower subsoils. High salinity levels occur below a depth of about 0.45 m. Typical vegetation includes Brigalow (VA1) or Brigalow with shrubs (VA8).

The **Ternallum (Tn)** soil is relatively minor in terms of extent and distribution and occurs mainly in narrow strips associated with labile, calcareous or feldspathic freshwater sedimentary rocks within the folded Permian landscape. Typically, it is a strongly self-mulching, alkaline, black cracking clay over marl or labile, fine grained calcareous sedimentary rocks (such as calcareous mudstone) or feldspathic sandstone. Occasionally linear or lattice gilgai (VI <0.1 m) are developed. Profiles have formed *in situ* and overlie weathering substrate from a depth of 0.7–1.3 m. Soils are moderately well drained with moderate to high salinity levels below a depth of about 1.2 m, probably sourced directly from the underlying weathered substrate. Upper profiles are generally non-sodic and sodicity at depth, where it occurs, is dependent on the nature of the underlying sediments. Typical vegetation includes Brigalow with shrubs (VA8), Brigalow (VA1) or occasionally Belah (VA9).

6.2 Soil landscapes on coarse grained, acid to intermediate, Cretaceous igneous rocks (Ki)

6.2.1 Landscape development

A small number of Cretaceous–Tertiary age intrusions (approximately 60–70 million years old) ranging from gently undulating low rises to steep hills occur within the study area. They were probably exposed during the Late Tertiary Period (1.8–24 million years ago) when widespread stripping and erosion of the Tertiary Land Surface occurred. The intrusions are aligned with the north-westerly strike of the folded Permian sediments that underlie the area and were emplaced along lines of weakness associated with folding and faulting in the area. Pattison *et al.* (1988) further suggests the intrusive structures between German Creek and Norwich Park coal mines are predominantly sills that migrated westward from the Jellinbah and Foxleigh faults to the east. In all, five structures which probably have similar origins and ages are recognised in the south-west of the study area. Lithology is somewhat variable and ranges from syenite through to trachyte.

Middlemount is the most obvious example. It occurs as an elongated, high cresentic ridge that rises between 60–110 m (mostly <80 m) above the surrounding plain. The Middlemount hill originally formed from magma which cooled well underground. Its current elevation above the surrounding landscape gives an indication of the extent and depth of stripping and landscape change that has occurred during the Late Tertiary. It has undulating to steep, rocky sideslopes and a well developed colluvial apron surrounding its base. Slopes range from 5 to 100%, but are mostly 10–50%. The other intrusions are smaller and occur south-west of Middlemount on ‘Booroondarra’, ‘Tralee’ and the German Creek Mine Lease. These are mainly gently undulating to undulating low rises with local elevations <20 m and slopes 1–15%.

Photograph 13. Cross section view of the Middlemount intrusive (Ki) showing the gentle eastern slopes and west facing scarp

Photograph 14. Narrow-leaved ironbark (VA12) vegetation and extensive rock outcrop on upper slopes of the Middlemount intrusive (Ki)

6.2.2 Soil development

Soil development within this landscape is variable because of differences in lithology and landform between each intrusion. Even within the Middlemount intrusive itself, profile development along crests and gentler upper slopes differs from that on the steep, scarp-like sideslopes and colluvial footslopes below. Only two soils are described, namely **Middlemount (Mi)** and **Middlemount colluvial variant (MiCv)**. Typical landform–soil–vegetation relationships for this landscape are illustrated diagrammatically in Figure 9.

The **Middlemount (Mi)** soil is dominant and encompasses significant variation. It ranges from a shallow, rocky, hard setting, acid loam to clay loam (0.05–0.15 m deep) on steeper slopes grading to a moderately deep, loamy or clay loamy surfaced, neutral, brown or red, non-sodic gradational or texture contrast soil on gentler slopes. Deeper profiles have developed *in situ* and overlie weathering syenite, trachy–syenite or trachyte from a depth of 0.4 m. Surface stone, boulders and rock outcrop are variable and range from 10% to almost 100%. Profiles are moderately well drained to well drained, with non-sodic subsoils (where present) and very low levels of salinity throughout. Typical vegetation includes Ironbark–bloodwood–ghost gum (VA43), Silver-leaved ironbark (VA17) or Narrow-leaved ironbark (VA12).

The **Middlemount colluvial variant (MiCv)** soil only occurs around the base of larger intrusives, such as Middlemount, where colluvial deposition on footslopes and pediments has been significant. Profile development is variable and ranges from a shallow, stony, conspicuously bleached, acid, sand to clay loam (<0.4 m deep) on steeper slopes grading to a moderately deep (0.4–1.1 m), sandy to clay loamy surfaced, conspicuously bleached, alkaline, grey or brown, sodic texture contrast soil or gradational soil on gentler slopes. Deeper profiles are developed from colluvial material which in turn overlies syenite, trachy–syenite or trachyte bedrock from a depth of 0.4–1.1 m. Stone and outcrop are only minor compared with the **Middlemount (Mi)** soil on upper slopes. Profiles are imperfectly to moderately well drained and appear subject to significant lateral seepage from the hillslopes above. While subsoil salinity levels are low, the intermittent shape of the salt profile suggests seepage and capillary rise sometimes occur. Conspicuous bleaching in the sand and loam profiles and the presence of paper barked teatree on the texture contrast soils indicate that seepage-induced, seasonal water logging is probably occurring. Typical vegetation includes Eucalypts with shrubby teatree (VA13) or Narrow-leaved ironbark (VA12).

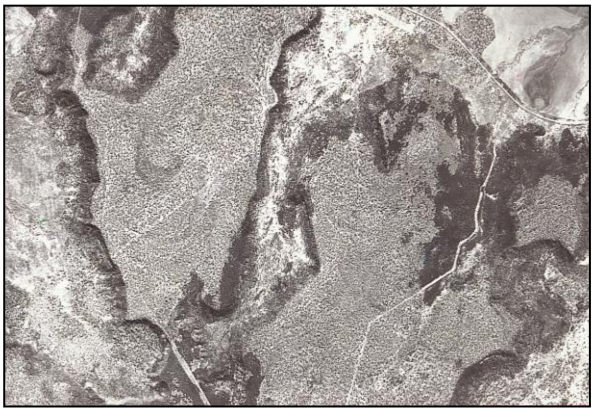
6.3 Soil landscapes on deeply weathered Tertiary sediments (Td, Ta)

6.3.1 Landscape development

The Tertiary sediments consist predominantly of poorly consolidated deposits, mostly 100–200 m thick, that were deposited during the Mid-Tertiary in rivers, flood plains and temporary lakes. Deposition occurred within a gentle land surface with similar topography to that seen today. Dickens and Malone (1973) suggest most of the deposits were laid down in isolated basins, and local variations in the lithology and nature of the sediments probably relates to catchment size and provenance lithology within each basin. The largest of these basins is the Duaringa Basin, stretching from 'May Downs' in the north to the Duaringa township in the south, where deposits up to 1000 m thick have accumulated.

Examples of the Tertiary sediments within the study area include the Junee Tablelands in the east and mesas and dissected remnants in the German Creek area. The Junee Tablelands lie at the northern end of the Duaringa Basin and are typical of the sediments mapped in that system as the Duaringa Formation (Td). The undifferentiated Tertiary cover (Ta) that is mapped outside the Duaringa Basin (such as the sediments in the German Creek area) is much thinner (probably <100 m thick) and may reflect lithological differences in Tertiary sedimentation across the catchments.

Photograph 15. Cross section view of a typical Tertiary plateau (Td, Ta) at the northern end of the Junee Tablelands



Photograph 16. Aerial image showing intact Tertiary plateaus, scarps and valley floors at the northern end of the Junee Tablelands

In either case, the Tertiary sediments are predominantly fine grained with lithologies ranging from argillaceous sandstone or occasional conglomerate through to siltstone and claystone. They were subjected to a prolonged period of intense weathering during the Mid-Tertiary and thick, deeply weathered laterite profiles developed uniformly across the extensive deposits of permeable, poorly consolidated sediments. Intact profiles are currently preserved only on remnant tablelands and mesas. Typically, they include an indurated cap (petroreticulite or less commonly ferricrete or silcrete) that is resistant to dissection and protects the thick underlying mottled (ferruginised) and pallid (kaolinised) zones. Following dissection of the resistant upper profile, the underlying zones are readily eroded and deflated.

The terms reticulite and petroreticulite from Isbell (1996) have been adopted to describe the lithology of the upper parts of the exposed laterite profiles. Apart from gross changes in the lithology of the original deposits, the nature and form of deeply weathered substrates across the study area is very uniform and reflects the intensity of weathering that has occurred.

The extent and distribution of soils within the deeply weathered Tertiary landscape therefore, is largely controlled by variation in the sedimentary layers exposed following stripping and dissection of the intact surface. This lithological variation is usually reflected by corresponding changes in landscape position. Where strong dissection has occurred, soil–landform relationships are usually distinct and easily recognised (e.g. scarp footslopes lying below intact plateaus) and associated soils are quite specific. But in areas where only gentle dissection has occurred, changes are often subtle and complex. Soil prediction based on landscape position in these areas is less reliable (e.g. where gently dissected pediments lie immediately adjacent to intact plateau residuals not bounded by scarps) and a wider range of soils may be associated.

Spatial changes also occur in the nature and lithology of the Tertiary sediments within the two catchments. These changes are geographically based and probably reflect differences in the provenance areas from which the sediments were originally sourced. Differences in soil development between intact plateau surfaces in the German Creek area (thick, sandy surfaced, sodic texture contrast soils), the Junee Tablelands (loamy red earths) and around 'Annandale' (sandy red earths) illustrate this point.

Landform complexity within the deeply weathered Tertiary landscapes of the study area can be grouped according to the following categories:

- intact plateau surfaces
- plateau margins and dissected plateau remnants
- footslopes, pediments and dissected residuals below intact plateaus
- plateau scarps.

Intact plateau surfaces are mostly level to gently undulating plains that are scarp bounded and elevated 5 to 130 m above surrounding areas. Intact plateaus are located mainly in the German Creek area and around the Junee Tablelands. Differences in the gross nature of the sediments and subsequent dissection in these two areas has produced very different soils and landscapes however.

Around German Creek the depth of soil cover above the underlying deeply weathered profile is much shallower than on the Junee Tablelands and the presence of petroreticulite and ferricrete close to the surface has significantly influenced soil development. While the intact Tertiary surface around German Creek does include occasional scarp-bounded mesas, it mainly occurs as poorly defined, intact residual surfaces (without scarps) that cap the surrounding, extensive, gentle pediments. Differences in elevation between the intact surface and gently dissected pediments are only slight. This has probably occurred because resistant layers in the sedimentary sequence are largely absent, and widespread, gentle dissection and downwearing has taken place across the entire intact surface. It differs from the majority of Tertiary surfaces within the two catchments where the process of scarp retreat and the formation of elevated plateaus and mesas has occurred.

6.3.2 Soil development

In all, ten soils are described within the deeply weathered Tertiary (Td, Ta) landscape. The majority are eucalypt soils, with the exception of the **Bellarine (Bz)** soil which is associated with steep scarps and *Acacia* scrub. To simplify the discussion that follows the soils are grouped according to landscape position. The **Bills Hut (Bh)** and **Wyndham (Wm)** soils occur predominantly on intact plateau surfaces, while the **Bul Bul (Bb), Bundoora (Bd), Bills Hut sandy variant (BhSv), Red Cliff (Rc)** and **Wieta (Wt)** soils are associated with stripped plateau margins and dissected plateau remnants. The **Anncrouye (Ac)** and **Merion (Mr)** soils are mainly found on footslopes, pediments and dissected residuals at the base of intact plateaus. Typical landform–soil–vegetation relationships for this landscape are illustrated diagrammatically in Figures 10 and 12.

The **Wyndham (Wm)** soil only occurs on intact plateau surfaces in the German Creek area and is characterised by its relative elevation and level terrain compared with the pediment soils that mostly surround it. Typically, it is a sandy surfaced, conspicuously bleached, acid to alkaline, mottled, grey, sodic texture contrast soil with coarse columnar structure over ferricrete or deeply weathered sediments below a depth of 0.8–>1.5 m. The A horizon depth is variable and ranges from 0.4 m to greater than 1.5 m. Where A horizons are very thick (>1.1 m), profiles grade to a deep, soft or loose,

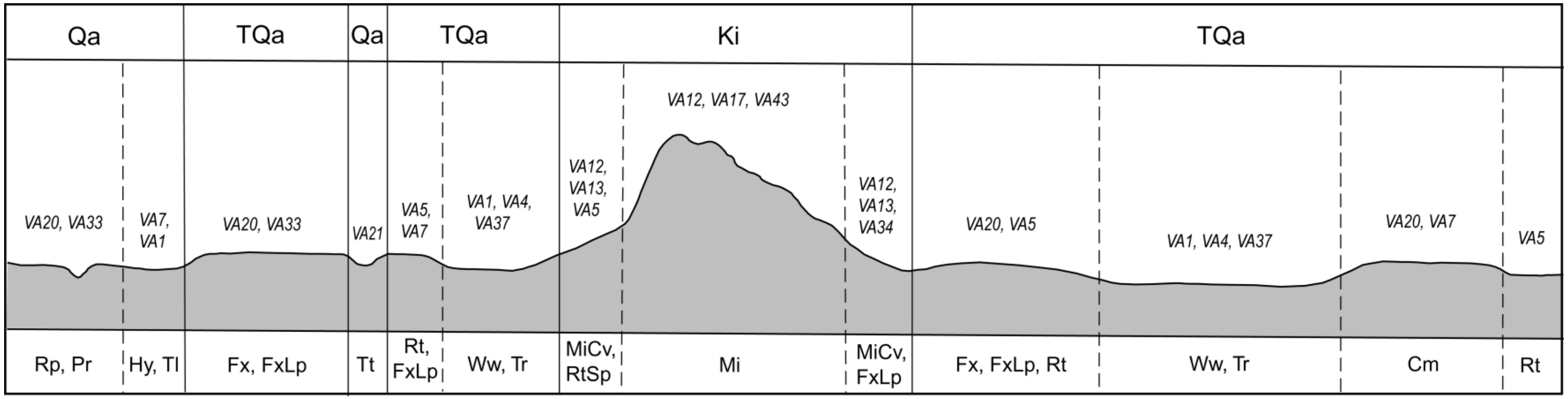


Figure 9. Typical landform, soil and vegetation relationships for soil landscapes developed on Cretaceous intrusives (Ki) and surrounding unconsolidated Tertiary–Quaternary sediments of sedimentary origins (TQa)

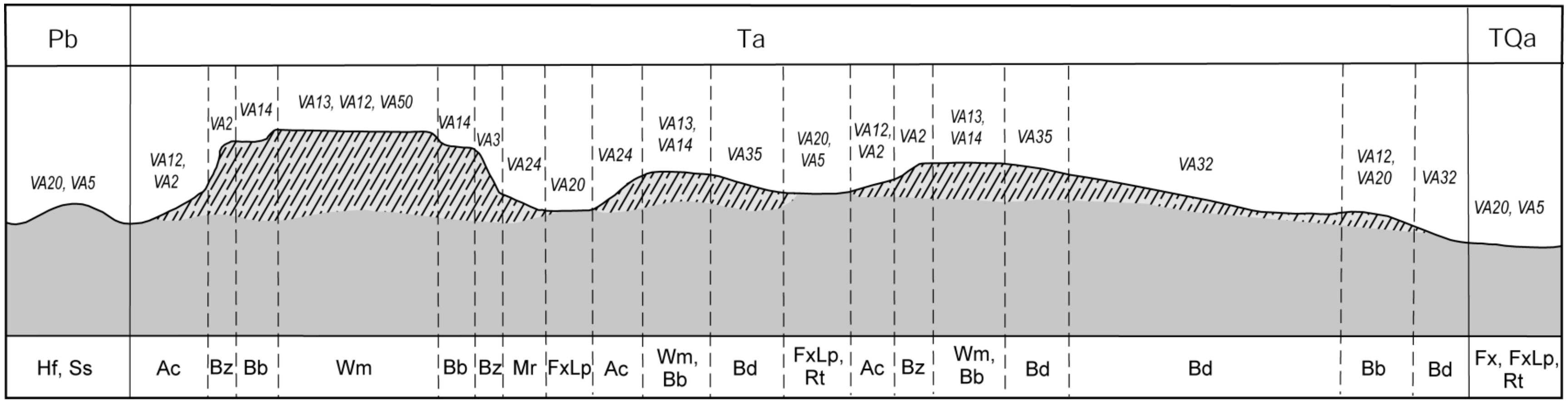


Figure 10. Typical landform, soil and vegetation relationships for soil landscapes developed on deeply weathered Tertiary sediments (Ta) in the German Creek area

acid, brown or yellow, uniform sand. Subsoil material in texture contrast profiles is strongly to extremely sodic and is developed *in situ* from underlying deeply weathered sediments. Irrespective of A horizon thickness, profiles are imperfectly drained. Typically, sub-surface drainage is impeded temporarily at the base of the sandy surface soil causing bleaching, mottling and the formation of ironstone nodules. Salinity levels are very low throughout. Associated vegetation typically includes Eucalypts with shrubby teatree (VA13), Narrow-leaved ironbark (VA12), Ironbark–bloodwood–ghost gum (VA50), Long-fruited bloodwood (VA15) or occasionally Queensland peppermint (VA25).

The **Bul Bul (Bb)** soil occurs on intact plateau surfaces such as those described for the **Wyndham (Wm)** soil and also on dissected residuals and pediments. On intact plateaus, particularly in the German Creek area, it is normally associated with plateau margins where ferricrete deposits are present. These areas are easily identified by the presence of a very thick, shrubby understorey of heath myrtle (*Micromyrtus capricornia*) and are useful as a source of gravel for extractive purposes. Typically, it is a hard setting, uniform or gradational, loamy or clay loamy surfaced, acid, brown, massive earth over ferricrete or deeply weathered sediments (e.g. petroreticulite) from a depth of 0.4–1.0 m. Termite mounds are common and profiles are moderately well to well drained with very low levels of salinity throughout. While soil materials are usually non-sodic, underlying deeply weathered substrates are often strongly to extremely sodic. On dissected residuals and pediments, profiles directly overlie petroreticulite and are mostly gravel-free, gradational earths that grade towards the **Wieta (Wt)** soil. Gravelly versions occur only on plateau margins and are usually associated with significant ferricrete deposits. Associated vegetation on intact plateau surfaces typically includes Eucalypts with shrubby heath myrtle (VA14) or Narrow-leaved ironbark (VA12), while on dissected residuals and pediments Narrow-leaved ironbark (VA12), Poplar box (VA20) or Poplar box–ironbark (VA34) are more common. The **Bul Bul (Bb)** soil occurs predominantly in the German Creek area, both on intact plateaus and dissected residuals. Isolated examples also occur on strongly dissected residuals around the Junee Tablelands and further north.

Intact plateau surfaces within the Junee Tablelands occur only as scarp bounded mesas. Tertiary sediments in this area were deposited within the Duaringa Basin and are finer than in the German Creek area. Deep weathering profiles and soil cover are much thicker as a result. The **Bills Hut (Bh)** soil is typically a very deep, hard setting, clay loamy surfaced, red massive earth over deeply weathered sediments at depth (>1.5 m). It occupies extensive areas within the level to gently undulating plateau surfaces of the Junee Tablelands. Profiles are uniform to gradational, well drained, non-sodic, acidic and without gravel or stone. Salinity levels are very low throughout. Typical vegetation includes Ironbark–bloodwood–ghost gum (VA50) or Narrow-leaved ironbark (VA12). Less commonly Budgeroo (VA26) or Narrow-leaved white mahogany (VA41) may be associated with this soil.

The **Bills Hut sandy variant (BhSv)** soil is a thick (0.4–0.9 m), firm, sandy or loamy surfaced, acid or neutral, variant of the **Bills Hut (Bh)** soil over ferricrete or deeply weathered sediments below a depth of 1.2–>1.5 m. Profiles are typically gradational, well drained, non-sodic and without gravel or stone. Salinity levels are very low throughout. It is restricted to a small area of partially dissected residuals, without significant elevation, immediately north of the Junee Tablelands near 'Wieta'. The area occurs as gently undulating plains and rises without scarps and is typical of the gently undulating sandy red earths that are common further north in the catchment around Iffley. Associated vegetation is typically Narrow-leaved ironbark (VA12), although occasionally Ironbark–bloodwood–ghost gum (VA50) may be present.

Plateau margins within the Junee Tablelands are mostly gently dissected and stripped to some extent. The **Red Cliff (Rc)** soil is developed in these areas on sediments that normally lie well below the intact plateau surface. It also occurs on partially dissected residuals and mesas well away from the main tablelands, where similar sediments have been exposed following deflation. Because the degree of stripping and exact nature of the exposed deeply weathered sediments is not constant, profile development within the **Red Cliff (Rc)** soil encompasses significant variation. It ranges from a shallow, hard setting, uniform, clay loamy surfaced, acid, red, massive earth (<0.5 m deep), (similar to a shallow version of the **Bills Hut (Bh)** soil), grading to a moderately deep, clay loamy surfaced, acid, red, structured, gradational soil over deeply weathered sediments from a depth of 0.5–1.1 m. Profiles are developed *in situ* and variations in the nature of the underlying sediments appear largely responsible for the range in profile features. Shallow profiles mostly overlie petroreticulite or occasionally ferricrete, while deeper structured profiles are developed over red or grey kaolinitic clay layers. In addition, colluvial influences are likely where significant stripping has occurred. Profiles are moderately well to well drained, non-sodic and acidic, with very low salinity levels throughout. Typical vegetation includes Narrow-leaved ironbark (VA12) or Ironbark–bloodwood–ghost gum (VA50). In more dissected areas, Bendee (VA30), Eucalypts with shrubby heath myrtle (VA14), Queensland peppermint (VA25) or Lancewood (VA3) may be present.

Where scarp retreat, dissection and stripping has been more severe, residuals occur mostly as gently undulating to undulating pediments and rises. In the German Creek area, the **Bundoora (Bd)** soil occurs on extensive pediments formed at elevations only slightly below the intact surface. Across the remainder of the study area, the **Anncrouye (Ac)** and **Wieta (Wt)** soils have developed on deflated Tertiary residuals at much lower elevations.

The **Bundoora (Bd)** soil is a hard setting, sandy surfaced, conspicuously bleached, mostly alkaline, mottled, grey or brown, sodic texture contrast soil with coarse columnar structure over deeply weathered sediments from a depth of 0.7–>1.5 m. It occurs exclusively on broad, gently undulating Tertiary pediments in the German Creek area. Soil development is very uniform and the subsoil is developed *in situ* from the deeply weathered sediments into which the pediments have been etched. The distribution of this soil is useful as a guide to the extent and occurrence of these pediments. The extremely sodic clay subsoil is poorly structured, imperfectly drained, impenetrable when dry and extremely dispersible. Levels of subsoil salinity are low to moderate below a depth of about 0.9 m. The combination of sloping terrain (1–5%), an erodible sandy surface and a very unstable subsoil make this a particularly fragile soil. Gully and tunnel erosion are prevalent and inevitable following disturbance. Typical vegetation includes Eucalypts with bull oak (VA32) or Bull oak (VA35).

The **Wieta (Wt)** soil occurs throughout the study area on very low (<5 m), residual rises and isolated pediments. Field evidence suggests these areas are the final remnants of former Tertiary plateaus or mesas. They lack local elevation (<5 m) and are probably developed on layers well down in the deeply weathered sedimentary sequence. Substrate materials are variable and range from hard petroreticulite through to mottled, grey kaolinitic clay. Petroreticulite outcrop often occurs around the margins of each unit. Variation in the degree of stripping means the exact nature of the exposed sediments is not constant, and profile development is variable as a result. Typically, it occurs as a hard setting, clay loamy surfaced, acid to alkaline, brown structured gradational soil over deeply weathered sediments from a depth of 0.6–1.0 m. In some profiles it grades to a hard setting, acid to alkaline, brown, structured non-cracking clay, particularly where profiles overlie kaolinitic clay layers. The clay layers are developed *in situ* and are often strongly to extremely sodic with moderate to high salinity levels. Salinity levels in the soil horizons above, however, are normally very low due to leaching. Profiles may be uniform or gradational and are imperfectly to moderately well drained. Associated vegetation typically includes Poplar box (VA20), Poplar box–ironbark (VA34), Narrow-leaved ironbark (VA12) or Silver-leaved ironbark (VA17).

The **Anncrouye (Ac)** soil occurs throughout the study area, on gently undulating to undulating, scarp footslopes and pediments below intact plateaus. It also occurs on strongly dissected residual rises with more relief and slope than those of the **Wieta (Wt)** soil. Field evidence suggests it is also developed from deeply weathered sediments well down in the sedimentary sequence. The distribution of both the **Anncrouye (Ac)** and **Wieta (Wt)** soils across the study area, and the fact they are both developed from sediments towards the bottom of the deeply weathered sequence, suggests the basal sediments of the deeply weathered Tertiary profile are relatively uniform. Typically, the **Anncrouye (Ac)** soil is a hard setting, loamy or clay loamy surfaced, sporadically bleached, acid, mottled, red texture contrast soil over deeply weathered (mainly kaolinitic) sediments from a depth of 0.3–0.8 m. Profiles range from imperfectly to moderately well drained on footslopes and pediments to well drained on elevated residuals. Mottling in the subsoil appears related more to the mottled nature of the underlying substrate than to restrictions in drainage. Subsoils are generally non-sodic and relatively stable when exposed, but difficult to rehabilitate because of strong acidity ($pH_{1:5}$ <5.5). Kaolinitic substrates at the base of the profile are occasionally sodic to strongly sodic and have low levels of salinity. Salinity within the soil horizons above is normally very low due to leaching. The exception to this occurs on upper footslopes below elevated, permeable Tertiary plateaus where seepage induced salinity within the profile may be present. Typical vegetation includes Narrow-leaved ironbark (VA12), Rosewood (VA2) or Yapunyah (VA24).

Occasionally scarp footslopes and pediments immediately adjacent to elevated, intact Tertiary plateaus intersect partially altered, labile sediments and argillaceous layers at the base of the Tertiary sequence. Cracking clay soils developed in these areas have been mapped as the **Merion (Mr)** soil. Typically, this soil is a hard setting, firm pedal or weakly self-mulching, acid, black, saline, sodic cracking clay over reticulite or partially altered, fine grained sandstone or siltstone below a depth of 0.9–>1.5 m. Profiles are imperfectly to moderately well drained and occasionally develop shallow, normal gilgai (VI <0.1 m). They are strongly to extremely sodic throughout except for very thin surface horizons. High salinity levels are normally present from about 0.4 m. Where seepage and capillary rise from surrounding elevated plateaus is occurring, salinity levels may be very high right to the surface. Profiles are developed *in situ* with partially altered fine grained Tertiary sediments normally found weathering at depth. Yapunyah (VA24) is the dominant vegetation, but occasionally Gum-topped box (VA18) or Poplar box–ironbark (VA34) may be present.

Undulating to precipitous scarps are found associated with intact plateaus and dissected residuals across the study area. Scarps are typically steep (>10–300%) and rocky, with >50–90% outcrop exposed. Outcrop is normally hard resistant petroreticulite. The **Bellarine (Bz)** soil is developed on these scarps and typically occurs as a shallow, stony, firm or hard setting, acid, black or brown loam or clay loam over deeply weathered sediments (or less commonly deeply weathered basalt) from a depth of 0.05–0.4 m. Profiles are well drained to rapidly drained, non-sodic and strongly acidic ($pH_{1:5}$ <5.5 throughout). Because of slope and elevation they are strongly leached and have very low salinity levels. Lancewood (VA3), Rosewood (VA2) or Bendee (VA30) are normally associated, although occasionally Yapunyah (VA24), Narrow-leaved ironbark (VA12) or Queensland peppermint (VA25) may be present.

6.4 Soil landscapes on deeply weathered Tertiary basalt (Tb_d)

6.4.1 Landscape development

While the extent of this landscape within the study area is only minor, significant areas occur further north in the catchment, between Moranbah and Glenden. It is identical in most respects to landscapes developed on deeply weathered Tertiary sediments, and mesas developed on both lie adjacent to each other at the northern end of the Junee Tablelands. Differences in substrate lithology between the two landscapes are minimal because of the extensive alteration that occurred during deep weathering. This alteration has meant rock features and mineralogy associated with the original basalt (or sediments) is no longer discernible and similar reticulite or petroreticulite substrates are developed on both landscapes.

At Windeyers Hill, which is a partially dissected mesa on deeply weathered basalt near ‘May Downs’, a weathered profile >30 m thick has developed. Resistant petroreticulite on the upper scarp face becomes less altered as it is traced downwards before contacting fresh basalt at its base. Field evidence indicates the pediments surrounding the Windeyers Hill mesa have cut well into and in many places right through the deeply weathered profile exposing fresh basalt underneath. Plateau elevations above the fresh basalt provide an indication of the former extent and thickness of the original basalt surface.

6.4.2 Soil development

Soil development on intact or partially dissected plateau surfaces derived from deeply weathered basalt is consistent with that on plateaus derived from deeply weathered sediments, because both situations share similarities in substrate (reticulite or petroreticulite), landscape position and drainage. Because of the limited extent of the deeply weathered basalt landscape within the study area, however, only one soil has been mapped, namely the **Red Hill (Rh)** soil. Typical landform–soil–vegetation relationships for this landscape are illustrated diagrammatically in Figure 11.

The **Red Hill (Rh)** soil resembles the **Red Cliff (Rc)** soil in many respects, although field textures are normally heavier, pH is neutral rather than acid and the profile is underlain by a characteristic layer of red kaolinitic clay nodules at its base. Because the degree of stripping and the exact nature of the sediments exposed is not constant, profile development within the **Red Hill (Rh)** soil encompasses significant variation. It ranges from a hard setting, clay loamy surfaced, acid or neutral, red, structured gradational soil or non–cracking clay grading to a uniform or gradational, clay loamy surfaced, acid, red massive earth over deeply weathered basalt from a depth of 0.6–1.1 m. Profiles are moderately well to well drained, non-sodic and slightly acidic to neutral. Salinity levels are very low throughout. The soil is largely developed *in situ* although colluvial influences are likely where significant stripping has occurred. Normally Narrow-leaved ironbark (VA12) is associated, although occasionally Bendee (VA30) or Ironbark–bloodwood–ghost gum (VA43 or VA50) may be present.

6.5 Soil landscapes on fresh or partially altered Tertiary basalt (Tb, Tb_a)

6.5.1 Landscape development

Landscapes developed on fresh or partially altered basalt (i.e. basal layers below the deeply weathered basalt profile) within the study area lie adjacent to and are contemporaneous with the sediments deposited during the Mid-Tertiary (mainly 20–35 million years ago). Sedimentation within the former valleys, plains and drainage systems of the Tertiary Land Surface were interrupted by basalt flows throughout this period. It is likely that the basalt flows occurred in a number of events of different ages and sedimentation continued in the intervening periods. At their peak the basalt flows were thought to cover much of the landscape to depths much greater that the depths seen today. It is probable the basalts were deeply weathered at this stage and remnant mesas at 'Windeyers Hill' and 'Red Hill' (north of Moranbah) provide evidence both of the depth of deep weathering and the thickness of the former basalt surface.

Photograph 17. Partially dissected, deeply weathered basaltic plateau (Tb_d) overlying partially altered (Tb_a) and fresh basalt (Tb) exposed on pediments and lower slopes, 'Windeyers Hill'

Photograph 18. Typical Queensland bluegrass downs (VA28) developed on fresh basalt (Tb), 'May Downs'

Whether deeply weathered, partially altered or fresh basalt substrates are exposed in the landscape is largely a function of the degree of deep weathering to which the basalt has been exposed and the amount of dissection and stripping that has occurred since. In general, the distribution and extent of each form is dependent on:

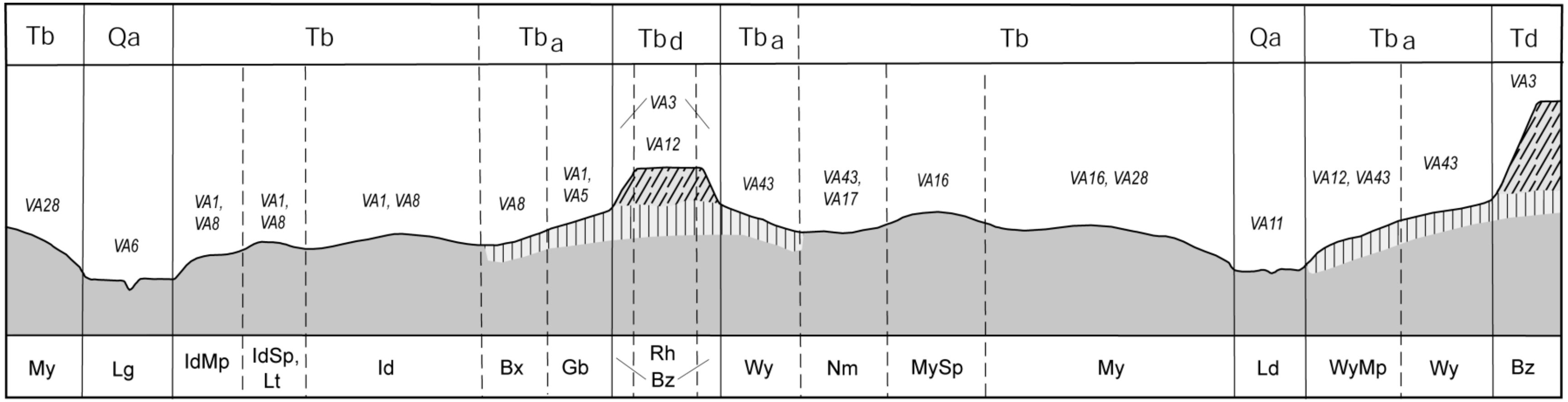


Figure 11. Typical landform, soil and vegetation relationships for soil landscapes developed on deeply weathered, partially altered and fresh basalts (Tb_d, Tb_a, Tb)

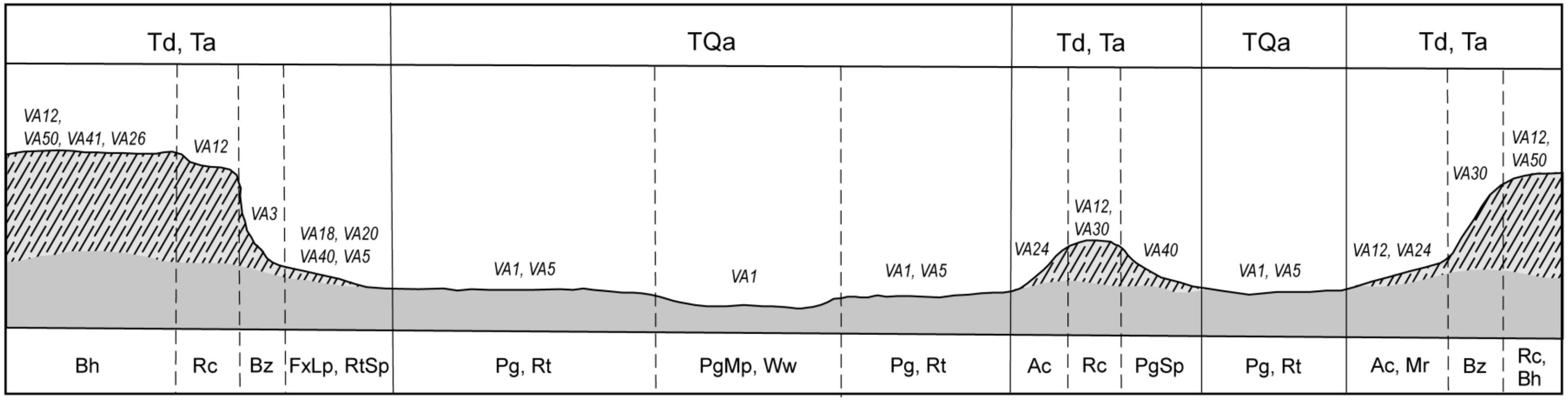


Figure 12. Typical landform, soil and vegetation relationships for soil landscapes developed on unconsolidated Tertiary–Quaternary sediments of sedimentary origins (TQa) lying below deeply weathered Tertiary plateaus (Td) of the Junee Tablelands

- the thickness of the deep weathering front;
- whether flows were buried (i.e. interbedded) or surficial during deep weathering;
- the depth of overburden above interbedded flows;
- the thickness of the basalt flow itself; and
- the degree of dissection and stripping post deep weathering.

Where interbedded flows were buried at depths greater than the deep weathering front, fresh basalt still remains. Conversely, where flows were surficial or interbedded at shallow depths, deeply weathered or partially altered substrates developed, depending on substrate depth and the thickness of the weathering front.

Similarly, the thickness of a flow is important. Complete alteration probably occurred in thin flows that were exposed during weathering, while a gradation from completely altered to partially altered to fresh rock would have developed in thick flows.

Finally, the degree of dissection and stripping that has occurred since deep weathering ceased has largely determined the weathering status, distribution and extent of the basalt currently exposed in the landscape. For example, differential stripping down the length of a pediment slope often uncovers substrates with varying degrees of alteration depending on which part of the deeply weathered profile has been intersected.

On basalt landscapes within the study area, dissection, scarp retreat and stripping during the Late Tertiary and Quaternary Periods (24 million years ago to present day) has left a complex pattern of deeply weathered, scarp-bounded remnants surrounded by gently undulating to undulating pediments, plains and rises overlying a range of partially altered to fresh basaltic substrates. Field evidence suggests the partially altered basalts are probably basal layers within the deeply weathered profile. They occur mainly on upper pediment slopes below mesas and on crests and rises within areas of otherwise fresh basalt, suggesting they lie between the fresh basalts below and the deeply weathered profiles above. The distribution of the partially altered basalts provides evidence of the original extent of the deeply weathered basalt surface. Where the deeply weathered basalt profiles have been completely stripped, a gently undulating landscape on the underlying fresh basalts has developed. Exposures of both partially altered and fresh basalts are common around the base of the Junee Tablelands near ‘May Downs’.

Different soils have generally developed on the **partially altered basalts (Tb_a)** compared with **fresh basalts (Tb)**. Partially altered basaltic substrates typically retain most of the petrological features (i.e. rock features) associated with fresh basalts, such as crystalline fabric and vesicular structure, but are pinkish or yellowish brown in colour and weather to produce red-brown or brown, structured heavy clays that may be either acid or alkaline. Fresh basalts, in contrast, weather to pale grey and produce black, structured heavy clays that are always alkaline. It is assumed some degree of mineralogical change has occurred during alteration to produce these differences.

In general, soils developed from partially altered basaltic substrates occur either on sloping pediments adjacent to residuals or on occasional, elevated crests and rises left remnant following dissection and stripping. In contrast, soils developed on fresh basalts occur predominantly on gently undulating plains and rises. These are often devoid of features associated with deep weathering and field evidence suggests they occur at lower elevations and/or down slope positions when compared with deeply weathered or partially altered features. Complete dissection and stripping of the overlying deeply weathered profile (either sediments or basalt) appears to have occurred.

Some soils (e.g. Windeyers Hill (Wy), Battery (Bx) etc.) appear to have developed from partially altered substrates in some locations and fresh basalts at others. Field evidence suggests this mainly occurs where soils are developed from thin layers of partially altered substrate that overlie fresh basalts underneath. During soil formation the partially altered material weathers out completely leaving apparently *in situ* fresh basalts below the profile.

6.5.2 Soil development on partially altered Tertiary basalt (Tb_a)

Eleven soils are described within the fresh or partially altered basaltic landscape. Of these, seven have developed predominantly from partially altered basalts, namely the **Windeyers Hill (Wy), Windeyers Hill melonhole phase (WyMp), Ninemile (Nm), Battery (Bx), Gordons Bore (Gb), Indicus melonhole phase (IdMp)** and **Leitrim (Lt)** soils. The remaining four soils, **May (My), May shallow phase (MySp), Indicus (Id)** and **Indicus shallow phase (IdSp)**, have developed only where fresh basalts are exposed. Typical landform–soil–vegetation relationships for the soils developed on partially altered basalts are illustrated diagrammatically in Figure 11.

Of the seven soils developed on partially altered basaltic substrates, the **Windeyers Hill (Wy), Windeyers Hill melonhole phase (WyMp)** and **Ninemile (Nm)** soils are associated with eucalypt woodland, while the remainder are brigalow soils.

The **Windeyers Hill (Wy)** soil occurs predominantly on gently undulating mid to upper pediments and colluvial footslopes adjacent to deeply weathered residuals and plateaus (basaltic and sedimentary). Because the degree of stripping and exact nature of the partially altered basaltic substrate is not constant, profile development within the **Windeyers Hill (Wy)** soil encompasses significant variation. It ranges from a hard setting, alkaline, brown or red non-cracking clay grading to a clay loamy surfaced, alkaline, brown or red, non-sodic texture contrast soil over partially altered basalt or occasionally fresh basalt from a depth of 0.5–>1.5 m. In many profiles, weathered rock is absent and the soil is underlain by a characteristic layer of strongly structured, brown basaltic clay that continues at depth (>1.5 m). Profiles are developed *in situ*, but are subject to considerable colluvial influence where Tertiary plateaus lie adjacent. They are moderately well drained, predominantly non-sodic and have low salinity levels in the subsoil. Salinity increases to moderate levels where weathered substrate occurs below a depth of about 1.2 m. Typically, Ironbark–bloodwood–ghost gum (VA43) is associated with this soil, although occasionally Narrow-leaved ironbark (VA12), Silver-leaved ironbark (VA17), Poplar box–ironbark (VA34) or Poplar box (VA20) may be present.

On flat to very gentle lower slopes of some pediments, a gilgaied version of the **Windeyers Hill (Wy)** soil has developed, probably as a consequence of restricted landscape drainage. The **Windeyers Hill melonhole phase (WyMp)** soil occurs as a gilgai complex of lattice or shallow, melonhole gilgai (VI 0.3–0.5 m). Typically, mounds and shelves are associated with a hard setting, firm pedal or weakly self-mulching, alkaline, brown non-cracking to cracking clay. In depressions, a hard setting, firm pedal or weakly self-mulching, acid, grey cracking clay normally develops because of restricted drainage. Both profiles overlie acid, basaltic clay from a depth of 0.6–1.1 m. Mounds and shelves are moderately well drained, while depressions are imperfectly drained due to seasonal ponding. Upper subsoils are mostly non-sodic while lower subsoils range from sodic to strongly sodic. High salinity levels occur below a depth of about 0.9 m in both mound and depression profiles. Typical vegetation includes Narrow-leaved ironbark (VA12) or Ironbark–bloodwood–ghost gum (VA43). A cover of Sedges (VA29) is present in most depressions.

The **Gordons Bore (Gb)** soil is equivalent to the **Windeyers Hill (Wy)** soil in terms of landscape position, profile development and substrate, but is associated with brigalow scrub. Typically, it is a hard setting, firm pedal or weakly self-mulching, alkaline, brown non-cracking to cracking clay over partially altered basalt or strongly structured, basaltic clay from a depth 0.7–1.3 m. Profiles are developed *in situ*, but are also subject to considerable colluvial influence. They are moderately well drained and are significantly more sodic and saline in the subsoil than the **Windeyers Hill (Wy)** soil. The upper subsoil is mostly non-sodic, while the lower subsoil is sodic to strongly sodic at depth. High salinity levels are present below a depth of about 0.7 m. Surface soil fertility, particularly phosphorus and nitrogen, is also significantly higher in the **Gordons Bore (Gb)** soil. Typical vegetation includes Brigalow with shrubs (VA8), Brigalow (VA1) or Brigalow–Dawson gum (VA5).

The **Battery (Bx)** soil is similar to the **Gordons Bore (Gb)** soil but is a heavier clay and has a self-mulching surface. It occurs on pediments and footslopes below deeply weathered plateaus, as well as crests and residual low rises within gently undulating areas on fresh basalt. Normally, it lacks the colluvial influences that are apparent with the **Gordons Bore (Gb)** and **Windeyers Hill (Wy)** soils, although significant 'billy' gravels may be present. Typically, it is a weakly to strongly self-mulching, alkaline, brown cracking clay over partially altered basalt or acid, basaltic clay from a depth of 0.5–1.0 m. Profiles are moderately well drained, with non-sodic upper subsoils and sodic to strongly sodic lower subsoils. High levels of subsoil salinity occur from a depth of about 0.5 m. Occasionally normal gilgai (VI 0.05–0.3 m) are developed. Typical vegetation includes Brigalow with shrubs (VA8) or Brigalow (VA1).

The **Ninemile (Nm)** and **Leitrim (Lt)** soils are associated with similar partially altered basaltic substrates. They appear to lack significant colluvial influences however, and occur mostly on crests and residual rises that mark the final remnants capping the gently undulating fresh basalt landscape. Both soils are self-mulching, alkaline, red or brown cracking clays that are developed *in situ* and overlie pinkish or yellowish brown, partially altered basalt from about 0.5–0.9 m. The **Ninemile (Nm)** soil is associated with Silver-leaved ironbark (VA17) or Ironbark–bloodwood–ghost gum (VA43), while **Leitrim (Lt)** is a scrub soil on which Brigalow with shrubs (VA8) or Brigalow (VA1) are normally found. Outside the study area, particularly in the Barmount district and also north of Nebo and Moranbah, the **Leitrim (Lt)** soil is often associated with significant areas of brigalow–softwood scrub. Both soils are moderately well drained and frequently develop weak linear gilgai (VI 0.05–0.2 m) where slopes are >2%. While detailed laboratory analyses are unavailable, field evidence suggests the soils are non-sodic and lack significant subsoil salinity. Surface soil fertility, however, is significantly higher in the **Leitrim (Lt)** soil. The spatial extent of the soils within the study area is minor, and their distribution is restricted to the 'May Downs'–'Ninemile' area, east of Middlemount.

6.5.3 Soil development on fresh Tertiary basalt (Tb)

Fresh basaltic substrates within the study area are typically fine grained olivine basalts, that are often vesicular (i.e. bubbly in appearance) and contain amygdales (i.e. filled-in vesicles) of zeolites, calcite or chalcedony (Malone *et al.* 1969). Flow thicknesses range between 5 and 35 m and flows are often overlain by or interbedded with Tertiary sediments.

In the area between 'May Downs' and 'Tiny Downs', exposures of fresh basalt are associated with completely stripped landscapes where the overlying partially altered and/or deeply weathered basaltic or sedimentary material has been removed. In these areas, a landscape of gently undulating plains and rises directly overlying fresh basalt has developed. Typically slopes are 0.5–3%, but occasionally range up to 5% where rocky ridges occur.

Soil development is typical of basalt landscapes elsewhere in Central Queensland with heavy clay soils and open downs or brigalow vegetation. Soils have developed *in situ* and overlie fresh basalt from a depth of <0.5–1.5 m. Clay mineralogy is predominantly montmorillonitic and clay contents are very high (>70%). Interestingly, phosphorus levels are often much lower where soils have developed from fresh basalts compared with the adjacent partially altered basaltic substrates.

Only four soils are described. The **May (My)** and **May shallow phase (MySp)** soils are associated with areas of open downs, while the **Indicus (Id)** and **Indicus shallow phase (IdSp)** soils are associated with brigalow scrub. Shallow phases are described where profile depths are <0.5 m. Typical landform–soil–vegetation relationships for the soils developed on fresh basalts are illustrated diagrammatically in Figure 11.

The **May (My)** soil is a strongly self-mulching, alkaline, black cracking clay with a very coarse (2–10 mm) self-mulching surface. Profiles have developed *in situ* and overlie fresh basalt from a depth of 0.65–1.0 m. A characteristic layer of grey decomposing basalt of variable thickness is normally developed above any hard rock. Profiles are moderately well drained, non-sodic and have very low salinity levels throughout. The **May (My)** soil frequently develops weak linear gilgai (VI <0.1 m) on slopes >2%. Typical vegetation includes Gum-topped bloodwood (VA16) or Queensland bluegrass downs (VA28). Mountain coolibah (VA19) also occurs but is more widespread further north around Nebo and Moranbah. Occasionally Coolibah (VA11) occurs on lower footslopes adjacent to alluvium.

The **Indicus (Id)** soil is a strongly self-mulching, alkaline, black cracking clay, which is similar in many respects to the **May (My)** soil. Profile morphology is almost identical except the **Indicus (Id)** soil has a fine (<2 mm), strongly self-mulching surface and is often slightly deeper (0.7–1.2 m). Similar differences in surface condition between basalt clays with scrub and basalt clays with eucalypt were also described by Shields and Williams (1991) at Kilcummin. In addition, analytical data for the **Indicus (Id)** soil indicates higher surface soil fertility and significant subsoil salinity below a depth of about 0.9 m compared with the **May (My)** soil. Subsoils are predominantly non-sodic, although sodicity levels also increase at the base of the profile. Such increases in both sodicity and salinity at depth suggest sodium and salts are sourced directly from the weathered substrate. Typical vegetation includes Brigalow with shrubs (VA8) or Brigalow (VA1).

Shallow phases of both these soils have been described where the depth to substrate (C or R horizons) is less than about 0.5 m. Profile features of both the **May shallow phase (MySp)** and **Indicus shallow phase (IdSp)** soils are identical to the deeper versions, except for shallower soil depth and increased stone and rock outcrop. The **Indicus shallow phase (IdSp)** soil in particular, is often very stony with between 10 and >50% basalt stones and/or outcrop. Both soils are moderately well drained, non-sodic and have very low salinity levels. Vegetation is similar to that described for the deeper versions, although eucalypt woodland (predominantly Gum-topped bloodwood (VA16) within the study area and Mountain coolibah (VA19) further north) is far more common than Queensland bluegrass downs (VA28) on the **May shallow phase (MySp)** soil. In addition, tree height and size is often much larger because of reduced soil movement and the presence of stable, root-friendly substrate at shallow depths.

The **Indicus melonhole phase (IdMp)** soil is a minor soil that occurs where basalt and unconsolidated Tertiary–Quaternary clay sheets (TQa) overlap and interfinger on level to very gently undulating plains around the margins of the basalt flows. It occurs as a weakly to strongly developed melonhole gilgai complex (VI 0.3–1 m) that has:

- a firm pedal or weakly to strongly self-mulching, alkaline, grey, brown or black, sodic cracking clay on mounds; and
- a hard setting or weakly to strongly self-mulching, acid or alkaline, grey, sodic cracking clay in depressions.

The profiles have developed *in situ* and overlie partially altered basalt or acid, basaltic clay from a depth of 0.5–>1.5 m. The upper profile is sodic except for thin surface horizons and becomes strongly sodic at depth on mounds and in depressions. Salinity levels in the subsoil are high from a depth of about 0.2 m on mounds and 0.6 m in depressions (due to ponding induced leaching). Mound profiles are moderately well drained, while depressions are imperfectly drained due to temporary ponding. Typical vegetation includes Brigalow (VA1) or Brigalow with shrubs (VA8).

6.6 Soil landscapes on unconsolidated Tertiary–Quaternary sediments sourced from sedimentary landscapes (TQa)

6.6.1 Landscape development

Much of the study area and surrounding catchments are mantled by unconsolidated transported sediments that are derived largely from the dissection and stripping of the Tertiary land surface during the Late Tertiary Period (1.8–24 million years ago). Sediments from the stripping of exposed Permian, Triassic and Jurassic strata during this period are also included but are relatively minor. In some areas outwash fans or colluvial deposits close to distinct provenance areas such as the Triassic quartzose sandstones of the Carborough Range or Permian sandstones of the Cherwell Range significantly influence local soil development. In comparison with the contribution from the down wearing of the extensive Tertiary Land Surface, however, these influences are mostly minor and localised. Similarly, unconsolidated sediments derived from the dissection and stripping of basaltic (or andesitic) landscapes differ significantly in terms of particle size, mineralogy and chemistry from those of sedimentary origins (i.e. derived from the Tertiary Land Surface). Soil development on basaltic (or andesitic) derived sediments is discussed in more detail in the following section.

The extent and distribution of soils in this landscape is largely controlled by the source, nature and depositional pattern of the unconsolidated sediments. Spatial variation in the characteristics of the sediments is evidenced by the apparently complex and random soil distributions that occur within the level to gently undulating plains associated with this landscape. Where the relative age, mode of deposition and immediate source of the sediments can be interpreted or inferred this complexity is more easily understood.

The depositional nature of the unconsolidated sediments ranges from:

- obvious relict alluvial deposits; to
- extensively transported and reworked alluvium/colluvium on plains and pediments; and
- basal layers from the Tertiary Land Surface that have been reworked locally but with significant colluvial or relict alluvial input (i.e. reworked, acid Tertiary clay).

The distinguishing feature in all cases is that the sediments are unconsolidated and have been transported and deposited following Late Tertiary dissection and erosion. The sediments vary enormously in thickness from only 1–2 m on pediment slopes adjacent to Tertiary landforms up to >50 m in lower landscape positions where significant alluviation has occurred.

Lithology is predominantly sand or clay material derived from the dissection of the Tertiary Land Surface or other later Tertiary–Quaternary sediments. Clays range from sodic, alkaline, mixed mineralogy deposits through to reworked, acid Tertiary clays associated with basal layers of the Tertiary Land Surface. Purplish silcrete or 'billy' gravels are a characteristic surface feature of these sediments and provide a useful field marker.

Soils that overlie rock substrates (e.g. petroreticulite), but have developed from unconsolidated colluvial material rather than the underlying substrate, have been included in this landscape. This is common on Tertiary pediments where soil development in some situations is influenced more by the colluvial material mantling the pediment than the underlying substrate.

Photograph 19. Typical level to gently undulating poplar box country associated with the TQa landscape

Photograph 20. Typical level to gently undulating brigalow country associated with the TQa landscape

Photograph 21. Level, melonholed clay plains with brigalow or blackwood occupy extensive areas within the TQa landscape

Photograph 22. The level to gently undulating nature of the TQa landscape is obvious where extensive clearing has occurred

6.6.2 Soil development

Ten soils (including four phases) are described within this landscape. Of these, the **Collawmar (Cm), Foxleigh (Fx)** and **Foxleigh clay loamy phase (FxLp)** soils are associated with eucalypt woodland, while the remainder are brigalow soils. Typical landform–soil–vegetation relationships for the eucalypt soils in this landscape are illustrated diagrammatically in Figures 9 and 12.

The **Foxleigh (Fx)** soil is the most extensive of the three eucalypt soils and occurs on level to gently undulating plains that are widespread south-west of Middlemount, and also in the north-east of the study area. Field evidence suggests the unconsolidated sediments on which this soil develops are mostly relict alluvial deposits. Internally drained seasonal swamps with Blue gum (VA21) are a common feature where large expanses of the **Foxleigh (Fx)** soil occur. It is possible these are relict alluvial features, although they may simply reflect poor surface drainage on areas that are acting as level watersheds. Typically, it is a soft, firm or hard setting, sandy surfaced, conspicuously bleached, alkaline, mottled, brown or grey, sodic texture contrast soil over unconsolidated sediments. Surface horizons range in thickness from 0.2 to 0.6 m. Profiles are imperfectly to moderately well drained with strongly to extremely sodic subsoils and moderate to strong, coarse, columnar structure. Subsoil salinity levels are, however, low throughout. This suggests the profiles are significantly more leached than adjacent brigalow soils and potentially represent areas of significant recharge within the catchment. Typical vegetation includes Poplar box (VA20) or Poplar box–bloodwood–Moreton Bay ash (VA33), although occasionally Poplar box–ironbark (VA34) or Eucalypts with bull oak (VA32) also occur.

The **Collawmar (Cm)** soil resembles the **Foxleigh (Fx)** soil in many ways and the two are sometimes difficult to differentiate in the field. Whilst differences in profile morphology are only slight, fertility differences, particularly the level of both Available Phosphorus (Bicarb. P) and Total Phosphorus, suggest the soils are developed on sediments of different ages or origins. The **Collawmar (Cm)** soil has levels of Bicarb. P that range from 2 to 12 ppm, with a mean value of 6 ppm. In comparison, levels for the **Foxleigh (Fx)** soil range from 1 to 6 ppm with a mean value of 3 ppm. Whilst these differences appear relatively minor they are enough to significantly lift the grazing productivity of the **Collawmar (Cm)** soil from breeding country to growing country. Subtle vegetation differences with the **Collawmar (Cm)** soil, particularly the inclusion of Dawson gum as an associate with poplar box, reflect this variation. Typically, it occurs as a soft, firm or hard setting, sandy surfaced, conspicuously or sporadically bleached, alkaline, mottled, grey, sodic texture contrast soil over unconsolidated sediments. The thickness of the surface horizons is more variable than the **Foxleigh (Fx)** soil and ranges from 0.2 to 0.9 m. Profile drainage, subsoil structure (coarse columnar), and sodicity and salinity levels are all similar to the **Foxleigh (Fx)** soil. Typical vegetation includes Shrubby poplar box (VA7) or Poplar box (VA20), although occasionally Dawson gum (VA10) or Brigalow–Dawson gum (VA5) may be associated with this soil.

The **Foxleigh clay loamy phase (FxLp)** soil is a loamy surfaced version of the **Foxleigh (Fx)** soil. It has similar profile morphology to the **Foxleigh (Fx)** soil except surface horizons are thinner (0.1–0.35 m) and textures are loamy (sandy loam to clay loam) rather than sandy. Its distribution is not as widespread however, and is associated mainly with subtle depressions and lower lying areas within the level to gently undulating plains dominated by the **Foxleigh (Fx)** soil. It also occurs on gently undulating pediments below Tertiary plateaus and residuals where it is developed from colluvial material mantling the underlying deeply weathered sediments. Typically, it occurs as a hard setting, loamy or clay loamy surfaced, conspicuously or sporadically bleached, alkaline, brown, sodic texture contrast soil over unconsolidated sediments. Profile drainage, subsoil structure (coarse columnar) and subsoil sodicity are all similar to the **Foxleigh (Fx)** soil. Subsoil salinity levels, while only low, (bordering on moderate) are noticeably higher than the levels recorded for the **Foxleigh (Fx)** soil. It is probable less leaching (and possibly less recharge) is occurring because surface soils are loamy rather than sandy. Poplar box (VA20) or Shrubby poplar box (VA7) are normally associated with this soil, although occasionally Poplar box–ironbark (VA34), Gum-topped box (VA18) or Yapunyah (VA24) may also occur.

The **Foxleigh clay loamy phase (FxLp)** soil often occurs as an intergrade between the sandy **Foxleigh (Fx)** or **Collawmar (Cm)** soils and the heavier brigalow soils. In such cases, it occupies a relatively narrow zone that lies between both sets of soils and over which the gradual change from eucalypt to brigalow occurs.

Of the six brigalow soils described, the **Racetrack (Rt), Warwick (Ww)** and **Turon (Tr)** soils occur on the same level to gently undulating plains described above. The remainder of the brigalow soils, namely **Pomegranate (Pg), Pomegranate melonhole phase (PgMp), Pomegranate shallow phase (PgSp)** and **Racetrack shallow phase (RtSp)** occur on plains, pediments and footslopes adjacent to Tertiary plateaus, particularly around the Junee Tablelands and are discussed later. While the distribution of soils within the level to gently undulating, TQa landscape is largely unpredictable, subtle relationships with regard to the distribution of eucalypt and scrub do appear to exist. They are much less predictive however, than in landscapes where soils are developed *in situ* from underlying substrates. Typical landform–soil–vegetation relationships for the brigalow soils in this landscape are illustrated diagrammatically in Figures 9 and 12.

Variation in depositional patterns associated with the unconsolidated sediments probably accounts for much of the apparently random distribution of these soils. The spatial complexity observed in the progression from sandy surfaced, texture contrast soils through to gilgaied clays is best explained by subtle differences in relative elevation. In general, the eucalypt soils **Foxleigh (Fx)** and **Collawmar (Cm)** occupy slightly more elevated areas within the plains, and probably represent relict alluvial deposits. They grade to flatter, less undulating areas that are intermediate in elevation and are associated with the **Foxleigh clay loamy phase (FxLp)** and **Racetrack (Rt)** soils. The **Warwick (Ww)** and **Turon (Tr)** soils, which are gilgaied brigalow clays, occur on level plains that lack relief and occupy comparatively low lying areas.

This same progression becomes more meaningful when surface fertility, particularly Available Phosphorus (Bicarb. P) and Total Nitrogen, of each soil is compared. The levels of both nutrients gradually increase from very low or low levels on the sandy surfaced, texture contrast soils (**Foxleigh (Fx)** and **Collawmar (Cm)**) to low or moderate levels on the intermediate fertility soils (**Foxleigh clay loamy phase (FxLp)** and **Racetrack (Rt)**) and finally moderate to very high levels on the gilgaied brigalow clays (**Warwick (Ww)** and **Turon (Tr)**). The progression in mean Bicarb. P and Total N values for each soil is shown in Table 14.

The **Racetrack (Rt), Warwick (Ww)** and **Turon (Tr)** soils all occur extensively within the study area and represent the major land types developed during Brigalow Scheme III. The **Racetrack (Rt)** soil is a hard setting, clay loamy surfaced, conspicuously or sporadically bleached, alkaline, brown, sodic texture contrast soil over unconsolidated sediments. Profiles are moderately well drained with

Table 14. Progression in fertility levels from sandy surfaced, texture contrast soils through to gilgaied clays within the TQa landscape

Soil	Gilgai comp.	Bicarb P (ppm)	Total N (%)
Sandy surfaced, texture contrast			
Foxleigh (Fx)	–	3 (very low)	0.03 (very low)
Collawmar (Cm)	–	6 (low)	0.04 (low)
Loamy surfaced, texture contrast			
Foxleigh clay loamy phase (FxLp)	–	9 (low)	0.05 (moderate)
Racetrack (Rt)	–	13 (moderate)	0.05 (moderate)
Gilgaied clays			
Warwick (Ww)	m/s	14 (moderate)	0.09 (high)
	d	29 (high)	0.09 (high)
Turon (Tr)	m/s	10 (moderate)	0.10 (high)
	d	34 (high)	0.10 (high)

strongly to extremely sodic subsoils and moderate to strong, coarse columnar structure. Subsoil salinity levels are moderate. Typically, Brigalow–Dawson gum (VA5) is associated with this soil, although occasionally Brigalow (VA1), Dawson gum (VA10) or Brigalow–yapunyah (VA40) may also occur. The **Racetrack (Rt)** soil occupies an intermediate position within the level to gently undulating TQa landscape and is usually found intermixed with and adjacent to both eucalypt soils and gilgaied brigalow clays. It also occurs on level to gently undulating plains, valley floors and pediments surrounding the Junee Tablelands in association with the **Pomegranate (Pg)** soil.

The **Warwick (Ww)** and **Turon (Tr)** soils are gilgaied heavy clays that occur on relatively low-lying, level plains. Field evidence suggests the clays are developed from a combination of reworked basal layers of the Tertiary Land Surface (i.e. Tertiary clay sheets) and more recent, relict alluvial and colluvial deposits. The two soils are essentially the same and differ only in the size and regularity of gilgai microrelief. Microrelief associated with the **Warwick (Ww)** soil is variable and ranges from irregular or weakly developed normal gilgai through to regular, shallow melonholes (VI 0.25–0.5 m).

The **Turon (Tr)** soil is characterised by uniform, closely to widely-spaced, strongly developed, deep melonholes (VI >0.6–1.5 m). Both soils typically occur as a gilgai complex with:

- a hard setting, firm pedal or weakly self-mulching, alkaline, grey or brown, sodic cracking clay on mounds and shelves (if present); and
- a hard setting, firm pedal or weakly to moderately self-mulching, acid, grey, sodic cracking clay in depressions.

Profiles overlie unconsolidated, reworked, acid Tertiary clay from a depth of about 0.5–>1.5 m. It is unclear whether profile development has occurred *in situ* from these materials. The soils are imperfectly to moderately well drained on mounds and shelves and poorly to imperfectly drained in depressions because of seasonal ponding. Both soils have sodic upper profiles, with the exception of thin surface horizons, and strongly to extremely sodic lower subsoils. High salinity levels normally occur somewhere in the range 0.1–0.3 m on mounds and shelves and 0.45–0.6 m in depressions. Typical vegetation includes Brigalow (VA1), Blackwood (VA37) or Brigalow–blackwood (VA4). Occasionally Brigalow–Dawson gum (VA5) is associated with the **Warwick (Ww)** soil and Brigalow with shrubs (VA8) or Belah (VA9) is associated with the **Turon (Tr)** soil.

In areas lying below elevated Tertiary plateaus and residuals that have been subject to significant scarp retreat and dissection, such as the Junee Tablelands, a series of level to gently undulating plains, valley floors and coalescing pediments is often developed. Soil development within these areas differs from the remainder of the TQa landscape because of the strong colluvial influences that stripping and dissection of the adjacent plateaus has had on the nature of the deposited sediments. Soils are predominantly hard setting clays with brigalow scrub that have characteristic red-brown or brown colours and purplish ('billy') surface gravels (2–20%). The soils have high levels of fine sand in the clay matrix, which reflect the fine sandy nature of the Tertiary sediments from which they are derived. In general, the soils are developed entirely from unconsolidated materials, although on some pediments, deeply weathered Tertiary sediments into which the pediment has been etched may influence subsoil development. The distribution of these soils within the study area is mainly associated with the dissected valleys immediately north, west and south of the Junee Tablelands, such as the catchment of Pomegranate Creek. More isolated occurrences, north of Middlemount, appear to have formed on similar unconsolidated sediments that have accumulated following the complete dissection of former plateaus in that area.

The dominant soil developed on these largely Tertiary derived, unconsolidated sediments is the **Pomegranate (Pg)** soil. Typically, it is a hard setting, gravelly, alkaline, brown, sodic cracking to non-cracking clay over unconsolidated sediments on valley floors and pediments below Tertiary plateaus. Profiles are moderately well drained with sodic upper subsoils and strongly to extremely sodic lower subsoils. High salinity levels normally occur below a depth of about 0.4 m, but may occur closer to the surface on pediments where seepage from adjacent tablelands is occurring. Profiles are either non-gilgaied or have normal or shallow, melonhole gilgai (VI 0.2–0.5 m), often with a prominent shelf. Where gilgaied, mound and depression profiles have similar morphology, except depressions are acid throughout. Typical vegetation is Brigalow (VA1) which often occurs as stunted 'whipstick' scrubs. Occasionally Brigalow–Dawson gum (VA5) may be present, particularly where the **Racetrack (Rt)** soil is associated.

In some areas, the **Pomegranate (Pg)** soil becomes strongly gilgaied and has been mapped as the **Pomegranate melonhole phase (PgMp)** soil. It occurs mainly in low-lying areas within the plains and valley floors surrounding the Junee Tablelands and is probably developed on reworked basal layers of the dissected Tertiary sequence (i.e. reworked Tertiary clays) mixed with colluvium. It occurs as a strongly developed melonhole gilgai complex (VI >0.6–1.5 m) with:

- a firm pedal, gravelly, alkaline, brown, sodic cracking clay on mounds; and
- a hard setting, firm pedal or weakly self-mulching, gravelly, acid, brown or grey, sodic cracking clay in depressions.

Profiles overlie reworked, acid Tertiary clay from a depth of 0.7–>1.5 m or undifferentiated unconsolidated sediments. They are moderately well drained on mounds and poorly to imperfectly drained in depressions because of seasonal ponding. Mounds and depressions are sodic in the upper profile, except for thin surface horizons, and strongly to extremely sodic in the lower subsoil. High salinity levels normally occur at depths somewhere between 0.1 and 0.3 m on mounds and below about 0.6 m in depressions. Vegetation is similar to the **Pomegranate (Pg)** soil, except occasionally Brigalow with shrubs (VA8) may be present.

The **Pomegranate shallow phase (PgSp)** soil occurs on distinct sloping pediments and footslopes below Tertiary plateaus and residuals, particularly around the margins of the Junee Tablelands. The pediments are etched into the underlying deeply weathered sediments and often coalesce to form a characteristic apron around adjacent residuals. Typically, it occurs as a moderately deep, very hard setting, gravelly, acid to alkaline, strongly sodic version of the **Pomegranate (Pg)** soil developed on colluvium over deeply weathered sediments from a depth of 0.6–1.1 m. Profiles are imperfectly to moderately well drained and strongly to extremely sodic throughout, except for thin surface horizons. High salinity levels typically occur at depths somewhere below about 0.5 m, but may occur closer to the surface on pediments where seepage from adjacent tablelands is occurring. Saline and/or sodic erosion scalds are a common and characteristic feature with this soil and provide strong evidence that adjacent elevated tablelands should be left uncleared because of the potential for increased salinisation of footslopes, pediments and valley floors lying below. Brigalow–yapunyah (VA40) is typically associated with this soil, although occasionally Brigalow (VA1) also occurs.

On some pediments and footslopes, the **Racetrack shallow phase (RtSp)** soil occurs in place of the **Pomegranate (Pg)** and **Pomegranate shallow phase (PgSp)** soils. Typically, it is a moderately deep, hard setting, loamy surfaced, sporadically bleached, gravelly, neutral or alkaline, brown, sodic texture contrast soil that has similar morphology to the **Racetrack (Rt)** soil, but overlies deeply weathered sediments from a depth of 0.5–1.1 m. Profiles are developed from unconsolidated colluvium that mantles the pediment slopes. The underlying deeply weathered sediments (usually hard petroreticulite) appear to have had little influence on soil development and evidence of *in situ* development was not observed. Profiles are moderately well drained with similar sodicity and salinity levels to the **Racetrack (Rt)** soil. Subsoil structure is often blocky rather than coarse columnar. Salinity levels, whilst only moderate, continue to increase at the base of the profile, which suggests the underlying substrate is either contributing to subsoil salinity or lateral seepage at the soil–substrate contact is occurring. Brigalow–Dawson gum (VA5) is typically associated with this soil, although occasionally Dawson gum (VA10) or Brigalow–yapunyah (VA40) also occur.

6.7 Soil landscapes on unconsolidated Tertiary–Quaternary sediments sourced from basaltic landscapes (TQa_b)

6.7.1 Landscape development

Much of the north-east of the study area, from Dysart east to ‘Carfax’ and south to ‘Warwick Park’, is mantled by unconsolidated, transported sediments that have come largely from the dissection and stripping of Tertiary basalts in the Peak Range. Weathered basaltic material, marl, clay, sand, gravel and stone were transported by easterly flowing streams through the Cherwell Range and laid down as deltaic (river delta) or paludal (swampy) deposits. Deposition appears to have occurred where the fast flowing precursors of Phillips, Stephens and Scott Creeks (and possibly other relict streams) slowed considerably before joining the Isaacs system or its precursor.

Drilling logs from BHP in the vicinity of the Golden Mile Road confirm there is 10–40 m (mostly 25–35 m) of Tertiary–Quaternary cover overlying consolidated Permian sandstones and siltstones. The logs indicate significant layering is present within the unconsolidated sediments. A general sequence is described which includes soil material for the first 1–2 m overlying fine grained, basaltic-derived, powdery sandy clay sediments up to 5 m thick. These in turn overlie varying thicknesses of sand or clay lenses, marl beds, secondary carbonate deposits, gravel beds and stone layers. While the majority of the sediments are alkaline and often calcareous, lenses of acid clay also occur within the sedimentary sequence. The acid clays probably represent deposits derived either from localised stripping of the Tertiary land surface in the same area or from dissection and erosion of deeply weathered fine grained sedimentary rocks within the Cherwell Range to the west.

The presence of calcareous sediments within the TQa_b sequence is widespread and has had a significant influence on soil development. The calcareous (or dolomitic) materials mostly occur as marl, calcareous fine grained sediments or secondary carbonate deposits. The origin of the free carbonates is associated with the release of abundant calcium (Ca) from Ca-rich feldspars (plagioclase) and lower levels of magnesium (Mg) from ferro-magnesian minerals within the basaltic-derived sediments (Gray and Murphy 1999). Leaching and translocation has concentrated soluble Ca and Mg over time and resulted in the precipitation of calcium carbonate ($CaCO_3$) and lesser amounts of magnesium carbonate ($MgCO_3$) deposits at depth. As this process has continued over time significant secondary carbonate deposits have formed at different depths within the sedimentary sequence. Where subsequent stripping and dissection has occurred, deposits have been exposed, particularly on active sideslopes or beneath resistant crests, providing calcareous substrates for soil development.

A level to gently undulating landscape of plains and low rises has developed on the TQa_b sediments. More relief is apparent in areas immediately north of Stephens Creek where deposits are possibly thicker and post depositional erosion has dissected the landscape to a greater extent. Areas south of Stephens Creek, particularly around 'Warwick Park', occur mostly as level to very gently undulating plains with little local relief. Significant changes in elevation (>40 m) occur from west to east and are probably related to the gentle easterly dip in the underlying Permian strata, as well as a possible reduction in depositional thickness in this direction (i.e. further from the sediment source). Current drill logs indicate significant variation in the thickness of the sediments, but data is insufficient to reliably establish any directional trends in depositional thickness. While elevations are similar from north to south, dissection and stream incision associated with Stephens Creek and the Isaac River have meant deposits east of Dysart give the appearance of an elevated, gently undulating plateau. This apparent elevation is only relative and is associated with the presence of distinct undulating sideslopes that rise from adjacent alluvial or TQa landscapes to the north, south and east of the deposits. Exposures of calcareous substrates are commonly intersected on these sideslopes and soil development differs significantly from that on the plains and low rises above.

Photograph 23. A gently undulating landscape of plains and low rises has developed on the basaltic-derived Tertiary–Quaternary sediments (TQa_b), east of Dysart

Photograph 24. Extensive dryland cropping development on the TQa_b landscape (sorghum crop at 'Coolibah')

6.7.2 Soil development

The distribution of soils on the TQa_b landscape varies from north to south, and also east to west, and is a function mainly of the homogeneity of the sediments. Areas between Dysart and 'Carfax' are dominated by thick, almost purely basaltic-derived sequences, while to the north and south and particularly around the margins of the deposits significant mixing has occurred during deposition. Additions of fine sand, silt and sodic and/or acid clay derived largely from the stripping of the Tertiary Land Surface have effectively diluted the basaltic nature of the sediments in these areas. The soils occurring around these margins, particularly where the TQa landscape lies adjacent, differ significantly from areas in the centre of the deposits where predominantly basaltic-derived material is present. In general, loamy surfaced texture contrast soils and clays that are not strongly self-mulching occur around the margins, while in the centre deep, strongly self-mulching clay soils have developed. Even within the self-mulching clays between Dysart and 'Carfax', significant variation from east to west was observed. Western areas are closer to the basaltic provenance areas and deposits are relatively pure. Further east significant mixing has occurred, and while the soils are still largely basaltic in nature, they have lower clay contents, higher sand fractions and clay mineralogies that are mixed rather than purely basaltic in origin.

Soil development has also been influenced by the presence or absence of calcareous substrates. Exposures of calcareous material are most common on the gently dissected sideslopes that bound the TQa_b landscape in the Dysart area. Examples of this are evident where the Golden Mile Road descends eastwards from the undulating TQa_b landscape onto the alluvial plain of Stephens Creek. Secondary carbonate deposits are sometimes more resistant than adjacent clays or fine grained sediments and may form residual crests and low rises following stripping and erosion. Soils developed on these residual calcareous deposits are usually relatively shallow, very friable black or brown clays that are not self-mulching. More common are the heavy black clays with open downs that develop from calcareous deposits intersected and exposed on sideslopes.

Soils have been grouped by vegetation into eucalypt and brigalow soils as on other landscapes. Whilst vegetation differences have not directly influenced soil development, they are strongly correlated with surface soil fertility and to a lesser extent subsoil salinity and represent a valid basis on which to group the soils.

Nine soils (including two phases) were described. Of these, the **Carfax (Cx), Kirkcaldy (Kc), Mayfair (Mf)** and **Mayfair sandy surface variant (MfSv)** soils are associated with eucalypt woodland, while the remainder are brigalow soils. Typical landform–soil–vegetation relationships for the eucalypt soils in this landscape are illustrated diagrammatically in Figure 13.

The **Carfax (Cx)** soil is the dominant soil of the sideslopes bounding the gently dissected TQa_b deposits in the Dysart area. It is almost always associated with calcareous substrates and typically occurs on gently undulating to undulating sideslopes and low rises with slopes 1–5%. It occurs most commonly around the margins of the deposits east of Dysart, particularly on sideslopes adjacent to drainage lines and creeks that traverse the area. Dissection associated with stream incision in these areas has intersected and exposed the calcareous substrates on which this soil develops. It typically occurs as a strongly self-mulching, alkaline, black cracking clay with strongly developed linear gilgai (VI 0.1–0.4 m). Profiles have developed *in situ* and overlie unconsolidated calcareous, basaltic-derived sediments below a depth of 0.8–1.3 m. Soils are moderately well drained, mostly non-sodic throughout and have low levels of subsoil salinity, irrespective of gilgai component. Differences between mounds and depressions relate mainly to surface condition. Mound profiles have a thick (0.05–0.07 m), fine (<2 mm) self-mulch with significant amounts of free carbonate (10–20%), while depression profiles have thinner (0.03–0.05 m), coarser (2–5 mm) surface soils that appear darker in colour. Typical vegetation includes Mountain coolibah (VA19), Queensland bluegrass downs (VA28) or occasionally Ironbark–bloodwood–ghost gum (VA43).

The **Kirkcaldy (Kc)** soil is often closely associated with the **Carfax (Cx)** soil and usually develops where relatively resistant secondary carbonate deposits are exposed. It differs from the **Carfax (Cx)** soil in that it is developed predominantly from calcareous substrate rather than basaltic-derived material. Typically, it occurs as a hard setting, firm pedal or weakly to strongly self-mulching, alkaline, black or brown non-cracking to cracking clay. Profiles have developed *in situ* and overlie unconsolidated calcareous sediments from a depth of 0.3–1.1 m. Soils are moderately well drained, with non-sodic upper subsoils and non-sodic to sodic lower subsoils. Salinity levels are low throughout. The chemistry of the underlying calcareous substrate may vary considerably from predominantly calcium carbonates through to predominantly magnesium carbonates, which may or may not be sodic. In sloping areas, weakly developed linear gilgai (VI 0.05–0.1 m) may be present. The gilgai typically have little or no vertical relief but are noticeable because of changes in surface condition between components and the presence of significant amounts of free carbonate on mounds. Typical vegetation includes Mountain coolibah (VA19), Silver-leaved ironbark (VA17) or Ironbark–bloodwood–ghost gum (VA43).

While the **Carfax (Cx)** and **Kirkcaldy (Kc)** soils occur throughout the TQa_b landscape, the texture contrast soils **Mayfair (Mf)** and **Mayfair sandy surface variant (MfSv)** are restricted to level or gently undulating plains around the margins of the landscape, where significant mixing of the unconsolidated sediments has occurred. These soils are of limited extent within the study area but are well represented in other areas with TQa_b sediments such as around Nebo. The **Mayfair (Mf)** soil is a hard setting, loamy or clay loamy surfaced, sporadically bleached, alkaline, brown or red, non-sodic texture contrast soil over unconsolidated calcareous sediments from a depth of 0.6–1.1 m. Profiles have developed *in situ* from a range of materials that include predominantly basaltic-derived calcareous deposits through to mixed mineralogy clay sediments with significant sand and silt contents. Soils are imperfectly to moderately well drained, with non-sodic upper subsoils and non-sodic to sodic lower subsoils. Salinity levels are low throughout. There are distinct similarities between this soil and the **Red-one (Rn)** soil overlying Permian sediments. The two soils have developed from substrates of similar lithology but very different origin, age and landscape position. Typical vegetation includes Silver-leaved ironbark (VA17) or Poplar box (VA20), although occasionally Narrow-leaved ironbark (VA12), Poplar box–ironbark (VA34) or Mountain coolibah (VA19) also occur.

The **Mayfair sandy surface variant (MfSv)** is a minor soil that occurs in just a few locations on level to gently undulating plains at the southern margin of the TQa_b landscape, near 'Warwick Park'. Typically, it occurs as a sandy surfaced, sporadically bleached, alkaline, mottled, brown or grey, sodic texture contrast soil with coarse columnar structure over unconsolidated calcareous sediments (probably of mixed origins) below a depth of 0.9–>1.5 m. It is, effectively, a sandy surfaced, sodic version of the **Mayfair (Mf)** soil, and in many respects also resembles the **Foxleigh (Fx)** soil developed on adjacent TQa sediments. Because of its limited extent, this soil was not sampled for laboratory analyses, and reference to the equivalent **Foxleigh (Fx)** soil is suggested for indicative analytical data. Profiles are imperfectly to moderately well drained and have low levels of subsoil salinity. Field evidence suggests subsoils are sodic to strongly sodic throughout and probably strongly to extremely sodic in the lower subsoil. Typical vegetation includes Poplar box (VA20), Poplar box–ironbark (VA34) or occasionally Ironbark–bloodwood–ghost gum (VA43).

Of the five brigalow soils described, the **Hazelbrae (Hb), Knockane (Kk)** and **Norwich (Nw)** soils occur on similar level to gently undulating plains and low rises to those described above for the eucalypt soils. The **Picardy (Pc)** and **Picardy surface seal phase (PcXp)** soils, however, are located predominantly in the centre of the TQa_b landscape (east of Dysart), where deposits are thickest and predominantly basaltic-derived. Landforms in this area have been subject to dissection and stream incision associated with Stephens Creek and the Isaac River. They occur as level to gently undulating plains and low rises that appear elevated and have significant local relief compared with surrounding Qa and TQa landscapes. The deposits resemble a low plateau to some extent and are bounded by distinct sideslopes that have formed following stream incision. Calcareous sediments are often exposed on the sideslopes, particularly where dissection has intersected beds of secondary carbonate originally at some depth within the sedimentary sequence. The eucalypt soils, **Carfax (Cx)** and **Kirkcaldy (Kc)**, are normally associated with these sideslopes. Typical landform–soil–vegetation relationships for the brigalow soils in this landscape are illustrated diagrammatically in Figure 13.

The **Hazelbrae (Hb)** soil is the brigalow equivalent of the **Mayfair (Mf)** soil. It occurs on similar level to gently undulating plains and is usually located along the margins of the TQa_b landscape. Typically, it is a hard setting, clay loamy surfaced, sporadically bleached, alkaline, brown or grey, non-sodic texture contrast soil over unconsolidated calcareous sediments below a depth of 1.0–>1.5 m. Profiles have developed *in situ* from a range of materials that include predominantly basaltic-derived calcareous deposits through to mixed mineralogy clay sediments with significant sand and silt contents. Soils are moderately well drained, with non-sodic upper subsoils and sodic to strongly sodic lower subsoils. Levels of subsoil salinity are low throughout. Typical vegetation includes Brigalow–Dawson gum (VA5), Belah (VA9) or occasionally Brigalow (VA1).

Closely associated with the **Hazelbrae (Hb)** soil, both spatially and morphologically, is the **Knockane (Kk)** soil. It often occurs adjacent to the **Hazelbrae (Hb)** soil and the two tend to grade into each other, particularly where the loamy surface horizons of the **Hazelbrae (Hb)** soil become very thin. Landscape position, subsoil characteristics and underlying substrate are all effectively the same for both soils. Typically, the **Knockane (Kk)** soil occurs as a hard setting, firm pedal or weakly self-mulching, alkaline, grey non-cracking to cracking clay over unconsolidated calcareous sediments below a depth of 1.1–>1.5 m. Normal gilgai (VI 0.1–0.3 m) are often present, and have a prominent shelf and indistinct mounds and depressions. Profiles have developed *in situ* on substrates similar to those described for the **Hazelbrae (Hb)** soil. They are moderately well drained, with upper subsoils that are mostly non-sodic and lower subsoils that increase from sodic to extremely sodic at depth. Moderate levels of subsoil salinity occur below a depth of about 0.5 m. Typical vegetation includes Brigalow (VA1), Brigalow–Dawson gum (VA5) or occasionally Brigalow with shrubs (VA8).

The **Norwich (Nw)** soil represents an intergrade between the firm to hard setting clays and texture contrast soils around the margins of the TQa_b landscape and the strongly self-mulching clays in the centre. It occurs on similar landscape positions to the **Hazelbrae (Hb)** and **Knockane (Kk)** soils but has developed where the underlying sediments have been subject to less mixing and are mostly basaltic in origin. Typically, it occurs as a weakly to strongly self-mulching, alkaline, grey or black cracking clay with normal (VI 0.1–0.3 m) or melonhole (VI 0.3–0.8 m) gilgai over unconsolidated calcareous sediments below a depth of 1.1–>1.5 m. A prominent shelf component is normally present irrespective of gilgai size or type. Profiles have developed *in situ* and overlie a range of substrates from predominantly basaltic-derived calcareous deposits through to mixed mineralogy clay sediments closer to the margins of the TQa_b landscape. Soils are moderately well drained, with upper subsoils that are mostly non-sodic and lower subsoils that increase from sodic to extremely sodic at depth. High levels of subsoil salinity occur below a depth of about 0.7 m. Mound, shelf and depression profiles have similar morphology, although surface condition is often coarser (2–5 mm) in depressions. Typical vegetation includes Brigalow (VA1) or Brigalow with shrubs (VA8).

The **Picardy (Pc)** soil is the dominant scrub soil within the TQa_b landscape. It is widespread east of Dysart where thick deposits of predominantly basaltic-derived sediments have formed gently undulating plains and low rises. The deposits are located centrally within the TQa_b landscape and have not been subject to the mixing and dilution that has occurred around the margins. Typically, it occurs as a strongly self-mulching, alkaline, black cracking clay over unconsolidated calcareous sediments below a depth of 0.8–>1.5 m. It is non-gilgaied except in sloping areas (>1–2%), where weak linear, lattice or normal gilgai (VI 0.05–0.1 m) are frequently developed. While the gilgai have little or no vertical relief, they are noticeable because of browner colours, the presence of significant free carbonates on mounds and a coarser surface condition (2–5 mm) in depressions. While it is clear the **Picardy (Pc)** soil has developed *in situ* from basaltic-derived sediments, the alluvial nature of the deposits means occasional gravel beds, acid clay layers or coarse sand lenses may directly underlie the profile at variable depths below 0.8 m. While these buried deposits are valid substrates within the TQa_b sedimentary sequence they are not considered parent materials for the **Picardy (Pc)** soil. Soils are moderately well drained, with non-sodic upper subsoils and sodic lower subsoils. High levels of subsoil salinity occur below a depth of about 1.2 m. Typical vegetation includes Brigalow with shrubs (VA8), Brigalow (VA1) or occasionally Belah (VA9).

The **Picardy surface seal phase (PcXp)** soil outwardly resembles the **Picardy (Pc)** soil but is prone to weak surface sealing after rain and has well developed normal or lattice gilgai. Its distribution is restricted to an area in the centre of the TQa_b landscape that lies between Dysart and 'Carfax' and is bounded by Stephens Creek and the Isaac River. It occurs mostly on level to very gently undulating plains that occur around the margins or at the eastern end of this area. Typically, it occurs as a strongly self-mulching, alkaline, black cracking clay that is morphologically similar to the **Picardy (Pc)** soil. However, laboratory analyses indicate there are slight but significant differences between the two soils, particularly in terms of particle size distribution, cation exchange capacity, clay mineralogy and sediment source. The **Picardy surface seal phase (PcXp)** soil has a lower cation exchange capacity, approximately 10% less clay through the profile and 10–15% more coarse sand in the surface soil. In addition, Total K levels and clay activity ratios in the subsoil are significantly lower indicating potential differences in sediment source, increased mixing of sediments during deposition, less basaltic influence and the presence of predominantly mixed mineralogy rather than montmorillonitic clays. Following rain, a weak seal forms on the surface of the soil that is characterised by a well developed flake or weak crust and a thin sandy surface veneer. This surface condition is only temporary and landholder experience suggests, whilst it is noticeable, it is not important agronomically. However, differences in infiltration rate, plant available water capacity and ameliorative response to compaction are predicted with long term cultivation.

Profiles of the **Picardy surface seal phase (PcXp)** soil are developed *in situ* from unconsolidated, largely basaltic-derived sediments that have undergone significantly more mixing than those associated with the **Picardy (Pc)** soil, and may or may not be calcareous. Occasionally acid clay layers underlie the profile from a depth of about 0.8–1.3 m. Soils have well developed normal or lattice (VI 0.1–0.3 m) gilgai and are moderately well drained irrespective of gilgai component. Profile morphology on mounds and depressions is similar, with the exception of some surface features. Typically, depressions have a darker, thinner (0.03–0.05 m), coarser (<2–5 mm) self-mulching surface, with lower surface pH and without free carbonate nodules when compared with mounds. Sodicity levels in the subsoil are similar to the **Picardy (Pc)** soil but subsoil salinity occurs at shallower depths. High salinity levels are normally present below a depth of about 0.9 m. Typical vegetation includes Brigalow with shrubs (VA8) or occasionally Brigalow (VA1). Photo patterns dating back to 1962 suggest scrubs associated with the **Picardy surface seal phase (PcXp)** soil were originally very open and were subject to regular burning compared with the adjacent thick scrubs on the **Picardy (Pc)** soil.

6.8 Soil landscapes on Quaternary alluvium (Qa)

6.8.1 Landscape development

Quaternary alluvium is defined for the purpose of this study as alluvial deposits associated with current streams. During the Quaternary Period (1.8 million years ago to present day) extensive alluviation occurred along all streams within the catchments, creating a complex landscape of channels, levees, alluvial plains, flood plains, scroll plains, backplains, back swamps, sand ridges and occasional terraces, depending on the size, location and flood regime of the stream. Higher parts of many alluvial plains, such as elevated levees and sand ridges, are now stable and generally above regular flood levels (>1 in 50 years average recurrence interval (ARI)). Lower parts, particularly along the Isaac and Mackenzie Rivers and major tributaries, are still subject to scouring, deposition and regular flooding (>1 in 1 to 1 in 10 years ARI).

The extent and distribution of soils within this landscape is largely controlled by landscape position and the age and nature of the sediments from which the soils are derived. Landscape position influences not only the conditions under which soil development occurs (e.g. flooded regularly vs not flooded; high and well drained vs low and swampy, etc.), but also the particle size of the flood sediments being deposited. Where overbank flow occurs and flood waters spread over adjacent alluvial plains, coarser sediments such as sand drop out of suspension first and are deposited on levees and flats close to channels. As floodwaters slow further and stagnate in backplain areas, finer sediments such as silt and clay material are deposited. The regularity and severity of flooding, as well as the nature of the sediments, obviously influence this process.

In general, the nature of the sediments deposited within an alluvial plain reflect the lithology of the provenance areas upstream. This relationship is particularly reliable for tributary streams that are close to a sediment source or in situations where lithology is uniform over large parts of the catchment. It becomes more complex, however, as down stream distance increases and mixing of sediments from a number of provenance areas occurs. Soil distribution along alluvial plains in the lower reaches of a catchment, such as the Isaac River flood plain, is dependent therefore on a range of factors which include:

- stream size and catchment position;
- landform position within the alluvial plain;
- flooding regime—frequency, severity and duration;
- depositional environment;
- age of deposits;
- sediment source; and
- nature of sediment and provenance lithology.

The interaction between these factors is often complex. Modelling the catchment in terms of relative stream size and catchment position is possible using 1:250 000 stream ordering and provides a useful starting point for understanding and predicting alluvial soil distribution. On this basis, streams within the study area can be grouped into three broad categories:

(i) upper tributaries – mostly stream orders 1 and 2 (St Lawrence 1:250 000 map sheet);
(ii) lower tributaries – mostly stream orders 3 and 4 (St Lawrence 1:250 000 map sheet); and
(iii) flood plains – mostly stream orders 5 and 6 (St Lawrence 1:250 000 map sheet).

Upper tributaries (stream orders 1 and 2) are located close to provenance areas and sediment deposition generally reflects surrounding lithologies. An example of this is the sandy sediments along German Creek in the south-west of the study area, which are sourced from the predominantly Permian sandstone lithologies of the surrounding upper catchment. The alluvial plains associated with these tributaries are relatively narrow (mostly <0.5 km) and subject to flash flooding (1–2 days) with the potential to carry coarse sediment loads. Dominant landforms include weakly incised, mostly single stream channels, channel benches, narrow alluvial flats and active levees. Soils are predominantly sands and sandy surfaced texture contrast soils in catchments dominated by sandy unconsolidated sediments or sandstone lithologies. Loams, loamy surfaced texture contrast soils or hard setting clays typically occur in catchments that are predominantly clay based (e.g. Pomegranate Creek).

Lower tributaries (stream orders 3 and 4) are usually major creeks with well developed alluvial plains. Deposited sediments generally come from more than one provenance area and significant mixing of sediments has generally occurred. Examples within the study area include Stephens Creek where both basaltic and sandstone provenance areas occur within the catchment and Rolf Creek which traverses a mix of unconsolidated sediments, Permian rocks, basalt and Tertiary sediments before joining the Isaac River. The alluvial plains are relatively wide (0.5–2 km) and subject to more generalised, longer duration flooding (<1 week) than the upper tributaries. Segregation of floodwaters into fast flowing streams and slower backplain floodways and the subsequent grading of depositional sediments from coarse to fine within different landscape positions across the alluvial plain begins to occur. Typical landforms include incised, mostly single stream channels, distinct narrow levees, level alluvial plains, backplain drainage areas and occasional sand ridges and seasonal swamps. A much wider range of soils are present on lower tributaries compared with upper tributaries and the relationship with specific provenance areas is less obvious. Soils are predominantly sandy or loamy surfaced texture contrast soils or hard setting to firm pedal clays. Deep sands are normally only present where source bordering, aeolian sand ridges (i.e. wind blown sand deposits sourced from adjacent stream bed loads) have developed. Similarly self-mulching clays are normally only present immediately downstream from labile provenance areas where basalt or calcareous sediments are contributing significantly (e.g. Rolf Creek downstream from ‘May Downs’).

Photograph 25. Ephemeral stream channel typical of upper and lower tributaries in the study area

Photograph 26. Aerial view showing the extent and complexity of the lower Isaac–Connors flood plain while in flood, September 1998

Flood plains (stream orders 5 and 6) have mainly developed at the lower end of the catchments and flank major rivers. Deposited sediments may be sourced from anywhere in the catchment and significant mixing and segregation of the sediments occurs prior to and during deposition. Typical examples include the flood plains along Funnel Creek and the Isaac–Connors and Mackenzie Rivers. The flood plains are often very wide (2–10 km) and subject to flooding that is both regular (every 1–2 years) and of extended duration (often a number of weeks or more). Segregation of the floodwaters and grading of sediments within the flood plain is very pronounced and sediment characteristics in different landscape positions differ markedly. Typical landforms include incised stream channels (single and meandering or braided), narrow active levees adjacent to channels, scroll plains, flood plain 'runners' (migrating and cross connecting channels), level clay flood plains, low lying backplains, seasonal swamps, permanent billabongs and relict, high levees, terraces and occasional aeolian sand ridges above regular flood levels. Soil distribution within the flood plains is usually predictive and well correlated with landscape position. Soils on the active levees, flats and scroll plains adjacent to flood plain channels are usually hard setting or firm pedal clays, while the level clay plains and low lying backplains are predominantly self-mulching clays. Sandy or loamy texture contrast soils and hard setting clays occur on the relict, high levees and terraces while deep sands may be present on source bordering aeolian sand ridges.

6.8.2 Soil development

Soils developed on alluvium have been grouped by vegetation into eucalypt and brigalow soils as in other landscapes. The vegetation groupings reflect significant differences in nitrogen fertility and subsoil salinity. Unlike other landscapes however, phosphorus fertility is generally similar across all soils and its predictive function is not particularly useful.

Twelve soils were described in this landscape. Of these, the **German (Gm), Isaac (Is), Booroondarra (Bn), Parrot (Pr), Roper (Rp), Stephens (St), Bluchers (Bc), Thirteenmile (Tt)** and **Lindsay (Ld)** soils are associated with eucalypt woodland, while **Honeycomb (Hy), Tralee (Tl)** and **Langley (Lg)** are brigalow soils. Typical landform–soil–vegetation relationships for the eucalypt soils in this landscape are illustrated diagrammatically in Figure 14.

The **German (Gm)** soil occurs almost exclusively on narrow alluvial plains associated with upper tributaries, mainly in the south-west of the study area. Provenance lithologies within the surrounding catchments are mainly Permain sandstones or sandy Tertiary sediments and alluvial deposits are characteristically sandy and coarse grained. Typically, it occurs as a moderately deep to deep, soft or loose, acid or neutral, brown, uniform sand with buried alluvial layers from a depth of 0.5–>1.5 m, on channel benches, active levees and flooded creek flats along narrow upper tributaries. The nature of the buried sediments is variable and ranges from sand to sandy medium clay. Multiple layers are common, and significant lithological variations are often apparent in adjacent layers. Stream channels are usually single and only weakly incised and flash flooding is common. Soils are well drained to rapidly drained depending on local elevation. Typical vegetation includes Blue gum–mixed eucalypts (VA22) or Moreton Bay ash (VA23).

The **Booroondarra (Bn), Parrot (Pr)** and **Roper (Rp)** soils are the dominant eucalypt soils on levees and alluvial plains along most upper and lower tributaries. The **Booroondarra (Bn)** soil is restricted to level or gently undulating, elevated levees, sand ridges and occasional flood plain terraces, all of which are irregularly flooded and in some cases possibly relict. Typically, it ranges from a deep, soft or loose, neutral, red, uniform sand (>1.5 m) on alluvial sand ridges to a thick (0.4–1.0 m), sandy surfaced, sporadically bleached, neutral or alkaline, red, non-sodic texture contrast soil on levees and occasional terraces adjacent to larger stream channels. The sand ridges often occur some distance from current stream channels and probably represent relict levees or source bordering, aeolian deposits (i.e. wind blown sand deposits sourced from adjacent stream bed loads). The distinguishing feature of the **Booroondarra (Bn)** soil is the red subsoil colour in both sand and texture contrast profiles. It indicates the alluvium has been *in situ* for some time and profile development is relatively mature. Texture contrast profiles are well drained and non-sodic with characteristic blocky subsoil structure, while the deep sands are rapidly drained. Subsoil salinity is very low in all profiles. Moreton Bay ash (VA23) is normally associated with this soil, although occasionally Poplar box–bloodwood–Moreton Bay ash (VA33) or Blue gum–mixed eucalypts (VA22) may also be present.

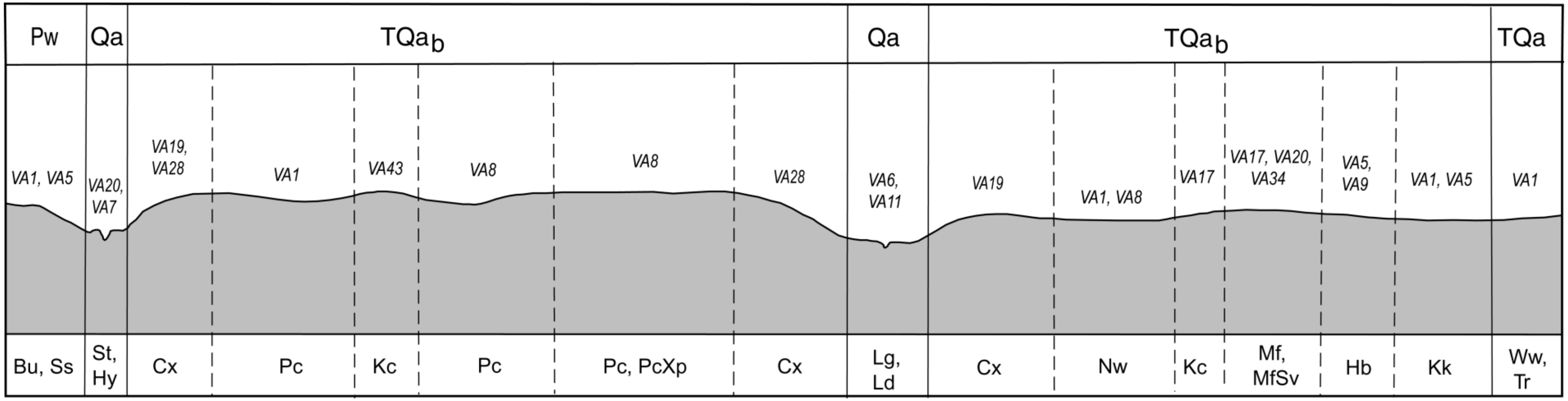


Figure 13. Typical landform, soil and vegetation relationships for soil landscapes developed on unconsolidated Tertiary–Quaternary sediments of basaltic origins (TQa_b)

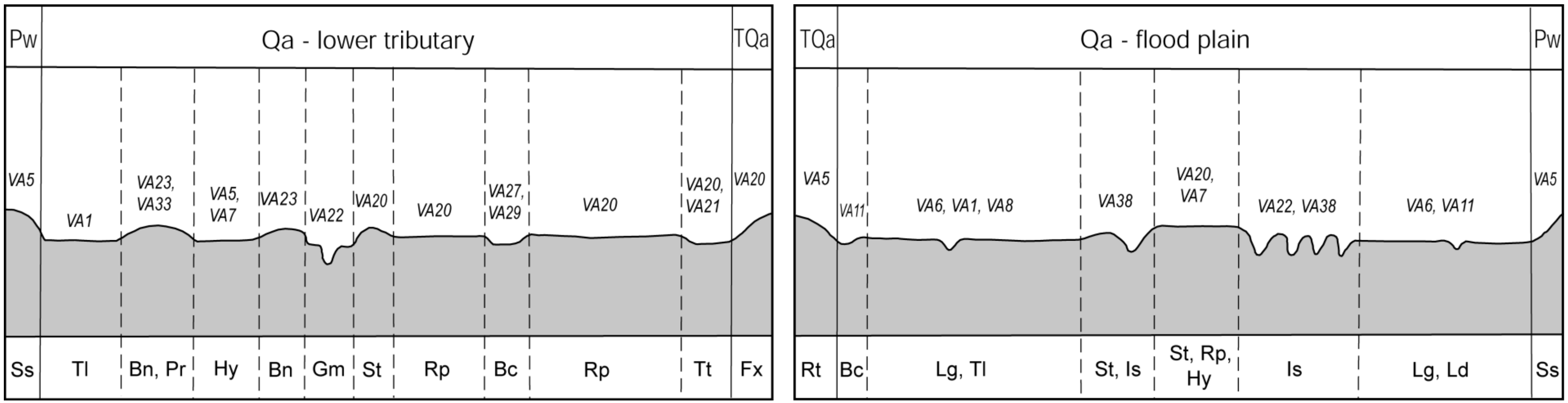


Figure 14. Typical landform, soil and vegetation relationships on Quaternary alluvium (Qa)

The **Parrot (Pr)** soil often occurs in areas of restricted drainage that lie within or adjacent to the elevated levees, sand ridges and occasional flood plain terraces of the **Booroondarra (Bn)** soil. It also occurs on alluvial plains and levees of upper and lower tributaries draining sandy provenance areas. A typical example would be Roper Creek. Most occurrences are irregularly flooded and possibly relict, particularly on sand ridges (relict levees or aeolian deposits) some distance from current stream channels. Typically, it occurs as a thick (0.5–1.0 m), sandy surfaced, conspicuously or sporadically bleached, acid to alkaline, mottled, brown texture contrast soil on alluvial plains and levees. Profiles are imperfectly to moderately well drained and subsoils range from non-sodic to sodic depending on sediment source. Subsoil salinity is very low in all profiles. Typical vegetation includes Poplar box (VA20) or Poplar box–bloodwood–Moreton Bay ash (VA33).

The **Roper (Rp)** soil is widespread on levees and level alluvial plains of most upper and lower tributaries. Occasionally, it also occurs on elevated, terrace plains and relict levees within the flood plains of the Isaac–Connors and Mackenzie Rivers. Typically, it occurs as a hard setting, sandy to clay loamy surfaced, sporadically or conspicuously bleached, alkaline, brown or black texture contrast soil on alluvial plains and levees. Surface horizons are much thinner (0.1–0.35 m) than the **Parrot (Pr)** soil, while surface textures grade from sand through to heavy clay loam, depending on the nature of the deposited sediments. Profiles are moderately well drained and subsoils range from non-sodic to strongly sodic depending on the sediment source. Levels of subsoil salinity are low in all profiles. Typical vegetation is Poplar box (VA20). Occasionally Poplar box–bloodwood–Moreton Bay ash (VA33), Blue gum–mixed eucalypts (VA22) or Coolibah–mixed eucalypts (VA38) may also be associated with this soil.

The **Stephens (St)** soil effectively represents a heavier version of the **Roper (Rp)** soil and the two soils grade into each other in some areas. It occurs mostly on lower tributaries receiving relatively uniform, clay based alluvium derived from catchments with basalt or labile sediments. Its distribution is restricted mainly to well defined, slightly elevated, narrow levees lying adjacent to well incised, major stream channels. A typical example of these levees occurs where the Golden Mile Road crosses Stephens Creek, near 'Kolora' east of Dysart. Occasionally, it has also developed further downstream on the flood plains of the Isaac–Connors and Mackenzie Rivers, but only on elevated, terrace plains and levees that are above regular flood levels and effectively relict. Minor occurrences are also described on lower tributaries with mixed sediment loads such as Roper Creek, where it is restricted to regularly inundated, backplain drainage areas favouring the deposition of finer sediments. Typically, it ranges from a hard setting, alkaline, black non-cracking clay (or occasional gradational soil) grading to a thin (0.04–0.1 m), clay loamy surfaced, alkaline, black texture contrast soil on levees and alluvial plains. Where loamy surface horizons are thicker than 0.1 m it grades into the **Roper (Rp)** soil. Profiles are moderately well drained with non-sodic to sodic upper subsoils and sodic to extremely sodic lower subsoils, depending on the nature of the alluvium. Moderate levels of subsoil salinity occur below a depth of about 1.0 m. Typical vegetation is Poplar box (VA20), although occasionally Blue gum–mixed eucalypts (VA22) or Coolibah–mixed eucalypts (VA38) may also be associated with this soil.

Where lower tributaries widen and sediment deposition is better differentiated, distinct levees, alluvial plains and backplain drainage areas have normally developed. In most catchments where sediment loads are of mixed origins, soil development on the levees and plains is dominated by the **Booroondarra (Bn), Parrot (Pr)** and **Roper (Rp)** soils described above. Stream channels in these areas are normally well incised and regular flooding (>1 in 10 years ARI) of these soils does not occur. In backplain drainage areas however, where regular inundation and restricted drainage promote the deposition of finer sediments (e.g. silts and clays), the **Thirteenmile (Tt)** and **Bluchers (Bc)** soils have developed.

The **Thirteenmile (Tt)** soil occurs in locally drained closed depressions and seasonal swamps on level alluvial plains along most upper and lower tributaries. It is also common on low lying, open backplain drainage areas where slow moving, shallow floodwaters either from overbank flow and/or local drainage regularly become ponded due to low gradients and restricted drainage. The **Thirteenmile (Tt)** soil also occurs on local alluvium developed in seasonal swamps on some non-alluvial landscapes. Examples of these swamps occur on level, Tertiary–Quaternary (TQa) plains on the watershed between Roper and Rolf Creeks, as well as level, internally drained, Tertiary (Td) plateaus within the Junee Tablelands. Typically, the **Thirteenmile (Tt)** soil occurs as a hard setting, silty surfaced, conspicuously or sporadically bleached, acid to alkaline, mottled, grey or brown, sodic texture contrast soil in seasonal swamps and backplains. It grades to a hard setting, silty non-cracking clay with similar morphology where loamy surface horizons are very thin. The soil is often actively aggrading with evidence of very fine silty deposits on the surface. Profiles are poorly to imperfectly drained, with sodic to extremely sodic subsoils depending on the nature of the sediment source. Levels of subsoil salinity are normally low throughout. Typical vegetation is Blue gum (VA21), although occasionally Poplar box (VA20), Blue gum–mixed eucalypts (VA22), Swamp mahogany (VA49) or treeless areas with Sedges (VA29) may also be associated with this soil.

The **Bluchers (Bc)** soil occupies similar landscape positions to the **Thirteenmile (Tt)** soil, but occurs only on alluvium associated with lower tributaries and flood plains. In general, it is more flood prone than the **Thirteenmile (Tt)** soil and occurs predominantly in low lying seasonal swamps and slowly drained backplains. It is regularly inundated (>1 in 2 years ARI) as a result of cross plain drainage following overbank flow. Seasonal ponding for extended periods (2–3 months) often results because of low gradients and restricted drainage. Typically, it occurs as a hard setting, firm pedal or weakly self-mulching, alkaline, black or grey cracking clay, frequently with normal gilgai (VI 0.1–0.3 m), on backplains and seasonal swamps. The soil is often actively aggrading with evidence of very fine, silty deposits on the surface. Profiles are poorly to imperfectly drained and have sodic to strongly sodic subsoils, depending on the nature of the deposited sediments. Levels of subsoil salinity are normally moderate to high below a depth of about 0.6–0.9 m. Where gilgai are developed, mound and depression profiles have similar morphology. Typical vegetation includes Coolibah (VA11), *Bothriochloa* grassland (VA27) or treeless areas with Sedges (VA29).

The **Isaac (Is)** and **Lindsay (Ld)** soils are eucalypt soils that occupy significant areas within the flood plains of the Isaac–Connors and Mackenzie Rivers. The distribution of the **Isaac (Is)** soil is restricted almost entirely to within the active, channelled areas of the flood plains, while the **Lindsay (Ld)** soil, in close association with the equivalent scrub soil **Langley (Lg)**, occupies the extensive, level clay plains lying between major flood plain channels.

The **Isaac (Is)** soil most commonly occurs on low lying channel benches, active levees and scroll plains (channelled areas resulting from stream migration) immediately adjacent to major flood plain channels and runners. Minor occurrences were also described on channelled flood-out areas along lower tributaries draining catchments developed from basalt (Tb) or other labile sediments (Pw, TQa_b). The soils are normally flood prone with an average recurrence interval between 1 in 1 year and 1 in 10 years. Typically, it occurs as a hard setting or firm pedal, silty surfaced, neutral or alkaline, black non-cracking to cracking clay on scroll plains, channel benches and active levees on flood plains. Profiles are imperfectly to moderately well drained, depending on landscape position. Upper subsoils are non-sodic to sodic, while lower subsoils range from sodic to extremely sodic depending on the nature of the deposited sediments. Levels of subsoil salinity are normally low throughout. Typical vegetation is Coolibah–mixed eucalypts (VA38), Blue gum–mixed eucalypts (VA22) or Coolibah (VA11).

The **Lindsay (Ld)** soil occurs predominantly on extensive, relatively low lying, level clay flood plains along Funnel Creek and the Isaac–Connors and Mackenzie Rivers. Minor occurrences are also described on upper and lower tributaries draining catchments developed from basalt (Tb) or other labile sediments (Pw, TQa_b). The **Lindsay (Ld)** soil is closely associated with the scrub soil **Langley (Lg)** and together the two soils cover the majority of the level flood plain surface lying between channelled areas. The **Langley (Lg)** soil is generally more extensive however, and reasons for the extent and distribution of the two soils are not clear. Field evidence suggests the **Lindsay (Ld)** soil occupies slightly lower lying, more heavily flooded areas within the level clay plains, as well as lower lying backplains around the margins of the flood plain. The **Lindsay (Ld)** soil is flood prone with an average recurrence interval between 1 in 1 year and 1 in 5 years, depending on position within the flood plain. Typically, it occurs as a strongly self-mulching, alkaline, black cracking clay on level flood plains. The self-mulching surface is thick (0.03–0.05 m) and characteristically coarse (2–5 mm). Occasionally indistinct, normal gilgai (VI 0.05–0.15 m) are developed. Gilgai effects are minimal however and mound and depression profiles have similar morphology. Profiles are mostly moderately well drained, with non-sodic to sodic upper subsoils and strongly to extremely sodic lower subsoils depending on the nature of the alluvium. High levels of subsoil salinity occur below a depth of about 0.8 m. Typical vegetation is Coolibah (VA11) or occasionally Queensland bluegrass downs (VA28).

Of the 12 alluvial soils described within the study area, only three, the **Honeycomb (Hy), Tralee (Tl)** and **Langley (Lg)** soils, are associated with brigalow scrub. The **Honeycomb (Hy)** soil is a texture contrast soil that occurs mostly on levees and alluvial plains of some upper and most lower tributaries, and represents the scrub equivalent of the eucalypt soil **Roper (Rp)**. The **Tralee (Tl)** soil is a hard setting clay that is mainly developed on alluvial plains of lower tributaries. It is often closely associated with the **Honeycomb (Hy)** soil and has a similar distribution and extent within the lower tributaries. There is no equivalent eucalypt soil that matches the **Tralee (Tl)** soil. The **Langley (Lg)** soil is a strongly self-mulching clay that occurs extensively on the level flood plains of the major rivers. It represents the scrub equivalent of the eucalypt soil **Lindsay (Ld)**, with which it is often closely associated. Typical landform–soil–vegetation relationships for the brigalow soils in this landscape are illustrated diagrammatically in Figure 14.

The **Honeycomb (Hy)** soil occurs predominantly on slightly elevated levees and level, alluvial plains on some upper and most lower tributaries, where it occupies a similar distribution to the eucalypt soil, **Roper (Rp)**. Minor occurrences are also described on elevated, terrace plains and relict levees within the flood plains of the Isaac–Connors and Mackenzie Rivers. These are mostly above regular flood levels (i.e. less frequent than 1 in 10 years ARI). Typically, it occurs as a hard setting, clay loamy surfaced, sporadically or conspicuously bleached, alkaline, black, sodic texture contrast soil with columnar or blocky structure on alluvial plains and levees. The **Honeycomb (Hy)** and **Tralee (Tl**) soils are often closely associated and the two grade into each other where surface horizons of the **Honeycomb (Hy)** soil become very thin (<0.05 m). Profiles are moderately well drained, with sodic upper subsoils and strongly to extremely sodic lower subsoils, depending on the nature of the deposited sediments. Levels of subsoil salinity are moderate from a depth of about 0.5 m and increase to high levels below about 1.1 m. Typical vegetation includes Brigalow–Dawson gum (VA5), Shrubby poplar box (VA7) with a significant brigalow component or occasionally Brigalow (VA1).

The **Tralee (Tl)** soil occurs predominantly on level, alluvial plains of lower tributaries, as well as slightly elevated terrace plains within the flood plains of the Isaac–Connors and Mackenzie Rivers. As such, it is commonly associated with both the **Honeycomb (Hy)** and **Langley (Lg)** soils, and encompasses a significant range in flood regime because of local variations in elevation. Flooding frequency is normally between 1 in 2 and 1 in 10 years ARI. Typically, it occurs as a hard setting, firm pedal or weakly to moderately self-mulching, alkaline, black, grey or brown cracking to non-cracking clay on alluvial plains. Microrelief is variable and ranges from non-gilgaied to normal gilgai (VI 0.1–0.3 m) or deeper melonhole gilgai (VI 0.3–0.8 m). A prominent shelf component is normally developed in most gilgaied areas. Profiles are imperfectly to moderately well drained on mounds and non-gilgaied areas and imperfectly to poorly drained in depressions, depending on depth. Upper subsoils are mostly sodic, while lower subsoils are strongly to extremely sodic. Levels of subsoil salinity are high below a depth of about 0.3 m on mounds, 0.6 m in non-gilgaied areas and 0.9 m in depressions. Typical vegetation is Brigalow (VA1), although occasionally Brigalow–coolibah (VA6) or Brigalow with shrubs (VA8) may also be associated with this soil.

The **Langley (Lg)** soil occurs predominantly on extensive, relatively low lying, level clay flood plains along the Isaac–Connors and Mackenzie Rivers. Occasionally, it is described on upper and lower tributaries draining catchments developed from basalt (Tb) or other labile sediments (Pw, TQa_b). The **Langley (Lg)** and **Lindsay (Ld)** soils are often closely associated, although the extent and distribution of the **Langley (Lg)** soil is much greater. It is the dominant soil of the flood plains and occupies the majority of the level flood plain surface lying between channelled areas. It is consistently flood prone with an average recurrence interval between 1 in 1 year and 1 in 5 years, depending on position within the flood plain. Typically, it occurs as a strongly self-mulching, alkaline, black cracking clay on level flood plains. The self-mulching surface is thick (0.03–0.07 m) and normally finer (<2–5 mm) than that of the equivalent **Lindsay (Ld)** soil. In most cases, the **Langley (Lg)** soil is non-gilgaied or has only indistinct, normal gilgai (VI 0.1–0.2 m) developed, although occasionally shallow, melonhole gilgai (VI 0.3–0.6 m) may be present. Gilgai effects are minimal however and mound and depression profiles have similar morphology. Profiles are mostly moderately well drained, with non-sodic to sodic upper subsoils and strongly to extremely sodic lower subsoils depending on the nature of the alluvium. High levels of subsoil salinity occur below a depth of about 0.6 m. Typical vegetation is Brigalow–coolibah (VA6), Brigalow (VA1) or Brigalow with shrubs (VA8).

7. VEGETATION

The vegetation of the inland sections of the Isaac–Connors and Mackenzie River catchments has been previously described by Story (1967) and Speck (1968) as part of the CSIRO land systems surveys. The vegetation of the coastal range areas that lie within the catchments have been described by Forster and Barton (in prep.), south of about 'Collaroy'. More recently, regional ecosystems at a scale of 1:100 000 have been mapped for areas of remnant vegetation across both catchments (Sattler and Williams 1999).

All vegetation within the Windeyers Hill study area fits one of four structural formation categories. These include **open forest** (crown separation ratio 0–0.25), **woodland** (crown separation ratio 0.25–1), **open woodland** (crown separation ratio 1–20) or **tussock grassland** (crown separation ratio >20), and within each structural category a number of individual floristic associations are described.

A total of 42 associations were identified during the study, at a mapping scale of 1:100 000. The structural formation (i.e. growth form, height and crown separation) and floristics (i.e. major plant species present) of the emergent, tallest, mid and lowest strata in each association were described according to the methodology of Walker and Hopkins (1990). Modal descriptions for each association are presented in Appendix 11 in Volume 2 of this report, and the dominant stratum (or strata) in each association is highlighted in bold. While the associations are numbered VA1–VA50, eight of these (VA36, VA39, VA42, VA44, VA45, VA46, VA47, VA48) were not described within the study area and are found elsewhere in the catchment. They are not documented in this report but are listed to save confusion.

The classification and naming of each association is based on the structure and floristics of the dominant stratum, and follows the conventions of Walker and Hopkins (1990). In most cases, the dominant stratum equates with the tallest stratum and associations are named after the dominant species in that stratum. In some associations however, such as **Brigalow–Dawson gum (VA5)**, both the tallest stratum and the mid-stratum are characteristic and both have been included as dominant strata. For similar reasons, the lowest stratum in tussock grasslands is considered dominant and has been used in classifying associations such as **Queensland bluegrass downs (VA28)**.

The classification name for each association (after Walker and Hopkins (1990)) is presented in Table 15 and also in Appendix 11 in Volume 2 of this report. Both sources provide a useful summary of the dominant structure and floristics of the associations, but are presented in different formats. The vegetation associations in Table 15 are arranged primarily by structural formation and then grouped by floristics, while the summary in Appendix 11 is purely numerical (VA1–VA50). Table 15, in addition, details the spatial extent of each of the major formations, floristic groups and individual vegetation associations within the study area, both in terms of absolute area (ha) and as a percentage of the total study.

The discussion below follows the same order as Table 15 and provides a brief explanation of the detail presented in Appendix 11. It also outlines the distribution and extent of each vegetation association and discusses the landscape positions and soils that are normally associated. A listing of the dominant and occasional soils on which each association is normally found is presented in Table 16. Common names for vegetation species are used throughout the text. Scientific names are listed only for the first occurrence of a species within each subsection (e.g. 7.1.1, 7.1.2, 7.1.3 etc.). A comprehensive list of both common and scientific names for all plants recorded in the study area is presented in Appendix 12 in Volume 2 of this report.

Table 15. Summary of the structure, floristics and spatial extent of the vegetation associations of the Windeyers Hill study area

VA Name [1]	VA Code[2]	Vegetation association classification [3]	Area (ha)	% of study
Open forest[3]				
Brigalow, blackwood or belah scrub				
Brigalow	VA1	Brigalow (*Acacia harpophylla*) mid-high open forest.	58582	21.6
Brigalow–blackwood	VA4	Brigalow (*Acacia harpophylla*), blackwood (*Acacia argyrodendron*) mid-high open forest.	1143	0.40
Brigalow with shrubs	VA8	Brigalow (*Acacia harpophylla*), yellowwood (*Terminalia oblongata*) mid-high open forest with a characteristic understorey of yellowwood, brigalow, currant bush (*Carissa ovata*) and many other shrubby species.	19381	7.1
Belah	VA9	Belah (*Casuarina cristata*) ± brigalow (*Acacia harpophylla*) tall open forest.	552	0.20
Blackwood	VA37	Blackwood (*Acacia argyrodendron*) mid-high to tall open forest.	18669	6.9
***Acacia*[4] scrub**				
Rosewood	VA2	Rosewood (*Acacia rhodoxylon*) mid-high open forest; or eucalypt tall woodland or open woodland with a characteristic understorey of rosewood.	855	0.30
Lancewood	VA3	Lancewood (*Acacia shirleyi*) mid-high to tall open forest.	6983	2.6
Bendee	VA30	Bendee (*Acacia catenulata*) mid-high to tall open forest.	630	0.25
Budgeroo scrub				
Budgeroo	VA26	Budgeroo (*Lysicarpus angustifolius*) mid-high or tall open forest to isolated trees with emergent long-fruited bloodwood (*Corymbia clarksoniana*) ± narrow-leaved ironbark (*Eucalyptus crebra*) and a characteristic understorey of budgeroo, quinine tree (*Petalostigma pubescens*), black wattle (*Acacia leiocalyx, Acacia* species) ± sticky hopbush (*Dodonaea viscosa*).	97	0.05
Eucalypt open forest				
Gum-topped box	VA18	Gum-topped box (*Eucalyptus moluccana*) tall open forest.	395	0.15
Yapunyah	VA24	Yapunyah (*Eucalyptus thozetiana*) tall open forest or woodland.	1675	0.60
Woodland or open woodland[3]				
Brigalow–eucalypt scrub				
Brigalow–Dawson gum	VA5	Dawson gum (*Eucalyptus cambageana*) mid-high to very tall woodland or open woodland with a characteristic understorey of brigalow (*Acacia harpophylla*).	44098	16.2
Brigalow–coolibah	VA6	Coolibah (*Eucalyptus coolabah*) ± brigalow (*Acacia harpophylla*) tall woodland or open woodland with a characteristic understorey of brigalow.	8081	3.0
Dawson gum	VA10	Dawson gum (*Eucalyptus cambageana*) tall woodland or open woodland.	803	0.30
Brigalow–yapunyah	VA40	Yapunyah (*Eucalyptus thozetiana*) ± Dawson gum (*Eucalyptus cambageana*) ± gum-topped box (*Eucalyptus moluccana*) tall woodland with a characteristic understorey of brigalow (*Acacia harpophylla*) ± false sandalwood (*Eremophila mitchellii*) ± scrub leopardwood (*Flindersia dissosperma*) ± currant bush (*Carissa ovata*) and other shrubby species.	2195	0.80
Coolibah and/or blue gum flooded country				
Coolibah	VA11	Coolibah (*Eucalyptus coolabah*) tall open woodland.	2359	0.85
Blue gum	VA21	Blue gum (*Eucalyptus tereticornis*) tall open woodland.	237	0.10
Blue gum–mixed eucalypts	VA22	Blue gum (*Eucalyptus tereticornis*) ± Moreton Bay ash (*Corymbia tessellaris*) ± long-fruited bloodwood (*Corymbia clarksoniana*) ± ghost gum (*Corymbia dallachyana*) ± coolibah (*Eucalyptus coolabah*) ± poplar box (*Eucalyptus populnea*) tall open forest to open woodland.	2524	0.95

Notes:
1. Colloquial names based on the common name used by local landholders for the dominant species within the dominant stratum.
2. The numerical vegetation association code (e.g. VA5) is abbreviated on the accompanying vegetation association map to a single number (e.g. 5). Vegetation associations 36, 39, 42, 44, 45, 46, 47 and 48 occur outside the Windeyers Hill study area and have not been described as part of this report.
3. Vegetation association classifications as described in Walker and Hopkins (1990).
4 Any *Acacia* open forest with species other than brigalow or its associates. Includes Rosewood (VA2), Lancewood (VA3) and Bendee (VA30).
5. Vegetation associations 27 and 31 are sub dominant units for which area (ha) figures are unavailable.

Table 15 (cont). Summary of the structure, floristics and spatial extent of the vegetation associations of the Windeyers Hill study area

VA Name [1]	VA Code[2]	Vegetation association classification [3]	Area (ha)	% of study
Coolibah and/or blue gum flooded country (continued)				
Sedges	VA29	*Cyperus* species mid-high sedgeland.	9	0.01
Coolibah–mixed eucalypts	VA38	Coolibah (*Eucalyptus coolabah*), poplar box (*Eucalyptus populnea*), Moreton Bay ash (*Corymbia tessellaris*) ± blue gum (*Eucalyptus tereticornis*) ± ghost gum (*Corymbia dallachyana*) tall woodland or open woodland.	2449	0.90
Swamp mahogany	VA49	Swamp mahogany (*Lophostemon suaveolens*) mid-high woodland ± emergent blue gum (*Eucalyptus tereticornis*).	27	0.01
Wooded downs				
Gum-topped bloodwood	VA16	Gum-topped bloodwood (*Corymbia erythrophloia*) mid-high woodland, open woodland or isolated trees.	6788	2.5
Mountain coolibah	VA19	Mountain coolibah (*Eucalyptus orgadophila*) tall open woodland.	2286	0.85
Ironbark–bloodwood–ghost gum (clay soil association)	VA43	Narrow-leaved ironbark (*Eucalyptus crebra*), silver-leaved ironbark (*Eucalyptus melanophloia*), gum-topped bloodwood (*Corymbia erythrophloia*), ghost gum (*Corymbia dallachyana*) ± mountain coolibah (*Eucalyptus orgadophila*) ± long-fruited bloodwood (*Corymbia clarksoniana*) ± Moreton Bay ash (*Corymbia tessellaris*) ± poplar box (*Eucalyptus populnea*) mid-high open woodland.	4286	1.6
Bloodwood woodland				
Long-fruited bloodwood	VA15	Long-fruited bloodwood (*Corymbia clarksoniana*) tall woodland or open woodland.	45	0.02
Moreton Bay ash	VA23	Moreton Bay ash (*Corymbia tessellaris*) tall open woodland.	1296	0.50
Poplar box woodland				
Shrubby poplar box	VA7	Poplar box (*Eucalyptus populnea*) tall woodland or open woodland with a characteristic understorey of false sandalwood (*Eremophila mitchellii*), currant bush (*Carissa ovata*), brigalow (*Acacia harpophylla*), Leichhardt bean (*Cassia brewsteri*) and many other shrubby species.	8728	3.2
Poplar box	VA20	Poplar box (*Eucalyptus populnea*) tall woodland or open woodland.	31288	11.5
Poplar box–bloodwood–Moreton Bay ash	VA33	Poplar box (*Eucalyptus populnea*), long-fruited bloodwood (*Corymbia clarksoniana*), Moreton Bay ash (*Corymbia tessellaris*) tall woodland.	1745	0.65
Poplar box–ironbark	VA34	Poplar box (*Eucalyptus populnea*) ± narrow-leaved ironbark (*Eucalyptus crebra*) ± silver-leaved ironbark (*Eucalyptus melanophloia*) tall woodland or open woodland.	6068	2.2
Silver-leaved ironbark woodland				
Silver-leaved ironbark	VA17	Silver-leaved ironbark (*Eucalyptus melanophloia*) mid-high to tall woodland or open woodland.	3349	1.2
Narrow-leaved ironbark woodland				
Narrow-leaved ironbark	VA12	Narrow-leaved ironbark (*Eucalyptus crebra*) tall woodland or open woodland.	13426	4.9
Eucalypts with shrubby teatree	VA13	Narrow-leaved ironbark (*Eucalyptus crebra*) and/or long-fruited bloodwood (*Corymbia clarksoniana*) tall woodland or open woodland with a characteristic understorey of paper barked teatree (*Melaleuca nervosa*) and other shrubby species.	2625	0.95
Eucalypts with shrubby heath myrtle	VA14	Narrow-leaved ironbark (*Eucalyptus crebra*) and/or ghost gum (*Corymbia dallachyana*) and/or long-fruited bloodwood (*Corymbia clarksoniana*) tall open woodland with a characteristic understorey of heath myrtle (*Micromyrtus capricornia*).	1418	0.51
Ironbark–bloodwood–ghost gum (red earth association)	VA50	Narrow-leaved ironbark (*Eucalyptus crebra*), long-fruited bloodwood (*Corymbia clarksoniana*), ghost gum (*Corymbia dallachyana*) tall woodland or open woodland.	4349	1.6

Notes:
1. Colloquial names based on the common name used by local landholders for the dominant species within the dominant stratum.
2. The numerical vegetation association code (e.g. VA5) is abbreviated on the accompanying vegetation association map to a single number (e.g. 5). Vegetation associations 36, 39, 42, 44, 45, 46, 47 and 48 occur outside the Windeyers Hill study area and have not been described as part of this report.
3. Vegetation association classifications as described in Walker and Hopkins (1990).
4 Any *Acacia* open forest with species other than brigalow or its associates. Includes Rosewood (VA2), Lancewood (VA3) and Bendee (VA30).
5. Vegetation associations 27 and 31 are sub dominant units for which area (ha) figures are unavailable.

Table 15 (cont). Summary of the structure, floristics and spatial extent of the vegetation associations of the Windeyers Hill study area

VA Name [1]	VA Code[2]	Vegetation association classification [3]	Area (ha)	% of study
Other eucalypt woodlands				
Queensland peppermint	VA25	Queensland peppermint (*Eucalyptus exserta*) mid-high open forest to open woodland.	414	0.15
Lemon-scented gum	VA31	Lemon-scented gum (*Corymbia citriodora*) tall woodland.	sub dominant[5]	–
Narrow-leaved white mahogany	VA41	Narrow-leaved white mahogany (*Eucalyptus tenuipes*) mid-high woodland.	727	0.25
Bull oak country				
Eucalypts with bull oak	VA32	Poplar box (*Eucalyptus populnea*) or narrow-leaved ironbark (*Eucalyptus crebra*) and/or long-fruited bloodwood (*Corymbia clarksoniana*) tall woodland with a characteristic understorey of bull oak (*Allocasuarina luehmannii*) and other shrubby species.	8673	3.2
Bull oak	VA35	Bull oak (*Allocasuarina luehmannii*) mid-high open forest or woodland.	523	0.20
Tussock grassland[3]				
Open downs				
Bothriochloa grassland	VA27	Forest bluegrass (*Bothriochloa bladhii*), pitted bluegrass (*Bothriochloa decipiens*) ± red Flinders grass (*Iseilema vaginiflorum*) ± silky browntop (*Eulalia aurea*) ± *Panicum* species mid-high to tall grassland.	sub dominant[5]	–
Queensland bluegrass downs	VA28	Queensland bluegrass (*Dichanthium sericeum*), red Flinders grass (*Iseilema vaginiflorum*) ± black speargrass (*Heteropogon contortus*) ± kangaroo grass (*Themeda triandra*) ± bull Mitchell grass (*Astrebla squarrosa*) ± *Bothriochloa* species ± silky browntop (*Eulalia aurea*) ± *Panicum* species ± *Ophiuros exaltatus* tall grassland.	2059	0.75
Undescribed associations				
Brigalow–Bauhinia	VA36	Not described within the study area.		
Brigalow–softwood scrub	VA39	Not described within the study area.		
Ghost gum	VA42	Not described within the study area.		
Poplar gum	VA44	Not described within the study area.		
Softwood scrub	VA45	Not described within the study area.		
Brigalow–gidgee	VA46	Not described within the study area.		
Gidgee	VA47	Not described within the study area.		
Ironbark–bloodwood–blue gum	VA48	Not described within the study area.		

Notes:
1. Colloquial names based on the common name used by local landholders for the dominant species within the dominant stratum.
2. The numerical vegetation association code (e.g. VA5) is abbreviated on the accompanying vegetation association map to a single number (e.g. 5). Vegetation associations 36, 39, 42, 44, 45, 46, 47 and 48 occur outside the Windeyers Hill study area and have not been described as part of this report.
3. Vegetation association classifications as described in Walker and Hopkins (1990).
4 Any *Acacia* open forest with species other than brigalow or its associates. Includes Rosewood (VA2), Lancewood (VA3) and Bendee (VA30).
5. Vegetation associations 27 and 31 are sub dominant units for which area (ha) figures are unavailable.

Table 16. Dominant (and occasional) soils associated with each vegetation association

Vegetation associations [1]		Dominant (and occasional) soils grouped by geological landscapes							
VA name	**VA code**	**Permian sediments (Pw/Pb)**	**Cretaceous intrusives (Ki)**	**Deeply weathered sediments (Td, Ta)**	**Deeply weathered basalt (Tb_d)**	**Tertiary basalt (Tb, Tb_a)**	**Unconsolidated sediments (TQa)**	**Unconsolidated sediments (TQa_b)**	**Quaternary alluvium (Qa)**
Open forest [2]									
Brigalow, blackwood or belah scrub									
Brigalow	VA1	Bu, BuZp, Fr, Tn, Ty (Ss)	–	–	–	Bx, Gb, Id, IdMp, IdSp	Pg, PgMp, Tr, Ww (Rt, PgSp)	Kk, Nw, Pc, PcXp (Hb)	Lg, Tl (Hy)
Brigalow–blackwood	VA4	(BuZp)	–	–	–	–	Tr, Ww (Pg, Rt)	–	–
Brigalow with shrubs	VA8	Bu, Fr, Tn, Ty (Ss, BuZp)	–	–	–	Bx, Gb, Id, IdMp, IdSp	(PgMp, Tr)	Nw, Pc, PcXp (Kk)	Lg (Tl)
Belah	VA9	Ss, Tn, Ty	–	–	–	–	Tr	Hb, Pc	–
Blackwood	VA37	(BuZp)	–	–	–	–	Tr, Ww	–	–
***Acacia* [3] scrub**									
Rosewood	VA2	(Cw)	–	Ac, Bz	–	–	–	–	–
Lancewood	VA3	Cw, Mw	–	Bz (Ac, Rc)	–	–	–	–	–
Bendee	VA30	–	–	Bz, Rc, Rh	–	–	–	–	–
Budgeroo scrub									
Budgeroo	VA26	–	–	Bh	–	–	–	–	–
Eucalypt open forest									
Gum-topped box	VA18	–	–	–	–	–	FxLp	–	–
Yapunyah	VA24	–	–	Ac, Bz, Mr	–	–	FxLp	–	–
Woodland or open woodland [2]									
Brigalow–eucalypt scrub									
Brigalow–Dawson gum	VA5	Ss (Bu)	–	–	–	(Gb)	Rt, RtSp (Ww, Cm, Pg)	Hb (Kk)	Hy (Tl)
Brigalow–coolibah	VA6	–	–	–	–	–	–	–	Lg (Tl)
Dawson gum	VA10	Ss	–	–	–	–	Rt, RtSp (Cm)	–	–
Brigalow–yapunyah	VA40	–	–	–	–	–	PgSp, RtSp	–	–

Notes: 1. Numerical code and colloquial name based on the common name used by local landholders for the dominant species within the dominant stratum for each vegetation association.
2. Structural formations as described in Walker and Hopkins (1990).
3. Any *Acacia* open forest with species other than brigalow or its associates. Includes Rosewood (VA2), Lancewood (VA3) and Bendee (VA30).

Table 16 (cont). Dominant (and occasional) soils associated with each vegetation association

Vegetation associations [1]		**Dominant (and occasional) soils grouped by geological landscapes**							
VA name	**VA code**	**Permian sediments (Pw/Pb)**	**Cretaceous intrusives (Ki)**	**Deeply weathered sediments (Td, Ta)**	**Deeply weathered basalt (Tb_d)**	**Tertiary basalt (Tb, Tb_a)**	**Unconsolidated sediments (TQa)**	**Unconsolidated sediments (TQa_b)**	**Quaternary alluvium (Qa)**
Coolibah and/or blue gum flooded country									
Coolibah	VA11	–	–	–	–	(My)	–	–	Bc, Ld (Is)
Blue gum	VA21	–	–	–	–	–	–	–	Tt (Gm)
Blue gum–mixed eucalypts	VA22	–	–	–	–	–	–	–	Gm, Is (Bn, Rp, St, Tt)
Sedges	VA29	–	–	–	–	–	–	–	Bc, Tt
Coolibah–mixed eucalypts	VA38	–	–	–	–	–	–	–	Is (Bc, Rp)
Swamp mahogany	VA49	–	–	–	–	–	–	–	Tt
Wooded downs									
Gum-topped bloodwood	VA16	(Cc, Ms)	–	–	–	My, MySp	–	(Cx, Kc)	–
Mountain coolibah	VA19	Ms (Cc)	–	–	–	My	–	Cx, Kc	–
Ironbark–bloodwood–ghost gum (clay soil association)	VA43	Cc, Ms (Ad, Rn)	Mi	–	(Rh)	Wy (MySp, Nm)	–	Kc (Cx)	–
Bloodwood woodland									
Long-fruited bloodwood	VA15	Cw, Mw	–	Wm	–	–	–	–	Bn
Moreton Bay ash	VA23	–	–	–	–	–	–	–	Bn, Gm (Pr)
Poplar box woodland									
Shrubby poplar box	VA7	Em, Ss (Ad, Bu)	–	–	–	–	Cm, FxLp (Rt, RtSp)	(MfSv)	Hy (Bn, Rp, Tl)
Poplar box	VA20	Ad, Em, Hf (Rn, Cc)	–	Wt (Ac, Bb, Bd)	–	(Wy)	Cm, Fx, FxLp	MfSv (Mf)	Pr, Rp, St (Tt)
Poplar box–bloodwood–Moreton Bay ash	VA33	–	–	–	–	–	Fx (FxLp)	–	Bn, Pr, Rp
Poplar box–ironbark	VA34	Ad, Cc, Em, Hf, Rn	–	Ac, Wt (Bb)	–	Wy	FxLp (Fx)	Mf	(Rp)

Notes: 1. Numerical code and colloquial name based on the common name used by local landholders for the dominant species within the dominant stratum for each vegetation association.
2. Structural formations as described in Walker and Hopkins (1990).
3. Any *Acacia* open forest with species other than brigalow or its associates. Includes Rosewood (VA2), Lancewood (VA3) and Bendee (VA30).

Table 16 (cont). Dominant (and occasional) soils associated with each vegetation association

Vegetation associations [1]		Dominant (and occasional) soils grouped by geological landscapes							
VA name	**VA code**	**Permian sediments (Pw/Pb)**	**Cretaceous intrusives (Ki)**	**Deeply weathered sediments (Td, Ta)**	**Deeply weathered basalt (Tb_d)**	**Tertiary basalt (Tb, Tb_a)**	**Unconsolidated sediments (TQa)**	**Unconsolidated sediments (TQa_b)**	**Quaternary alluvium (Qa)**
Silver-leaved ironbark woodland									
Silver-leaved ironbark	VA17	Ad, Rn (Cc)	Mi	Wt	–	Nm, Wy	–	Kc, Mf	(Rp)
Narrow-leaved ironbark woodland									
Narrow-leaved ironbark	VA12	Ad, Hf, Mw, Rn	Mi, MiCv	Ac, Bb, Bh, BhSv, Rc, Wm, Wt (Bz)	Rh	WyMp (Wy)	(FxLp)	–	–
Eucalypts with shrubby teatree	VA13	Cw, Mw	MiCv	Wm	–	–	–	–	Tt
Eucalypts with shrubby heath myrtle	VA14	–	–	Bb (Rc)	–	–	–	–	–
Ironbark–bloodwood–ghost gum (red earth association)	VA50	–	–	Bh, Wm (Bb, Rc)	–	–	–	–	–
Other eucalypt woodlands									
Queensland peppermint	VA25	Cw, Mw	–	Ac, Bz, Rc, Wm	–	–	–	–	–
Lemon-scented gum	VA31	Cw, Mw	–	–	–	–	–	–	–
Narrow-leaved white mahogany	VA41	–	–	Bh	–	–	–	–	–
Bull oak country									
Eucalypts with bull oak	VA32	Hf	–	Bd	–	–	(Fx)	–	–
Bull oak	VA35	(Hf)	–	Bd	–	–	–	–	–
Tussock grassland [2]									
Open downs									
Bothriochloa grassland	VA27	Ms	–	–	–	–	–	–	Bc
Queensland bluegrass downs	VA28	Ms	–	–	–	My, MySp	–	Cx	Ld

Notes: 1. Numerical code and colloquial name based on the common name used by local landholders for the dominant species within the dominant stratum for each vegetation association.
2. Structural formations as described in Walker and Hopkins (1990).
3. Any *Acacia* open forest with species other than brigalow or its associates. Includes Rosewood (VA2), Lancewood (VA3) and Bendee (VA30).

7.1 Open forests

Walker and Hopkins (1990) define an open forest as a vegetation type in which the dominant stratum is a tree layer with mid-dense canopy cover and touching or slightly separated crowns (i.e. crown separation ratio of 0–0.25 or percentage crown cover of 50–80%). Closed forests which have a dense canopy cover and touching to overlapping crowns (i.e. crown separation ratio of <0 or percentage crown cover of 80–>100%) were rarely described within the study area, and only occurred in some brigalow associations. The open forests are dominated by *Acacia* species, although a small number of eucalypt associations were also described. The colloquial term 'scrub' is used in the discussion that follows for any *Acacia* based open forests.

7.1.1 Brigalow, blackwood or belah scrub

Brigalow (VA1, VA8) scrubs were originally widespread on a range of clay soils across a number of different landscapes within the study area. In comparison, **Blackwood (VA37)** scrubs, which are at their southern-most extent, were confined mainly to unconsolidated clay sediments (TQa) in the north-east. Significant areas of mixed **Brigalow–blackwood (VA4)** regrowth were also observed in the same area. **Belah (VA9)** scrubs which approach their northern-most extent within the study area (and the surrounding catchments) are relatively uncommon. They occur in isolated pockets either in pure stands or in association with brigalow.

Brigalow (VA1) is probably the most widespread association within the study area. Typically, it occurs as a mid-high open forest of brigalow (*Acacia harpophylla*) with a sparse understorey predominantly of currant bush (*Carissa ovata*) and false sandalwood (*Eremophila mitchellii*) with other species such as yellowwood (*Terminalia oblongata*), whitewood (*Atalaya hemiglauca*) or bauhinia (*Lysiphyllum hookeri*) only occasionally present. It occurs on level to gently undulating plains and is associated with clay soils on nearly all landscapes, with the exception of the deeply weathered Tertiary landscapes (Td, Ta), Cretaceous igneous intrusives (Ki) and resistant Permian sandstones (Pb) in the Cherwell Range. **Brigalow (VA1)** is adaptable and tolerates a variety of physical and chemical soil characteristics. Soil types on which it is typically associated include deep, strongly self-mulching clays used for cropping, such as the Picardy (Pc) and Indicus (Id) soils, through to saline, sodic, hard setting clays such as Burradoo sodic phase (BuZp) and Pomegranate (Pg).

Brigalow with shrubs (VA8) is structurally similar to VA1 but differs markedly in the floristic composition of the understorey, and also the nature of the soils with which it is normally associated. Typically, it occurs as a mid-high open forest of brigalow and yellowwood with a characteristic shrubby understorey. Species in the understorey include yellowwood, bauhinia, whitewood, scrub holly (*Alectryon diversifolius*), sandalwood (*Santalum lanceolatum*), limebush (*Eremocitrus glauca*), myrtle tree (*Canthium oleifolium*), currant bush, false sandalwood, brigalow, *Denhamia oleaster*, *Capparis* species and occasional bonewood (*Macropteranthes leichhardtii*). It is normally associated with hard setting to self-mulching clay soils on level to gently undulating landscapes derived from Permian sediments (Pw), Tertiary basalt (Tb, Tb_a), unconsolidated sediments of basaltic origins (TQa_b) and Quaternary alluvium (Qa). The spatial extent of this association is much less than **Brigalow (VA1)**, although its distribution is just as widespread.

In the north-east of the study area, from 'May Downs' north to 'Batheaston', **Blackwood (VA37)** often occupies soil and landscape positions normally associated with **Brigalow (VA1)**. The distribution and extent of the **Blackwood (VA37)** association, however, is confined almost entirely to relatively low lying, gilgaied clay plains on which particularly saline, sodic versions of the Warwick (Ww) and Turon (Tr) soils are developed. Evidence from remnants, suggests the **Blackwood (VA37)** scrubs were generally much taller and individual stems much larger than the equivalent brigalow scrubs on these soils. **Blackwood (VA37)** typically occurs as a mid-high to tall open forest of blackwood (*Acacia argyrodendron*) that is floristically pure with a very sparse understorey and few associated species.

Brigalow, blackwood or belah scrub

Photograph 27. Typical brigalow scrub (VA1) on the Burradoo (Bu) soil, south of Middlemount

Photograph 28. Virgin whipstick brigalow scrub (VA1) developed to buffel pasture, on the Tiny (Ty) soil, 'Tiny Downs

Photograph 29. Melonholed brigalow scrub on the Farlane (Fr) soil, 'Essex'

Photograph 30. Brigalow scrub with a shrubby understorey (VA8), developed for cropping on the Picardy (Pc) soil, east of Dysart

Photograph 31. Brigalow–belah scrub (VA9) on the Turon (Tr) soil, 'Redcliff'

Photograph 32. Virgin blackwood scrub (VA37) on the Warwick (Ww) soil, 'Cosmos'

Acacia scrub, budgeroo scrub

Photograph 33. Narrow-leaved ironbark woodland with a rosewood understorey (VA2) on the Anncrouye (Ac) soil, 'Oak Park'

Photograph 34. Lancewood scrub (VA3) on the Bellarine (Bz) soil, Junee Tablelands

Photograph 35. Bendee scrub (VA30) on the Bellarine (Bz) soil, 'Roper Downs'

Photograph 36. Budgeroo scrub (VA26) on the Bills Hut (Bh) soil, 'Redcliff'

Eucalypt open forest

Photograph 37. Gum-topped box open forest (VA18) on the Foxleigh clay loamy phase (FxLp) soil, 'Redcliff'

Photograph 38. Yapunyah open forest (VA24) on the Merion (Mr) soil, German Creek East Mine Lease

Anecdotal evidence from local landholders and quotations by Story (1967) suggest the original **Brigalow (VA1)** and **Blackwood (VA37)** scrubs occurred mostly in pure stands. Mixing was uncommon and the two associations were normally sharply divided. However, significant areas of mixed regrowth were observed in cleared areas in the north-east of the study area, and suggest either colonisation by one species has occurred since clearing or mixing was more common along the margins of the original scrubs than at first thought. The few remnants of **Brigalow–blackwood (VA4)** that were observed were typically mid-high open forests with an equal mix of both species and without significant understorey species. The mixed **Brigalow–blackwood (VA4)** scrubs occur on similar soils and landscape positions to **Blackwood (VA37)**.

Belah (VA9) scrubs were not widespread and occurred mostly as small, isolated pockets. Their distribution and extent appears associated mainly with the presence of calcareous substrates on landscapes derived from Permian sediments (Pw) or unconsolidated calcareous sediments of basaltic origins (TQa_b). On other landscapes, it occurs in local niches that are protected from regular fire. Examples include areas of melonhole clays developed on internally drained depressions within the Junee Tablelands or areas developed on the flood plains of the Isaac or Mackenzie Rivers. Typically, it occurs as a tall open forest of belah (*Casuarina cristata*) $\pm$ brigalow. Often a significant shrubby understorey is present with similar species to those described for **Brigalow with shrubs (VA8)**. Stands of pure belah occur mainly on loamy duplex soils, while associations with brigalow occur predominantly on heavy clay soils.

7.1.2 *Acacia* scrub

An *Acacia* scrub is defined as any *Acacia* open forest with species other than brigalow or its associates. Whilst structurally similar to brigalow (*Acacia harpophylla*), blackwood (*Acacia argyrodendron*) or belah (*Casuarina cristata*) scrubs, the *Acacia* scrubs differ significantly in terms of floristics, soils and landscape position. They include **Rosewood (VA2), Lancewood (VA3)** and **Bendee (VA30)**.

Lancewood (VA3) is the most widespread of the *Acacia* scrubs and typically occurs as a mid-high to tall open forest of lancewood (*Acacia shirleyi*) that is floristically pure and has very few associates in the understorey. Occasionally narrow-leaved ironbark (*Eucalyptus crebra*), Queensland peppermint (*Eucalyptus exserta*), yapunyah (*Eucalyptus thozetiana*) or long-fruited bloodwood (*Corymbia clarksoniana*) may be associated with the upper storey or as emergents. It occurs mainly on scarps and residual features within the deeply weathered Permian (Pb) or Tertiary (Td, Ta) landscapes. It is most widespread on steep scarps surrounding Tertiary plateaus, but significant areas also occur on scarps and dissected residuals within the Cherwell Range. It grows predominantly on shallow, stony, acid loams or sands and is associated with the Bellarine (Bz), Cherwell (Cw) and Maywin (Mw) soils.

The distribution of **Rosewood (VA2)** is similar to that of **Lancewood (VA3)**, although its extent is more limited. While the two associations grow on similar landscapes and soils, reasons for the exact distribution of each association remain largely unclear. In areas where **Rosewood (VA2)** is present instead of **Lancewood (VA3)**, scarps and residuals are often gentler and a wider range of associated soils is usually present. Similar shallow, stony, acid loams (Bellarine (Bz) and minor Cherwell (Cw)) occur on steeply dissected areas, while loamy surfaced, acid, texture contrast soils (Anncrouye (Ac)) are associated in lower landscape positions such as footslopes. As such, the occurrence of **Rosewood (VA2)** is mostly restricted to dissected, deeply weathered Tertiary (Td, Ta) landscapes. Variations in the structure and floristics of the association match the variations described for the associated soils. It ranges from a relatively pure, mid-high open forest of rosewood (*Acacia rhodoxylon*) with little or no understorey in steeper areas, through to a tall, eucalypt woodland or open woodland with a prominent rosewood understorey in lower landscape positions.

Bendee (VA30) scrubs are structurally similar to **Lancewood (VA3)**, and are floristically very uniform. Typically, they occur as relatively pure, mid-high to tall open forests of bendee (*Acacia catenulata*) with little or no understorey. They have a very limited distribution within the study area and are associated mainly with residuals on deeply weathered Tertiary basalt (Tb_d) or deeply weathered Tertiary sediments (Td, Ta). Associated soils include shallow, stony, acid loams (Bellarine (Bz)) on scarps and steeper areas and shallow to moderately deep, red earths (Red Cliff (Rc) or Red Hill (Rh)) on stripped or gently dissected plateau margins.

7.1.3 Budgeroo scrub

Budgeroo (VA26) scrubs show considerable variation, most of which is probably related to fire history. The upper stratum ranges from a mid-high or tall open forest through to isolated trees. Most commonly it occurs in thickets or patches where an upper stratum of budgeroo (*Lysicarpus angustifolius*) with occasional red ash (*Alphitonia excelsa*), long-fruited bloodwood (*Corymbia clarksoniana*), ghost gum (*Corymbia dallachyana*), kurrajong (*Brachychiton populneus*) and bats-wing coral tree (*Erythrina vespertilio*) is present. Emergent narrow-leaved ironbark (*Eucalyptus crebra*) and long-fruited bloodwood may also be associated. The understorey is characteristically a tall shrubland (crown separation ratio 0–0.25, 1–3 m high) of budgeroo, quinine tree (*Petalostigma pubescens*), wattles (black wattle (*Acacia leiocalyx*) and other *Acacia* species) and sticky hopbush (*Dodonaea viscosa*). The occurrence of **Budgeroo (VA26)** within the study area is very limited. Its distribution is restricted entirely to the deep red earths of the Bills Hut (Bh) soil on intact, Tertiary plateaus within the Junee Tablelands and associated outliers. There were no significant soil differences, based on field description and laboratory data, between areas of budgeroo scrub and adjacent eucalypt woodlands. The factors controlling local distribution within the plateau surface remain largely unclear.

7.1.4 Eucalypt open forest

Only two eucalypt associations, both of which have restricted distributions within the study area, were recorded as open forests (crown separation ratio 0–0.25). These were **Gum-topped box (VA18)** and **Yapunyah (VA24)**. The remainder of the eucalypt associations are either woodlands (crown separation ratio 0.25–1) or open woodlands (crown separation ratio 1–20) and are described in the next section.

The occurrence of **Gum-topped box (VA18)** within the study area is very restricted, because it lies close to the limit of its northern extent. Typically, it occurs as a tall open forest of gum-topped box (*Eucalyptus moluccana*) with occasional Dawson gum (*Eucalyptus cambageana*) or yapunyah (*Eucalyptus thozetiana*) associates in the tallest stratum. An open shrub understorey of false sandalwood (*Eremophila mitchellii*) and currant bush (*Carissa ovata*) is normally present with occasional sticky hopbush (*Dodonaea viscosa*), whitewood (*Atalaya hemiglauca*), scrub holly (*Alectryon diversifolius*) and scrub leopardwood (*Flindersia dissosperma*). Small patches are located around the base of Tertiary plateaus in the Junee Tablelands, particularly where dissection and scarp retreat has left protected valleys and pediments. It is associated almost exclusively with the Foxleigh clay loamy phase (FxLp) soil on locally derived unconsolidated sediments (TQa) in these areas.

Yapunyah (VA24) has a similar distribution to **Gum-topped box (VA18)** but is more widespread. It generally exhibits more structural and floristic diversity than **Gum-topped box (VA18)** and grows on a wider range of soils. Typically, it occurs as a tall, open forest or woodland of yapunyah with occasional Dawson gum, poplar box (*Eucalyptus populnea*) or gum-topped box associates in the tallest stratum. A sparse shrub understorey of false sandalwood, scrub leopardwood and currant bush is normally present with occasional Leichhardt bean (*Cassia brewsteri*), cocaine tree (*Erythroxylum australe*), emu apple (*Owenia acidula*), rosewood (*Acacia rhodoxylon*), bendee (*Acacia catenulata*), lancewood (*Acacia shirleyi*) and wattles (*Acacia* species), depending on landscape position and soil type. Stands on steeper pediments and upper footslopes are normally associated with the Anncrouye (Ac) soil, while on gentle, lower pediments and valley floors where locally derived unconsolidated sediments (TQa) are located, it is associated with the Foxleigh clay loamy phase (FxLp) soil. Sometimes yapunyah is found on scarp sideslopes, particularly where the Bellarine (Bz) soil has developed from deeply weathered, argillaceous (clayey) sediments. The frequency of shrubby *Acacia* species such as rosewood, lancewood, bendee or wattles increases significantly in these areas. On gentle pediments immediately below Tertiary plateaus near the German Creek East Mine Lease and also at the southern end of the Junee Tablelands, it is associated with the Merion (Mr) soil. In these areas, heavy, saline, sodic, cracking clays have developed from argillaceous sediments at the base of the deeply weathered sequence. These have been exposed following scarp retreat and soils have developed *in situ*. The presence of deeply weathered argillaceous (clayey) substrates within or close to the root zone appears to control the distribution of **Yapunyah (VA24)** in all cases.

7.2 Woodlands or open woodlands

The majority of eucalypt vegetation types within the study area and surrounding catchments are classified as woodlands or open woodlands. Walker and Hopkins (1990) define a woodland as a vegetation type in which the dominant stratum is a tree layer with sparse canopy cover and clearly separated crowns (i.e. crown separation ratio of 0.25–1 or percentage crown cover of 20–50%). Where canopy cover becomes very sparse and crowns are well separated (i.e. crown separation ratio of 1–20 or percentage crown cover of 0.2–20%) the vegetation is then classified as an open woodland. Of the 29 woodlands or open woodlands described in the study, only the association **Bull oak (VA35)** lacks a eucalypt component. A further five associations namely **Brigalow–Dawson gum (VA5)**, **Brigalow–yapunyah (VA40)**, **Brigalow–coolibah (VA6)**, **Shrubby poplar box (VA7)** and **Swamp mahogany (VA49)** have significant shrubby understoreys that may be loosely classed as scrubs. The remainder are woodlands or open woodlands that are named after the dominant or co-dominant species in the tallest stratum.

7.2.1 Brigalow–eucalypt scrub

Of the four brigalow–eucalypt scrubs described, **Brigalow–Dawson gum (VA5)** (and associated **Dawson gum (VA10)** are by far the most widespread within the study area and surrounding catchments. They form one of the major land types developed during Brigalow Scheme III and occupy large areas within the extensive, gently undulating Permian (Pw) and Tertiary–Quaternary (TQa) landscapes. **Brigalow–coolibah (VA6)** is restricted to the flood plains of the Isaac–Connors and Mackenzie Rivers where it has also been extensively cleared and developed. **Brigalow–yapunyah (VA40)** is relatively minor by comparison and is restricted to pediments and footslopes mainly around the base of the Junee Tablelands.

Few remnants of **Brigalow–Dawson gum (VA5)** now remain because of its preferred development status during Brigalow Scheme III. Moderate to high fertility, easy establishment post clearing and minimal regrowth all contributed to its status as prime buffel country. Typically, it occurs as a mid-high to very tall woodland or open woodland of Dawson gum (*Eucalyptus cambageana*) with a characteristic and often very prominent understorey of brigalow (*Acacia harpophylla*). Other shrubby species occur only occasionally and include currant bush (*Carissa ovata*), false sandalwood (*Eremophila mitchellii*), scrub holly (*Alectryon diversifolius*), yellowwood (*Terminalia oblongata*), *Capparis* species, scrub leopardwood (*Flindersia dissosperma*), whitewood (*Atalaya hemiglauca*) and emu apple (*Owenia acidula*). **Brigalow–Dawson gum (VA5)** occurs extensively on level to gently undulating landscapes associated with Permian sediments (Pw), unconsolidated Tertiary–Quaternary sediments (TQa, TQa_b) and Quaternary alluvium (Qa). It characteristically grows on loamy surfaced, sodic texture contrast soils and occasionally on clay soils. Dominant soils include Stateschool (Ss), Racetrack (Rt), Racetrack shallow phase (RtSp), Hazelbrae (Hb) and Honeycomb (Hy).

Where the brigalow understorey is very sparse or not developed at all, **Dawson gum (VA10)** is described. Apart from the absence of a shrubby understorey, it is structurally and floristically the same as **Brigalow–Dawson gum (VA5)**. Distribution within the landscape and associated soils are also similar. Its extent is very limited however, and is mostly associated with the margins of the extensive **Brigalow–Dawson gum (VA5)** scrubs developed on unconsolidated Tertiary–Quaternary

Brigalow–eucalypt scrub

Photograph 39. Typical brigalow–Dawson gum scrub (VA5) on the Racetrack (Rt) soil, Middlemount area

Photograph 40. Brigalow–Dawson gum scrub (VA5) cleared and developed to buffel pasture, near Middlemount

Photograph 41. Virgin brigalow–coolibah scrub (VA6) on the Langley (Lg) soil, Isaac River flood plain

Photograph 42. Brigalow–coolibah scrub (VA6) developed for dryland cropping, 'Batheaston'

Photograph 43. Dawson gum woodland (VA10) on the Racetrack (Rt) soil, near Middlemount

Photograph 44. Yapunyah woodland with a brigalow understorey (VA40) on the Pomegranate shallow phase (PgSp) soil, 'Euroka'

Coolibah and/or blue gum flooded country

Photograph 45. Coolibah open woodland (VA11) on the Lindsay (Ld) soil, Stephens Creek

Photograph 46. Blue gum open woodland (VA21) in a seasonal swamp (Thirteenmile (Tt) soil), west of Middlemount

Photograph 47. Blue gum–mixed eucalypt woodland (VA22) on the Isaac (Is) soil, Isaac–Connors flood plain

Photograph 48. Coolibah–mixed eucalypt woodland (VA38) on the Isaac (Is) soil, Isaac–Connors flood plain

Wooded downs

Photograph 49. Gum-topped bloodwood open woodland (VA16) on the May (My) soil, 'May Downs'

Photograph 50. Mountain coolibah open woodland (VA19) on the Mt Stuart (Ms) soil, 'Mt Stuart'

sediments (TQa). Field and laboratory evidence have failed to show significant soil differences between the two associations and the factors controlling its local distribution remain largely unclear.

Brigalow–yapunyah (VA40), by comparison, has a very limited extent and occurs only on pediments and footslopes below Tertiary plateaus. It has a similar distribution to **Yapunyah (VA24)**, but generally occurs further downslope, where unconsolidated colluvial clay sediments overlie the deeply weathered substrates of the pediments. Typically, it occurs as a tall woodland of yapunyah (*Eucalyptus thozetiana*) with associated Dawson gum or occasional gum-topped box (*Eucalyptus moluccana*). A characteristic shrubby understorey with brigalow, false sandalwood, scrub leopardwood, currant bush and other occasional species is normally present. It occurs only on the Pomegranate shallow phase (PgSp) and Racetrack shallow phase (RtSp) soils, both of which are colluvial soils overlying deeply weathered substrates. The presence of deeply weathered substrates within or close to the root zone appears to control the distribution of both **Brigalow–yapunyah (VA40)** and **Yapunyah (VA24)**. **Brigalow–yapunyah (VA40)** is recorded on pediments around the base of the Junee Tablelands and also around Tertiary plateaus near the German Creek East Mine Lease.

Brigalow–coolibah (VA6) is structurally similar to the other brigalow–eucalypt scrubs. Typically, it occurs as a tall woodland or open woodland of coolibah (*Eucalyptus coolabah*), sometimes with varying amounts of associated brigalow in the tallest stratum. A characteristic and often very prominent understorey of brigalow with occasional bauhinia (*Lysiphyllum hookeri*), yellowwood and scrub holly is nearly always present. The distribution of **Brigalow–coolibah (VA6)** is restricted to the flood plains of the Isaac–Connors and Mackenzie Rivers where it occurs almost exclusively on extensive, level clay plains lying between flood plain channels. It grows mainly on the self-mulching clays of the Langley (Lg) soil. Sometimes within the flood plains it extends onto firm or hard setting clays associated with the Tralee (Tl) soil, but only where these are relatively low-lying and regularly flooded.

7.2.2 Coolibah and/or blue gum flooded country

A number of coolibah and/or blue gum associations are described within the regularly flooded landscapes of the study area and surrounding catchments. These range from pure stands of **Coolibah (VA11)** and **Blue gum (VA21)** through to coolibah and blue gum associations where a number of other eucalypts are associated (**Coolibah–mixed eucalypts (VA38)** and **Blue gum–mixed eucalypts (VA22)**). The distribution and extent of most flooded country is restricted almost exclusively to the flood plains along the Isaac–Connors and Mackenzie Rivers or their lower tributaries. Seasonal swamps, which are developed both on and off the alluvium, may be treeless or have any one of the coolibah or blue gum associations. Where seasonal swamps occur on Tertiary plateaus (i.e. internally drained, closed depressions), **Blue gum (VA21)** or **Swamp Mahogany (VA49)** are normally associated.

Coolibah (VA11) open woodlands are common along the flood plains of the Isaac–Connors and Mackenzie Rivers and the lower reaches of major tributaries such as Funnel Creek, Stephens Creek, Rolf Creek and Roper Creek. It occurs either on extensive, level clay plains lying between flood plain channels or in seasonal swamps and low lying, slowly drained backplains. Its distribution is similar to that of **Brigalow–coolibah (VA6)**, although often in lower lying, more flooded areas. Typically, it occurs as a tall open woodland of coolibah (*Eucalyptus coolabah*) that is usually monospecific and without an understorey. Isolated shrubs including sally wattle (*Acacia salicina*), whitewood (*Atalaya hemiglauca*), nelia (*Acacia oswaldii*), Leichhardt bean (*Cassia brewsteri*) and currant bush (*Carissa ovata*) are often scattered through the woodland. Shrub species are generally absent in swamps and regularly flooded areas. **Coolibah (VA11)** open woodlands are associated with the Lindsay (Ld) soil on flood plains and the Bluchers (Bc) soil in swamps and flooded backplains. It also occurs occasionally on lower slopes around 'May Downs' where basaltic colluvium lies adjacent to the Rolf Creek flood plain.

The **Coolibah–mixed eucalypts (VA38)** association is restricted mostly to active, channelled areas within the major flood plains and lower tributaries. Channel migration is common in these areas and active levees, channel benches and scroll plains are the dominant landforms. Typically, it occurs as a tall woodland or open woodland of coolibah, poplar box (*Eucalyptus populnea*) and Moreton Bay ash (*Corymbia tessellaris*) with occasional blue gum (*Eucalyptus tereticornis*) and ghost gum (*Corymbia dallachyana*). An open to sparse shrub understorey of Leichhardt bean, sally wattle, currant bush and other occasional species is normally present. It mostly grows on the Isaac (Is) soil, although occasionally it occurs on the Bluchers (Bc) soil in backplain areas and the Roper (Rp) soil on flood plain terraces. Typical examples occur along the lower reaches of Stephens Creek and along the centre of the Isaac River flood plain.

The **Blue gum–mixed eucalypts (VA22)** association is similar in many respects to the **Coolibah–mixed eucalypts (VA38)** association, but has a much wider distribution. It is associated with riparian areas along nearly all stream channels, from narrow upper tributaries through to major flood plains. On upper and lower tributaries it occurs mainly in narrow strips along stream banks and adjacent levees or channel benches. Further downstream on the major flood plains it occupies similar channelled floodways and scroll plains to the **Coolibah–mixed eucalypts (VA38)** association. Because of its extended distribution, the association is quite variable, both in terms of structure and floristics. Typically, it ranges from a tall open forest to open woodland of blue gum ± Moreton Bay ash ± long-fruited bloodwood (*Corymbia clarksoniana*) ± ghost gum ± coolibah ± poplar box. The proportion of each species is variable and depends to some extent on landscape position and soil type. Understorey species are the same as those described for **Coolibah–mixed eucalypts (VA38)** and occur mostly as scattered shrubs. It grows predominantly on the German (Gm) soil in upper tributaries and the Isaac (Is) soil on flood plains. Where well developed levees lie adjacent to stream channels on lower tributaries, the Booroondarra (Bn), Roper (Rp) and Stephens (St) soils may be associated.

Pure stands of **Blue gum (VA21)** are mainly associated with seasonal swamps. The swamps are developed either on level to gently undulating plains associated with unconsolidated Tertiary–Quaternary sediments (TQa) or on alluvium along lower tributaries and major flood plains. The **Blue gum (VA21)** association typically occurs as a tall open woodland of blue gum in which understorey species are absent. Its extent and distribution are restricted and it grows almost exclusively on the Thirteenmile (Tt) soil. Examples occur in seasonal swamps within gently undulating Tertiary–Quaternary plains west of Middlemount and also along Roper Creek.

Treeless versions of these same swamps also occur. They are similar in all respects to those described above for **Blue gum (VA21)** but have only a ground cover of **Sedges (VA29)** developed. Associated soils include both the Bluchers (Bc) and Thirteenmile (Tt) soils.

Swamp mahogany (VA49) is described only in internally drained, seasonal swamps on Tertiary plateaus within the Junee Tablelands. It was recorded in only one location within the study area, although more than one of these swamps are known to occur. It represents an outlier of an association that is much more common further east, particularly on alluvium within the coastal ranges and on the coastal plain. Typically, it occurs as a mid-high woodland of swamp mahogany (*Lophostemon suaveolens*), often with emergent blue gum. Its occurrence is restricted to the Thirteenmile (Tt) soil.

7.2.3 Wooded downs

The occurrence of treeless tussock grasslands on heavy clay soils (known locally as open downs) is relatively limited within the study area. In most cases, an open eucalypt woodland is associated. Three such associations are described, namely, **Gum-topped bloodwood (VA16)**, **Mountain coolibah (VA19)** and **Ironbark–bloodwood–ghost gum (VA43)**. All three occur on heavy clay soils developed from either Tertiary basalt (Tb), calcareous, basaltic-derived Tertiary–Quaternary sediments (TQa_b) or labile Permian sediments (Pw).

The most widespread and also most variable of the three is the **Ironbark–bloodwood–ghost gum (VA43)** association. Typically, it occurs as a mid-high open woodland of narrow-leaved ironbark (*Eucalyptus crebra*), silver-leaved ironbark (*Eucalyptus melanophloia*), gum-topped bloodwood (*Corymbia erythrophloia*) and ghost gum (*Corymbia dallachyana*) with varying amounts of mountain coolibah (*Eucalyptus orgadophila*), long-fruited bloodwood (*Corymbia clarksoniana*), Moreton Bay ash (*Corymbia tessellaris*) and poplar box (*Eucalyptus populnea*). A sparse understorey of Leichhardt bean (*Cassia brewsteri*) and currant bush (*Carissa ovata*) with occasional dead-finish (*Archidendropsis basaltica*), whitewood (*Atalaya hemiglauca*), ironwood (*Acacia excelsa*), bauhinia (*Lysiphyllum hookeri*), corkwood wattle (*Acacia bidwillii*) or sally wattle (*Acacia salicina*) is normally present. The exact mix of species at any particular location is variable. **Ironbark–bloodwood–ghost gum (VA43)** grows on the Carlo (Cc) and Mt Stuart (Ms) soils on Permian sediments (Pw), the Windeyers Hill (Wy) soil on basalt areas (Tb, Tb_a) and the Kirkcaldy (Kc) soil on basaltic-derived Tertiary–Quaternary sediments (TQa_b). In all cases, it occurs on gently undulating plains and low rises.

Gum-topped bloodwood (VA16) is confined mainly to the basalt landscapes in the 'May Downs' area. Structurally, it is quite variable and ranges from a mid-high woodland or open woodland through to isolated trees within a tussock grassland. Typically, the tallest stratum consists of a uniform, relatively sparse stand of gum-topped bloodwood that is floristically pure with only very occasional ghost gum, whitewood or silver-leaved ironbark. Understories are largely absent and shrubby species such as sally wattle, Leichhardt bean and occasional mimosa bush (*Acacia farnesiana*) or corkwood wattle are mostly scattered and isolated. **Gum-topped bloodwood (VA16)** occurs predominantly on the May (My) and May shallow phase (MySp) soils on gently undulating basalt plains and low rises. It also occurs occasionally on equivalent open downs soils on Permian (Pw) and Tertiary–Quaternary (TQa_b) landscapes.

Significant areas of wooded downs with **Mountain coolibah (VA19)** occur east of Dysart and also just south of the study area around 'Mt Stuart'. **Mountain coolibah (VA19)** typically occurs as a tall open woodland in which the upper stratum of mountain coolibah is largely monospecific. A sparse understorey of Leichhardt bean and currant bush with occasional sally wattle, corkwood wattle, bauhinia, emu apple (*Owenia acidula*), limebush (*Eremocitrus glauca*) or boonaree (*Alectryon oleifolius*) is normally present. Within the study area, it occurs predominantly on the Carfax (Cx) and Kirkcaldy (Kc) soils on gently undulating to undulating plains, sideslopes and low rises on unconsolidated, basaltic derived, Tertiary–Quaternary sediments (TQa_b). Outside the study area, it is also associated with labile Permian sediments (Pw), such as those at 'Mt Stuart', and fresh Tertiary basalts (Tb), such as those at 'Oxford Downs' and further north.

7.2.4 Bloodwood woodland

In general, bloodwoods mostly occur as associates with other more dominant species such as narrow-leaved ironbark (*Eucalyptus crebra*) or poplar box (*Eucalyptus populnea*). Two associations are described however, in which bloodwoods dominate the tallest stratum, namely the **Long-fruited bloodwood (VA15)** and **Moreton Bay ash (VA23)** associations.

The **Long-fruited bloodwood (VA15)** association is relatively minor and has a limited distribution. It is most common on shallow soils (Cherwell (Cw) and Maywin (Mw) soils) within the undulating to rolling rises and low hills on Permian sediments (Pb) at the southern end of the Cherwell Range. In addition, it occurs on sandy Tertiary plateaus (Wyndham (Wm) soil) around German Creek Mine and on alluvial sand ridges (Booroondarra (Bn) soil) where it sometimes replaces Moreton Bay ash (*Corymbia tessellaris*). Typically, the association occurs as a tall woodland or open woodland of long-fruited bloodwood (*Corymbia clarksoniana*). Occasional associated species in the upper stratum include red ash (*Alphitonia excelsa*), narrow-leaved ironbark or Queensland peppermint (*Eucalyptus exserta*) on rises, hills and plateaus, while Moreton Bay ash is more likely in alluvial situations. Similarly, an open understorey of quinine tree (*Petalostigma pubescens*), red ash and wattles (*Acacia* species) is normally present in upland areas, but is largely absent on alluvium.

The distribution of **Moreton Bay ash (VA23)** is restricted to Quaternary alluvium (Qa), where it occurs on sandy levees and alluvial sand ridges, from upper tributaries through to major flood plains. It is closely associated with the sandy Booroondarra (Bn) and German (Gm) soils, and its presence is normally indicative of well drained situations. Typically, it occurs as a tall open woodland of Moreton Bay ash that is either monospecific, or has occasional long-fruited bloodwood and/or poplar box associated. Understories are largely absent, but scattered Leichhardt bean (*Cassia brewsteri*), sally wattle (*Acacia salicina*) or ironwood (*Acacia excelsa*) may be present in the mid-stratum.

7.2.5 Poplar box woodland

In terms of extent and distribution, poplar box (*Eucalyptus populnea*) woodlands are second only to the brigalow (*Acacia harpophylla*) scrubs. They occur on almost every landscape, but are most common on Permian sediments (Pb, Pw), unconsolidated Tertiary–Quaternary sediments (TQa) and Quaternary alluvium (Qa). Four associations are described that range from almost monospecific stands of poplar box through to poplar box with associated bloodwoods or ironbark in the tallest stratum or prominent shrubby species in the understorey. The associations include **Shrubby poplar box (VA7)**, **Poplar box (VA20)**, **Poplar box–bloodwood–Moreton Bay ash (VA33)** and **Poplar box–ironbark (VA34).**

Poplar box (VA20) is the dominant association described within the poplar box woodlands and occupies significant areas both within the study area and across the surrounding catchments. The only landscapes it does not occur on are rises and hills associated with Cretaceous intrusions (Ki) and deeply weathered Tertiary basalts (Tb_d). It is most common on:

- unconsolidated Tertiary–Quaternary sediments (TQa), particularly the Foxleigh (Fx) and Collawmar (Cm) soils;
- Permian sediments (Pb, Pw), particularly the Heyford (Hf) and Adeline (Ad) soils; and
- Quaternary alluvium (Qa), particularly the Parrot (Pr), Roper (Rp) and Stephens (St) soils.

It also grows on the Wieta (Wt) soil on deeply weathered Tertiary sediments (Td, Ta) and the Mayfair sandy surface variant (MfSv) soil on Tertiary–Quaternary sediments of basaltic origins (TQa_b). Typically, it occurs as a tall woodland or open woodland of poplar box with very occasional ironwood (*Acacia excelsa*), long-fruited bloodwood (*Corymbia clarksoniana*), vine tree (*Ventilago viminalis*), ghost gum (*Corymbia dallachyana*) or Moreton Bay ash (*Corymbia tessellaris*) associates in the tallest stratum. An open to sparse shrubby understorey of false sandalwood (*Eremophila mitchellii*), Leichhardt bean (*Cassia brewsteri*), scrub leopardwood (*Flindersia dissosperma*), currant bush (*Carissa ovata*) and other occasional species is normally present. Typical examples on TQa sediments occur immediately west of Middlemount, while significant areas on Permian sandstones (Pb) occur between German Creek and Dysart. Alluvial examples occur along all upper and lower tributaries.

The **Poplar box–bloodwood–Moreton Bay ash (VA33)** association differs from **Poplar box (VA20)** in that associated species in the tallest stratum are always present rather than only occasionally. In addition, its extent and distribution are restricted almost entirely to Tertiary–Quaternary sediments (TQa) and alluvial landscapes (Qa). Typically, it occurs as a tall woodland of poplar box, long-fruited bloodwood and Moreton Bay ash, with approximately equal proportions of each species in the tallest stratum. A sparse shrubby understorey of Leichhardt bean, sally wattle (*Acacia salicina*) and other occasional species is normally present. It grows mainly on the Foxleigh (Fx) soil on Tertiary–Quaternary sediments (TQa) and the Parrot (Pr), Roper (Rp) and Booroondarra (Bn) soils on Quaternary alluvium (Qa). Examples occur immediately west of Middlemount and along most upper and lower tributaries.

Shrubby poplar box (VA7) differs both structurally and floristically from **Poplar box (VA20)**. It characteristically develops a thick shrubby understorey that is floristically diverse and includes many

Wooded downs (continued)

Photograph 51. Ironbark–bloodwood–ghost gum open woodland (VA43) on the Windeyers Hill (Wy) soil, 'Ninemile'

Bloodwood woodland

Photograph 52. Moreton Bay ash open woodland (VA23) on the Booroondarra (Bn) soil, Roper Creek

Poplar box woodland

Photograph 53. Shrubby poplar box woodland (VA7) on the Honeycomb (Hy) soil, Roper Creek

Photograph 54. Poplar box open woodland (VA20) on the Foxleigh (Fx) soil, Middlemount area

Photograph 55. Poplar box woodland (VA20) on the Roper (Rp) soil, Roper Creek

Photograph 56. Poplar box–ironbark woodland (VA34) on the Heyford (Hf) soil, west of Dysart

Silver-leaved ironbark woodland **Narrow-leaved ironbark woodland**

Photograph 57. Silver-leaved ironbark woodland (VA17) on the Red-one (Rn) soil, Dingo–Mt Flora Beef Road

Photograph 58. Narrow-leaved ironbark open woodland (VA12) on the Anncrouye (Ac) soil, south-east of Middlemount

Photograph 59. Narrow-leaved ironbark woodland (VA12) on the Maywin (Mw) soil, west of German Creek Mine

Photograph 60. Narrow-leaved ironbark–bloodwood woodland with an understorey of paper barked teatree and other shrubs (VA13) on the Wyndham (Wm) soil, 'Booroondarra'

Photograph 61. Narrow-leaved ironbark open woodland with a heath myrtle understorey (VA14) on the Bul Bul (Bb) soil, 'Booroondarra'

Photograph 62. Ironbark–bloodwood–ghost gum open woodland (VA50) on the Bills Hut (Bh) soil, 'Redcliff'

shrub species normally associated with brigalow scrubs. Typically, it occurs as a tall woodland or open woodland of poplar box with a very prominent understorey of false sandalwood, currant bush, brigalow, Leichhardt bean, scrub leopardwood and many other occasional species. Reasons for the increased shrub density probably relate to marginally higher soil fertility and, in most cases, loamier surface soils. In general, it occurs on similar landscapes to those of the more common **Poplar box (VA20)** association, but usually in intergrade areas where eucalypt woodland and brigalow scrubs lie adjacent. The range of soils with which it is associated differs slightly as a result and includes both poplar box texture contrast soils and texture contrast soils normally found associated with brigalow–eucalypt scrub. Associated soils include the Emoh (Em) and Stateschool (Ss) soils on Permian sediments (Pw), the Collawmar (Cm) and Foxleigh clay loamy phase (FxLp) soils on unconsolidated Tertiary–Quaternary sediments (TQa) and the Honeycomb (Hy) soil on Quaternary alluvium (Qa).

While most occurrences of **Poplar box–ironbark (VA34)** probably represent intergrade situations, it is common enough to be described as a separate association. Typically, it occurs as a tall woodland or open woodland of poplar box with greater or lesser amounts of narrow-leaved ironbark (*Eucalyptus crebra*) and/or silver-leaved ironbark (*Eucalyptus melanophloia*) and occasional vine tree, ironwood, ghost gum, long-fruited bloodwood or gum-topped bloodwood (*Corymbia erythrophloia*). An open to sparse understorey of Leichhardt bean, false sandalwood, currant bush and other occasional species is normally present. In general, it occurs on the same landscapes described for **Poplar box (VA20)**, with the exception of Quaternary alluvium (Qa). It is associated with different soils however, and occurs mainly on loamy surfaced texture contrast soils and hard setting clays rather than the sandy surfaced soils of the **Poplar box (VA20)** association. The range of soils normally associated with **Poplar box–ironbark (VA34)** is listed in Table 16. It is interesting to note, solid substrates (sandstone, siltstone, shale, basalt or deeply weathered sediments) underlie the majority of these soils and probably explain the presence of ironbark in this association.

7.2.6 Silver-leaved ironbark woodland

While the spatial extent of **Silver-leaved ironbark (VA17)** is relatively restricted, it occurs on all landscapes except two and is described on a number of different soils. The soils include a range of loamy surfaced, texture contrast soils and firm to hard setting clays, which are characteristically non-sodic, at least in the upper subsoil. The **Silver-leaved ironbark (VA17)** association typically occurs as a mid-high to tall woodland or open woodland of silver-leaved ironbark (*Eucalyptus melanophloia*) with occasional gum-topped bloodwood (*Corymbia erythrophloia*), ghost gum (*Corymbia dallachyana*) or poplar box (*Eucalyptus populnea*) associates in the tallest stratum. A sparse understorey of Leichhardt bean (*Cassia brewsteri*), currant bush (*Carissa ovata*) and other occasional species is normally present. Thicker understories are sometimes associated where it occurs on folded Permian sediments (Pw), depending on the proximity and nature (eucalypt or brigalow) of adjacent strips. The range of soils on which it normally grows is listed in Table 16. Typical examples of this association occur along the Dingo–Mt Flora Beef Road between Middlemount and the Isaac River.

7.2.7 Narrow-leaved ironbark woodland

The extent and distribution of narrow-leaved ironbark (*Eucalyptus crebra*) woodlands within the study area is significant, and is exceeded only by brigalow (*Acacia harpophylla*) scrubs and poplar box (*Eucalyptus populnea*) woodlands in terms of spatial dominance. They occur predominantly on hard rock landscapes where soils are either weathering *in situ* or directly overlie solid substrates. These include Permian sedimentary rocks (Pb, Pw), Cretaceous intrusives (Ki), deeply weathered Tertiary sediments (Td, Ta), deeply weathered Tertiary basalt (Tb_d) and fresh or partially altered Tertiary basalt (Tb). Four associations are described that range from almost monospecific narrow-leaved ironbark through to narrow-leaved ironbark with associated bloodwoods in the tallest stratum or characteristic shrubby species in the understorey. The associations include **Narrow-leaved ironbark (VA12)**, **Eucalypts with shrubby teatree (VA13)**, **Eucalypts with shrubby heath myrtle (VA14)** and **Ironbark–bloodwood–ghost gum (VA50).**

Narrow-leaved ironbark (VA12) is the dominant association described within the narrow-leaved ironbark woodlands and occupies significant areas both within the study area and across the surrounding catchments. The only landscapes it does not occur on are unconsolidated Tertiary–Quaternary sediments (TQa, TQa_b) and Quaternary alluvium (Qa). It is most common on hard rock landscapes where soils are developed *in situ*, particularly:

- the Maywin (Mw), Heyford (Hf), Adeline (Ad) and Red-one (Rn) soils on Permian sedimentary rocks (Pb, Pw);
- the Middlemount (Mi) and Middlemount colluvial phase (MiCv) soils on Cretaceous intrusives (Ki);
- all soils on deeply weathered Tertiary landscapes (Td, Ta, Tb_d), with the exception of the Bundoora (Bd) and Merion (Mr) soils; and
- the Windeyers Hill (Wy) and Windeyers Hill melonhole phase (WyMp) soils on Tertiary basalt (Tb, Tb_a).

Typically, **Narrow-leaved ironbark (VA12)** occurs as a tall woodland or open woodland of narrow-leaved ironbark with occasional long-fruited bloodwood (*Corymbia clarksoniana*) or ghost gum (*Corymbia dallachyana*) associates in the tallest stratum. An open to sparse understorey of quinine tree (*Petalostigma pubescens*), cocaine tree (*Erythroxylum australe*), Leichhardt bean (*Cassia brewsteri*), red ash (*Alphitonia excelsa*), currant bush (*Carissa ovata*) and other occasional species is normally present. Typical examples on Permian sandstones (Pb) occur at the southern end of the Cherwell Range, while examples on deeply weathered sediments (Td, Ta) are widespread on plateaus and dissected residuals around the Junee Tablelands.

The **Ironbark–bloodwood–ghost gum (VA50)** association differs from **Narrow-leaved ironbark (VA12)** in that associated species in the tallest stratum are always present rather than only occasionally. In addition, its extent and distribution are far more restricted, being described only on deeply weathered Tertiary plateaus where it is associated predominantly with the Bills Hut (Bh) and Wyndham (Wm) soils. Typically, it occurs as a tall woodland or open woodland of narrow-leaved ironbark, long-fruited bloodwood and ghost gum, with approximately equal proportions of each species in the tallest stratum. An open to sparse understorey of quinine tree, red ash, cocaine tree, wattles (*Acacia leiocalyx*, *Acacia* species) and occasional myrtle tree (*Canthium oleifolium*) and sticky hopbush (*Dodonaea viscosa*) is normally present. Typical examples occur on intact plateaus surfaces on the Junee Tablelands and also in the German Creek area.

The associations **Eucalypts with shrubby teatree (VA13)** and **Eucalypts with shrubby heath myrtle (VA14)** are narrow-leaved ironbark associations that are named after the distinctive shrubby understories that are normally present. While narrow-leaved ironbark is typically the dominant species in the tallest stratum, bloodwoods are always associated, often in equal proportions and sometimes as the dominant species.

Eucalypts with shrubby teatree (VA13) typically occurs as a tall woodland or open woodland of narrow-leaved ironbark and long-fruited bloodwood with a prominent, open to sparse understorey of paper barked teatree (*Melalueca nervosa*). Other shrubby species such as quinine tree, red ash, wattles and occasional bull oak (*Allocasuarina luehmannii*) are normally associated. It occurs mainly on sandy surfaced texture contrast soils subject to seasonal seepage or perched drainage. These include the Cherwell (Cw) and Maywin (Mw) soils on altered Permian sandstones (Pb) in the Cherwell Range and the Wyndham (Wm) soil on deeply weathered Tertiary plateaus (Ta) in the German Creek area. Minor occurrences are also described on the Middlemount colluvial variant (MiCv) soil around the base of Cretaceous intrusives (Ki) and the Thirteenmile (Tt) soil in upland seasonal swamps that are internally drained.

Eucalypts with shrubby heath myrtle (VA14) has a restricted distribution and is described only on intact and partially dissected Tertiary (Ta) plateaus in the German Creek area. Typically, it occurs as a tall open woodland of narrow-leaved ironbark, ghost gum and long-fruited bloodwood, with a prominent understorey of heath myrtle (*Micromyrtus capricornia*). Species dominance in the tallest stratum is variable, although normally there is a greater proportion of ironbark than bloodwoods. The heath myrtle understorey is mostly only 1–2 m high, mid-dense or thicker (crown separation ratio <0–0.25) and largely monospecific. **Eucalypts with shrubby heath myrtle (VA14)** is of limited extent and is restricted almost entirely to the Bul Bul (Bb) soil on plateau margins and gently dissected residuals south-west of Middlemount. The presence of shrubby heath myrtle in the understorey is usually a reliable indicator of ferricrete layers at shallow depths.

7.2.8 Other eucalypt woodlands

Three additional eucalypt woodlands are described that are of limited extent and restricted distribution within the study area and surrounding catchments, but are significant enough to be recognised as separate associations. Each of the three associations, namely **Queensland peppermint (VA25)**, **Lemon-scented gum (VA31)** and **Narrow-leaved white mahogany (VA41)**, is independent of the others and differs significantly in terms of structure, floristics and landscape position. They are grouped here for convenience.

Queensland peppermint (VA25) typically occurs as a mid-high open forest to open woodland of Queensland peppermint (*Eucalyptus exserta*) that is mostly monospecific, but occasionally has associated long-fruited bloodwood (*Corymbia clarksoniana*), narrow-leaved ironbark (*Eucalyptus crebra*), red ash (*Alphitonia excelsa*) or lemon-scented gum (*Corymbia citriodora*). While there is significant variation in crown cover and tree density in the tallest stratum, tree height is always between 6–12 m and is relatively uniform. An open to sparse understorey of red ash, quinine tree (*Petalostigma pubescens*) and various wattles (*Acacia* species) is normally present. It grows on the Cherwell (Cw) and Maywin (Mw) soils on partially altered Permian sedimentary rocks (Pb) in the Cherwell Range, or the Anncrouye (Ac), Bellarine (Bz), Red Cliff (Rc) and Wyndham (Wm) soils on deeply weathered Tertiary (Ta) plateaus, scarps and dissected residuals south-west of Middlemount.

Lemon-scented gum (VA31) is restricted to the Cherwell (Cw) and Maywin (Mw) soils on undulating to rolling rises and low hills associated with altered Permian sandstones (Pb) at the southern end of the Cherwell Range. Typically, it occurs as a tall woodland of lemon-scented gum with occasional narrow-leaved ironbark and long-fruited bloodwood associates in the tallest stratum. An open to sparse understorey of rosewood (*Acacia rhodoxylon*), red ash, cocaine tree (*Erythroxylum australe*), quinine tree and various wattles (*Acacia* species) is normally present.

Narrow-leaved white mahogany (VA41) occurs in predominantly monospecific stands that are only described on intact Tertiary plateau surfaces within the Junee Tablelands. It typically occurs as a mid-high woodland of narrow-leaved white mahogany (*Eucalyptus tenuipes*), without associates in the tallest stratum. Emergent species are sometimes present and include long-fruited bloodwood, narrow-leaved ironbark and kurrajong (*Brachychiton populneus*). Understorey species are largely absent, although occasional budgeroo (*Lysicarpus angustifolius*) and quinine tree were recorded. The association is often groved to some extent and forms a distinctive photo pattern on aerial photographs. It is described only on the Bills Hut (Bh) soil, and soil differences were not observed between this association and other more widespread associations such as **Narrow-leaved ironbark (VA12), Ironbark–bloodwood–ghost gum (VA50)** or **Budgeroo (VA26)** that also occur on this soil. The factors controlling the local distribution of **Narrow-leaved white mahogany (VA41)** remain largely unclear.

7.2.9 Bull oak country

Only two bull oak (*Allocasuarina luehmannii*) associations are described, namely **Eucalypts with bull oak (VA32)** and **Bull oak (VA35)**. They often occur in association and are found on the same soils and landscapes. They both have a limited distribution which is restricted to:

Other eucalypt woodlands

Photograph 63. Lemon-scented gum woodland (VA31) on the Maywin (Mw) soil, Cherwell Range

Photograph 64. Narrow-leaved white mahogany woodland (VA41) on the Bills Hut (Bh) soil, Junee Tablelands

Bull oak country

Photograph 65. Poplar box woodland with a bull oak understorey (VA32) on the Bundoora (Bd) soil, 'Oak Park'

Photograph 66. Bull oak open forest (VA35) on the Bundoora (Bd) soil, 'Booroondarra'

Open downs

Photograph 67. Treeless *Bothriochloa* grassland (VA27) on the Bluchers (Bc) soil, Roper Creek

Photograph 68. Treeless Queensland bluegrass downs (VA28) on the May (My) soil, 'Ninemile'

- broad, gently undulating pediments on partially dissected, deeply weathered Tertiary (Ta) landscapes, south-west of Middlemount; and
- partially altered, Permian sandstones (Pb) on gently undulating rises around the base of the Cherwell Range.

Eucalypts with bull oak (VA32) is the more common of the two associations and occupies a much larger spatial extent. Typically, it occurs as a tall woodland of poplar box (*Eucalyptus populnea*) and/or narrow-leaved ironbark (*Eucalyptus crebra*) and/or long-fruited bloodwood (*Corymbia clarksoniana*) with a prominent understorey of bull oak and other occasional species. Species dominance in the tallest stratum is variable, and ranges from almost total dominance by one associate through to roughly equal proportions of two or three. Most commonly it occurs as a poplar box woodland with associated long-fruited bloodwood. An open to sparse understorey of bull oak (3–6 m high) with occasional false sandalwood (*Eremophila mitchellii*), cocaine tree (*Erythroxylum australe*), Leichhardt bean (*Cassia brewsteri*), scrub leopardwood (*Flindersia dissosperma*), quinine tree (*Petalostigma pubescens*), ironwood (*Acacia excelsa*) and wattles (*Acacia* species) is normally present. It grows only on sandy surfaced, strongly to extremely sodic texture contrast soils that are very fragile and prone to extreme erosion and degradation following disturbance. Its occurrence is restricted to the Bundoora (Bd) soil and less commonly the Heyford (Hf) soil in the German Creek area, south-west of Middlemount.

The soils and landscape positions occupied by **Bull oak (VA35)** are the same as those described for **Eucalypts with bull oak (VA32)**. Factors controlling the distribution of the two associations remain largely unclear, although it is likely the distribution of monospecific bull oak stands are largely controlled by the pattern of exposure of particular layers within the deeply weathered sedimentary sequence following stripping and dissection. Tentative field evidence which suggests soil development may be subject to greater colluvial influences where eucalypts are associated confirms this suggestion. Typically, **Bull oak (VA35)** occurs as a mid-high open forest or woodland of bull oak with very occasional ghost gum (*Corymbia dallachyana*), long-fruited bloodwood or poplar box, either as associates or emergents. Understories are largely absent, but where present consist only of sparse bull oak regeneration and occasional wattles (*Acacia cretata*). **Bull oak (VA35)** is associated mainly with the Bundoora (Bd) soil, and experiences similar land management problems described above for **Eucalypts with bull oak (VA32)**.

7.3 Tussock grasslands

7.3.1 Open downs

Treeless tussock grasslands are relatively uncommon within the study area and surrounding catchments. They occur on the same soils and landscapes as the eucalypt woodlands described in section 7.2.3, namely **Gum-topped bloodwood (VA16)**, **Mountain coolibah (VA19)** or **Ironbark–bloodwood–ghost gum (VA43)**, and are often intimately associated. Their distribution is restricted to level or gently undulating plains and low rises on:

- labile Permian sediments (Pw);
- fresh Tertiary basalt (Tb);
- unconsolidated Tertiary–Quaternary sediments of basaltic origins (TQa_b); and
- occasionally Quaternary alluvium (Qa).

Two treeless tussock grassland associations are described, namely ***Bothriochloa* grassland (VA27)** and **Queensland bluegrass downs (VA28)**. Treeless areas of ***Bothriochloa* grassland (VA27)** are relatively uncommon and occur mainly as strips and patches within the folded Permian sediments (Pw) in the centre of the study area, or on treeless backplains along lower tributaries. Typically, it occurs as a mid-high to tall grassland (0.25–1 m high, 30–70% foliage cover) of forest bluegrass (*Bothriochloa bladhii* subsp. *bladhii*) and pitted bluegrass (*Bothriochloa decipiens* subsp. *decipiens*) with greater or lesser additions of red Flinders grass (*Iseilema vaginiflorum*), silky browntop (*Eulalia aurea*), *Panicum* species and other occasional grasses. Isolated eucalypts and shrubs such as ghost gum (*Corymbia dallachyana*), mountain coolibah (*Eucalyptus orgadophila*), gum-topped bloodwood (*Corymbia erythrophloia*), sally wattle (*Acacia salicina*), whitewood (*Atalaya hemiglauca*) and Leichhardt bean (*Cassia brewsteri*) are sometimes associated. It is described mostly on the Mt Stuart (Ms) soil and often occurs in association with **Ironbark–bloodwood–ghost gum (VA43)**. The structure and floristics of the lowest stratum under woodland is the same as that of the treeless areas. Reasons for the distribution of treeless and wooded areas remain unclear. It is also recorded on open, treeless backplains of lower tributaries such as Roper Creek, where the Bluchers (Bc) soil has developed on clay sediments deposited by local backwater flooding. It is often associated with **Poplar box (VA20)** in these areas.

Queensland bluegrass downs (VA28) is structurally similar but differs floristically. Typically, it occurs as a tall grassland (0.5–1 m high, 30–70% foliage cover) of Queensland bluegrass (*Dichanthium sericeum* subsp. *sericeum*) and red Flinders grass with greater or lesser additions of black speargrass (*Heteropogon contortus*), kangaroo grass (*Themeda triandra*), bull Mitchell grass (*Astrebla squarrosa*), silky browntop, *Bothriochloa* species, *Panicum* species, *Ophiuros exaltatus* and other occasional grasses. It has a wider distribution than ***Bothriochloa* grassland (VA27)** and is normally found associated with the Mt Stuart (Ms) soil on folded Permian sediments (Pw), the May (My) and May shallow phase (MySp) soils on fresh Tertiary basalt (Tb), the Carfax (Cx) soil on unconsolidated Tertiary–Quaternary sediments (TQa_b) and the Lindsay (Ld) soil on backplains of lower tributaries and flood plains (particularly in catchments developed from labile sediments (Pw, TQa_b) or basalt (Tb)). As with ***Bothriochloa* grassland (VA27)**, eucalypt woodlands are often closely associated, particularly **Gum-topped bloodwood (VA16)** and **Mountain coolibah (VA19)**, and reasons for the distribution of woodland and treeless areas remain unclear. Isolated eucalypts and shrubs such as gum-topped bloodwood, ghost gum, sally wattle and whitewood are sometimes present.

8. SOILS – DESCRIPTION AND CHARACTERISATION

8.1 Outline

The information presented in this chapter provides a summary of the most important characteristics associated with each soil profile class. It documents a range of information from landscape position, parent material and soil origins to distinguishing profile features, soil fertility status, physical characteristics (within the profile) and subsoil chemistry.

An outline of the information provided for each soil is given below with a brief explanation of its purpose, how the data was calculated (if applicable) and where more information may be found elsewhere in the report.

Information presented for each SPC	Brief explanation
• Soil Concept	• A conceptual description of the distinguishing profile features, parent material and vegetation for each soil.
• Soil Classification	• Australian soil classification – Soil Order, Great Group (Isbell 1996). • Great Soil Group (Stace *et al.* 1968). • Principal Profile Form (Northcote 1979).
• Geology/parent material	• Geological formation, dominant lithology of the parent material, degree of alteration and geographic location (if applicable) are discussed. • See Chapter 5 for further explanation.
• Landform	• Dominant relief/modal slope class, landform pattern and typical slope range are discussed.
• Vegetation	• Dominant and occasional vegetation associations are listed. • See Appendix 11 for further detail.
• Microrelief	• Presence of microrelief is discussed including type, degree of development (weak to strong), size (vertical interval – VI (m) and horizontal interval – HI (m)) and dominance of individual components (if applicable).
• Runoff, permeability and drainage	• Estimates as defined by McDonald *et al.* (1990) are listed; differences between microrelief components are described where applicable.
• Surface gravel, stone and rock outcrop	• Estimates as defined by McDonald *et al.* (1990) are listed.
• Surface condition	• Description of surface condition as defined by McDonald *et al.* (1990) is presented. • Self-mulching behaviour is further described in terms of strength of pedality, fineness of aggregates and thickness of the self mulching layer.
• Distinguishing profile features	• Descriptions of the depth, horizon designation and dominant colour, mottling, texture, structure, segregations, gravel and field pH of the major soil horizons and underlying substrate are presented. • See Appendix 2 for further detail.

Information presented for each SPC	Brief explanation
• Surface soil fertility status	• A summary of the fertility status of each soil including mean levels and ratings for organic carbon, total nitrogen, available phosphorus, micronutrients and exchangeable calcium and magnesium is presented and discussed. • See Appendix 4 for comprehensive data, Appendix 7 for laboratory methods and Appendix 8 for explanations of the assessment criteria.
• Representative profiles	• Typical soil profiles for each soil that have been described in detail and fully analysed are listed. • See Appendices 3 and 6 for complete descriptions and data.
• Salinity	• Graphs of mean profile salinity data (field EC $_{1:5}$) against depth are presented for each soil. • Explanation of the profile salinity curve, critical salinity levels, effective rooting depth and long term wetting front is given.
• Sodicity	• Graphs of typical sodicity data (ESP) against depth are presented for each soil. • The depth to critical sodicity levels (>20%) is discussed.
• Effective rooting depth (ERD) and plant available water capacity (PAWC)	• Mean ERD and PAWC values (calculated from individual field site data) are presented for each soil. • See Appendix 8 for the criteria and methodology used in determining ERD and PAWC. • See Appendix 5 for detail on the amount of water stored in each 0.1 m depth increment for each soil. • See Appendices 3 and 6 for actual examples of ERD and PAWC from representative profiles for each soil.
• Physical characteristics	• The important physical characteristics for each soil including clay content, sand fraction, surface condition, clay mineralogy, dispersion and origins of the soil material are discussed. • See Appendix 3 for detailed analytical data from representative profiles for each soil.
• Subsoil chemistry	• The important soil chemistry attributes of the subsoil including pH, cation exchange capacity, exchangeable cations, cation dominance and ESP are discussed. • See Appendix 3 for detailed analytical data from representative profiles for each soil.

The soils are presented alphabetically by soil name. An index to the page numbers is provided below. The pages that follow are intended only as a quick reference guide for the user. They are useful because they present in one location an overview of the most important and distinguishing features of each soil. Further detail is available in Chapters 1–7 and Appendices 1–12 of this report.

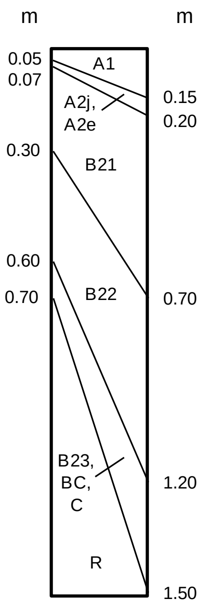
Copies of original field site, analytical or spatial data can be sourced by contacting the Principal Project Officer, Data Management, Natural Resource Information Management, Indooroopilly Sciences Centre, Department of Natural Resources and Mines, Indooroopilly, Brisbane.

8.2 Alphabetical index to the soil profile classes

ADELINE (Ad)

Concept:	A hard setting, loamy or clay loamy surfaced, sporadically or conspicuously bleached, alkaline, brown or black, sodic texture contrast soil over labile sandstone, siltstone or shale from 0.6–1.2 m. Eucalypt vegetation.
Aust. Soil Classification:	Brown or Black Sodosol.
Great Soil Group:	Solodic soil.
Principal Profile Form:	Db1.13, 1.33, 1.43, 2.33, Dy2.13, 2.43, Dd1.33, 1.43; occasionally Db2.43, Dd1.13, Dy2.33.
Geology:	Sandstones or occasionally mudstones or siltstones of the Blackwater Group (Pw). Mostly lithic, feldspathic or calcareous freshwater sedimentary rocks.
Landform:	Gently undulating plains and rises. Slopes 0.5 to 3%.
Vegetation Associations:	Poplar box (VA20) or Poplar box–ironbark (VA34); occasionally Narrow-leaved ironbark (VA12) or Silver-leaved ironbark (VA17).
Microrelief:	Absent.
Runoff:	Slow to moderately rapid.
Permeability:	Very slow to slow.
Drainage:	Moderately well drained.
Surface Features:	Hard setting or occasionally firm. Frequently 2 to 20% silcrete, sandstone, siltstone or quartz gravels 6 to 60 mm. Occasionally <2 to 10% stones 60 to 200 mm or <2 to 10% rock outcrop.
Representative Profiles:	**9004, 9100**

Typical Profile



Soil Description

The **surface soil** (A1, A2j, A2e) is a brown or black, sandy loam to clay loam (frequently fine sandy) with weak blocky or massive structure. Depths typically range from 0.05 to 0.20 m. A sporadically or conspicuously bleached layer is frequently developed immediately above the clay subsoil. Field pH is 6–6.5.

The **upper subsoil** (B21) is a brown or black, medium clay to medium heavy clay with moderate or strong prismatic or blocky structure. Field pH increases rapidly from 6 or 7 at the top of the B21 to 8.5–9.5 lower down.

The **lower subsoil** (B22, B23) is a brown, medium clay to medium heavy clay with moderate or strong angular blocky or lenticular structure. It is normally calcareous with 2 to 20% soft or nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (BC, C) is normally present below 0.6–1.2 m, although deeper profiles (>1.5 m) do occur. Substrate material is labile sandstone, siltstone or shale that is often calcareous and has a field pH of 9–9.5.

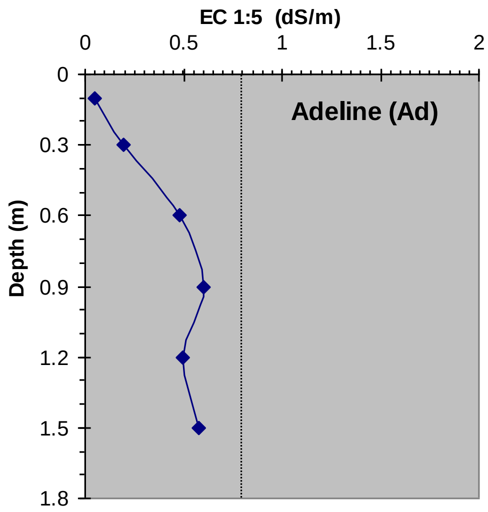
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.7	1.1	0.06	6	0.42	46	45	0.76	0.39	4.9	3.4
neutral	low	moderate	low	moderate	-	moderate	moderate	low	moderate	moderate

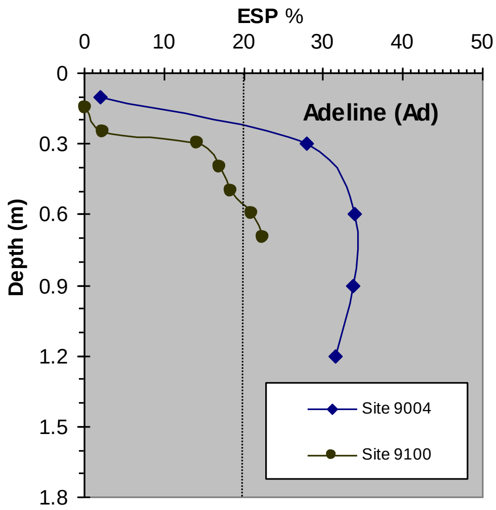
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are low. Most other nutrients are moderate with the exception of zinc (Zn) which is low. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Adeline (Ad) soil. The profile salinity curve reaches equilibrium between 0.6 and 0.9 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.6–1.2 m and contributes to the development of the salt bulge because of restricted subsoil drainage, as well as slight increases in salinity levels at depth. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.23	**0.69**	1.14	49	**95**	140

Typically, PAWC levels for the Adeline (Ad) soil are only moderate (approximately 95 mm) because mean ERD is <0.7 m. It is restricted by physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.7 m), maximum PAWC levels (95–140 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9004 and 9100 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (20–30%) and the subsoil (40–70%), while high levels of fine sand (40–60%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the subsoil are 0.4–0.7 and indicate the clay fraction is of mixed mineralogy. Measured dispersion (R1 ratio) in the subsoil ranges from high to very high (0.8–0.99) and correlates with high to very high sodicity levels (ESP >15). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9004 and 9100 are presented in Appendix 3.

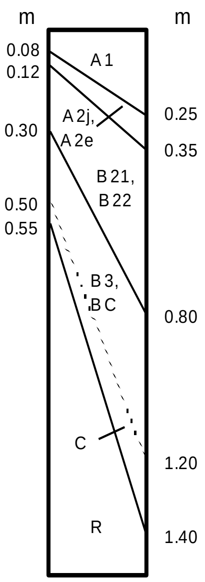
Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are low to moderate (10–20 meq/100 g) in the surface soil and moderate to high (20–30 meq/100 g) in the subsoil. Calcium (Ca) and magnesium (Mg) are the dominant cations and their relative dominance varies with substrate. Profiles are typically sodic to extremely sodic (ESP 6–>20) in the upper subsoil and extremely sodic (ESP >20) in the lower subsoil. Detailed chemical data from representative profiles 9004 and 9100 are presented in Appendix 3.

ANNCROUYE (Ac)

Concept:	A hard setting, loamy or clay loamy surfaced, sporadically bleached, acid, mottled, red texture contrast soil over deeply weathered sediments from 0.3–0.8 m. Eucalypt vegetation.
Aust. Soil Classification:	Red (or occasionally Brown or Grey) Kurosol; Red (or occasionally Brown or Grey) Chromosol.
Great Soil Group:	Red podzolic soil, soloth.
Principal Profile Form:	Dr2.11, 2.31, 3.11, 3.31, 3.41, Db2.11, 2.41, Dy3.11, 3.31.
Geology:	Fine grained sedimentary rocks altered by Tertiary deep weathering (Td, Ta). Substrate is reticulite or petroreticulite.
Landform:	Gently undulating to undulating footslopes, pediments and residual rises below Tertiary plateaus. Mainly dissected plateau remnants or footslopes below plateau scarps. Slopes mostly 1 to 3%, but occasionally up to 6%.
Vegetation Associations:	Narrow-leaved ironbark (VA12), Rosewood (VA2) or Yapunyah (VA24).
Microrelief:	Absent.
Runoff:	Slow to rapid.
Permeability:	Very slow to slow.
Drainage:	Imperfectly drained to well drained.
Surface Features:	Hard setting. Frequently 2 to 20% silcrete or sandstone gravels 6 to 60mm. Occasionally 2 to 20% stones 60 to 200 mm or 2 to 10% rock outcrop.
Representative Profiles:	**9036, 9047, 9083**

Typical Profile



Soil Description

The **surface soil** (A1, A2j) is a brown or black, sandy loam to clay loam (frequently fine sandy) with weak platy, blocky or massive structure. Depths typically range from 0.1 to 0.35 m. A sporadically bleached layer is frequently developed immediately above the clay subsoil. Field pH is 5.5–6.5.

The **subsoil** (B21, B22) is a mottled, red, light medium clay to medium heavy clay with moderate or strong blocky or polyhedral structure. Field pH is 5–6.

Weathered **substrate** (B3, BC, C) normally occurs below 0.3–0.8 m. Substrate material is brown, red or grey, mottled, reticulite or petroreticulite with a field pH of 4–6.

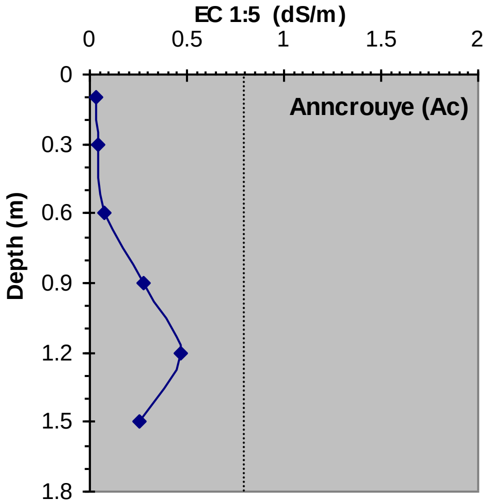
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.7	1.2	0.05	6	0.21	34	7	0.40	0.18	1.9	1.3
acid	low	moderate	low	low	-	moderate	moderate	very low	low	moderate

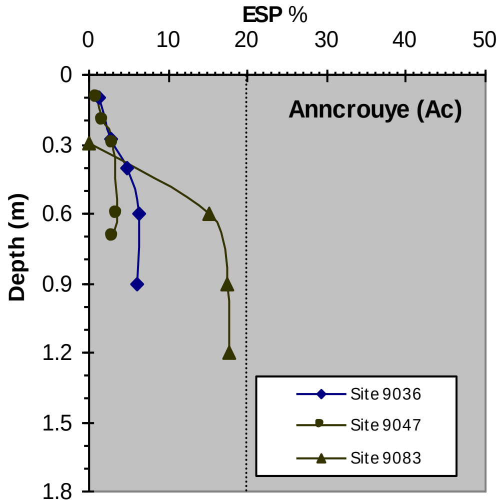
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are low. Most other nutrients are moderate with the exception of potassium (K), calcium (Ca) and zinc (Zn) which are low or very low. The phosphorus infertility of the Anncrouye (Ac) soil reflects its leached nature and the low phosphorus status of the underlying deeply weathered Tertiary substrate. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Anncrouye (Ac) soil. The profile salinity curve reaches equilibrium between 1.0 and 1.2 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is generally present somewhere below 0.3–0.8 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Sodicity levels in the subsoil (ESP <6) are normally well below critical levels (ESP >20). Elevated sodicity levels (ESP >15) at site 9083 are indicative of episodic footslope seepage below the Junee Tablelands.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.25	**0.57**	0.89	45	**72**	99

Typically, PAWC levels for the Anncrouye (Ac) soil are low (approximately 70 mm) because mean ERD is <0.6 m. It is restricted by the presence of deeply weathered, acidic substrate at relatively shallow depths in most profiles. Even where deeper profiles occur (ERD >0.6 m), maximum PAWC levels (70–100 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy surface) and excessive runoff (elevated, sloping landforms). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9036, 9047 and 9083 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (20–30%) and the subsoil (45–65%), while high levels of fine sand (40–60%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the subsoil are <0.15 and indicate the clay fraction is predominantly kaolinitic. Measured dispersion (R1 ratio) in the subsoil is typically low (<0.6) and reflects the non-sodic (ESP <6), acidic, kaolinitic nature of the subsoil. Profile 9083 is moderately dispersive (0.6–0.8) because of high sodicity levels associated with footslope seepage below the Junee Tablelands. High to very high Total K and Total S levels for profile 9083 are indicative of seepage activity. Levels in other profiles are only low or moderate and reflect levels in the underlying substrate confirming soil development has been *in situ*. Detailed physical data from representative profiles 9036, 9047 and 9083 are presented in Appendix 3.

Subsoil Chemistry

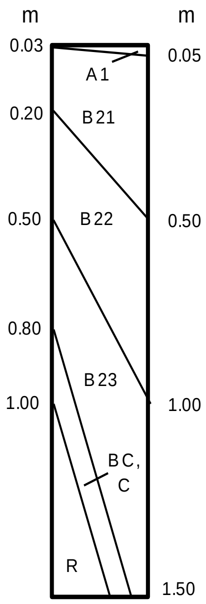
Laboratory pH ranges from 4.5–6 in both the surface soil and the subsoil. CEC levels are very low (3–4 meq/100 g) in the surface soil and low (5–9 meq/100 g) in the subsoil. Magnesium (Mg) is the dominant cation and its relative dominance increases markedly with depth. Profiles are typically non-sodic (ESP <6), with the exception of profile 9083 which is subject to saline/sodic seepage. Detailed chemical data from representative profiles 9036, 9047 and 9083 are presented in Appendix 3.

BATTERY (Bx)

Concept:	A weakly to strongly self-mulching, alkaline, brown cracking clay over partially altered basalt or acid, basaltic clay from 0.5–1.0 m. Brigalow vegetation.
Aust. Soil Classification:	Brown (or occasionally Black) Vertosol.
Great Soil Group:	Brown clay.
Principal Profile Form:	Ug5.34, 5.15, 5.13, 5.32, 5.35.
Geology:	Partially altered Tertiary basalt (Tb_a).
Landform:	Gently undulating pediments, colluvial footslopes and occasional rises associated with partially altered basalt flows exposed following scarp retreat of Tertiary plateaus in the Duaringa Basin. Slopes 0.5 to 1.5%.
Vegetation Associations:	Brigalow with shrubs (VA8) or Brigalow (VA1).
Microrelief:	Occasionally normal gilgai VI 0.05–0.3 m, HI 6–10 m.
Runoff:	Slow.
Permeability:	Slow.
Drainage:	Moderately well drained.
Surface Features:	Cracking with a fine (<2 mm), weakly to strongly self-mulching surface. Frequently 2 to 20% silcrete gravels 6 to 60 mm.

Representative Profile: **9094**

Typical Profile



Soil Description

The **surface soil** (A1) is a brown, light medium clay to medium clay with strong granular structure. Depths typically range from 0.03 to 0.05 m and field pH is 7–9.

The **upper subsoil** (B21, B22) is a brown, medium clay to medium heavy clay with strong lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH increases rapidly from 7–8 at the top of the B21 to 8.5–9.5 lower down.

The **lower subsoil** (B23) is a brown, medium clay to medium heavy clay with moderate or strong, coarse lenticular structure. Field pH is 8.5–9.5 but decreases to 6 where substrate is absent.

Weathered **substrate** (BC, C) often occurs from 0.8–>1.5 m. Substrate material (where present) is partially altered basalt. Typically it is brown or grey with a field pH of 8.5–9.5. In deep profiles (>1.5 m) acid basaltic clay continues at depth.

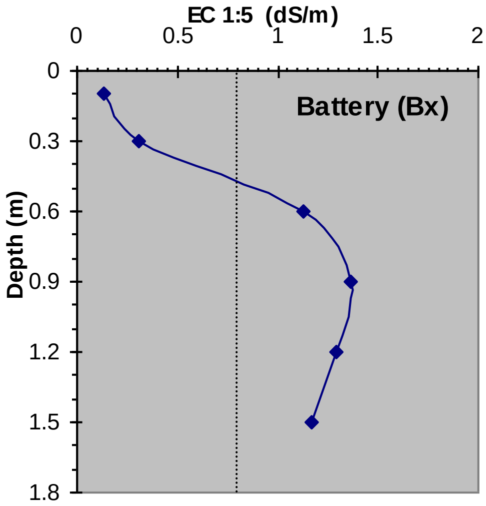
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.3	1.6	0.12	17	0.36	33	31	2.1	0.81	17	11
neutral	moderate	high	high	moderate	-	moderate	moderate	moderate	very high	high

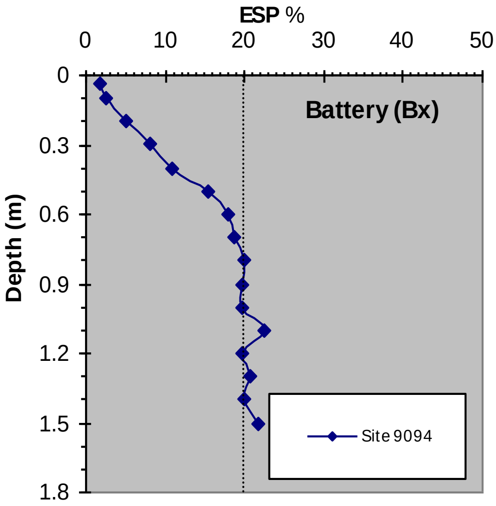
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are high. Most other nutrients are moderate with the exception of calcium (Ca) and magnesium (Mg) which are high to very high. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P), calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.5 m in the Battery (Bx) soil. The profile salinity curve reaches equilibrium between 0.7 and 0.9 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.8–>1.5 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below about 0.6 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**
	0.26	**0.47**	0.68	83	**98**	113

Typically, PAWC levels for the Battery (Bx) soil are only moderate (approximately 100 mm) because mean ERD is <0.5 m. It is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Where deeper profiles without significant salinity or sodicity occur (ERD >0.5 m), maximum PAWC levels (100–115 mm) are still limited by the presence of basaltic substrate or acid clay at depth. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9094 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (55–60%) throughout the profile. CEC/Clay% ratios in the profile are mostly 0.55–0.65 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (i.e. partially altered basaltic clay with colluvial influences). Measured dispersion (R1 ratio) in the profile is only low to moderate (0.4–0.65) and does not reflect the high sodicity levels (ESP 15–20) present in the subsoil. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9094 are presented in Appendix 3.

Subsoil Chemistry

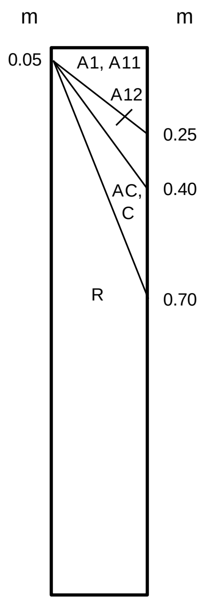
Laboratory pH is similar to field pH (see profile description). CEC levels are high (25–35 meq/100 g) throughout the profile. Calcium (Ca) is the dominant cation in the surface soil (0–0.2 m), but is replaced by magnesium (Mg) in the subsoil. Sodicity (ESP) in the profile also reflects this trend. The surface soil is non-sodic (ESP <6) while the subsoil increases to strongly sodic (ESP 15–20) at depth. Detailed chemical data from representative profile 9094 are presented in Appendix 3.

BELLARINE (Bz)

Concept: A shallow, stony, firm or hard setting, acid, black or brown loam or clay loam over deeply weathered sediments from 0.05–0.4 m. *Acacia* vegetation.
Aust. Soil Classification: Petroferric Leptic Rudosol.
Great Soil Group: Lithosol.
Principal Profile Form: Um5.51, 1.43; occasionally Um1.23, Uc1.23, 1.44, 5.11.
Geology: Fine grained sedimentary rocks (or occasionally basalt) altered by Tertiary deep weathering (Td, Ta or occasionally Tb_d). Substrate is reticulite or petroreticulite.
Landform: Undulating to precipitous hillslopes and scarps bounding intact and dissected Tertiary plateaus. Slopes 3 to 300%.
Vegetation Associations: Lancewood (VA3), Rosewood (VA2) or Bendee (VA30); occasionally Yapunyah (VA24), Narrow-leaved ironbark (VA12) or Queensland peppermint (VA25).
Microrelief: Absent.
Runoff: Moderate to very rapid.
Permeability: Moderate to high.
Drainage: Well drained to rapidly drained.
Surface Features: Firm to hard setting with 10 to 90% petroreticulite fragments 20 to 200 mm and 2 to >50% rock outcrop.

Representative Profiles: **9034, 9095, 9096**

Typical Profile



Soil Description

The **surface soil** (A1, A11, A12) is a black or brown, sandy loam to clay loam (frequently fine sandy) with massive structure and significant (2–50%) gravel. Depths typically range from 0.05 to 0.4 m. Field pH is 5–6.

Weathered **substrate** is always present below 0.05–0.4 m. Substrate material is grey or red, mottled, reticulite or petroreticulite with a field pH <5.5.

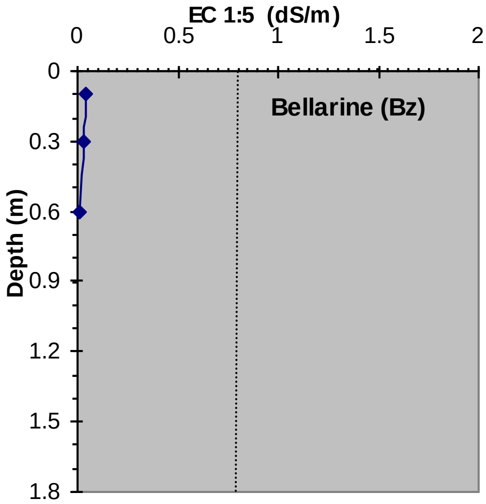
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
4.8	2.2	0.13	6	0.33	79	4	0.19	0.37	2.1	1.2
strongly acid	moderate	high	low	moderate	-	moderate	low	low	moderate	moderate

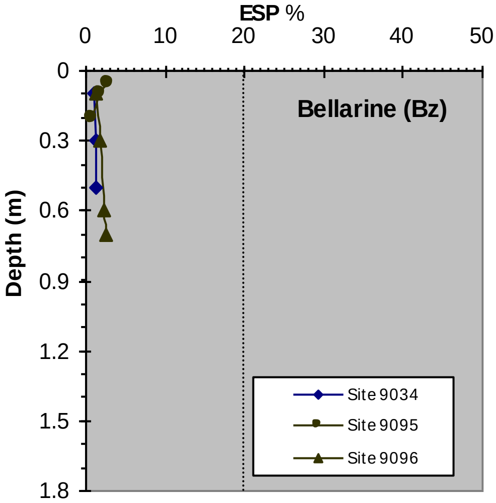
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are high while phosphorus (Bicarb. P) levels are low. Most other nutrients are moderate with the exception of copper (Cu) and zinc (Zn) which are low. The phosphorus infertility of the Bellarine (Bz) soil reflects its leached nature and the low phosphorus status of the underlying deeply weathered Tertiary substrate. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the Bellarine (Bz) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Sodicity levels within the profile (ESP <3) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.07	**0.22**	0.37	23	**40**	56

Typically, PAWC levels for the Bellarine (Bz) soil are low to very low (approximately 40 mm) because mean ERD is only 0.2 m. It is restricted by the presence of deeply weathered, acidic substrate at very shallow depths. Even where deeper profiles occur (ERD 0.2–0.4 m), maximum PAWC levels (40–55 mm) are rarely achieved because of excessive runoff and rapid drainage (steep, elevated scarp slopes). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9034, 9095 and 9096 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (20–30%) or increases gradually (20–40%) within the profile. Levels of fine sand (35–45%) and coarse sand (25–30%) are relatively similar in the surface soil. CEC/Clay% ratios are 0.15–0.3 and indicate the clay fraction is predominantly kaolinitic with some illite. Measured dispersion (R1 ratio) in the profile is low (0.4–0.5) and reflects the non-sodic (ESP <6), acidic, kaolinitic nature of the subsoil/substrate. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9034, 9095 and 9096 are presented in Appendix 3.

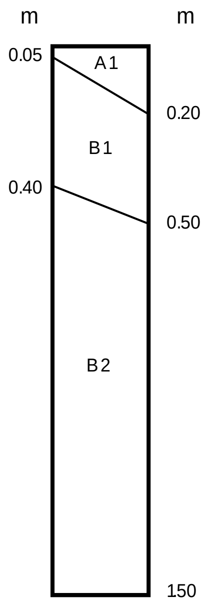
Subsoil Chemistry

Laboratory pH is between 4.5–5 throughout the profile. CEC levels are low to moderate (3–10 meq/100 g) with calcium (Ca) dominant in the surface soil and magnesium (Mg) dominant in the underlying substrate. Profiles are typically non-sodic (ESP <6) throughout. Detailed chemical data from representative profiles 9034, 9095 and 9096 are presented in Appendix 3.

BILLS HUT (Bh)

Concept:	A hard setting, uniform or gradational, clay loamy surfaced, acid, red massive earth over deeply weathered sediments below 1.5 m. Eucalypt vegetation.
Aust. Soil Classification:	Red Kandosol.
Great Soil Group:	Red earth.
Principal Profile Form:	Um5.52, Gn2.11.
Geology:	Fine grained sedimentary rocks altered by Tertiary deep weathering (Td, Ta). Substrate is reticulite or petroreticulite.
Landform:	Level to gently undulating intact Tertiary plateaus bounded by distinct scarps. Occasionally gently undulating rises associated with dissected plateau remnants. Slopes 0.5 to 3%.
Vegetation Associations:	Ironbark–bloodwood–ghost gum (VA50), Narrow-leaved ironbark (VA12) or Budgeroo (VA26); occasionally Narrow-leaved white mahogany (VA41).
Microrelief:	Absent.
Runoff:	Slow.
Permeability:	Moderate.
Drainage:	Well drained.
Surface Features:	Hard setting.
Representative Profiles:	**9002, 9017**

Typical Profile



Soil Description

The **surface soil** (A1) is a red, sandy clay loam to clay loam (fine sandy) with massive structure. Depths typically range from 0.05 to 0.2 m. Field pH is 5.5–6.5.

The **subsoil** (B1, B2) is a red, clay loam to light clay (fine sandy) with massive structure. Field pH is 5.5–6.5.

Weathered **substrate** (reticulite or petroreticulite) normally occurs well below 1.5 m.

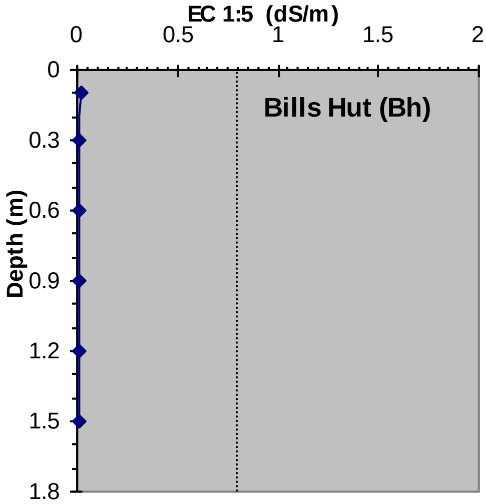
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.7	1.2	0.05	3	0.32	14	23	0.63	0.16	2.6	1.4
acid	low	low	very low	moderate	-	moderate	moderate	very low	moderate	moderate

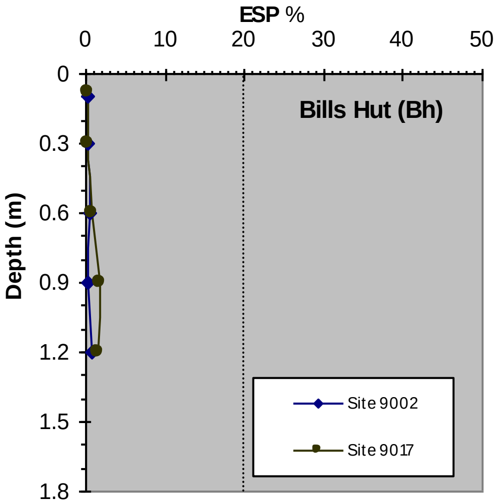
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are low while phosphorus (Bicarb. P) levels are very low. Most other nutrients are moderate with the exception of zinc (Zn) which is very low. The phosphorus infertility of the Bills Hut (Bh) soil reflects its leached nature and the low phosphorus status of the underlying deeply weathered Tertiary substrate. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the upper 1.5 m of the Bills Hut (Bh) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Sodicity levels within the profile (ESP <2) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.77	**1.22**	1.67	81	**112**	143

Typically, PAWC levels for the Bills Hut (Bh) soil are only moderate (approximately 110 mm) even though mean ERD is >1.2 m. Restrictions to rooting depth are generally absent other than the presence of deeply weathered, acidic substrate at the base of some profiles. Maximum PAWC levels (110–140 mm) are rarely achieved on a regular basis because profiles are permeable and subject to continued deep drainage and evaporation losses over time. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9002 and 9017 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases gradually down the profile from 20–25% in the surface soil to 30–35% in the subsoil. High levels of fine sand (60%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios are typically <0.2 throughout and indicate the clay fraction is entirely kaolinitic. Measured dispersion (R1 ratio) is low (<0.35) throughout and correlates with the non-sodic (ESP <6), kaolinitic, sesquioxidic nature of this soil. Total K in the soil profile reflects levels in the underlying substrate (e.g. similar to the Red Cliff (Rc) soil) and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9002 and 9017 are presented in Appendix 3.

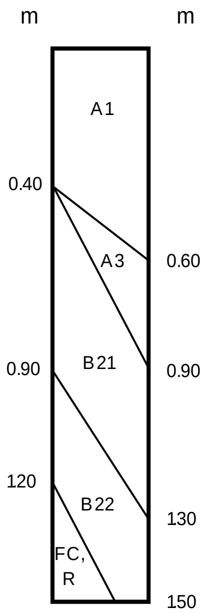
Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are low (5–7 meq/100 g) in the surface soil and very low (3–4 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil while magnesium (Mg) is dominant at depth. Profiles are non-sodic (ESP <2) throughout. Detailed chemical data from representative profiles 9002 and 9017 are presented in Appendix 3.

BILLS HUT SANDY VARIANT (BhSv)

Concept:	A thick (0.4–0.9 m), firm, sandy or loamy surfaced, acid or neutral, gradational variant of the Bills Hut (Bh) soil over ferricrete or deeply weathered sediments below 1.2–>1.5 m. Eucalypt vegetation.
Aust. Soil Classification:	Red Kandosol.
Great Soil Group:	Red earth.
Principal Profile Form:	Gn2.12, Dr4.12.
Geology:	Fine grained sedimentary rocks altered by Tertiary deep weathering (Td, Ta). Substrate is ferricrete, reticulite or petroreticulite.
Landform:	Gently undulating rises associated with remnants of dissected Tertiary plateaus. Slopes 0.5 to 2%.
Vegetation Associations:	Narrow-leaved ironbark (VA12); occasionally Ironbark–bloodwood–ghost gum (VA50).
Microrelief:	Absent.
Runoff:	Very slow to slow.
Permeability:	Moderate.
Drainage:	Well drained.
Surface Features:	Firm.
Representative Profiles:	**Not sampled** (see sites 9002 and 9017 from the Bills Hut (Bh) soil).

Typical Profile



Soil Description

The **surface soil** (A1, A3) is a red, sandy loam with massive structure. Depths typically range from 0.4 to 0.9 m. Field pH is 5.5–6.5.

The **subsoil** (B21, B22) is a red, sandy light clay, often grading to a sandy light medium clay at depth. Subsoil structure is massive or weak blocky. Field pH is 6–7.5, typically increasing with depth.

Weathered **substrate** (FC, R) frequently occurs below 1.2–>1.5 m. Substrate material is ferricrete, reticulite or petroreticulite.

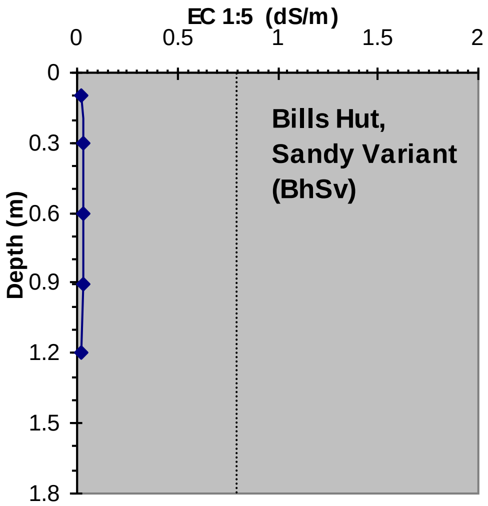
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.1	0.52	0.02	1	-	-	-	-	-	0.88	0.49
acid	low	very low	very low	-	-	-	-	-	low	low

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are very low. Levels of calcium (Ca) and magnesium (Mg) are also low, while results for potassium (K) and the micronutrients are unavailable. The infertility of the Bills Hut sandy variant (BhSv) soil reflects its leached, sandy nature and the low nutrient status of the underlying deeply weathered Tertiary substrate. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data ($EC_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the upper 1.5 m of the Bills Hut sandy variant (BhSv) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Comparison with the Bills Hut (Bh) soil suggests sodicity levels within the profile (ESP <2) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	1.33	**1.42**	1.52	102	**109**	117

Typically, PAWC levels for the Bills Hut sandy variant (BhSv) soil are only moderate (approximately 110 mm) even though mean ERD is >1.4 m. Restrictions to rooting depth are generally absent other than the presence of deeply weathered, acidic substrate or ferricrete at the base of some profiles. Maximum PAWC levels (110–120 mm) are rarely achieved on a regular basis because profiles are permeable and subject to continued deep drainage and evaporation losses over time. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available, but data from representative profiles 9002 and 9017 in Appendices 3 and 6 may be useful as a guide.

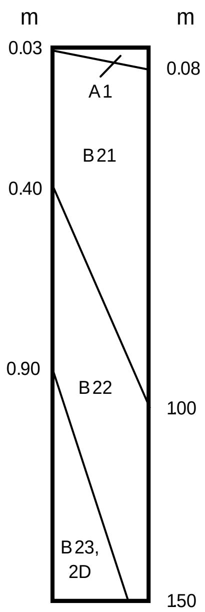
Physical Characteristics and Subsoil Chemistry

Interpretations and descriptions of the physical characteristics and chemistry of the Bills Hut sandy variant (BhSv) soil are unavailable, but are probably comparable with those presented for the Bills Hut (Bh) soil.

BLUCHERS (Bc)

Concept:	A hard setting, firm pedal or weakly self-mulching, alkaline, black or grey cracking clay, frequently with normal gilgai (VI 0.1–0.3 m), over recent alluvium on backplains and seasonal swamps. Eucalypt vegetation.
Aust. Soil Classification:	Black or Grey Vertosol.
Great Soil Group:	Grey clay, no suitable group.
Principal Profile Form:	Ug5.16, 5.17, 5.24, 5.25.
Geology:	Quaternary alluvium (Qa).
Landform:	Slowly drained backplains and seasonal swamps within level alluvial plains, mainly on lower tributaries and flood plains; flooded by low velocity events. ARI is more frequent than 1 in 2 years. Slopes <0.5%.
Vegetation Associations:	Coolibah (VA11), *Bothriochloa* grassland (VA27) or Sedges (VA29).
Microrelief:	Either non-gilgaied (50%) or with normal gilgai (50%) VI 0.1–0.3 m, HI 5–8 m. Gilgaied areas occasionally have a prominent shelf with indistinct mounds and depressions.
Runoff:	Very slow.
Permeability:	Very slow to slow.
Drainage:	Poorly drained to imperfectly drained.
Surface Features:	**Mound** - cracking with a firm pedal to weakly self-mulching surface; occasionally 2 to 10% free carbonate nodules. **Shelf/depression** - cracking with a firm pedal or hard setting surface and a silty surface crust after flooding.
Representative Profile:	**9102**

Typical Profile



Soil Description

The **surface soil** (A1) is a black or grey, light medium clay to medium clay (frequently fine sandy or silty) with moderate or strong blocky structure. Depths typically range from 0.03 to 0.08 m. Field pH is 6–6.5.

The **upper subsoil** (B21) is a black or grey, medium heavy clay to heavy clay with moderate or strong blocky or lenticular structure. Field pH is 7–9.5 (increasing with depth).

The **lower subsoil** (B22, B23) is a black or grey, medium heavy clay to heavy clay with moderate or strong lenticular structure; often grading to a mottled, brown medium clay at depth. It is frequently calcareous with <2–10% nodular carbonate. Field pH is 8–9.5.

Buried alluvial layers (2D) are often present from 0.9–>1.5 m. Buried materials are typically a mottled, brown, sandy light medium clay to sandy medium clay (frequently fine sandy) with moderate blocky or polyhedral structure. They are frequently calcareous with 2–10% nodular carbonate. Field pH is 8.5–9.

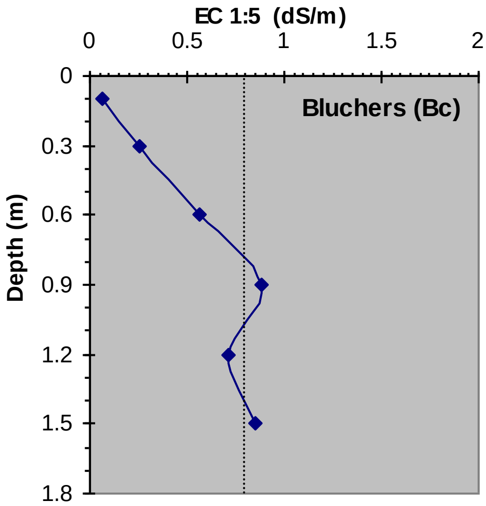
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.1	1.1	0.08	10	0.92	54	11	1.3	0.50	13	9.6
neutral	low	moderate	moderate	high	-	moderate	moderate	low	high	high

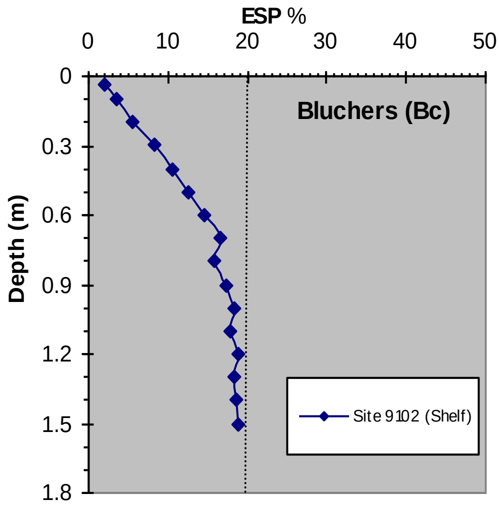
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are only moderate. Most other nutrients are moderate to high with the exception of zinc (Zn) which is low. Elevated potassium (K) levels indicate the young age of this soil and reflect its recent alluvial origins. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.75 m in the Bluchers (Bc) soil. The profile salinity curve reaches equilibrium between 0.7 and 0.9 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below about 0.9 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.39	**0.75**	1.11	92	**131**	170

Typically, PAWC levels for the Bluchers (Bc) soil are borderline moderate to high (approximately 130 mm) because mean ERD is only 0.75 m. It is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the subsoil associated with ESP levels close to 20. Even where deeper profiles occur (ERD >0.75 m), maximum PAWC levels (130–170 mm) are rarely achieved because of restricted infiltration (hard setting, fine sandy or silty, clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9102 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases gradually from 45–50% in the surface soil to 55–65% in the subsoil. Significant fine sand (30–35%) and silt (10–20%) in the surface soil promote hard setting and surface sealing behaviour. CEC/Clay% ratios in the profile are 0.55–0.65 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (depending on sediment source). Measured dispersion (R1 ratio) in the profile ranges from moderate (0.65) in the upper subsoil to high (0.8–0.95) in the lower subsoil, and appears well correlated with subsoil sodicity levels. High Total K levels throughout the profile reflect the young age and recent alluvial origins of this soil. Detailed physical data from representative profile 9102 are presented in Appendix 3.

Subsoil Chemistry

While laboratory pH is within the range described for field pH (see profile description), pH values in the upper subsoil of profile 9102 are neutral (7–7.5) rather than alkaline. CEC levels are high throughout with calcium (Ca) slightly more dominant than magnesium (Mg). Profiles are typically non-sodic (ESP <6) in the surface soil and upper subsoil but become strongly sodic (ESP >15) at depth. Detailed chemical data from representative profile 9102 are presented in Appendix 3.

BOOROONDARRA (Bn)

Concept: A deep, soft or loose, neutral, red uniform sand (>1.5 m) grading to a thick (0.4–1.0 m), sandy surfaced, sporadically bleached, neutral or alkaline, red, non-sodic texture contrast soil over recent alluvium on levees and sand ridges. Eucalypt vegetation.

Aust. Soil Classification: Orthic Tenosol; Red Chromosol.

Great Soil Group: Siliceous sand, earthy sand, no suitable group.

Principal Profile Form: Uc5.11, 5.21, Dr2.12, 2.33, 4.13, 4.22, 4.23, 4.32.

Geology: Quaternary alluvium (Qa).

Landform: Level to gently undulating, elevated levees and sand ridges on alluvial plains along upper and lower tributaries; or occasionally on flood plain terraces. Deep sands associated with sand ridges are most probably source bordering aeolian deposits. Flooded in lower lying parts by short duration, high velocity events. ARI is less frequent than 1 in 10 years. Slopes 0.5 to 1.5%.

Vegetation Associations: Moreton Bay ash (VA23); occasionally Poplar box–bloodwood–Moreton Bay ash (VA33) or Blue–gum–mixed eucalypts (VA22).

Microrelief: Absent.

Runoff: Very slow to slow.

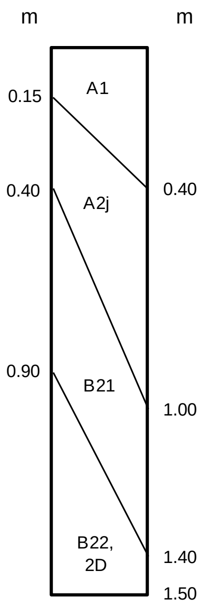
Permeability: **Sand** - high.
Texture contrast - moderate.

Drainage: **Sand** - rapidly drained.
Texture contrast - well drained.

Surface Features: Soft or loose.

Representative Profiles: **9009, 9021**

Typical Profile



Soil Description

The **surface soil** (A1, A2j) is a brown or black, sand to loamy sand with massive structure. Depths typically range from 0.4 to 1.0 m where clay subsoils are developed or >1.5 m where profiles grade to a deep sand. A sporadic bleach is normally developed in texture contrast profiles. Field pH is 6–7.

The **subsoil** (B21) in texture contrast profiles is a red, sandy light clay to sandy medium clay with moderate or strong prismatic or blocky structure. Where deep sand profiles occur a red, loamy sand to sandy loam subsoil with massive structure is normally developed. Field pH is 6.5–8.5, generally increasing with depth.

Buried alluvial layers (2D) are often present below 0.9–1.4 m in texture contrast profiles. Buried materials range from loamy sand to sandy medium clay. They are typically brown with massive structure. Field pH is 6.5–7.5.

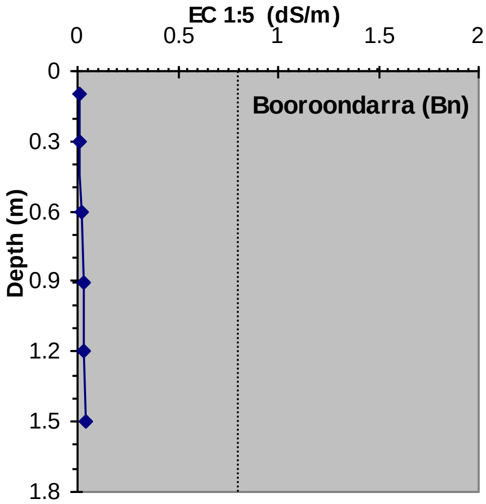
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.8	0.59	0.03	16	0.26	11	18	0.32	0.28	2.6	0.82
neutral	low	very low	high	very low	-	moderate	moderate	low	moderate	low

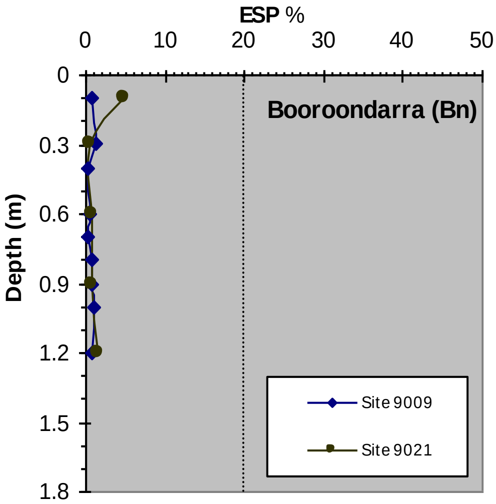
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are very low while phosphorus (Bicarb. P) levels are high. Most other nutrients are low to moderate with the exception of potassium (K) which is very low. The very low nitrogen and potassium status of this soil is indicative of its leached sandy nature, while elevated phosphorus levels reflect its alluvial origins. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the upper 1.5 m of the Booroondarra (Bn) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Sodicity levels in the subsoil (ESP <1) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	1.28	**1.46**	1.63	74	**90**	105

Typically, PAWC levels for the Booroondarra (Bn) soil are borderline low to moderate (approximately 90 mm) even though mean ERD is >1.5 m. Restrictions to rooting depth are generally absent. Maximum PAWC levels (90–105 mm) are rarely achieved on a regular basis however, because profiles are permeable and subject to continued deep (or lateral) drainage and evaporation losses over time. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9009 and 9021 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content in texture contrast profiles increases significantly between the surface soil (<10%) and the subsoil (30–40%), while in deep sand profiles clay content is <5–10% throughout. Significant levels of coarse sand (25–40%) in the surface soil are responsible for its soft or loose surface condition. CEC/Clay% ratios in the subsoil of texture contrast profiles are 0.3–0.4 and indicate the clay fraction is of mixed mineralogy. Measured dispersion (R1 ratio) in the clay subsoil is borderline moderate to high (0.8–0.85), due mainly to low clay content (i.e. profiles are non-sodic). High Total K levels in texture contrast profiles reflect the alluvial origins of this soil. Detailed physical data from representative profiles 9009 and 9021 are presented in Appendix 3.

Subsoil Chemistry

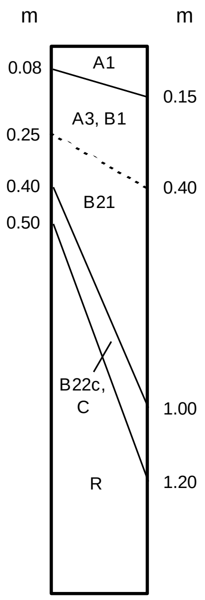
Laboratory pH is similar to field pH (see profile description). CEC levels are very low (<5 meq/100 g) in the surface soil (and deep sand profiles) but increase marginally to low levels (10 meq/100 g) in the clay subsoil of texture contrast profiles. Calcium (Ca) is the dominant cation in both the surface soil and subsoil. Profiles are non-sodic (ESP <1) throughout. Detailed chemical data from representative profiles 9009 and 9021 are presented in Appendix 3.

BUL BUL (Bb)

Concept: A hard setting, uniform or gradational, loamy or clay loamy surfaced, acid, brown massive earth over ferricrete or deeply weathered sediments from 0.4–1.0 m. Eucalypt vegetation.
Aust. Soil Classification: Brown Kandosol.
Great Soil Group: Yellow earth.
Principal Profile Form: Um5.51, Gn2.21, 2.41.
Geology: Fine grained sedimentary rocks altered by Tertiary deep weathering (Td, Ta). Substrate is reticulite or petroreticulite often with a distinct ferricrete layer immediately above.
Landform: Level to gently undulating intact Tertiary plateaus. Occasionally gently undulating plains and rises associated with weakly dissected plateau remnants. Slopes 0.5 to 2%.
Vegetation Associations: Narrow-leaved ironbark (VA12) or Eucalypts with shrubby heath myrtle (VA14); occasionally Poplar box (VA20) or Poplar box–ironbark (VA34).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Moderate.
Drainage: Moderately well drained to well drained.
Surface Features: Hard setting. Occasionally 2 to 10% ironstone gravel 6 to 20 mm.

Representative Profiles: **9037, 9040**

Typical Profile



Soil Description

The **surface soil** (A1) is a brown, sandy loam to sandy clay loam (frequently fine sandy) with massive structure and <2–10% ironstone gravel. Depths typically range from 0.08 to 0.15 m. Field pH is 5–6.

The **subsoil** (A3, B1, B21) is a brown, sandy clay loam to light clay (frequently fine sandy) with massive structure and <2–10% ironstone gravel. Field pH is 5.5–6.5.

Frequently an **ironstone layer** (B22c) with similar characteristics to the subsoil above, but with 10–>90% ferruginous nodules is developed above the underlying substrate.

Weathered **substrate** (C) normally occurs below 0.4–1.0 m. Substrate material is grey, mottled reticulite or petroreticulite with a field pH of 6–7.

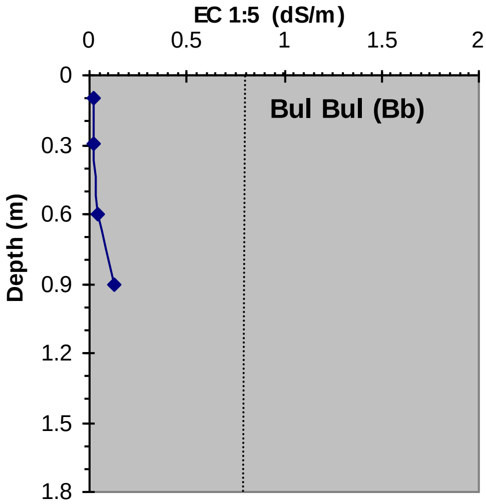
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.4	0.90	0.04	2	0.24	30	9	0.30	0.22	0.91	0.48
strongly acid	low	low	very low	low	-	moderate	low	low	low	low

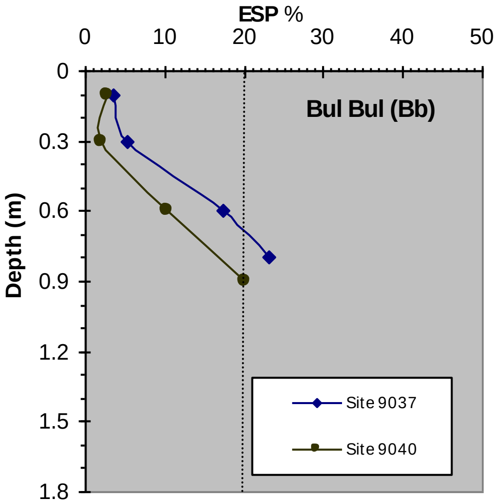
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are low while phosphorus (Bicarb. P) levels are very low. Most other nutrients are low with the exception of manganese (Mn) which is moderate. The infertility of the Bul Bul (Bb) soil reflects its leached nature and the low nutrient status of the underlying deeply weathered Tertiary substrate. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the upper 1.5 m of the Bul Bul (Bb) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Weathered substrate is normally present somewhere below 0.4–1.0 m and contributes to slight increases in salinity levels at depth because of restricted drainage. Critical sodicity levels (ESP >20) are often present in the kaolinitic substrate material underlying the profile.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.22	**0.48**	0.74	33	**55**	76

Typically, PAWC levels for the Bul Bul (Bb) soil are low (approximately 55 mm) because mean ERD is <0.5 m. It is restricted by the presence of deeply weathered, strongly sodic, acidic substrate at relatively shallow depths. Even where deeper profiles occur (ERD >0.5 m), maximum PAWC levels (55–75 mm) are rarely achieved on a regular basis because profiles are permeable and subject to continued deep drainage and evaporation losses over time. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9037 and 9040 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (15–20%) throughout the profile, increasing to 30–40% in the underlying deeply weathered substrate. High levels of fine sand (55–65%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios are <0.2 throughout and indicate the clay fraction is predominantly kaolinitic. Measured dispersion (R1 ratio) in the subsoil is only low to moderate (0.45–0.75), but increases to high (0.9–0.95) in the underlying kaolinitic substrate. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9037 and 9040 are presented in Appendix 3.

Subsoil Chemistry

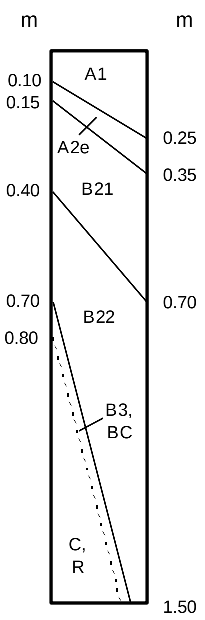
Laboratory pH is similar to field pH (see profile description). CEC levels are very low (<3 meq/100 g) in the profile and low (9 meq/100 g) in the underlying kaolinitic substrate. Calcium (Ca) and magnesium (Mg) are co-dominant in the surface soil, while magnesium (Mg) becomes dominant at depth. Soil profiles are non-sodic (ESP <6), however the underlying kaolinitic substrate is often strongly to extremely sodic (ESP >15). Detailed chemical data from representative profiles 9037 and 9040 are presented in Appendix 3.

BUNDOORA (Bd)

Concept: A hard setting, sandy surfaced, conspicuously bleached, alkaline, mottled, grey or brown, sodic texture contrast soil with coarse columnar structure over deeply weathered sediments from 0.7–>1.5 m. Eucalypt vegetation.
Aust. Soil Classification: Grey or Brown Sodosol.
Great Soil Group: Solodized solonetz, soloth.
Principal Profile Form: Dy3.41, 2.43, 3.43; occasionally Db1.43, 2.41, Dy5.41, 5.43, 2.41.
Geology: Fine grained sedimentary rocks altered by Tertiary deep weathering (Ta). Substrate is reticulite or petroreticulite.
Landform: Gently undulating to undulating plains and rises associated with only partially dissected Tertiary plateau remnants. Slopes 1 to 3%, occasionally up to 5%.
Vegetation Associations: Eucalypts with bull oak (VA32) or Bull oak (VA35).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Very slow.
Drainage: Imperfectly drained.
Surface Features: Hard setting or occasionally firm. Occasionally <2 to 10% silcrete gravels 6 to 20 mm.

Representative Profiles: **9039, 9045, 9059**

Typical Profile



Soil Description

The **surface soil** (A1, A2e) is a brown or grey, loamy sand with massive structure. Depths typically range from 0.15 to 0.35 m. A conspicuously bleached layer with 2–10% ferruginised gravels is normally developed immediately above the clay subsoil. Field pH is 5–6.

The **upper subsoil** (B21) is a mottled, grey or brown, sandy light medium clay to sandy medium clay with strong, coarse columnar structure. Field pH normally increases from 5.5–6.5 at the top of the B21 to 8.5–9.5 lower down.

The **lower subsoil** (B22) is a brown or grey, sandy light clay to sandy light medium clay with moderate blocky or polyhedral structure. It is normally calcareous and manganiferous with <2–10% soft or nodular carbonate and <2–10% manganese soft segregations. Field pH is 8.5–9.5, although occasionally acid profiles (pH 6–6.5) occur.

Weathered **substrate** (B3, BC, C) is normally present below 0.7 m, although deeper profiles >1.5 m do occur. Substrate material is grey, mottled reticulite or petroreticulite with a field pH of 6–6.5.

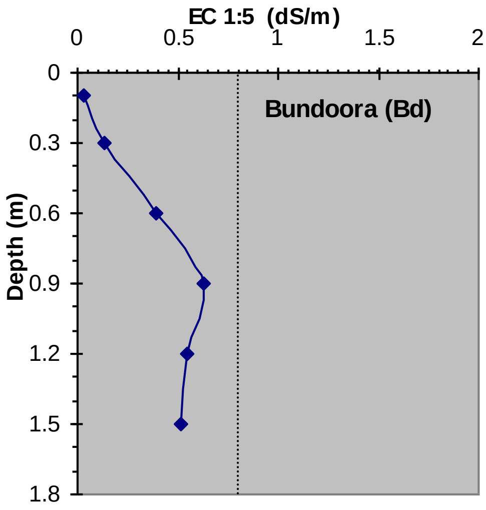
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.8	0.78	0.03	3	0.14	41	6	0.21	0.15	1.2	0.95
acid	low	very low	very low	very low	-	moderate	low	very low	low	low

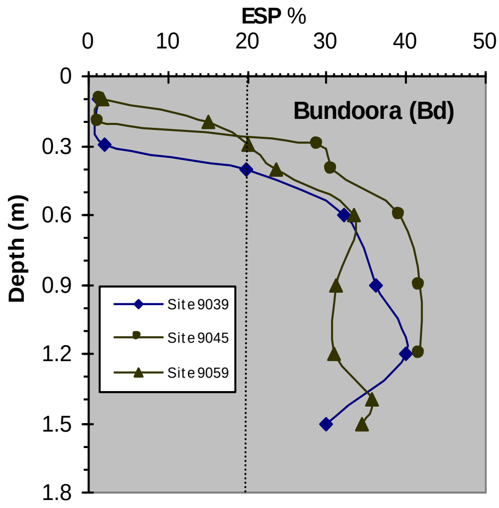
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are very low. Most other nutrients are low to very low with the exception of manganese (Mn) which is moderate. The infertility of the Bundoora (Bd) soil reflects the leached sandy nature of its surface horizons and the low nutrient status of the underlying deeply weathered Tertiary substrate. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Bundoora (Bd) soil. The profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.7–>1.5 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Critical sodicity levels (ESP >20) typically occur within the upper 0.2 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.13	**0.28**	0.42	22	**37**	52

Typically, PAWC levels for the Bundoora (Bd) soil are low to very low (approximately 35 mm) because mean ERD is <0.3 m. It is restricted by physical limitations and reduced permeability in the upper subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.3 m), maximum PAWC levels are only 35–50 mm, and are subject to significant evaporation and lateral drainage losses because of the highly permeable nature of the surface horizons. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9039, 9045 and 9059 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (5–15%) and the subsoil (25–35%), while high levels of fine sand (55–65%) in the surface soil are responsible for its predominantly hard setting nature. CEC/Clay% ratios in the subsoil are 0.35–0.75 and indicate the clay fraction is mostly of mixed mineralogy. Measured dispersion (R1 ratio) in the subsoil is consistently high to very high (0.90–0.99) and reflects the very high sodicity levels (ESP >20) normally associated with this soil. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9039, 9045 and 9059 are presented in Appendix 3.

Subsoil Chemistry

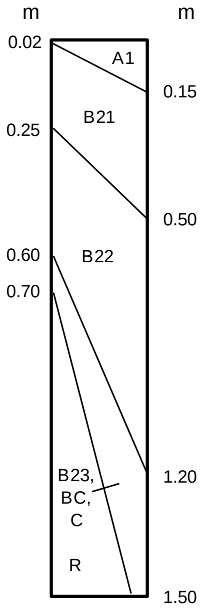
Laboratory pH is similar to field pH (see profile description). CEC levels are mostly very low (<5 meq/100 g) in the surface soil increasing to low or moderate levels (10–20 meq/100 g) in the subsoil. Calcium (Ca) and magnesium (Mg) are co-dominant in the surface horizons, while magnesium (Mg) and sodium (Na) completely dominate the subsoil. Profiles are typically extremely sodic (ESP 20–45) throughout the subsoil, making them very dispersive and erodible and particularly fragile following disturbance. Detailed chemical data from representative profiles 9039, 9045 and 9059 are presented in Appendix 3.

BURRADOO (Bu)

Concept: A hard setting or firm pedal, alkaline, brown or black non-cracking to cracking clay over labile sandstone, siltstone or shale from 0.6–1.2 m. Brigalow vegetation.
Aust. Soil Classification: Brown, Black (or occasionally Grey) Dermosol; Brown, Black (or occasionally Grey) Vertosol.
Great Soil Group: Brown clay, no suitable group, grey clay.
Principal Profile Form: Uf6.31, 6.32, Ug5.13, 5.14, 5.32; occasionally Uf6.33, Ug5.22, 5.15, 5.16, 5.34, 5.35.
Geology: Sandstones, siltstones and mudstones of the Blackwater Group (Pw). Mostly lithic, feldspathic or calcareous freshwater sedimentary rocks.
Landform: Gently undulating plains and rises. Slopes 0.5 to 3%.
Vegetation Associations: Brigalow (VA1) or Brigalow with shrubs (VA8); occasionally Brigalow–Dawson gum (VA5).
Microrelief: Occasionally normal gilgai VI 0.05–0.4 m, HI 8–20 m; frequently with a prominent shelf and indistinct mounds and depressions.
Runoff: Slow (or occasionally moderately rapid).
Permeability: Slow (or occasionally very slow).
Drainage: Moderately well drained.
Surface Features: Frequently cracking with a hard setting, firm pedal or occasionally weakly self-mulching surface. Where gilgaied, mounds are occasionally moderately to strongly self-mulching. Frequently 2 to 20% sandstone, siltstone, petrified wood or silcrete gravels 6 to 60 mm. Occasionally 2 to 10% sandstone or siltstone rocks 60 to 200 mm or <2 to 10% sandstone outcrop.

Representative Profiles: **9091, 9092**

Typical Profile



Soil Description – Non-gilgaied/mound profile

The **surface soil** (A1) is a black or brown, fine sandy light clay to fine sandy light medium clay with moderate or strong blocky structure. Depths typically range from 0.02 to 0.15 m. Field pH is 6–9.5.

The **upper subsoil** (B21) is a brown or black, medium clay to medium heavy clay with moderate to strong blocky or lenticular structure. Field pH is 7–9.5.

The **lower subsoil** (B22, B23) is a brown, medium clay to medium heavy clay with moderate to strong blocky or lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (BC, C) is normally present below 0.6 m, although deeper profiles (>1.5 m) do occur. Substrate material is labile sandstone, siltstone or shale that is often calcareous and has a field pH of 8.5–9.5.

Soil Description – Depression profile

Depression profiles have similar horizons, depths and morphology to non-gilgaied and mound profiles.

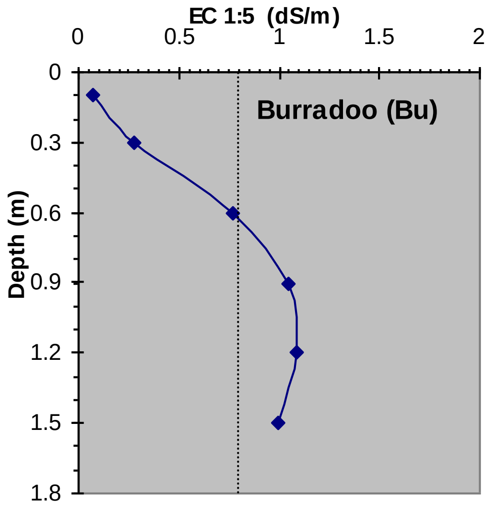
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.4	1.5	0.11	12	0.36	20	17	1.4	0.51	12	5.7
neutral	low	high	moderate	moderate	-	moderate	moderate	low	high	high

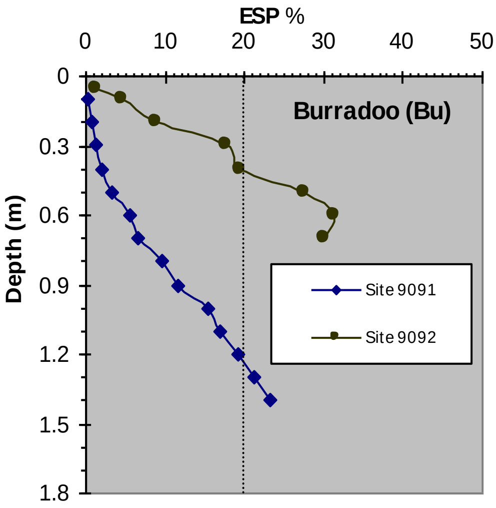
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are high while phosphorus (Bicarb. P) levels are moderate. Most other nutrients are moderate to high with the exception of zinc (Zn) which is low. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying labile, calcareous sedimentary rocks. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.65 m in the Burradoo (Bu) soil. The profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.6–1.2 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (0.3–>1.5 m) and are largely substrate dependent.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.34	**0.67**	1.00	76	**106**	136

Typically, PAWC levels for the Burradoo (Bu) soil are only moderate (approximately 110 mm) because mean ERD is about 0.65 m. It is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20 in most profiles. Even where deeper profiles occur (ERD >0.7 m), maximum PAWC levels (110–135 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9091 and 9092 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (40–50%) throughout the profile, but decreases in the underlying substrate (<35%). Relatively high levels of fine sand (35–45%) in the surface soil are responsible for its predominantly hard setting nature. CEC/Clay% ratios in the profile are mostly 0.45–0.75 and indicate the clay fraction is of mixed mineralogy with greater or lesser proportions of montmorillorite depending on substrate. Measured dispersion (R1 ratio) in the profile ranges from low to high (0.3–0.9) and is largely substrate dependent and correlated with sodicity levels. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9091 and 9092 are presented in Appendix 3.

Subsoil Chemistry

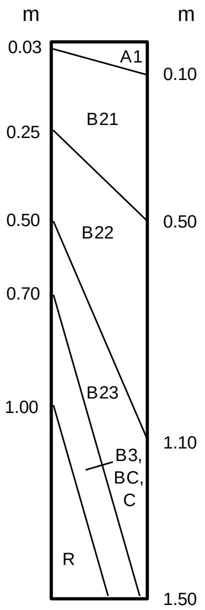
Laboratory pH is similar to field pH (see profile description). CEC levels range from moderate to high (18–35 meq/100 g) and are probably substrate dependent. Calcium (Ca) dominates the surface soil and upper subsoil while magnesium (Mg) and sodium (Na) dominate the lower subsoil and substrate. Sodicity (ESP) in the profile also reflects this trend. The surface soil and immediate upper subsoil are generally non-sodic (ESP <6) while levels in the lower subsoil and substrate gradually increase from sodic to extremely sodic (ESP 7–32). Detailed chemical data from representative profiles 9091 and 9092 are presented in Appendix 3.

BURRADOO SODIC PHASE (BuZp)

Concept: A very hard setting, saline, sodic version of the Burradoo (Bu) soil over acid clay or fine grained marine sedimentary rocks from 0.7–>1.5 m. Brigalow vegetation.
Aust. Soil Classification: Grey, Brown or Black Vertosol; Grey, Brown or Black Dermosol.
Great Soil Group: Grey clay, brown clay.
Principal Profile Form: Ug5.24, 5.32, Uf6.33, 6.32, Ug5.22, 5.35, 5.14, 5.16; occasionally Uf6.31, Ug5.23, 5.25, 5.34, 5.13, 5.15.
Geology: Undifferentiated, fine grained sedimentary rocks of the Blackwater Group (Pw) and/or Back Creek Group (Pb) that are probably of marine origins. Predominantly fine grained sandstone (often yellow), siltstone or shale (often grey and laminated).
Landform: Gently undulating plains and rises. Slopes 0.5 to 2%.
Vegetation Associations: Brigalow (VA1); occasionally Blackwood (VA37) or Brigalow–blackwood (VA4).
Microrelief: Occasionally normal or shallow melonhole gilgai VI 0.1–0.4 m, HI 10–25 m; frequently with a prominent shelf and indistinct mounds and depressions.
Runoff: Slow.
Permeability: Very slow.
Drainage: Moderately well drained (or occasionally imperfectly drained).
Surface Features: Frequently non-cracking with a very hard setting surface. Where gilgaied, mounds and depressions are cracking with a hard setting, firm pedal or weakly self-mulching surface . Frequently 2 to 50% silcrete or ferruginised sandstone and siltstone gravels 6 to 60 mm and occasionally <2 to 10% sandstone, siltstone or petrified wood rocks 60 to 200 mm.

Representative Profiles: **9063, 9084**

Typical Profile



Soil Description – Non-gilgaied/mound profile

The **surface soil** (A1) is a black, brown or grey, fine sandy light clay to fine sandy light medium clay with moderate blocky structure. Depths typically range from 0.03 to 0.1 m. Field pH is 6–7.

The **upper subsoil** (B21) is a grey, brown or black, medium clay to medium heavy clay (frequently fine sandy) with moderate blocky or lenticular structure. Field pH is 7–9.5.

The **lower subsoil** (B22, B23) is a brown or grey, medium clay to medium heavy clay (frequently fine sandy) with moderate lenticular structure grading to blocky or polyhedral at depth. It is frequently calcareous with <2–20% soft or nodular carbonate. Field pH is 8–9.5, but may decrease with depth to as low as 5.

Weathered **substrate** (B3, BC, C) is often present from 0.7–>1.5 m. Substrate material is typically labile, fine grained sandstone, siltstone or shale of marine origins. Field pH ranges from 6–9. In deep profiles (>1.5 m) acid clay continues at depth.

Soil Description – Depression profile

Depression profiles have similar horizons, depths and morphology to non-gilgaied and mound profiles.

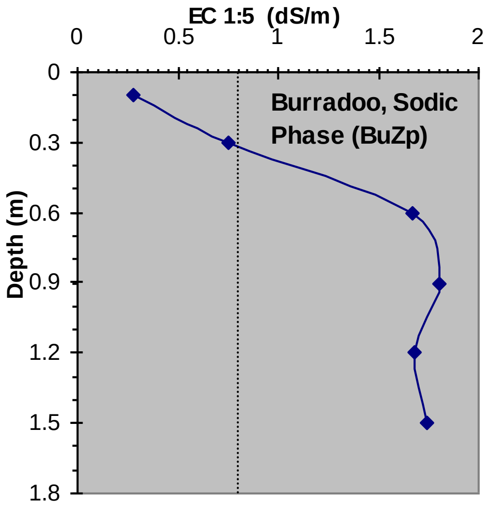
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.2	1.2	0.10	10	0.29	32	50	1.7	0.90	9.2	5.0
neutral	low	high	moderate	low	-	moderate	moderate	moderate	high	moderate

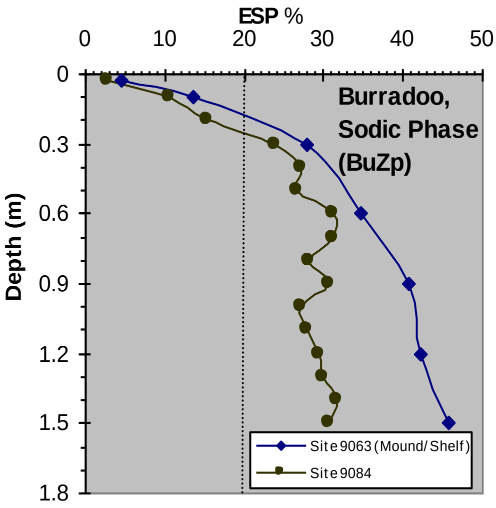
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are high while phosphorus (Bicarb. P) levels are moderate. Most other nutrients are moderate to high with the exception of potassium (K) which is low. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated calcium (Ca) levels are derived directly from the underlying labile, calcareous sedimentary rocks. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.25–0.45 m in the Burradoo sodic phase (BuZp) soil. The profile salinity curve reaches equilibrium between 0.6 and 0.8 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.7–>1.5 m and contributes to the development of the salt bulge because of restricted subsoil drainage, as well as slight increases in salinity levels at depth. Critical sodicity levels (ESP >20) typically occur within the upper 0.2 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.09	**0.45**	0.82	39	**76**	113

Typically, PAWC levels for the Burradoo sodic phase (BuZp) soil are low (approximately 75 mm) because mean ERD is <0.45 m. It is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.45 m), maximum PAWC levels (75–110 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface; surface sealing and dispersive behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9063 and 9084 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (40–50%) throughout the profile. Occasionally a thin surface layer with <35% clay is developed. High levels of fine sand (40–60%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the profile are 0.4–0.6 and indicate the clay fraction is of mixed mineralogy. Measured dispersion (R1 ratio) in the profile ranges from high to very high (0.8–0.96) and reflects the very high sodicity levels (ESP >20) present in the subsoil. Dispersion still occurs even with the flocculative effect of high salinity levels in the subsoil. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9063 and 9084 are presented in Appendix 3.

Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels range from moderate to high (17–30 meq/100 g) and are probably substrate dependent. Calcium (Ca) is dominant or co-dominant only in the surface soil, while magnesium (Mg) and sodium (Na) dominate the remainder of the profile. Sodicity (ESP) also reflects this trend. The immediate surface horizons are typically non-sodic (ESP <6), while levels in the upper subsoil increase rapidly to extremely sodic (ESP >25). In the lower subsoil and substrate levels range between 30 and 45%. Detailed chemical data from representative profiles 9063 and 9084 are presented in Appendix 3.

CARFAX (Cx)

Concept: A strongly self-mulching, alkaline, black cracking clay with strongly developed, linear gilgai (VI 0.1–0.4 m) over unconsolidated, calcareous sediments below 0.8–1.3 m. Eucalypt vegetation or open downs.

Aust. Soil Classification: **Mound:** Black Vertosol **Depression:** Black Vertosol

Great Soil Group: **Mound:** Black earth **Depression:** Black earth

Principal Profile Form: **Mound:** Ug5.17, 5.15 **Depression:** Ug5.17, 5.15

Geology: Unconsolidated calcareous Tertiary–Quaternary sediments (TQa_b). Mainly relict alluvial deposits sourced from basaltic or andesitic landscapes in the Isaac–Connors and Mackenzie River catchments. Fine grained basaltic derived sediment, clay, marl, secondary carbonate deposits, gravel beds and sand lenses.

Landform: Gently undulating plains and low rises. Often as sideslopes to broad gentle ridges. Slopes mostly 1 to 3%, occasionally <1% on plains and up to 5% on side slopes.

Vegetation Associations: Mountain coolibah (VA19) or Queensland bluegrass downs (VA28); occasionally Ironbark–bloodwood–ghost gum (VA43).

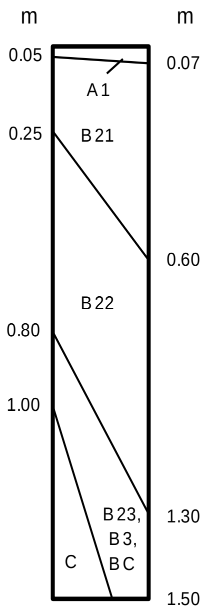
Microrelief: Strongly developed linear gilgai VI 0.1–0.4 m, HI 7–12 m.

Runoff: Slow to moderately rapid. **Permeability:** Slow. **Drainage:** Moderately well drained.

Surface Features: **Mound** - cracking with a fine (<2 mm), strongly self-mulching surface and 2 to >20% free carbonate nodules.
Depression - cracking with a coarse (2 to 5 mm), strongly self-mulching surface.
Occasionally 2 to 10% calcrete fragments and waterworn quartz gravels 6 to 20 mm, mainly on mounds.

Representative Profiles: **9033, 9054**

Typical Profile



Soil Description – Mound profile

The **surface soil** (A1) is a black, light medium clay to medium clay with strong granular structure. Depths typically range from 0.05 to 0.07 m. It is frequently calcareous with 2–20% nodular carbonate and a field pH of 8–9.5.

The **upper subsoil** (B21) is a black, medium heavy clay to heavy clay with strong lenticular structure. It is calcareous with <2–10% soft or nodular carbonate and a field pH of 8.5–9.5.

The **lower subsoil** (B22, B23) is a black or brown, medium clay to heavy clay with strong coarse lenticular structure. It is calcareous with 2–20% soft or nodular carbonate and a field pH of 8.5–9.5.

Substrate material (B3, BC, C) is normally present below 0.8–1.3 m and consists of unconsolidated, calcareous, fine sandy clay sediments, marl and gravel beds. Field pH is 8.5–9.

Soil Description – Depression profile

Depression profiles generally have similar horizons, depths and morphology to mound profiles. Differences relate to coarser surface structure, darker surface colours, neutral field pH (6–7) in the surface soil and an absence of free carbonate in A1 and B21 horizons.

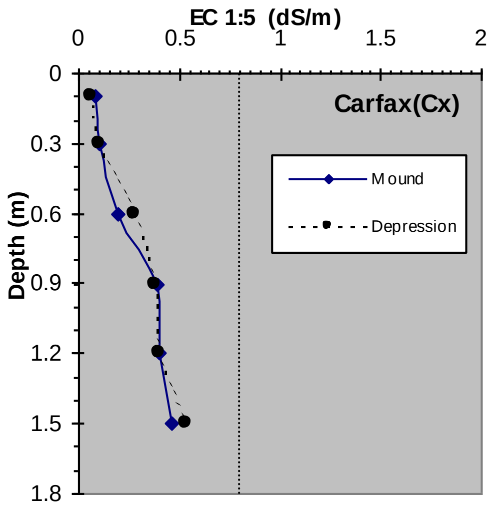
Surface Soil Fertility[1]

Gilgai comp.	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
mound	8.1	1.2	0.08	8	0.31	14	11	0.68	0.25	33	14
	alkaline	low	moderate	low	moderate	-	moderate	moderate	very low	very high	high
dep.	7.2	1.4	0.09	15	0.45	34	41	1.2	0.47	28	15
	neutral	low	high	moderate	moderate	-	moderate	moderate	low	very high	high

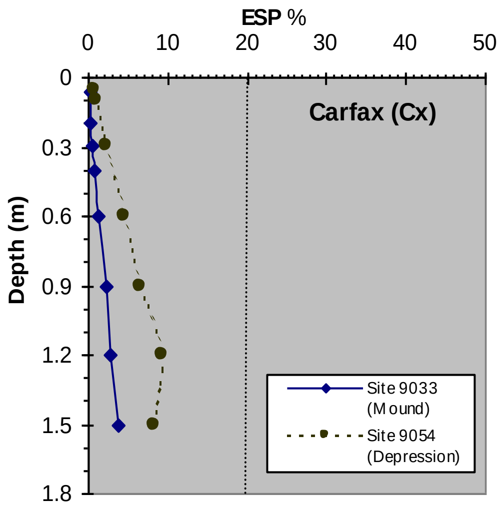
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (mounds and depressions). Typically, nitrogen (Total N) levels increase from moderate on mounds to high in depressions, although absolute differences are only slight. Phosphorus (Bicarb. P) levels follow a similar trend, increasing from low to moderate. Absolute differences in phosphorus are much greater however, with levels almost doubling. Most other nutrients are moderate to very high with similar levels on both gilgai components. The exception is zinc (Zn) which is low in depressions and very low on mounds. Elevated calcium (Ca) levels are derived directly from the underlying, calcareous, basaltic-derived, unconsolidated sediments. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Carfax (Cx) soil. The profile salinity curves for mounds and depressions are identical. Both curves reach equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Unconsolidated substrate is normally present somewhere below 0.8–1.3 m and contributes to slight increases in salinity levels at depth. Sodicity levels within the profile (ESP <6–10) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	1.03	**1.28**	1.53	143	**163**	182

Typically, PAWC levels for the Carfax (Cx) soil are very high (approximately 160 mm) with a mean ERD of about 1.3 m. Significant differences in ERD or PAWC between gilgai components were not observed. Restrictions to rooting depth are generally absent other than the presence of hard calcareous material or gravel at the base of some profiles. Maximum PAWC levels (160–180 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9033 and 9054 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is relatively uniform (50–60%) throughout the profile, but decreases in the underlying substrate (30–45%) where appreciable levels of coarse sand, fine sand and silt are present. CEC/Clay% ratios in the profile are 1.1–1.3 and indicate the clay fraction is montmorillonitic. Ratios as high as 1.5 in the underlying unconsolidated substrate indicate the material from which the soil has developed is of basaltic origins. Measured dispersion (R1 ratio) in the profile is low (0.25–0.6) throughout because of very high levels of exchangeable calcium (Ca) and low sodicity levels (ESP <6). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been insitu. Detailed physical data from representative profiles 9033 and 9054 are presented in Appendix 3.

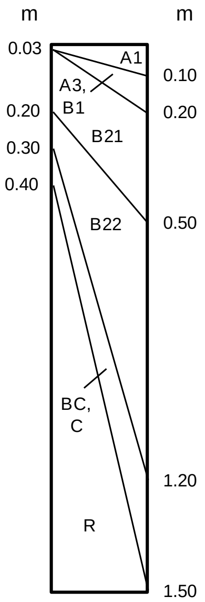
Laboratory pH is similar to field pH (see profile description). CEC levels are very high (40–70 meq/100 g) throughout the profile and also in the underlying substrate. Calcium (Ca) is the dominant cation although significant levels (15–25 meq/100 g) of magnesium (Mg) are also present. Profiles are non-sodic (ESP <1–6) throughout while substrate material is sometimes sodic (ESP 6–10). Detailed chemical data from representative profiles 9033 and 9054 are presented in Appendix 3.

CARLO (Cc)

Concept: A hard setting or firm pedal, alkaline, black, brown or red non-cracking clay over marl or labile, fine grained calcareous sedimentary rocks from 0.3–1.2 m. Eucalypt vegetation.
Aust. Soil Classification: Black, Brown or Red Dermosol; occasionally Black, Brown or Red Vertosol.
Great Soil Group: No suitable group; occasionally brown clay or red clay.
Principal Profile Form: Uf6.31, 6.32; occasionally Ug5.12, 5.13, 5.14.
Geology: Sandstones, siltstones and mudstones of the Blackwater Group (Pw). Mostly thin beds of calcareous freshwater sedimentary rocks such as marl or calcareous mudstone underlain by fine grained sandstone (lithic or feldspathic) or siltstone.
Landform: Gently undulating plains and rises. Slopes 1 to 3%.
Vegetation Associations: Ironbark–bloodwood–ghost gum (VA43); occasionally Mountain coolibah (VA19), Silver-leaved ironbark (VA17), Poplar box–ironbark (VA34) or Poplar box (VA20).
Microrelief: Occasionally weakly developed linear or lattice gilgai VI <0.05 m, HI 8–10 m.
Runoff: Slow to moderately rapid.
Permeability: Slow to moderate.
Drainage: Moderately well drained to well drained.
Surface Features: Occasionally cracking with a hard setting or firm pedal surface and 2 to 20% sandstone, siltstone or petrified wood gravels 20 to 200 mm. Where gilgaied, mounds have a fine (<2 mm), weakly to strongly self-mulching surface (in thin strips), while depressions are hard setting and cracking. A weak surface seal with a thin sandy veneer often forms after rain.

Representative Profiles: **Not sampled** (see site 9072 from the Kirkcaldy (Kc) soil).

Typical Profile



Soil Description

The **surface soil** (A1, A3, B1) is a black, light clay to light medium clay (frequently fine sandy) with moderate or strong blocky structure. Depths typically range from 0.03 to 0.2 m. Field pH is 6.5–8.5.

The **upper subsoil** (B21) is a black, brown or red, light medium clay to medium heavy clay with strong blocky structure. It is normally calcareous with 2–10% soft or nodular carbonate. Field pH is 6.5–8.5, generally increasing with depth.

The **lower subsoil** (B22) is a black, brown or red, medium clay to medium heavy clay with moderate to strong angular blocky or lenticular structure. It is calcareous with 2–20% soft or nodular carbonate and a field pH of 8.5–9.5.

Weathered **substrate** (BC, C) is normally present from 0.3–1.2 m. Substrate material is marl or labile, calcareous mudstone, sandstone or siltstone. Field pH is 8.5–9.5.

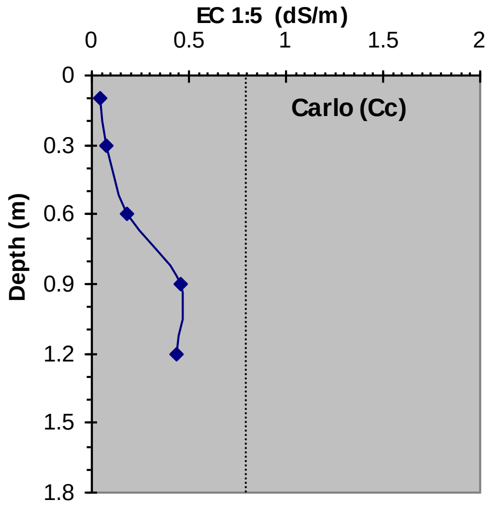
Surface Soil Fertility[1]

Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	7.4	1.4	0.08	7	0.67	8	21	0.47	0.37	16	3.7
	neutral	low	moderate	low	high	-	moderate	moderate	low	very high	moderate
dep.	6.4	1.2	0.07	11	-	-	-	-	-	11	4.5
	acid	low	moderate	moderate	-	-	-	-	-	high	moderate

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility between gilgai components were only observed for phosphorus (Bicarb. P) and calcium (Ca). Phosphorus (Bicarb. P) levels are low on mounds and non-gilgaied areas, but increase to moderate levels in depressions. In contrast, calcium levels are highest on mounds where abundant free carbonate is often present. Most other nutrients, including nitrogen (Total N), are moderate with similar levels on both gilgai components. The exceptions are zinc (Zn) which is low and potassium (K) which is high. Elevated calcium (Ca) levels are derived directly from the underlying labile, calcareous sedimentary rocks. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data ($EC_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Carlo (Cc) soil. The profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.3–1.2 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Comparison with the Mt Stuart (Ms) soil suggests sodicity levels within the profile (ESP <6–10) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.39	**0.86**	1.34	59	**97**	136

Typically, PAWC levels for the Carlo (Cc) soil are only moderate (approximately 100 mm) because mean ERD is <0.9 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is restricted by the presence of hard calcareous material or weathering mudstone, sandstone or siltstone. Even where deeper profiles occur (ERD >0.9 m), maximum PAWC levels (100–140 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available, but data from representative profile 9072 in Appendices 3 and 6 may be useful as a guide.

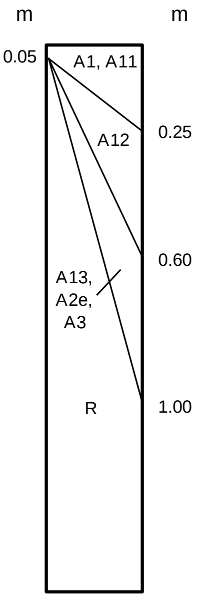
Physical Characteristics and Subsoil Chemistry

Interpretations and descriptions of the physical characteristics and chemistry of the Carlo (Cc) soil are unavailable, but are probably comparable with those presented for the Kirkcaldy (Kc) soil.

CHERWELL (Cw)

Concept:	A shallow to moderately deep, stony, loose, acid, black or brown, uniform coarse sand over quartzose sandstone from 0.05–1.0 m. Eucalypt or *Acacia* vegetation.
Aust. Soil Classification:	Leptic Rudosol.
Great Soil Group:	Siliceous sand, lithosol.
Principal Profile Form:	Uc1.21, 1.23; occasionally Uc2.12, 5.11.
Geology:	Predominantly quartzose sandstones of the Back Creek Group (Pb). Occasionally fine grained sedimentary rocks (sandstone and shale) partially altered by Tertiary deep weathering.
Landform:	Gently undulating rises to steep hills and plateaus of the Cherwell Range. Areas of lower relief and less slope occur as foothills and footslopes surrounding the main range or where outcrop of the Back Creek Group (Pb) occurs elsewhere. Slopes 1 to >50 %.
Vegetation Associations:	Queensland peppermint (VA25), Lemon-scented gum (VA31), Lancewood (VA3) or Rosewood (VA2) in steeper areas; Long-fruited bloodwood (VA15) or Eucalypts with shrubby teatree (VA13) on gentler foothills and footslopes.
Microrelief:	Absent.
Runoff:	Slow to very rapid.
Permeability:	High.
Drainage:	Imperfectly drained to rapidly drained.
Surface Features:	Soft or loose. Frequently 10 to 50% sandstone fragments 6 to 200 mm or 2 to 50% rock outcrop.
Representative Profile:	**9011**

Typical Profile



Soil Description

The **surface soil** (A1, A11) is a black or brown, coarse sand to loamy coarse sand with massive or single grain structure and significant gravel or rock (2–50%). Depths typically range from 0.05 to 0.25 m. Field pH is 5–6.

The **subsoil** where developed (A12, A13, A2e, A3) is a brown or grey, coarse sand with single grain structure and significant gravel and rock (2–50%). Field pH is 5–6.

Substrate material normally occurs from 0.05–1.0 m and is predominantly hard, fresh quartose sandstone.

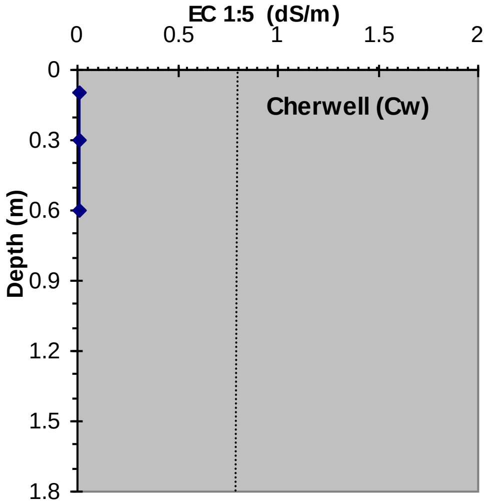
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.7	0.60	0.02	3	0.15	31	5	0.08	0.16	0.93	0.47
acid	low	very low	very low	very low	-	moderate	very low	very low	low	low

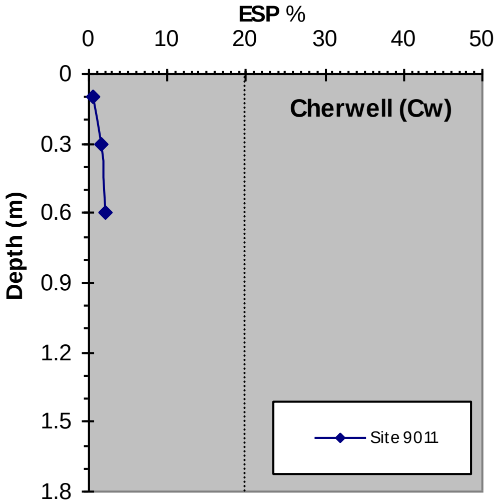
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are very low. Most other nutrients are low to very low with the exception of manganese (Mn) which is moderate. The infertility of the Cherwell (Cw) soil reflects its leached sandy nature and the low nutrient status of the underlying quartzose sandstones. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the Cherwell (Cw) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Sodicity levels within the profile (ESP <2) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.16	**0.51**	0.85	31	**47**	62

Typically, PAWC levels for the Cherwell (Cw) soil are low (approximately 45 mm) because mean ERD is only 0.5 m. It is restricted by the presence of hard quartose sandstone. Even where deeper profiles occur (ERD >0.5 m), maximum PAWC levels (45–60 mm) are rarely achieved on a regular basis because profiles are highly permeable and subject to continued deep drainage and evaporation losses over time. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9011 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is very low (4–7%) throughout the profile, while coarse sand levels are 55–70%. High levels of coarse sand (70%) in the surface soil are responsible for its soft or loose surface condition. Values for CEC/Clay% ratio, measured dispersion (R1 ratio) and sodicity are misleading and have not been considered because of very low clay contents. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9011 are presented in Appendix 3.

Subsoil Chemistry

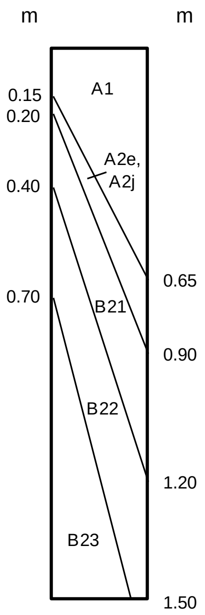
Laboratory pH is similar to field pH (see profile description). CEC levels are very low (2–4 meq/100 g) throughout the profile, while calcium (Ca) is the dominant cation even though levels are low to very low. Detailed chemical data from representative profile 9011 are presented in Appendix 3.

COLLAWMAR (Cm)

Concept: A sandy surfaced, conspicuously or sporadically bleached, alkaline, mottled, grey, sodic texture contrast soil with coarse columnar structure over unconsolidated sediments. Eucalypt vegetation.
Aust. Soil Classification: Grey (or occasionally Brown) Sodosol.
Great Soil Group: Solodized solonetz, solodic soil.
Principal Profile Form: Dy5.43, 3.43, 4.43, 5.33, 4.13, 3.33, 4.33, 2.43, 2.13.
Geology: Unconsolidated Tertiary–Quaternary sediments (TQa). Includes relict alluvial deposits and widespread reworked local colluvium. Sand, clay and gravel sourced from sedimentary landscapes in the Isaac–Connors and Mackenzie River catchments.
Landform: Gently undulating plains and low rises. Slopes 0.5 to 2%.
Vegetation Associations: Shrubby poplar box (VA7) or Poplar box (VA20); occasionally Dawson gum (VA10) or Brigalow–Dawson gum (VA5).
Microrelief: Absent.
Runoff: Very slow to moderately rapid.
Permeability: Very slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Soft, firm or hard setting. Occasionally 2 to 10% quartz or silcrete gravels 2 to 6 mm.

Representative Profiles: **9075, 9093**

Typical Profile



Soil Description

The **surface soil** (A1, A2e, A2j) is a brown, black or grey, loamy sand to sandy loam with massive structure. Depths typically range from 0.2 to 0.9 m. A conspicuously or sporadically bleached layer is normally developed immediately above the clay subsoil. Field pH is 6–7 at the surface, increasing with depth to pH 9 where A horizons are thick.

The **upper subsoil** (B21) is a mottled, grey, sandy light clay to sandy medium heavy clay with moderate or strong, coarse columnar structure. Field pH is 7–9.5, generally increasing with depth.

The **lower subsoil** (B22, B23) is a mottled, grey or brown, sandy light clay to sandy medium heavy clay with moderate or strong blocky structure. It is normally calcareous and manganiferous with 2–20% soft or nodular carbonate and 2–10% soft manganese veins. Field pH is 9–9.5.

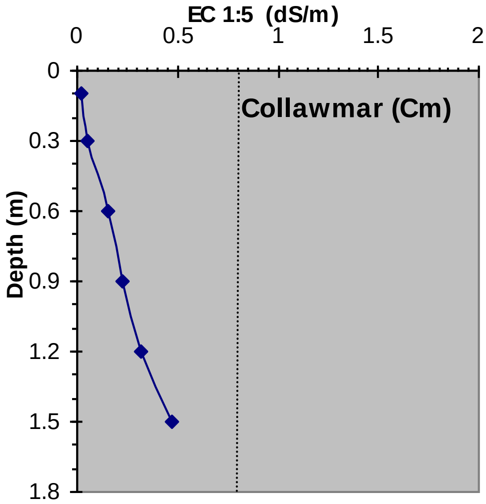
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.9	0.72	0.04	6	0.14	13	23	0.31	0.18	3.4	0.82
neutral	low	low	low	very low	-	moderate	moderate	very low	moderate	low

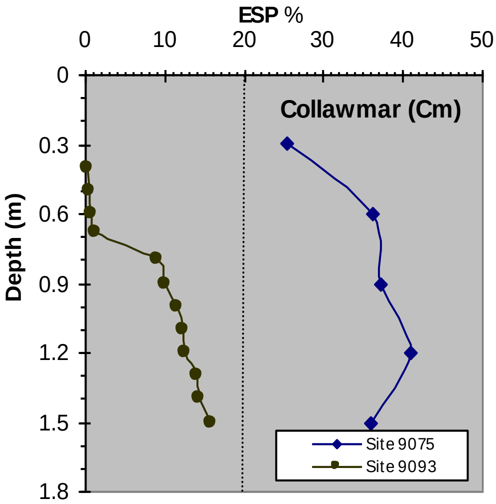
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are low. Most other nutrients are low to moderate with the exception of potassium (K) and zinc (Zn) which are very low. Fertility levels in the Collawmar (Cm) soil are similar to those of the Emoh (Em) soil. Phosphorus fertility is generally one category higher than that of equivalent sandy surfaced, sodic texture contrast soils such as Bundoora (Bd) or Foxleigh (Fx). Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Collawmar (Cm) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Critical sodicity levels (ESP >20) often occur in the subsoil, but are substrate dependent and vary in depth depending on surface horizon thickness.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.19	**0.73**	1.28	35	**68**	101

Typically, PAWC levels for the Collawmar (Cm) soil are low (approximately 70 mm) because mean ERD is <0.75 m. It is usually restricted by physical limitations and reduced permeability in the upper subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.75 m), maximum PAWC levels are only 70–100 mm and are subject to significant evaporation and lateral drainage losses because of the highly permeable nature of the surface horizons. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9075 and 9093 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (10–15%) and the subsoil (20–35%), while high levels of fine sand (65%) in the surface soil are responsible for the predominantly firm to hard setting nature. CEC/Clay% ratios in the subsoil are 0.35–0.65 and indicate the clay fraction is of mixed mineralogy. Measured dispersion (R1 ratio) in the subsoil ranges from high to very high (0.85–0.99) because of moderate to very high sodicity levels (ESP 6–>25) and relatively low clay contents (<35%). Detailed physical data from representative profiles 9075 and 9093 are presented in Appendix 3.

Subsoil Chemistry

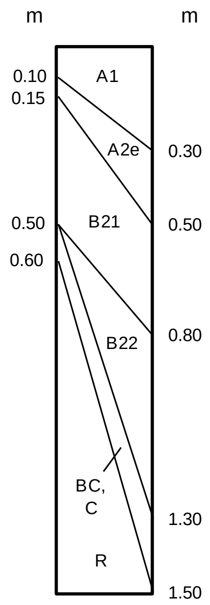
Laboratory pH is similar to field pH (see profile description). CEC levels are very low (<5 meq/100 g) in the surface soil and only increase to low levels (10–15 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil, while magnesium (Mg) and sodium (Na) dominate the subsoil. Profiles vary from sodic to extremely sodic (ESP 10–>25) in the upper subsoil but are consistently strongly to extremely sodic (ESP 15–45) in the lower subsoil. Detailed chemical data from representative profiles 9075 and 9093 are presented in Appendix 3.

EMOH (Em)

Concept: A firm or hard setting, sandy surfaced, conspicuously bleached, alkaline, mottled, brown or grey, sodic texture contrast soil with coarse columnar structure over lithic sandstone from 0.5–1.3 m. Eucalypt vegetation.
Aust. Soil Classification: Brown or Grey Sodosol.
Great Soil Group: Solodized solonetz, solodic soil.
Principal Profile Form: Dy3.43, 5.43, 2.43, 3.23, 4.33, 4.43, Db1.43, 2.43.
Geology: Undifferentiated, fine grained sedimentary rocks of the Blackwater Group (Pw) and/or Back Creek Group (Pb). Mostly lithic sandstones, but occasionally calcareous or quartzose sandstones.
Landform: Gently undulating plains and rises. Slopes 0.5 to 2%, occasionally up to 4%.
Vegetation Associations: Shrubby poplar box (VA7) or Poplar box (VA20); occasionally Poplar box–ironbark (VA34).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Very slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Firm or hard setting. Occasionally 2 to 20% sandstone or quartz gravels 6 to 200 mm or <2% rock outcrop.

Representative Profiles: **Not sampled** (see sites 9075 and 9093 from the Collawmar (Cm) soil).

Typical Profile



Soil Description

The **surface soil** (A1, A2e) is a brown or grey, loamy sand to sandy loam with massive structure. Depths typically range from 0.15 to 0.5 m. A conspicuously bleached layer is normally developed immediately above the clay subsoil. Field pH is 6–8.

The **upper subsoil** (B21) is a mottled, brown or grey, sandy light medium clay to sandy medium clay with moderate or strong, coarse columnar structure. Field pH is 6–9.5, increasing with depth.

The **lower subsoil** (B22) is a brown or grey, sandy light medium clay to sandy medium clay with moderate blocky structure. It is normally calcareous with 10–50% soft or nodular carbonate. Field pH is 9–9.5.

Weathered **substrate** (BC, C) is normally present below 0.5–1.3 m. Substrate material is lithic sandstone that is often calcareous and has a field pH of 9–9.5.

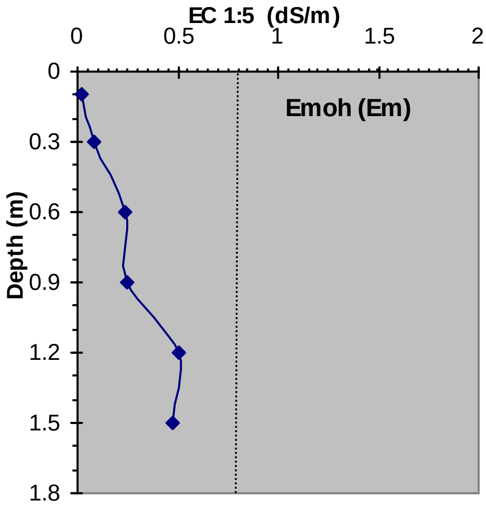
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)	(meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.9	0.79	0.04	7	0.60	35	19	0.21	0.38	3.2	0.67
neutral	low	low	low	moderate	-	moderate	low	low	moderate	low

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are low. Most other nutrients are low to moderate. Fertility levels in the Emoh (Em) soil are similar to those of the Collawmar (Cm) soil. Phosphorus fertility is generally one category higher than that of equivalent sandy surfaced, sodic texture contrast soils such as Bundoora (Bd) or Foxleigh (Fx). Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Emoh (Em) soil. The profile salinity curve reaches equilibrium between 1.1 and 1.3 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.5–1.3 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Comparison with the Collawmar (Cm) soil suggests critical sodicity levels (ESP >20) are likely in the subsoil, but will be substrate dependent and vary in depth.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.19	**0.67**	1.15	31	**61**	92

Typically, PAWC levels for the Emoh (Em) soil are low (approximately 60 mm) because mean ERD is <0.7 m. It is restricted by physical limitations and reduced permeability in the upper subsoil associated with ESP levels >20 or by the presence of weathering sandstone in shallower profiles. Even where deeper profiles occur (ERD >0.7 m), maximum PAWC levels are only 60–90 mm and are subject to significant evaporation and lateral drainage losses because of the highly permeable nature of the surface horizons. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available, but data from representative profiles 9075 and 9093 in Appendices 3 and 6 may be useful as a guide.

Physical Characteristics and Subsoil Chemistry

Interpretations and descriptions of the physical characteristics and chemistry of the Emoh (Em) soil are unavailable, but are probably comparable with those presented for the Collawmar (Cm) soil.

FARLANE (Fr)

Concept: A strongly developed melonhole gilgai complex (VI 0.5–1.2 m) with:
- a firm pedal or weakly to moderately self-mulching, alkaline, grey or brown, sodic cracking clay on mounds; and
- a weakly self-mulching, acid, grey, sodic cracking clay in depressions;

over strongly structured, acid clay or fine grained marine sedimentary rocks from 0.8–>1.5 m. Brigalow vegetation.

Aust. Soil Classification: **Mound:** Grey, Brown (or occasionally Black) Vertosol
Depression: Grey (or occasionally Black) Vertosol

Great Soil Group: **Mound:** Grey clay, brown clay
Depression: Grey clay, no suitable group

Principal Profile Form: **Mound:** Ug5.24, 5.25, 5.28, 5.29, 5.34, 5.35; occasionally Ug5.16, 5.14, 5.15, Uf6.32
Depression: Ug5.24, 5.25, 5.28, 5.29, 5.13, 5.14, 5.15

Geology: Undifferentiated, fine grained sedimentary rocks of the Blackwater Group (Pw) and/or Back Creek Group (Pb) that are probably of marine origins. Mostly fine grained sandstone, siltstone or laminated shale.

Landform: Level to very gently undulating plains. Mostly broad, flat, relatively elevated plains within gently undulating areas developed on folded Permian sediments. Slopes <0.5 to 1%, occasionally up to 1.5%.

Vegetation Associations: Brigalow with shrubs (VA8) or Brigalow (VA1).

Microrelief: Strongly developed melonhole gilgai VI 0.5–1.2 m, HI 15–25 m; occasionally with a prominent shelf.

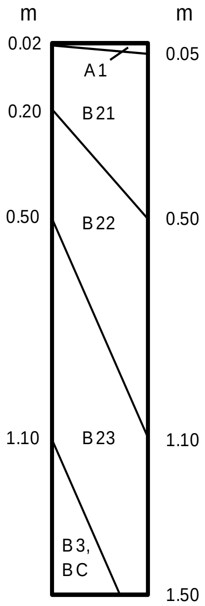
Runoff: Slow on mounds; no run off in depressions. **Permeability:** Very slow.

Drainage: Imperfectly to moderately well drained on mounds; poorly to imperfectly drained in depressions.

Surface Features: **Mound** - cracking with a firm pedal or fine (<2 mm), weakly to moderately self-mulching surface.
Depression - cracking with a coarse (2 to 5 mm), weakly self-mulching surface.
Frequently 2 to 20% silcrete or shale gravels 6 to 60 mm and occasionally <2 to 20% sandstone rocks 60 to 200 mm.

Representative Profiles: **9015, 9016, 9073, 9074**

Typical Profile



Soil Description – Mound profile

The **surface soil** (A1) is a black, brown or grey, light medium clay to medium clay (frequently fine sandy) with moderate to strong blocky or granular structure. Depths typically range from 0.02 to 0.05 m. Field pH is 6–9.5.

The **upper subsoil** (B21, B22) is a grey or brown, medium clay to medium heavy clay with moderate to strong angular blocky or lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

The **lower subsoil** (B23) is a grey or brown, medium clay to medium heavy clay with moderate or strong, coarse lenticular structure. Field pH is 5–9, frequently decreasing with depth.

Weathered **substrate** (B3, BC) is sometimes present from 1.1 m. Substrate material where present is typically labile, fine grained sandstone, siltstone or shale of marine origins. Field pH ranges from 5–9. In deep profiles (>1.5 m) acid clay continues at depth.

Soil Description – Depression profile

Depression profiles have similar horizons, texture and structure but differ significantly in terms of colour and pH. Profiles are typically grey and acid throughout. Field pH is normally 6–7 in the upper profile, decreasing to 5.5–6.5 at depth. Occasionally alkaline profiles similar to those on mounds are developed.

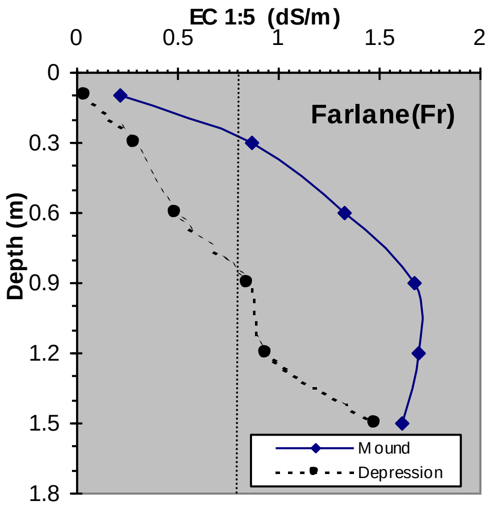
Surface Soil Fertility[1]

Gilgai comp.	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
mound	8.2	1.4	0.10	16	0.66	16	13	1.1	0.47	20	9.2
	alkaline	low	high	high	high	-	moderate	moderate	low	very high	high
dep.	6.9	1.7	0.12	43	0.61	49	24	2.1	0.91	13	5.8
	neutral	moderate	high	very high	high	-	moderate	moderate	moderate	high	high

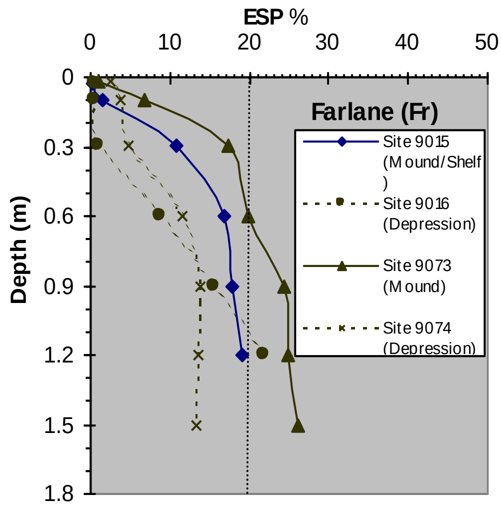
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (mounds and depressions). Typically, nitrogen (Total N) levels are high irrespective of gilgai component, while phosphorus (Bicarb. P) levels are high on mounds and very high in depressions. Absolute differences in phosphorus (Bicarb. P) fertility between components are significant with levels more than doubling in depressions. Most other nutrients are moderate to high with similar levels on both gilgai components. The exceptions are zinc (Zn) which is lower (on mounds) and calcium (Ca) which is higher (on mounds), due to the presence of free carbonates. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P), calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying labile, calcareous sedimentary rocks. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

The Farlane (Fr) soil normally has significant salinity (EC >0.8 dS/m) developed by about 0.25–0.35 m on mounds and 0.85–0.95 m in depressions. The mound profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with mound profiles. The depression curve in contrast does not reach equilibrium (salt bulge is not developed) suggesting significant drainage moves below depressions. Weathered substrate is often present somewhere below 0.8–>1.5 m in depressions however, and contributes to increased salinity levels at depth. Critical sodicity levels (ESP >20) are mainly associated with the lower subsoil of mound profiles (below 0.6–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
mound	0.09	**0.36**	0.63	46	**79**	112
dep.	0.51	**0.96**	1.41	95	**129**	162

Typically, PAWC levels for the Farlane (Fr) soil are low (approximately 80 mm) on mounds and borderline moderate to high (approximately 130 mm) in depressions. Mean ERD on mounds is only 0.35 m, compared with 0.95 m in depressions. In both cases, ERD is restricted by high salinity levels (EC >0.8 dS/m) in the subsoil. Regular seasonal ponding in depressions has resulted in significant leaching and a downward movement of the salt bulge. Even where deeper mound profiles occur (ERD >0.35 m), maximum PAWC levels (80–110 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface; surface sealing and dispersive behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9015, 9016, 9073 and 9074 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is relatively uniform (45–60%) throughout both mound and depression profiles, although thin surface horizons with <45% clay are often developed on mounds. Significant fine sand (30–45%) and silt (10–15%) in the surface soil of both gilgai components promotes surface sealing behaviour. CEC/Clay% ratios in both profiles are mostly 0.55–0.85 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite. Measured dispersion (R1 ratio) in the surface soil is low (0.45), while in the upper subsoil it ranges from low to moderate (0.45–0.75) irrespective of gilgai component. Dispersion (R1 ratio) in the lower subsoil ranges from moderate to very high (0.65–0.95) and varies according to substrate and salinity concentrations. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been insitu. Detailed physical data from representative profiles 9015, 9016, 9073 and 9074 are presented in Appendix 3.

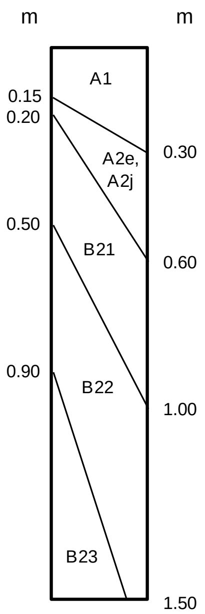
Laboratory pH is similar to field pH (see profile description). CEC levels are high to very high (25–45 meq/100 g) in the surface soil and moderate to high (20–40 meq/100 g) in the subsoil, irrespective of gilgai component. Typically, calcium (Ca) is the dominant cation in both mound and depression profiles. Magnesium (Mg) is sometimes co-dominant at depth and is probably substrate dependent. Both mound and depression profiles are non-sodic (ESP <3) in the surface soil. Mound profiles are strongly to extremely sodic (ESP 17–26) at depth however, while depression profiles are generally only sodic to strongly sodic (ESP 9–16) in the lower subsoil. Detailed chemical data from representative profiles 9015, 9016, 9073 and 9074 are presented in Appendix 3.

FOXLEIGH (Fx)

Concept: A sandy surfaced, conspicuously bleached, alkaline, mottled, brown or grey, sodic texture contrast soil with coarse columnar structure over unconsolidated sediments. Eucalypt vegetation.
Aust. Soil Classification: Brown or Grey Sodosol.
Great Soil Group: Solodized solonetz, solodic soil.
Principal Profile Form: Dy2.43, 5.43, 3.43, 4.43, Db1.43, 4.43; occasionally Db2.33, 3.33, 3.43, Dy2.33, 5.33.
Geology: Unconsolidated Tertiary–Quaternary sediments (TQa). Includes relict alluvial deposits and widespread reworked local colluvium. Sand, clay and gravel sourced from sedimentary landscapes in the Isaac–Connors and Mackenzie River catchments.
Landform: Level to gently undulating plains and occasional low rises. Slopes 0.5 to 3%.
Vegetation Associations: Poplar box (VA20) or Poplar box–bloodwood–Moreton Bay ash (VA33); occasionally Poplar box–ironbark (VA34) or Eucalypts with bull oak (VA32).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Very slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Soft, firm or hard setting.

Representative Profiles: **9001, 9020**

Typical Profile



Soil Description

The **surface soil** (A1, A2e) is a brown, black or grey, sand to sandy loam with massive structure. Depths typically range from 0.2 to 0.6 m. A conspicuously bleached layer is normally developed immediately above the clay subsoil. Field pH is 6–7.

The **upper subsoil** (B21) is a mottled, brown or grey, sandy light medium clay to sandy medium heavy clay (frequently fine sandy) with moderate or strong, coarse columnar structure. It is frequently manganiferous with <2–10% soft or nodular manganese. Field pH is 6–9.5, increasing with depth.

The **lower subsoil** (B22, B23) is a brown, sandy light clay to sandy medium clay (frequently fine sandy) with moderate blocky or polyhedral structure. It is normally calcareous and manganiferous with 2–>50% soft or nodular carbonate and 2–20% manganese soft segregations. Field pH is 8.5–9.5.

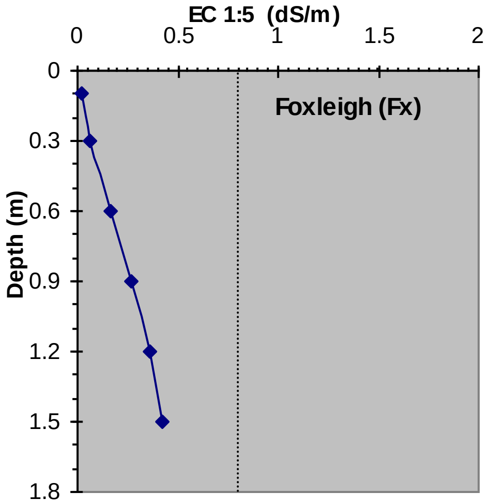
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.5	0.58	0.03	3	0.20	24	13	0.36	0.19	2.5	0.98
acid	low	very low	very low	very low	-	moderate	moderate	very low	moderate	low

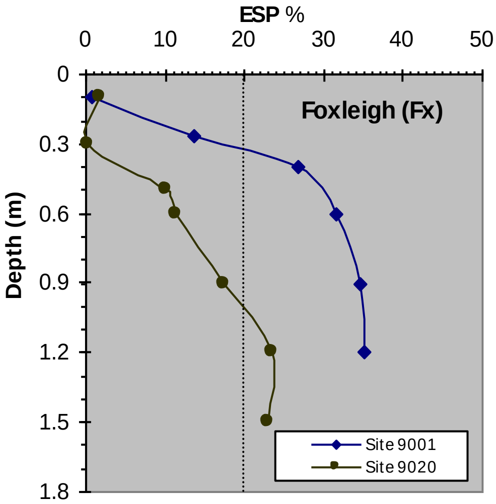
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of nitrogen (Total N), phosphorus (Bicarb. P), potassium (K) and zinc (Zn) are very low. Most other nutrients are low to moderate. The infertility of the Foxleigh (Fx) soil reflects its leached sandy nature and the low nutrient status of the underlying unconsolidated parent material (particularly compared with adjacent younger alluvium). Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Foxleigh (Fx) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Critical sodicity levels (ESP >20) typically occur in the subsoil, but are substrate dependent and vary in depth (below 0.3–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.11	**0.60**	1.10	20	**55**	91

Typically, PAWC levels for the Foxleigh (Fx) soil are low (approximately 55 mm) because mean ERD is only 0.6 m. It is restricted by physical limitations and reduced permeability in the upper subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.6 m), maximum PAWC levels are only 55–90 mm and are subject to significant evaporation and lateral drainage losses because of the highly permeable nature of the surface horizons. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9001 and 9020 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (10–15%) and the subsoil (30–50%), while high levels of fine sand (55–65%) and coarse sand (20–30%) in the surface soil are responsible for its soft, firm or hard setting nature. CEC/Clay% ratios in the subsoil are 0.35–0.55 and indicate the clay fraction is of mixed mineralogy. Measured dispersion (R1 ratio) in the subsoil increases from moderate to high (0.7–0.9) in the upper subsoil to very high (0.99) in the lower subsoil because of increasing sodicity and decreasing clay content. Detailed physical data from representative profiles 9001 and 9020 are presented in Appendix 3.

Subsoil Chemistry

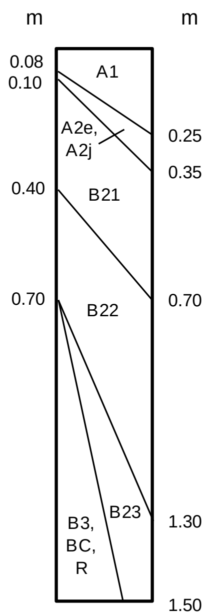
Laboratory pH is similar to field pH (see profile description). CEC levels are typically very low (<5 meq/100 g) in the surface soil and low (10–15 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil, while magnesium (Mg) and to a lesser extent sodium (Na) dominate the subsoil. Profiles vary from sodic to extremely sodic (ESP 10–>25) in the upper subsoil, but are extremely sodic (ESP 17–35) in the lower subsoil. Detailed chemical data from representative profiles 9001 and 9020 are presented in Appendix 3.

FOXLEIGH CLAY LOAMY PHASE (FxLp)

Concept:	A hard setting, loamy or clay loamy surfaced, conspicuously or sporadically bleached, alkaline, brown, sodic texture contrast soil with coarse columnar structure over unconsolidated sediments. (Loamy surfaced version of the Foxleigh (Fx) soil). Eucalypt vegetation.
Aust. Soil Classification:	Brown Sodosol.
Great Soil Group:	Solodic soil, solodized solonetz.
Principal Profile Form:	Db1.43, 1.33, Dy2.43, 2.33, 3.43, 3.33; occasionally Db1.41, 1.42, 1.31, 1.32, Dy2.41, 2.31.
Geology:	Unconsolidated Tertiary–Quaternary sediments (TQa). Includes relict alluvial deposits and widespread reworked local colluvium. Sand, clay and gravel sourced from sedimentary landscapes in the Isaac–Connors and Mackenzie River catchments.
Landform:	Level to gently undulating plains. Occasionally gently undulating pediments or rises below Tertiary plateaus. Slopes 0.5 to 3%.
Vegetation Associations:	Poplar box (VA20); occasionally Shrubby poplar box (VA7), Poplar box–ironbark (VA34), Gum-topped box (VA18) or Yapunyah (VA24).
Microrelief:	Absent.
Runoff:	Slow to moderately rapid.
Permeability:	Very slow.
Drainage:	Imperfectly drained to moderately well drained.
Surface Features:	Hard setting and occasionally cryptogam. Occasionally 2 to 20% silcrete gravels 6 to 60 mm.

Representative Profile: **9041**

Typical Profile



Soil Description

The **surface soil** (A1, A2e, A2j) is a brown or black, sandy loam to clay loam (frequently fine sandy) with massive to weak platy or blocky structure. Depths typically range from 0.1 to 0.35 m. A conspicuously or sporadically bleached layer is normally developed immediately above the clay subsoil. Field pH is 5.5–6.5.

The **upper subsoil** (B21) is a brown, light medium clay to medium heavy clay (frequently fine sandy) with moderate or strong, coarse columnar structure. Field pH is 6–9.5, increasing with depth.

The **lower subsoil** (B22, B23) is a brown, light medium clay to medium clay (frequently fine sandy) with moderate to strong blocky or polyhedral structure. It is frequently calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (B3, BC) is sometimes present from 0.7–>1.5 m on pediments and footslopes below Tertiary plateaus. Substrate material is brown or grey, mottled, reticulite or petroreticulite. Field pH ranges from 5–9.5.

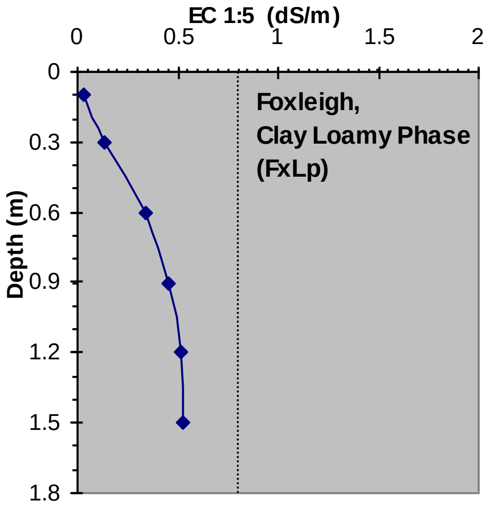
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.1	1.1	0.05	9	0.31	43	55	0.94	0.28	2.8	2.0
acid	low	moderate	low	moderate	-	high	moderate	low	moderate	moderate

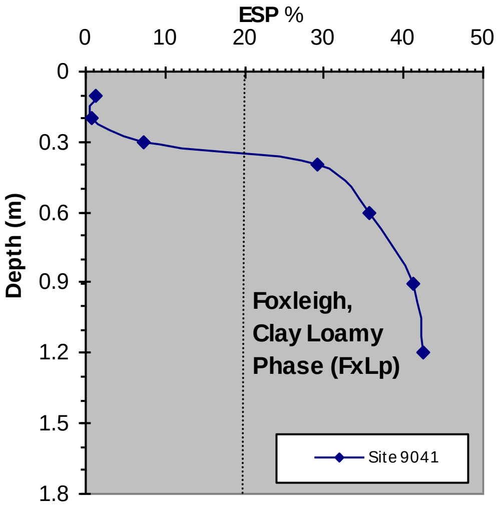
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are low. Most other nutrients are moderate with the exception of zinc (Zn) which is low and manganese (Mn) which is high. Both nitrogen (Total N) and phosphorus (Bicarb. P) fertility is significantly higher than that of the Foxleigh (Fx) soil because of lower leaching losses associated with heavier clay loamy surface horizons. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Foxleigh clay loamy phase (FxLp) soil. The profile salinity curve reaches equilibrium between 1.1 and 1.3 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.19	**0.74**	1.29	33	**80**	127

Typically, PAWC levels for the Foxleigh clay loamy phase (FxLp) soil are low (approximately 80 mm) because mean ERD is <0.75 m. It is restricted by physical limitations and reduced permeability in the upper subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.75 m), maximum PAWC levels (80–130 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9041 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (15–25%) and the subsoil (30–45%), while high levels of fine sand (50%) and significant silt (15%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the subsoil are 0.3–0.4 and indicate the clay fraction is predominantly of mixed mineralogy. Measured dispersion (R1 ratio) in the subsoil ranges from high to very high (0.83–0.97) because of very high sodicity levels (ESP >30) and relatively low clay contents. Detailed physical data from representative profile 9041 are presented in Appendix 3.

Subsoil Chemistry

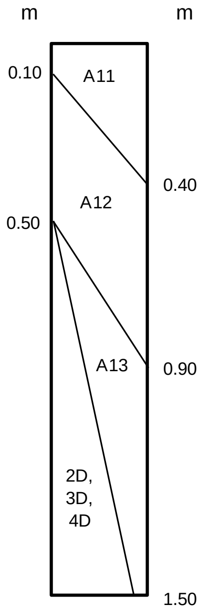
Laboratory pH is similar to field pH (see profile description). CEC levels are low (5–7 meq/100 g) in the surface soil. They increase marginally (10–15 meq/100 g) in the subsoil but are still in the low range. Calcium (Ca) is the dominant cation only in the immediate surface soil, while magnesium (Mg) and sodium (Na) dominate the subsoil. Profiles are typically extremely sodic (ESP >20) in the upper subsoil, with ESP levels as high as 45 in the lower subsoil. Detailed chemical data from representative profile 9041 are presented in Appendix 3.

GERMAN (Gm)

Concept: A moderately deep to deep, soft or loose, acid or neutral, brown uniform sand with buried alluvial layers (sand to sandy medium clay) from 0.5–>1.5 m on channel benches and narrow alluvial plains on upper tributaries. Eucalypt vegetation.
Aust. Soil Classification: Stratic Rudosol.
Great Soil Group: Alluvial soil, earthy sand, siliceous sand.
Principal Profile Form: Uc5.21, 5.11; occasionally Uc1.23, 1.22.
Geology: Quaternary alluvium (Qa).
Landform: Low lying channel benches, active levees and flooded creek flats on narrow alluvial plains associated with upper tributaries. Flooded by short duration, high velocity events. ARI is more frequent than 1 in 2 years. Slopes <0.5 to 1.0%, occasionally up to 2%.
Vegetation Associations: Blue gum–mixed eucalypts (VA22) or Moreton Bay ash (VA23).
Microrelief: Absent.
Runoff: Very slow to slow.
Permeability: Moderate to high.
Drainage: Well drained to rapidly drained.
Surface Features: Soft or loose.

Representative Profile: **9010**

Typical Profile



Soil Description

The **surface soil** (A11) is a black or brown, sand or loamy sand with massive structure. Depths typically range from 0.1 to 0.4 m. Field pH is 5.5–7.

The **subsoil** (A12, A13) is a brown, sand or loamy sand with massive structure. Field pH is 5.5–7.

Buried alluvial layers (2D, 3D, 4D) are often present from 0.5–>1.5 m. Buried materials are typically brown or grey and range from sand to sandy medium clay with massive or weak to moderate blocky structure. Field pH ranges from 5.5–8.5.

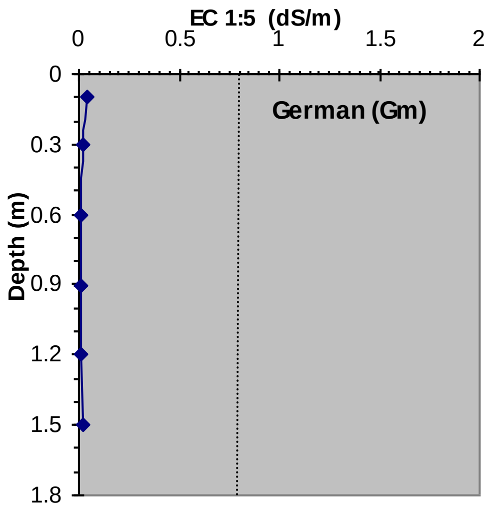
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.5	0.83	0.05	8	0.41	12	12	0.22	0.50	3.9	1.7
acid	low	low	low	low	-	moderate	low	low	moderate	moderate

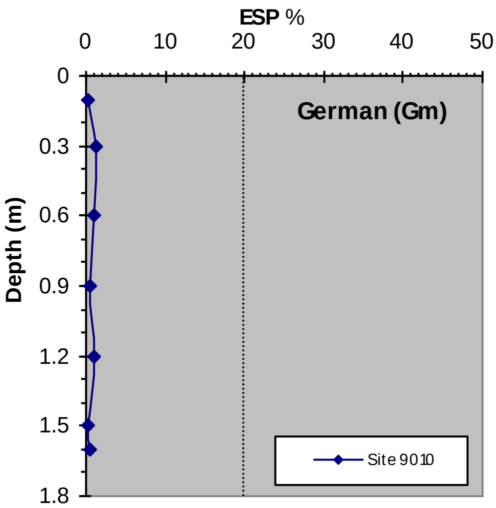
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are low. Most other nutrients are low to moderate. The relative infertility of the German (Gm) soil compared with other alluvial soils relates to its leached sandy nature and the low nutrient status of provenance areas supplying sediment. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the upper 1.5 m of the German (Gm) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Sodicity levels within the profile (ESP <1) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**
	1.33	**1.47**	1.61	67	**80**	94

Typically, PAWC levels for the German (Gm) soil are low (approximately 80 mm) even though mean ERD is almost 1.5 m. Restrictions to rooting depth are generally absent. Maximum PAWC levels (80–95 mm) are rarely achieved on a regular basis however, because profiles are highly permeable and subject to continued deep drainage and evaporation losses over time. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9010 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is uniformly low (<10%) throughout the profile. Sand fractions may be either fine or coarse depending on sediment source and clay contents in buried layers are variable (10–50%). Values for CEC/Clay% ratio, measured dispersion (R1 ratio) and sodicity are misleading and have not been considered because of very low clay contents. Moderate to high Total K levels throughout the profile reflect the young age and recent alluvial origins of this soil. Detailed physical data from representative profile 9010 are presented in Appendix 3.

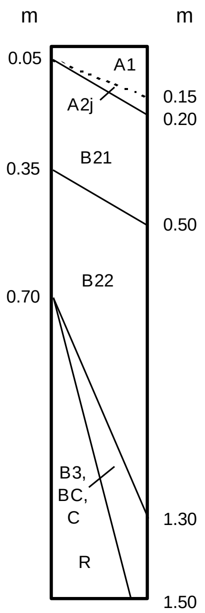
Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are very low (2–4 meq/100 g) throughout. Levels in buried layers are variable and will depend on clay% and mineralogy. Calcium (Ca) is the dominant cation within the profile even though levels are only low. Detailed chemical data from representative profile 9010 are presented in Appendix 3.

GORDONS BORE (Gb)

Concept:	A hard setting, firm pedal or weakly self-mulching, alkaline, brown non-cracking to cracking clay over partially altered basalt or strongly structured, basaltic clay from 0.7–1.3 m. Brigalow vegetation.
Aust. Soil Classification:	Brown Dermosol; Brown Vertosol; occasionally Brown Chromosol.
Great Soil Group:	No suitable group, brown clay; occasionally solodic soil.
Principal Profile Form:	Uf6.31, Ug5.34, 5.35, Uf6.32, Ug5.32; occasionally Db1.33.
Geology:	Partially altered Tertiary basalt (Tb_a).
Landform:	Gently undulating pediments, colluvial footslopes and occasional rises associated with partially altered basalt flows exposed following scarp retreat of Tertiary plateaus in the Duaringa Basin. Slopes 0.5 to 2%, occasionally up to 3%.
Vegetation Associations:	Brigalow with shrubs (VA8), Brigalow (VA1) or Brigalow–Dawson gum (VA5).
Microrelief:	Occasionally normal gilgai VI <0.2 m, HI 10 m; frequently with a prominent shelf and indistinct mounds and depressions.
Runoff:	Slow.
Permeability:	Slow.
Drainage:	Moderately well drained.
Surface Features:	Frequently cracking with a hard setting, firm pedal or fine (<2 mm), weakly self-mulching surface. Frequently 2 to 20% silcrete gravel 6 to 60 mm.
Representative Profiles:	**9057, 9085**

Typical Profile



Soil Description

The **surface soil** (A1, occasionally A2j) is a brown or black, fine sandy light clay to fine sandy light medium clay with moderate blocky structure. Depths typically range from 0.05 to 0.15 m. Field pH is 6–7.5.

The **upper subsoil** (B21) is a brown, medium clay to medium heavy clay with moderate to strong blocky or lenticular structure. Field pH is 7–9.5, increasing with depth.

The **lower subsoil** (B22) is a brown, medium clay to medium heavy clay with moderate or strong, coarse lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 9–9.5.

Weathered **substrate** (B3, BC, C) sometimes occurs below 0.7–1.3 m. Substrate material (where present) is partially altered basalt. Typically it is brown or grey with a field pH of 7–9.5. In deep profiles (>1.5 m) alkaline or acid basaltic clay continues at depth.

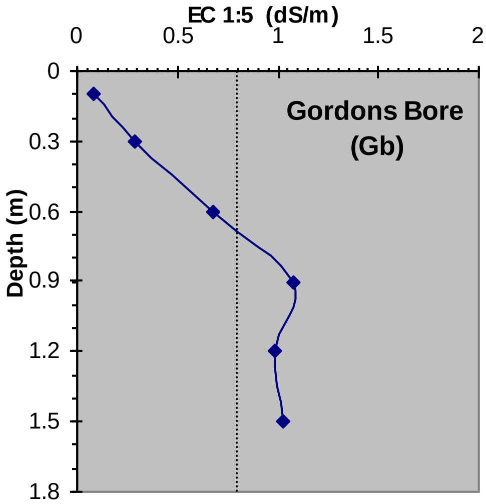
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P Bicarb. (mg/kg)	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Exchangeable Cations [2] Ca (meq/100g)	Mg (meq/100g)
6.9	1.3	0.10	21	0.33	26	28	1.5	1.0	9.5	5.2
neutral	low	high	high	moderate	-	moderate	moderate	moderate	high	high

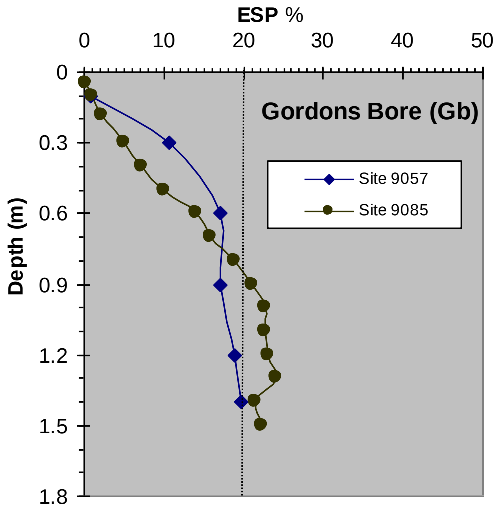
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are high. Most other nutrients are moderate to high. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P), calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.65–0.75 m in the Gordons Bore (Gb) soil. The profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present below 0.7–1.3 m and contributes to the development of the salt bulge because of restricted subsoil drainage, as well as slight increases in salinity levels at depth. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below 0.6–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**
	0.47	**0.78**	1.09	98	**119**	140

Typically, PAWC levels for the Gordons Bore (Gb) soil are only moderate (approximately 120 mm) because mean ERD is about 0.75 m. It is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the subsoil associated with ESP levels close to 20. Even where deeper profiles occur (ERD >0.8 m), maximum PAWC levels (120–140 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9057 and 9085 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases gradually between the surface soil (30–35%) and the subsoil (45–50%), while significant levels of fine sand (40–45%) in the surface soil are responsible for its predominantly firm to hard setting nature. CEC/Clay% ratios in the profile are mostly 0.45–0.7 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (i.e. partially altered basaltic clay with significant colluvial influence). Measured dispersion (R1 ratio) in the surface soil and upper subsoil is low (<0.6), but gradually increases to moderate levels (0.7–0.8) in the lower subsoil because of high to very high sodicity (ESP >15). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9057 and 9085 are presented in Appendix 3.

Subsoil Chemistry

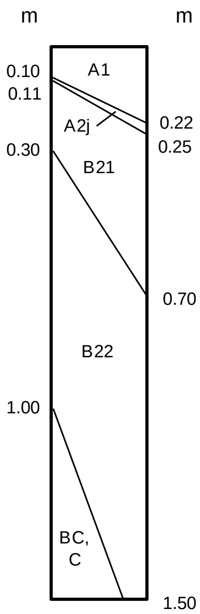
Laboratory pH is similar to field pH (see profile description). CEC levels are moderate (18–20 meq/100 g) in the surface soil and moderate to high (18–35 meq/100 g) in the subsoil. Very high levels (40–60 meq/100 g) are often present where weathered substrate occurs. Calcium (Ca) is the dominant cation in the surface soil, but is replaced by magnesium (Mg) and to a lesser extent sodium (Na) in the subsoil. Profiles are typically non-sodic (ESP <6) in the surface soil, but become sodic (ESP 6–10) in the upper subsoil and strongly to extremely sodic (ESP 15–25) at depth. Detailed chemical data from representative profiles 9057 and 9085 are presented in Appendix 3.

HAZELBRAE (Hb)

Concept: A hard setting, clay loamy surfaced, sporadically bleached, alkaline, brown or grey, non-sodic texture contrast soil over unconsolidated, calcareous sediments below 1.0–>1.5 m. Brigalow vegetation.
Aust. Soil Classification: Brown or Grey Chromosol.
Great Soil Group: Solodic soil, no suitable group.
Principal Profile Form: Db1.33, Dy2.13; occasionally Db1.13, Dy2.33, 3.13, 3.33.
Geology: Unconsolidated calcareous Tertiary–Quaternary sediments (TQa$_b$). Mainly relict alluvial deposits sourced from basaltic or andesitic landscapes in the Isaac–Connors and Mackenzie River catchments. Fine grained basaltic derived sediment, clay, marl, gravel beds and sand lenses.
Landform: Level to gently undulating plains. Slopes 0.5 to 1.5%, occasionally up to 3%.
Vegetation Associations: Brigalow–Dawson gum (VA5) or Belah (VA9); occasionally Brigalow (VA1).
Microrelief: Absent.
Runoff: Slow.
Permeability: Slow.
Drainage: Moderately well drained.
Surface Features: Hard setting or occasionally firm. Frequently <2 to 10% water worn quartz gravels 6 to 60 mm.

Representative Profile: **9119**

Typical Profile



Soil Description

The **surface soil** (A1, A2j) is a black or brown, sandy clay loam to clay loam sandy with massive or weak blocky structure. Depths typically range from 0.1 to 0.25 m. A sporadically bleached layer is frequently developed immediately above the clay subsoil. Field pH is 6–8.5.

The **upper subsoil** (B21) is a brown or grey, sandy light medium clay to sandy medium clay with moderate to strong blocky or lenticular structure. Field pH is 8–9, generally increasing with depth.

The **lower subsoil** (B22) is a brown, sandy light clay to sandy medium clay with moderate blocky or lenticular structure. It is normally calcareous with 2–50% soft or nodular carbonate. Field pH is 8.5–9.5.

Substrate material (BC, C) is sometimes present below 1.0–>1.5 m. Where present, it typically consists of marl or unconsolidated, calcareous fine sandy clay sediments with a field pH of 8.5–9.5.

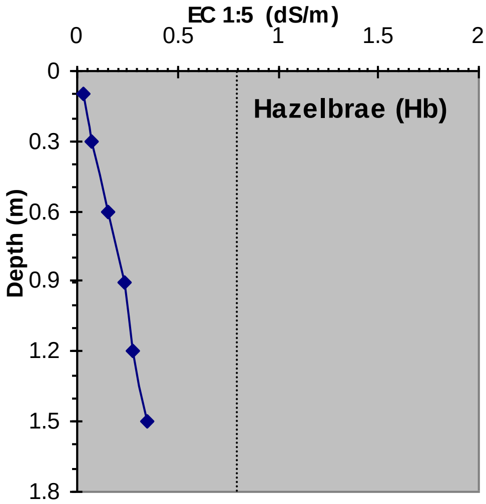
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.5	1.1	0.07	11	0.17	18	15	0.52	0.28	8.9	2.4
neutral	low	moderate	moderate	low	-	moderate	moderate	very low	high	moderate

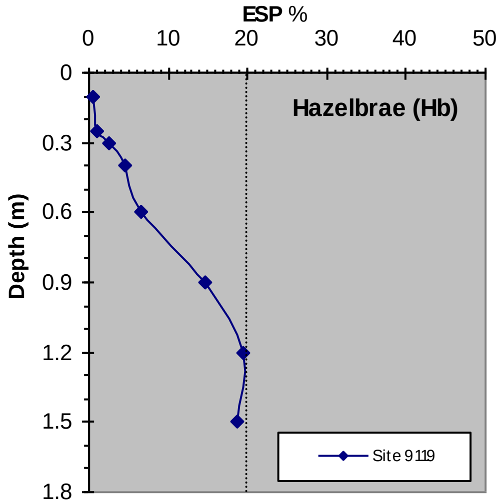
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are moderate. Most other nutrients are moderate to high with the exception of potassium (K) which is low and zinc (Zn) which is very low. Nitrogen (Total N) fertility is lower than expected for a brigalow scrub soil because of the significant eucalypt component normally associated in the upper storey (e.g. Dawson gum). Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Hazelbrae (Hb) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below about 1.2–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.99	**1.35**	1.70	76	**114**	152

Typically, PAWC levels for the Hazelbrae (Hb) soil are only moderate (approximately 115 mm) even though mean ERD is about 1.35 m. Restrictions to rooting depth are generally absent, although physical limitations and reduced permeability associated with ESP levels close to 20 occur at the base of some profiles. Maximum PAWC levels (115–150 mm) are rarely achieved on a regular basis however, because of restricted infiltration (hard setting, clay loamy surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9119 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (15–25%) and the subsoil (30–45%), while high levels of fine sand (50–55%) in the surface soil are responsible for its predominantly hard setting nature. CEC/Clay% ratios in the subsoil are 0.55–0.7 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (i.e. derived from basaltic sediments). Measured dispersion (R1 ratio) is low (0.45–0.55) in the upper subsoil, but increases to moderate or high (0.75–0.85) at depth because of increasing sodicity (ESP 15–20) and lower clay content. Detailed physical data from representative profile 9119 are presented in Appendix 3.

Subsoil Chemistry

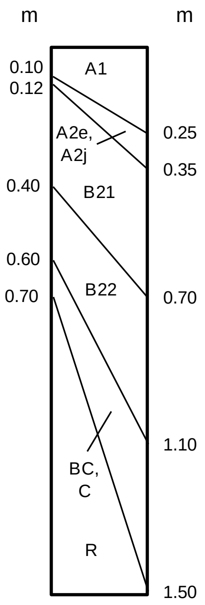
Laboratory pH is similar to field pH (see profile description). CEC levels are mostly low (10–15 meq/100 g) in the surface soil and moderate (20–25 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while magnesium (Mg) is dominant in the lower subsoil. Profiles are typically non-sodic (ESP <6) in the upper subsoil, but become sodic (ESP 6–15) or strongly sodic (ESP 15–20) with depth. Detailed chemical data from representative profile 9119 are presented in Appendix 3.

HEYFORD (Hf)

Concept: A sandy surfaced, conspicuously bleached, gravelly, alkaline, mottled, brown, sodic texture contrast soil with coarse columnar structure over micaceous or lithic sandstone from 0.6–1.1 m. Eucalypt vegetation.
Aust. Soil Classification: Brown (or occasionally Grey) Sodosol.
Great Soil Group: Solodized solonetz.
Principal Profile Form: Dy2.43, 5.43, 3.43, 4.43, Db3.43; occasionally Dy2.33, 5.33, Db1.33, 1.43, 4.33, 4.43.
Geology: Fine grained marine sedimentary rocks of the Back Creek Group (Pb). Mostly micaceous and lithic sandstone.
Landform: Gently undulating rises to undulating low hills. Occurs mainly on foothills, footslopes and pediments around the base of the Cherwell Range. Slopes 1 to 5%, occasionally up to 10%.
Vegetation Associations: Poplar box (VA20) or Eucalypts with bull oak (VA32); occasionally Poplar box–ironbark (VA34) or Narrow-leaved ironbark (VA12).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Very slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Soft, firm or hard setting. Occasionally 2 to 20% sandstone or quartz gravels 6 to 60 mm or 2 to 10% sandstone outcrop.

Representative Profile: **9035**

Typical Profile



Soil Description

The **surface soil** (A1, A2e, occasionally A2j) is a brown or black, loamy sand with massive structure. Depths typically range from 0.1 to 0.35 m. A conspicuously bleached layer with 2–20% sandstone or quartz gravels is normally developed immediately above the clay subsoil. Field pH is 5.5–6.5.

The **upper subsoil** (B21) is a mottled, brown, sandy light medium clay to medium clay (frequently fine sandy) with strong, coarse columnar structure. Field pH is 6–9.5, increasing with depth.

The **lower subsoil** (B22) is a brown, sandy light clay to sandy medium clay with weak to moderate blocky or polyhedral structure. It is calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (BC, C) is normally present below 0.6–1.1 m. Substrate material is micaceous or lithic sandstone with a field pH of 8.5–9.5.

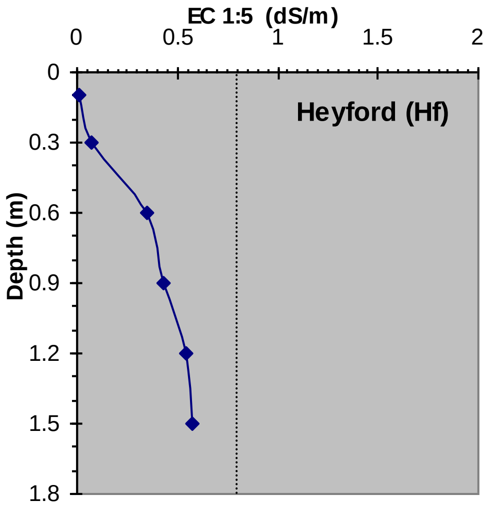
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.2	1.5	0.03	2	0.29	102	1	0.05	0.16	0.69	0.61
strongly acid	low	very low	very low	very low	-	low	very low	very low	low	low

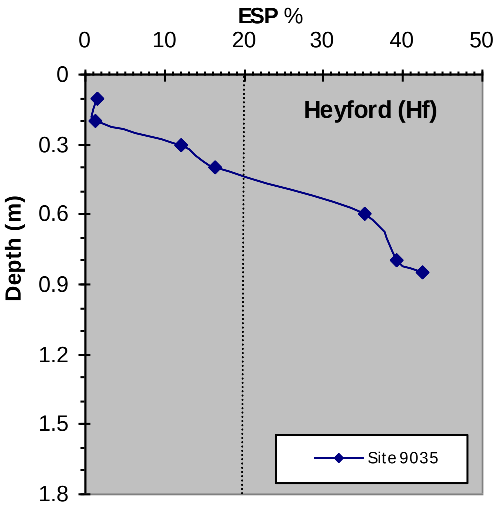
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are very low. Most other nutrients are also low to very low. The infertility of the Heyford (Hf) soil reflects the leached sandy nature of its surface horizons and the low nutrient status of the underlying micaceous and lithic sandstones. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Heyford (Hf) soil. The profile salinity curve reaches equilibrium between 1.1 and 1.3 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.6–1.1 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Critical sodicity levels (ESP >20) typically occur within the upper 0.2 m of the subsoil (B21).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.08	**0.30**	0.51	23	**44**	65

Typically, PAWC levels for the Heyford (Hf) soil are low (approximately 45 mm) because mean ERD is only 0.3 m. It is restricted by physical limitations and reduced permeability in the upper subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.3 m), maximum PAWC levels are only 45–65 mm and are subject to significant evaporation and lateral drainage losses because of the highly permeable nature of the surface horizons. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9035 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (10%) and the upper subsoil (50–60%) but decreases at depth (<40%) due to the influence of the underlying substrate. High levels of fine sand (up to 80%) are often present in the surface soil. CEC/Clay% ratios in the subsoil are 0.25–0.45 and indicate the clay fraction is of mixed mineralogy with significant kaolinite and illite. Measured dispersion (R1 ratio) in the subsoil ranges from high to very high (0.9–0.96), gradually increasing at depth because of increasing sodicity and lower clay content. High Total K levels in the soil profile reflects similar levels in the underlying predominantly micaceous substrate and confirm soil development has been *in situ*. Detailed physical data from representative profile 9035 are presented in Appendix 3.

Subsoil Chemistry

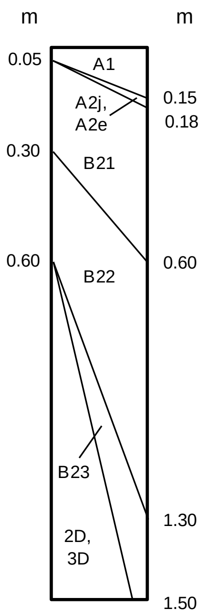
Laboratory pH is similar to field pH (see profile description). CEC levels are very low (<5 meq/100 g) in the surface soil but increase to moderate (15–20 meq/100 g) in the upper subsoil. Levels often decrease again in the lower subsoil. Magnesium (Mg) and sodium (Na) are the dominant cations within the profile, and their relative dominance varies with substrate. Calcium (Ca) is co-dominant only in the immediate surface horizon. Profiles are typically strongly to extremely sodic throughout the subsoil, with ESP levels >40 common at depth. Detailed chemical data from representative profile 9035 are presented in Appendix 3.

HONEYCOMB (Hy)

Concept: A hard setting, clay loamy surfaced, sporadically or conspicuously bleached, alkaline, black, sodic texture contrast soil with columnar or blocky structure over recent alluvium on alluvial plains and levees. Brigalow vegetation.
Aust. Soil Classification: Black (or occasionally Brown) Sodosol.
Great Soil Group: Solodic soil.
Principal Profile Form: Dd1.13, 1.33, 1.43; occasionally Db1.33, 1.43, Dy2.13, 2.33, 2.43.
Geology: Quaternary alluvium (Qa).
Landform: Slightly elevated levees and level alluvial plains on some upper and most lower tributaries; or occasionally elevated, terrace plains and relict levees on flood plains along major rivers. Flooded in lower lying parts. ARI is between 1 in 2 years and 1 in 10 years. Slopes <1%, occasionally up to 1.5% on levees.
Vegetation Associations: Brigalow–Dawson gum (VA5) or Shrubby poplar box (VA7); occasionally Brigalow (VA1).
Microrelief: Absent.
Runoff: Slow.
Permeability: Very slow to slow.
Drainage: Moderately well drained.
Surface Features: Hard setting.

Representative Profiles: **9014, 9022**

Typical Profile



Soil Description

The **surface soil** (A1, A2j, A2e) is a black, fine sandy clay loam to clay loam fine sandy with massive or weak to moderate platy or blocky structure. Depths typically range from 0.05 to 0.2 m. A sporadically or conspicuously bleached layer is frequently developed immediately above the clay subsoil. Field pH is 6–7.5.

The **upper subsoil** (B21) is a black, light medium clay to medium heavy clay (frequently fine sandy) with moderate to strong columnar or blocky structure. Field pH is 6–9.5, increasing with depth.

The **lower subsoil** (B22, B23) is a brown, black or grey, light clay to medium clay (frequently fine sandy) with moderate to strong blocky or polyhedral structure. It is calcareous with 2–50% soft or nodular carbonate. Field pH is 8.5–9.5.

Buried alluvial layers (2D, 3D) are sometimes present from 0.6–>1.5 m. Buried materials are typically a brown, loamy sand to sandy light medium clay with massive or weak to moderate blocky structure. They are frequently calcareous with 2–10% soft or nodular carbonate. Field pH is 7–9.5.

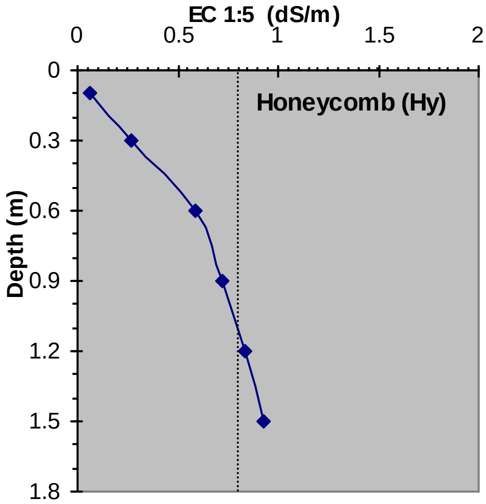
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.7	1.3	0.07	25	0.62	51	17	0.81	1.1	6.8	2.7
neutral	low	moderate	high	high	-	moderate	moderate	moderate	high	moderate

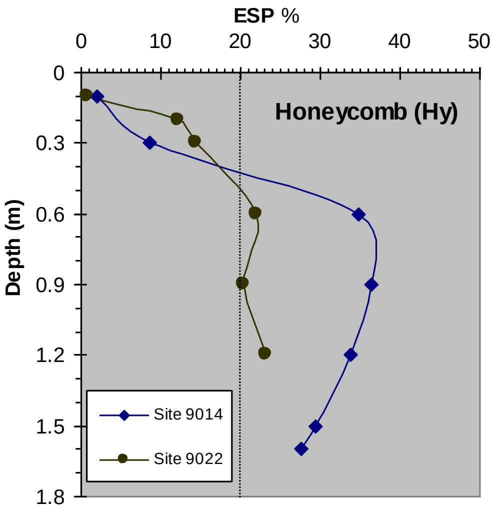
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are high. Most other nutrients are moderate to high. Nitrogen (Total N) fertility is lower than expected for a brigalow scrub soil because of the significant eucalypt component normally associated in the upper storey (e.g. Dawson gum, poplar box). Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 1.1 m in the Honeycomb (Hy) soil. The profile salinity curve reaches an indistinct equilibrium between 0.6 and 0.9 m (salt bulge becomes constant) indicating the probable depth of long term wetting normally associated with this soil. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.23	**0.71**	1.19	56	**95**	134

Typically, PAWC levels for the Honeycomb (Hy) soil are only moderate (approximately 95 mm) because mean ERD is <0.75 m. It is restricted by physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.75 m), maximum PAWC levels (95–135 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9014 and 9022 are presented in Appendices 3 and 6.

Physical Characteristics

Typically, clay content increases significantly between the surface soil (15–25%) and the subsoil (30–50%). In some profiles differences are less well defined and increase only gradually. High levels of fine sand (50%) and silt (15–25%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the subsoil are 0.5–0.6 and indicate the clay fraction is predominantly of mixed mineralogy (depending on sediment source). Measured dispersion (R1 ratio) in the upper subsoil is moderate (0.7–0.8), but increases to high or very high levels (0.85–0.97) in the lower subsoil because of very high sodicity levels (ESP >20). Moderate to high levels of Total K throughout the profile reflect the young age and recent alluvial origins of this soil. Detailed physical data from representative profiles 9014 and 9022 are presented in Appendix 3.

Subsoil Chemistry

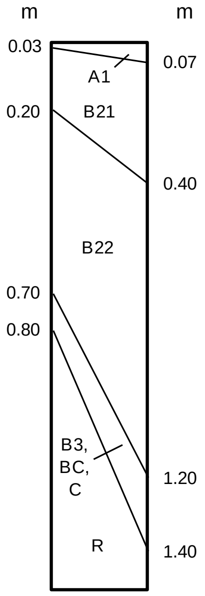
Laboratory pH is similar to field pH (see profile description). CEC levels are low to moderate (12–20 meq/100 g) in the surface soil and moderate to high (15–28 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation throughout the profile, although significant magnesium (Mg) and sodium (Na) are normally present in the lower subsoil. Profiles are typically sodic (ESP 8–14) in the upper profile, but become strongly to extremely sodic (ESP 20–40) at depth. Detailed chemical data from representative profiles 9014 and 9022 are presented in Appendix 3.

INDICUS (Id)

Concept: A strongly self-mulching, alkaline, black cracking clay over fresh basalt from 0.7–1.2 m. Brigalow vegetation.
Aust. Soil Classification: Black Vertosol.
Great Soil Group: Black earth.
Principal Profile Form: Ug5.12; occasionally Ug5.13, 5.14, 5.15, 5.16.
Geology: Fresh Tertiary basalt (Tb).
Landform: Gently undulating plains and rises associated with basalt flows near May Downs, Tiny Downs and in the Barmount area. Mostly broad gentle ridges with long sideslopes. Slopes 0.5 to 2%.
Vegetation Associations: Brigalow with shrubs (VA8) or Brigalow (VA1).
Microrelief: Occasionally weakly developed normal or linear gilgai VI <0.1 m, HI 7–10 m.
Runoff: Slow.
Permeability: Slow.
Drainage: Moderately well drained.
Surface Features: Cracking with a fine (<2 mm), strongly self-mulching surface and frequently <2 to 10% free carbonate nodules. Occasionally 2 to 10% silcrete gravels 6 to 60 mm or basalt fragments 60 to 200 mm or <2% basalt outcrop. Variation between gilgai components is minimal.

Representative Profile: **9076**

Typical Profile



Soil Description

The **surface soil** (A1) is a black, medium clay to medium heavy clay with strong granular structure. Depths typically range from 0.03 to 0.07 m. It is frequently calcareous with 2% nodular carbonate and a field pH of 8–9.

The **upper subsoil** (B21) is a black, medium heavy clay to heavy clay with moderate to strong blocky or lenticular structure. It is frequently calcareous with 2–10% nodular carbonate. Field pH is 8–9.5.

The **lower subsoil** (B22) is a black, medium heavy clay to heavy clay with strong, coarse lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (B3, BC, C) is normally present below 0.7–1.2 m. Substrate material is fresh basalt which is typically brown or grey and frequently calcareous. Field pH is 8.5–9.5.

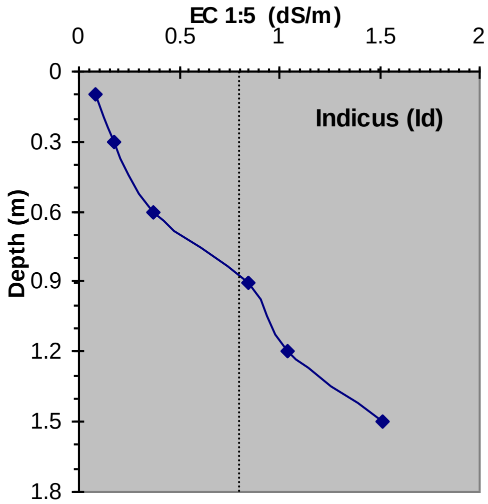
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.7	1.4	0.09	12	0.55	21	15	1.8	0.41	29	18
alkaline	low	high	moderate	high	-	moderate	moderate	low	very high	very high

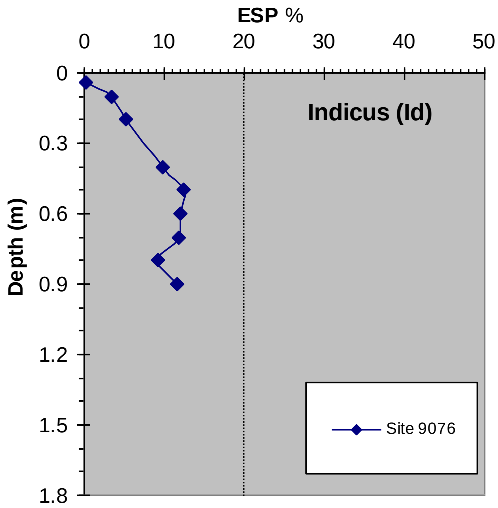
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are high while phosphorus (Bicarb. P) levels are moderate. Most other nutrients are moderate to very high with the exception of zinc (Zn) which is low. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.85 m in the Indicus (Id) soil. The profile salinity curve reaches an indistinct equilibrium between 0.9 and 1.1 m (salt bulge becomes constant) indicating the probable depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.7–1.2 m and contributes to increased salinity levels at depth. Sodicity levels in the lower subsoil (ESP 10–15) are below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.71	**0.84**	0.97	121	**135**	150

Typically, PAWC levels for the Indicus (Id) soil are high (approximately 135 mm) with a mean ERD of about 0.85 m. ERD is defined simply by the depth to weathered basalt. Restrictions to rooting depth are generally absent in the profile, although high salinity levels (EC >0.8 dS/m) are present in the underlying weathered substrate. Where deeper profiles occur (ERD >0.85 m), maximum PAWC levels (135–150 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9076 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (65–70%) throughout the profile, but decreases in the underlying weathered basaltic substrate (40%), where appreciable levels of coarse sand, fine sand and silt occur. CEC/Clay% ratios in the profile are 1.1–1.2 and indicate the clay fraction is montmorillonitic. Ratios as high as 1.4 are present in the underlying weathered basalt. Measured dispersion (R1 ratio) in the profile is low (0.35–0.55) throughout because of very high levels of exchangeable calcium (Ca) and relatively low sodicity levels (ESP <12). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9076 are presented in Appendix 3.

Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are very high (75–85 meq/100 g) throughout the profile, and also in the underlying weathered substrate (55 meq/100 g). Calcium (Ca) is the dominant cation down the profile, although significant magnesium (Mg) is also present and is often co-dominant at depth. Profiles are always non-sodic (ESP <6) in the upper subsoil, but may become sodic (ESP 6–15) at depth. Detailed chemical data from representative profile 9076 are presented in Appendix 3.

INDICUS MELONHOLE PHASE (IdMp)

Concept: A weakly to strongly developed melonhole gilgai complex (VI 0.3–1.0 m) with:

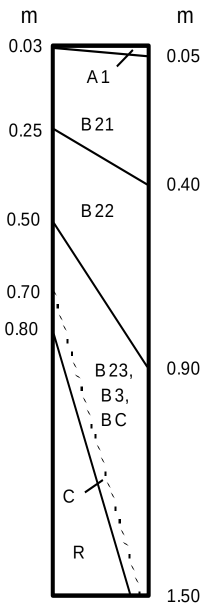
- a firm pedal or weakly to strongly self-mulching, alkaline, grey, brown or black, sodic cracking clay on mounds; and
- a hard setting or weakly to strongly self-mulching, acid or alkaline, grey, sodic cracking clay in depressions;

over partially altered basalt or acid, basaltic clay from 0.5–>1.5 m. Brigalow vegetation.

Aust. Soil Classification: **Mound:** Grey, Brown or Black Vertosol **Depression:** Grey Vertosol
Great Soil Group: **Mound:** Grey clay, brown clay **Depression:** Grey clay
Principal Profile Form: **Mound:** Ug5.24, 5.28, 5.32, 5.35, 5.12 **Depression:** Ug5.22, 5.24, 5.28
Geology: Partially altered Tertiary basalt (Tb_a).
Landform: Level to very gently undulating plains associated with basalt flows near May Downs, Tiny Downs and in the Barmount area. Mostly lower slopes and flow margins lying adjacent to surrounding unconsolidated Tertiary–Quaternary sediments. Slopes <1%.
Vegetation Associations: Brigalow (VA1) or Brigalow with shrubs (VA8).
Microrelief: Weakly to strongly developed melonhole gilgai VI 0.3–1 m, HI 10–25 m; occasionally with a prominent shelf.
Runoff: Slow on mounds; no run off in depressions. **Permeability:** Slow.
Drainage: Moderately well drained on mounds; imperfectly drained in depressions.
Surface Features: **Mound -** cracking with a firm pedal or fine (<2 mm), weakly to strongly self-mulching surface.
Depression - cracking with a hard setting or coarse (2 to >5 mm), weakly to strongly self-mulching surface.
Frequently 2 to 20% silcrete gravels 6 to 60 mm and occasionally <2% basalt rocks 60 to 200 mm, mainly on mounds.

Representative Profiles: **9065, 9066**

Typical Profile



Soil Description – Mound profile

The **surface soil** (A1) is a grey or black, light medium clay to medium heavy clay with moderate to strong blocky or granular structure. Depths typically range from 0.03 to 0.05 m. Field pH is 6.5–9.5.

The **upper subsoil** (B21) is a grey, brown or black, medium heavy clay to heavy clay with moderate or strong blocky to lenticular structure. It is frequently calcareous with <2–10% soft or nodular carbonate. Field pH is 8.5–9.5.

The **lower subsoil** (B23) is a grey or brown, medium heavy clay to heavy clay with moderate or strong, coarse lenticular structure. Field pH is 5.5–6.5.

Weathered **substrate** (B3, BC, C) is often present below 0.5–0.9 m, although deeper profiles >1.5 m also occur. Substrate material is partially altered basalt. Typically it is grey with a field pH of 5.5–6.5. In deep profiles (>1.5 m) acid basaltic clay continues at depth.

Soil Description – Depression profile

Depression profiles have similar horizons and structure, but differ in colour, texture and surface soil thickness (0.03–0.1 m). Profiles are typically grey and have medium clay to heavy clay textures throughout that are frequently fine sandy. Field pH is normally 6–8.5 in the upper profile decreasing to 5.5–6.5 at depth.

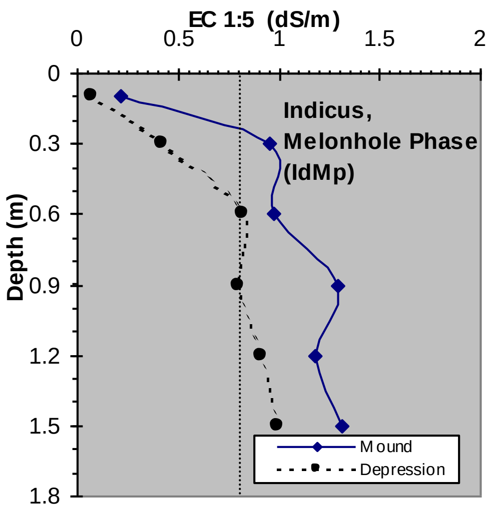
Surface Soil Fertility[1]

Gilgai comp.	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P Bicarb. (mg/kg)	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Exchangeable Cations [2] Ca (meq/100g)	Mg (meq/100g)
mound	7.3	1.2	0.09	12	0.42	31	46	2.4	0.72	14	12
	neutral	low	high	moderate	moderate	-	moderate	moderate	low	high	high
dep.	5.5	1.1	0.07	26	0.48	73	53	3.0	0.76	10.0	15
	strongly acid	low	moderate	high	moderate	-	high	moderate	moderate	high	high

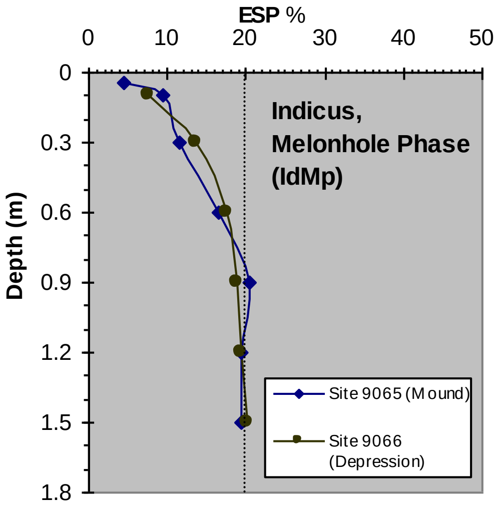
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (mounds and depressions). Typically, nitrogen (Total N) levels are high on mounds but only moderate in depressions, while phosphorus (Bicarb. P) levels are moderate on mounds and high in depressions. Absolute differences in phosphorus fertility between components are significant with levels more than doubling in depressions. Most other nutrients are moderate to high with similar levels on both gilgai components. The exception is zinc (Zn) which is generally lower on mounds. High nitrogen (Total N) levels on mounds are associated with the presence of brigalow scrub, while elevated calcium (Ca) and magnesium (Mg) levels (irrespective of component) are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

The Indicus melonhole phase (IdMp) soil normally has significant salinity (EC >0.8 dS/m) developed by about 0.25 m on mounds and 0.55 m in depressions. The mound profile salinity curve reaches equilibrium between 0.2 and 0.4 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with mounds. The depression curve in contrast reaches equilibrium between 0.5–0.7 m suggesting only minor leaching has occurred because of seasonal ponding (i.e. depressions are relatively shallow). Weathered substrate is often present somewhere below 0.5–>1.5 m and contributes to increased salinity levels at depth. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below 0.6–>1.5 m), both on mounds and in depressions.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.15	**0.40**	0.65	64	**102**	140

Typically, PAWC levels for the Indicus melonhole phase (IdMp) soil are only moderate (approximately 100 mm) because mean ERD is about 0.4 m. It is restricted by high salinity levels (EC >0.8 dS/m) in the upper subsoil. While slight differences in ERD are apparent between gilgai components (mound – 0.25 m, depression – 0.55 m) they were not considered significant and an average has been used to calculate PAWC values. Even where deeper profiles occur (ERD >0.4 m), maximum PAWC levels (100–140 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, clay surface; surface sealing and dispersive behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9065 and 9066 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is relatively uniform throughout both mound (50–70%) and depression (50–55%) profiles, although immediate surface horizons are often lighter (45–50%). Significant fine sand (35%) and silt (15%) in the surface soil of both gilgai components promote surface sealing behaviour. CEC/Clay% ratios in both profiles are mostly 0.5–0.7 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (i.e. basaltic clay with considerable colluvial/depositional influence). Measured dispersion (R1 ratio) in the upper subsoil is only moderate (0.65–0.8), but increases to very high levels (0.95–0.99) in the lower subsoil (irrespective of gilgai component), because of increased sodicity levels (ESP 15–20). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9065 and 9066 are presented in Appendix 3.

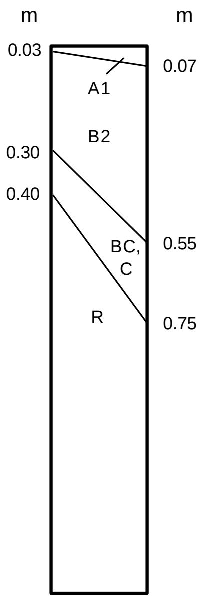
The laboratory pH measured for profiles 9065 and 9066 is neutral to acidic throughout (on both mounds and in depressions), suggesting measured values for the upper subsoil are somewhat atypical. Normal pH ranges are listed in the profile description above. CEC levels are uniformly high (28–38 meq/100 g) throughout both mound and depression profiles. Magnesium (Mg) is the dominant cation in both cases, while the relative sub-dominance of calcium (Ca) and sodium (Na) vary with depth. Profiles are mostly non-sodic (ESP <6) in the immediate surface soil, becoming sodic (ESP 8–15) in the upper subsoil and strongly sodic (ESP 16–20) in the lower subsoil. Detailed chemical data from representative profiles 9065 and 9066 are presented in Appendix 3.

INDICUS SHALLOW PHASE (IdSp)

Concept:	A shallow, stony version of the Indicus (Id) soil over fresh basalt from 0.3–0.55 m. Brigalow vegetation.
Aust. Soil Classification:	Black Vertosol.
Great Soil Group:	Black earth.
Principal Profile Form:	Ug5.12.
Geology:	Fresh Tertiary basalt (Tb).
Landform:	Gently undulating plains and rises associated with basalt flows near May Downs, Tiny Downs and in the Barmount area. Restricted to occasional rocky slopes and crests. Slopes 0.5 to 3%.
Vegetation Associations:	Brigalow with shrubs (VA8) or Brigalow (VA1).
Microrelief:	Absent.
Runoff:	Slow to moderately rapid.
Permeability:	Slow.
Drainage:	Moderately well drained.
Surface Features:	Cracking with a fine (<1 to 2 mm), strongly self-mulching surface. Frequently 10 to >50% basalt rocks 20 to 200 mm or 2 to 10% basalt outcrop.

Representative Profile: **9079**

Typical Profile



Soil Description

The **surface soil** (A1) is a black, medium clay to medium heavy clay with strong granular structure. Depths typically range from 0.03 to 0.07 m. Field pH is 6.5–9.5.

The **subsoil** (B2) is a black, medium heavy clay to heavy clay with strong lenticular structure. It is frequently calcareous with <2–10% soft or nodular carbonate. Field pH is 7–9.5.

Weathered **substrate** (BC, C) is normally present from 0.3–0.55 m. Substrate material is fresh basalt which is typically brown or grey and frequently calcareous. Field pH of 7.5–9.5.

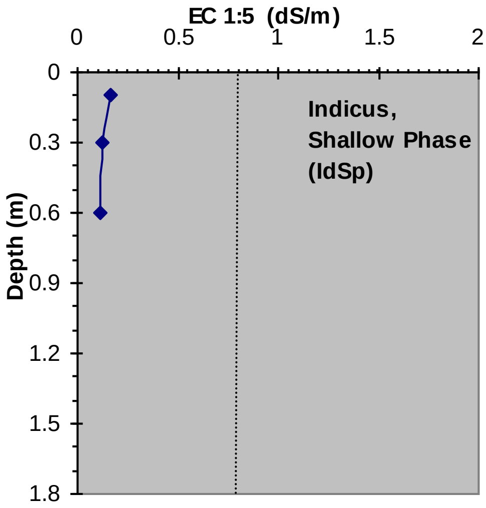
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P Bicarb. (mg/kg)	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Exchangeable Cations [2] Ca (meq/100g)	Mg (meq/100g)
7.1	1.4	0.09	18	0.57	26	34	2.5	0.83	27	21
neutral	low	high	high	high	-	moderate	moderate	moderate	very high	very high

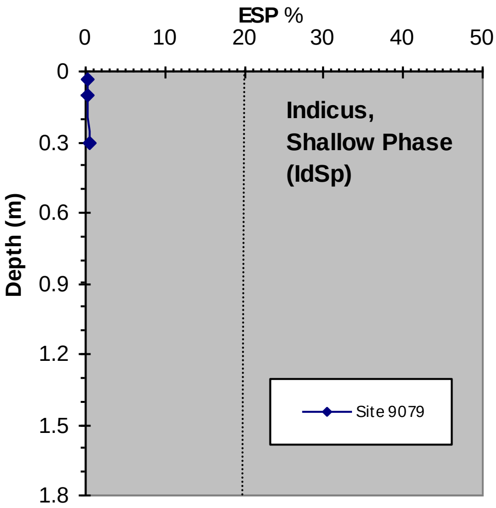
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are high. Most other nutrients are moderate to very high. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the Indicus shallow phase (IdSp) soil. The profile salinity curve is in equilibrium throughout (salt bulge is not developed) indicating significant drainage normally moves below the profile. Sodicity levels within the profile (ESP <1) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.30	**0.51**	0.71	52	**85**	119

Typically, PAWC levels for the Indicus shallow phase (IdSp) soil are low (approximately 85 mm) because mean ERD is <0.5 m. It is restricted by the presence of weathered basalt at relatively shallow depths in most profiles. Restrictions to rooting depth are generally absent in the profile itself. Where deeper profiles occur (ERD >0.5 m), maximum PAWC levels (85–120 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9079 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (60–70%) throughout the profile, but decreases in the underlying weathered basaltic substrate (25%), where appreciable levels of coarse sand, fine sand and silt occur. CEC/Clay% ratios in the profile are 1.1–1.2 and indicate the clay fraction is montmorillonitic. Ratios as high as 2.2 are present in the underlying weathered basalt. Measured dispersion (R1 ratio) in the profile is low (0.3–0.5) throughout because of very high levels of exchangeable calcium (Ca) and very low sodicity levels (ESP <1). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9079 are presented in Appendix 3.

Subsoil Chemistry

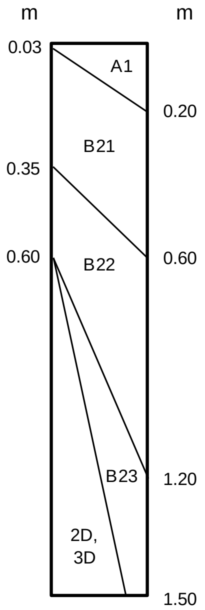
Laboratory pH is similar to field pH (see profile description). CEC levels are very high (70–75 meq/100 g) throughout the profile, and also in the underlying weathered substrate (50 meq/100 g). Calcium (Ca) is the dominant cation down the profile, although significant magnesium (Mg) is usually also present. Profiles are non-sodic (ESP <1) throughout. Detailed chemical data from representative profile 9079 are presented in Appendix 3.

ISAAC (Is)

Concept: A hard setting or firm pedal, silty surfaced, neutral or alkaline, black non-cracking to cracking clay over recent alluvium on scroll plains, channel benches and active levees on flood plains. Eucalypt vegetation.
Aust. Soil Classification: Black Dermosol; Black Vertosol.
Great Soil Group: No suitable group.
Principal Profile Form: Uf6.32, Ug5.15, 5.16, 5.17.
Geology: Quaternary alluvium (Qa).
Landform: Low lying channel benches, active levees, scroll plains and channelled river flats on flood plains and some lower tributaries. Flooded by high velocity events. ARI ranges from more frequent than 1 in 2 years down to 1 in 10 years. Slopes <0.5 to 1%.
Vegetation Associations: Coolibah–mixed eucalypts (VA38), Blue gum–mixed eucalypts (VA22) or Coolibah (VA11).
Microrelief: Absent.
Runoff: Very slow to moderately rapid.
Permeability: Slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Frequently cracking with a hard setting or firm pedal surface.

Representative Profiles: **9105, 9109, 9110**

Typical Profile



Soil Description

The **surface soil** (A1) is a black, light medium clay to medium heavy clay (frequently fine sandy or silty) with moderate or strong blocky structure. Depths typically range from 0.03 to 0.2 m. Field pH is 6.5–7.

The **upper subsoil** (B21) is a black, medium clay to medium heavy clay with moderate or strong blocky structure. Field pH is 6.5–9.5.

The **lower subsoil** (B22, B23) is a black or brown, medium clay to medium heavy clay with moderate or strong blocky or lenticular structure. It is normally calcareous with 2–10% soft or nodular carbonate. Field pH is 8.5–9.5.

Buried alluvial layers (2D, 3D) are sometimes present from 0.6–>1.5 m. Buried materials are typically a brown or black, loamy sand to fine sandy medium heavy clay with structure that ranges from massive to strong blocky or lenticular. They are normally calcareous with 2–20% soft or nodular carbonate. Field pH is 7–9.5.

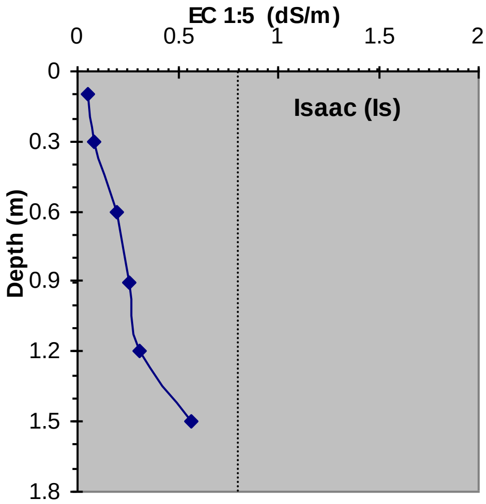
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.5	1.7	0.11	52	0.80	69	40	2.4	1.3	21	12
neutral	moderate	high	very high	high	-	moderate	moderate	moderate	very high	high

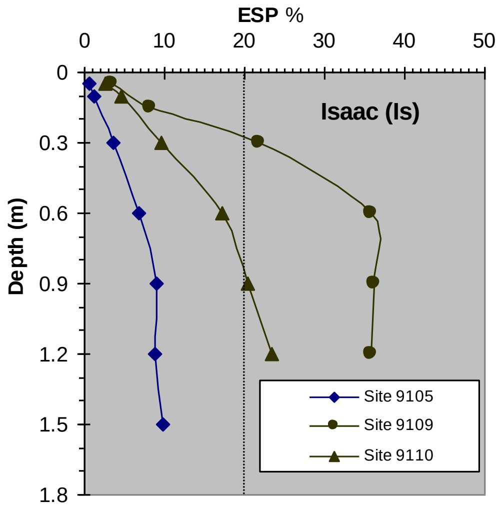
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are high while phosphorus (Bicarb. P) levels are very high Most other nutrients are moderate to very high. Elevated phosphorus (Bicarb. P) and potassium (K) levels reflect the young age and recent alluvial origins of this soil. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Isaac (Is) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Critical sodicity levels (ESP >20) often occur in the lower subsoil, but are substrate dependent and vary in depth (below 0.3–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.77	**1.20**	1.63	109	**139**	169

Typically, PAWC levels for the Isaac (Is) soil are high (approximately 140 mm) with a mean ERD of about 1.2 m. It is restricted only by physical limitations and reduced permeability in the lower subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >1.2 m), maximum PAWC levels (140–170 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy or silty, clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9105, 9109 and 9110 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases gradually from 35–45% in the surface soil to 45–60% in the subsoil. High levels of silt (30–35%) and lesser fine sand (20–35%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the profile are 0.55–0.75 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (depending on sediment source). Measured dispersion (R1 ratio) in the surface soil is low (0.5–0.6) but gradually increases to moderate or high levels (0.7–0.9) in the lower subsoil because of increasing sodicity. High Total K levels throughout the profile reflect the young age and recent alluvial origins of this soil. Detailed physical data from representative profiles 9105, 9109 and 9110 are presented in Appendix 3.

Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are moderate to high (20–40 meq/100 g) in the surface soil and consistently high (25–40 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while calcium (Ca) and magnesium (Mg) are often co-dominant in the lower subsoil. Profiles are typically non-sodic (ESP <6) in the surface soil, but become sodic to extremely sodic (ESP 8–35) in the subsoil, depending on sediment source and sediment chemistry. Detailed chemical data from representative profiles 9105, 9109 and 9110 are presented in Appendix 3.

KIRKCALDY (Kc)

Concept: A hard setting, firm pedal or weakly to strongly self-mulching, alkaline, black or brown non-cracking to cracking clay over unconsolidated, calcareous sediments from 0.3–1.1 m. Eucalypt vegetation.

Aust. Soil Classification: Black, Brown (or occasionally Red) Dermosol; Black, Brown (or occasionally Red) Vertosol.

Great Soil Group: Brown clay, no suitable group, red clay.

Principal Profile Form: Uf6.31, Ug5.13; occasionally Uf6.32, Ug5.12, 5.15, 5.38.

Geology: Unconsolidated calcareous Tertiary–Quaternary sediments (TQa_b). Mainly relict alluvial deposits sourced from basaltic or andesitic landscapes in the Isaac–Connors and Mackenzie River catchments. Fine grained basaltic derived sediment, clay, marl, secondary carbonate deposits, gravel beds and sand lenses.

Landform: Gently undulating plains and low rises. Often as sideslopes to broad gentle ridges. Slopes mostly 1 to 3%, occasionally <1% on plains and up to 4% on sideslopes.

Vegetation Associations: Mountain coolibah (VA19), Silver-leaved ironbark (VA17) or Ironbark–bloodwood–ghost gum (VA43).

Microrelief: Occasionally weakly developed linear gilgai VI 0.05–0.1 m, HI 7–10 m; frequently with a prominent shelf and indistinct mounds and depressions.

Runoff: Slow to moderately rapid.

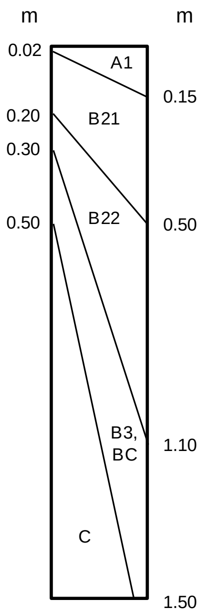
Permeability: Slow.

Drainage: Moderately well drained.

Surface Features: **Non-gilgaied/shelf/mound** - frequently cracking with a hard setting, firm pedal or fine (<2 mm), weakly to strongly self-mulching surface.
Depression - cracking with a coarse (2 to 5 mm), weakly to strongly self-mulching surface.
Frequently 2 to 10% silcrete or water worn quartz gravels 6 to 60 mm and occasionally 2 to 10% sandstone rocks 60 to 200 mm. A weak surface seal with a well developed flake and thin sandy veneer forms after rain.

Representative Profile: **9072**

Typical Profile



Soil Description

The **surface soil** (A1) is a black, sandy light clay to sandy medium clay with moderate blocky or strong granular structure. Depths typically range from 0.02 to 0.15 m. Field pH is 6.5–7.5.

The **upper subsoil** (B21) is a black, medium clay to heavy clay with strong blocky or lenticular structure. Field pH is 7–9.5.

The **lower subsoil** (B22) is a brown or black, medium clay to heavy clay with strong lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Substrate material is normally present from 0.3–1.1 m and consists of marl, gravel beds or unconsolidated, calcareous, fine sandy clay sediments. Field pH is 8.5–9.5.

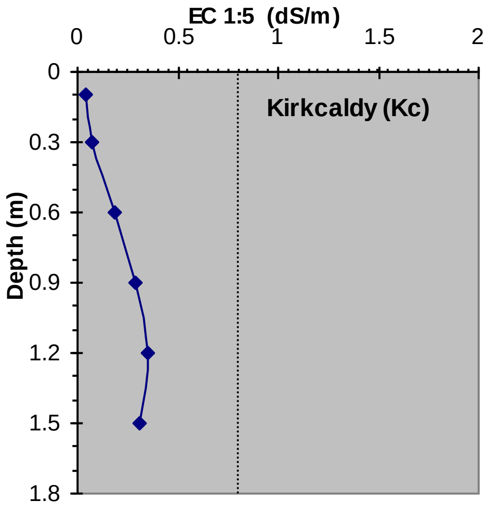
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.2	1.4	0.07	11	0.31	12	16	0.52	0.21	13	7.9
neutral	low	moderate	moderate	moderate	-	moderate	moderate	very low	high	high

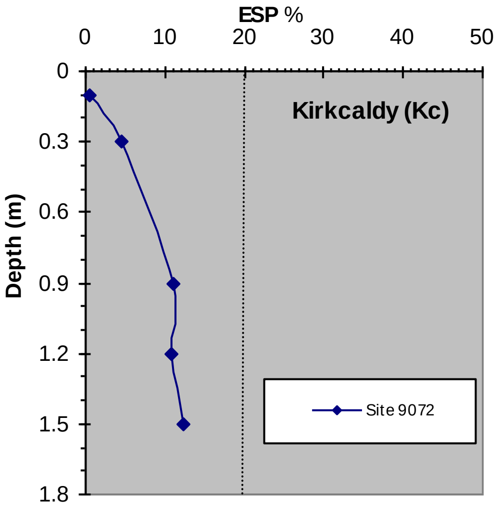
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are moderate. Most other nutrients are moderate to high with the exception of zinc (Zn) which is very low. Elevated calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying, calcareous, basaltic-derived, unconsolidated sediments. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Kirkcaldy (Kc) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Sodicity levels in the subsoil (ESP <6–12) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.56	**1.04**	1.53	71	**126**	180

Typically, PAWC levels for the Kirkcaldy (Kc) soil are only moderate (approximately 125 mm) because mean ERD is <1.1 m. It is restricted by the presence of hard calcareous material or other unconsolidated substrate (sand, gravel, basaltic sediments). Even where deeper profiles occur (ERD >1.1 m), maximum PAWC levels (125–180 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, sandy, clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9072 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content increases gradually between the surface soil (25–35%) and the subsoil (40–55%), while high levels of fine sand (40–50%) in the surface soil promote surface sealing behaviour. CEC/Clay% ratios in the profile are 0.55–0.8 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (i.e. derived from basaltic sediments). Measured dispersion (R1 ratio) is low (0.35–0.6) throughout the profile and corresponds with low sodicity levels (ESP <5). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9072 are presented in Appendix 3.

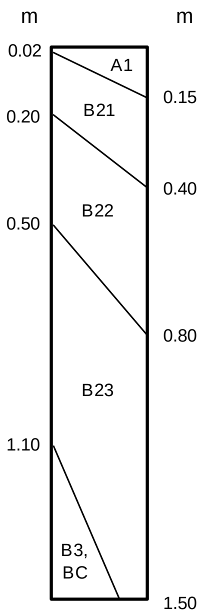
Laboratory pH is similar to field pH (see profile description). CEC levels are moderate (15–20 meq/100 g) in the surface soil and subsoil, increasing to high levels (28–30 meq/100 g) in the underlying substrate. Calcium (Ca) and magnesium (Mg) are co-dominant in the upper part of the profile, but magnesium (Mg) becomes consistently dominant in the lower subsoil and substrate. Profiles are non-sodic (ESP <6) throughout, although sodicity levels increase marginally (ESP 10–12) in the underlying unconsolidated substrate. Detailed chemical data from representative profile 9072 are presented in Appendix 3.

KNOCKANE (Kk)

Concept: A hard setting, firm pedal or weakly self-mulching, alkaline, grey non-cracking to cracking clay, frequently with normal gilgai (VI 0.1–0.3 m), over unconsolidated, calcareous sediments below 1.1–>1.5 m. Brigalow vegetation.
Aust. Soil Classification: Grey (or occasionally Black) Dermosol; Grey (or occasionally Black) Vertosol.
Great Soil Group: Grey clay, no suitable group.
Principal Profile Form: Uf6.33, Ug5.24, 5.28, 5.16.
Geology: Unconsolidated calcareous Tertiary–Quaternary sediments (TQa_b). Mainly relict alluvial deposits sourced from basaltic or andesitic landscapes in the Isaac–Connors and Mackenzie River catchments. Fine grained basaltic-derived sediment, clay, marl, gravel beds and sand lenses.
Landform: Level to gently undulating plains. Slopes 0.5 to 1.5%, occasionally up to 3%.
Vegetation Associations: Brigalow (VA1) or Brigalow–Dawson gum (VA5); occasionally Brigalow with shrubs (VA8).
Microrelief: Frequently normal gilgai VI 0.1–0.3 m, HI 8–15 m; occasionally non-gilgaied or with a prominent shelf and indistinct mounds and depressions.
Runoff: Slow on mounds and shelves; no runoff in depressions.
Permeability: Slow.
Drainage: Moderately well drained.
Surface Features: **Mound/shelf -** frequently cracking with a hard setting, firm pedal or fine (<2 mm), weakly self-mulching surface.
Depression - cracking with a fine (<2 mm), weakly to moderately self-mulching surface. Frequently <2 to 20% silcrete or water worn quartz and sandstone gravels 6 to 60 mm.

Representative Profiles: **9111, 9116**

Typical Profile



Soil Description – Mound/shelf profile

The **surface soil** (A1) is a black, sandy light clay to sandy light medium clay with moderate or strong blocky structure. Depths typically range from 0.02 to 0.15 m. Field pH is 6.5–8.

The **upper subsoil** (B21, B22) is a grey, light medium clay to medium heavy clay (frequently sandy or fine sandy) with moderate to strong blocky or lenticular structure. It is normally calcareous with 2–50% soft or nodular carbonate. Field pH is 8–9.5.

The **lower subsoil** (B23) is a grey, light medium clay to medium heavy clay (frequently sandy or fine sandy) with weak to strong coarse lenticular or moderate polyhedral structure. Field pH is 8–9.5, but decreases with depth to <6 where substrate material is absent.

Substrate material is sometimes present below 1.1–>1.5 m and consists of marl or unconsolidated, calcareous, fine sandy clay sediments. Field pH is 8.5–9.5. In deep profiles (>1.5 m) acid clay continues at depth.

Soil Description – Depression profile

Depression profiles have similar horizons, depths and morphology to non-gilgaied and mound/shelf profiles.

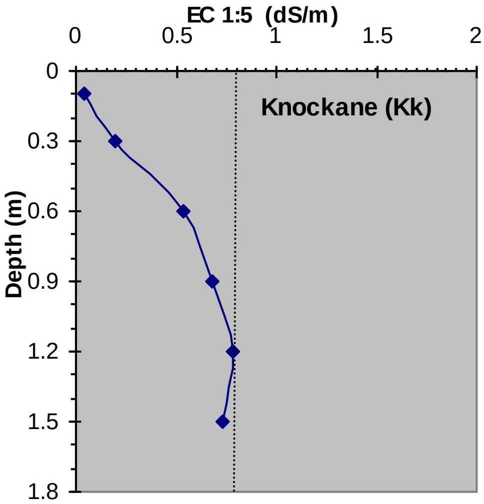
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.6	1.4	0.10	13	0.20	21	20	0.77	0.31	14	5.3
alkaline	low	high	moderate	low	-	moderate	moderate	low	high	high

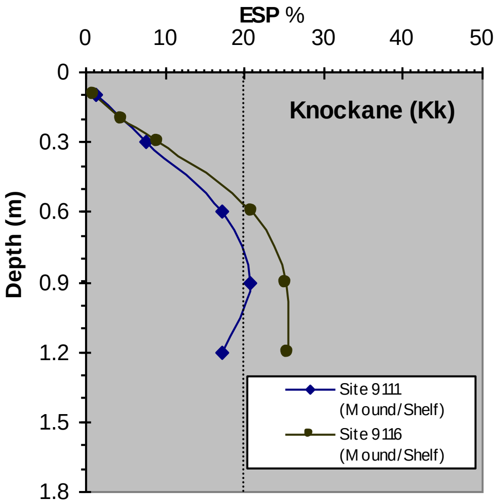
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are high while phosphorus (Bicarb. P) levels are moderate. Most other nutrients are low to moderate with the exception of calcium (Ca) and magnesium (Mg) which are high. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying calcareous, basaltic-derived, unconsolidated sediments. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 1.1–1.2 m in the Knockane (Kk) soil. The profile salinity curve reaches equilibrium between 1.0 and 1.2 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below 0.6–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.71	**1.12**	1.53	105	**139**	172

Typically, PAWC levels for the Knockane (Kk) soil are high (approximately 140 mm) with a mean ERD of about 1.1 m. It is restricted by high salinity levels (EC >0.8 dS/m) and/or physical limitations and reduced permeability in the lower subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >1.1 m), maximum PAWC levels (140–170 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, sandy, clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9111 and 9116 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases gradually between the surface soil (30–40%) and the subsoil (35–45%), while high levels of fine sand (40–45%) in the surface soil promote surface sealing behaviour. CEC/Clay% ratios in the profile are 0.7–0.8 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (i.e. derived from basaltic sediments). Measured dispersion (R1 ratio) in the surface soil and upper subsoil is low (0.3–0.55), but gradually increases to moderate or high levels (0.7–0.95) in the lower subsoil because of high to very high sodicity levels (ESP 15–25). Detailed physical data from representative profiles 9111 and 9116 are presented in Appendix 3.

Subsoil Chemistry

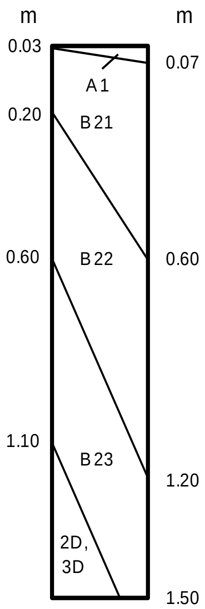
Laboratory pH is similar to field pH (see profile description). CEC levels are high (25–35 meq/100 g) throughout the profile. Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while magnesium (Mg) becomes dominant in the lower subsoil. Profiles are non-sodic (ESP <6) in the immediate surface soil, but become sodic (ESP 7–10) in the upper subsoil and strongly or extremely sodic (ESP 17–25) at depth. Detailed chemical data from representative profiles 9111 and 9116 are presented in Appendix 3.

LANGLEY (Lg)

Concept: A strongly self-mulching, alkaline, black cracking clay over recent alluvium on level flood plains. Brigalow vegetation.
Aust. Soil Classification: Black (or occasionally Grey) Vertosol.
Great Soil Group: Black earth, occasionally grey clay.
Principal Profile Form: Ug5.15, 5.16, 5.17; occasionally Ug5.24, 5.28.
Geology: Quaternary alluvium (Qa).
Landform: Low lying, extensive, level flood plains along major rivers. Flooded by low to high velocity events, depending on flood plain position. ARI ranges from more frequent than 1 in 2 years down to 1 in 10 years. Occasionally on alluvial plains along upper and lower tributaries in catchments developed from basalt (Tb) or other labile sediments (Pw, TQa$_b$). Slopes <1%.
Vegetation Associations: Brigalow–coolibah (VA6), Brigalow (VA1) or Brigalow with shrubs (VA8).
Microrelief: Either non-gilgaied (60%) or with indistinct normal gilgai (20%) VI 0.1–0.2 m, HI 5–15 m; or occasionally shallow, melonhole gilgai (20%) VI 0.3–0.6 m, HI 10–20 m.
Runoff: Very slow to slow.
Permeability: Slow.
Drainage: Moderately well drained (or occasionally poorly to imperfectly drained).
Surface Features: Cracking with a fine to coarse (<2 to 5 mm), strongly (or occasionally moderately) self-mulching surface. Variation between gilgai components is minimal, except occasionally <2 to 10% free carbonate nodules occur on mounds. A weak surface seal with a well developed flake frequently forms after rain.

Representative Profiles: **9031, 9080, 9081**

Typical Profile



Soil Description – Non-gilgaied/mound profile

The **surface soil** (A1) is a black, light medium clay to medium heavy clay with strong granular structure. Depths typically range from 0.03 to 0.07 m. Field pH is 7–9.5.

The **upper subsoil** (B21) is a black, medium heavy clay to heavy clay with moderate to strong lenticular or blocky structure. It is frequently calcareous with <2–10% soft or nodular carbonate. Field pH is 7–9.5.

The **lower subsoil** (B22, B23) is a black, brown or grey, medium heavy clay to heavy clay with strong, coarse lenticular structure. It is normally calcareous with <2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Buried alluvial layers (2D, 3D) are sometimes present from 1.1–>1.5 m. Buried materials are typically a black, brown or grey, light medium clay to meduim heavy clay (frequently sandy) with moderate or strong lenticular, blocky or polyhedral structure. They are frequently calcareous with 2–20% soft carbonate. Field pH is 8.5–9.5.

Soil Description – Depression profile

Depression profiles have similar horizons, depths and morphology to non-gilgaied or mound profiles.

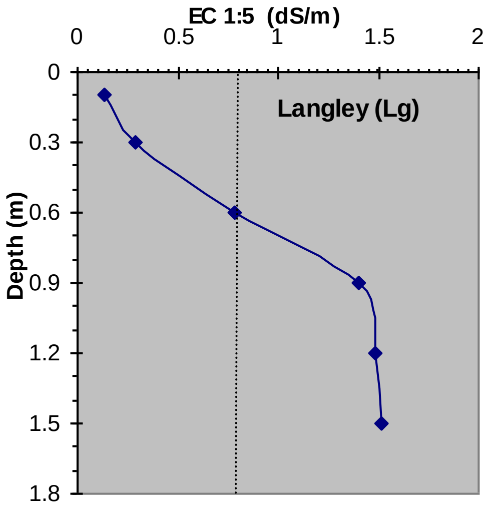
Surface Soil Fertility[1]

Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	8.1	1.3	0.09	39	1.09	23	9	1.8	0.44	35	17
	alkaline	low	high	high	very high	-	moderate	moderate	low	very high	very high
dep.	6.9	1.3	0.09	61	1.00	45	26	2.4	0.77	-	-
	neutral	low	high	very high	high	-	moderate	moderate	moderate	-	-

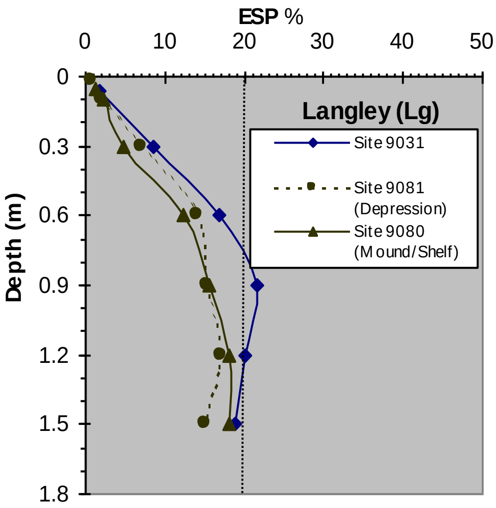
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility between gilgai components (non-gilgaied/mound versus depressions) were not observed. Typically, nitrogen (Total N) levels are high irrespective of gilgai component, while phosphorus (Bicarb. P) levels increase from high on mounds to very high in depressions. Most other nutrients are moderate to very high with similar levels on both gilgai components. The exception is zinc (Zn) which is generally lower on mounds. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P) and potassium (K) levels reflect the young age and recent alluvial origins of this soil. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.55–0.65 m in the Langley (Lg) soil. The profile salinity curve reaches equilibrium between 0.9 and 1.1 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Critical sodicity levels (ESP >20) often occur in the lower subsoil, but are substrate dependent and vary in depth (below about 0.6–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.29	**0.64**	1.00	85	**124**	164

Typically, PAWC levels for the Langley (Lg) soil are only moderate (approximately 125 mm) because mean ERD is <0.65 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is restricted by high salinity levels (EC >0.8 dS/m) and/or physical limitations and reduced permeability in the lower subsoil associated with ESP levels close to 20. Where deeper profiles occur (ERD >0.65 m), maximum PAWC levels (125–165 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9031, 9080 and 9081 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is relatively uniform (60–70%) throughout the profile, irrespective of gilgai component. CEC/Clay% ratios in the profile are 0.6–1.0 and indicate the clay fraction varies from mixed mineralogy with a high proportion of montmorillonite through to almost purely montmorillonitic (depending on sediment source). Measured dispersion (R1 ratio) in the surface soil and upper subsoil is low (0.4–0.6), but gradually increases to moderate or very high levels (0.7–0.99) because of high sodicity levels at depth. High Total K levels throughout the profile reflect the young age and recent alluvial origins of this soil. Detailed physical data from representative profiles 9031, 9080 and 9081 are presented in Appendix 3.

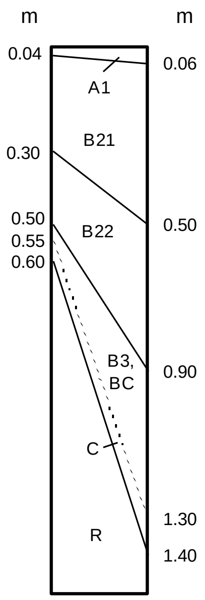
Laboratory pH is similar to field pH (see profile description). CEC levels are very high (40–75 meq/100 g) throughout the profile. Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while calcium (Ca) and magnesium (Mg) become co-dominant at depth. Profiles are non-sodic (ESP <6) in the surface soil and immediate upper subsoil, but gradually increase to strongly sodic (ESP 15–20) at depth. Detailed chemical data from representative profiles 9031, 9080 and 9081 are presented in Appendix 3.

LEITRIM (Lt)

Concept: A strongly self-mulching, alkaline, red or brown cracking clay over partially altered basalt from 0.5–0.9 m. Brigalow vegetation.
Aust. Soil Classification: Red or Brown Vertosol.
Great Soil Group: Red clay, brown clay.
Principal Profile Form: Ug5.37, 5.32.
Geology: Partially altered Tertiary basalt (Tb_a).
Landform: Gently undulating plains and rises associated with partially altered basalt flows near May Downs, Tiny Downs and in the Barmount area. Slopes 1 to 3%.
Vegetation Associations: Brigalow with shrubs (VA8) or Brigalow (VA1).
Microrelief: Absent.
Runoff: Slow.
Permeability: Slow.
Drainage: Moderately well drained.
Surface Features: Cracking with a fine (<1 to 2 mm), strongly self-mulching surface and <2 to 10% free carbonate nodules. Frequently 2 to 10% silcrete gravels 6 to 20 mm.

Representative Profiles: **Not sampled** (see site 9076 from the Indicus (Id) soil).

Typical Profile



Soil Description

The **surface soil** (A1) is a red or brown, medium clay with strong granular structure. Depths typically range from 0.04 to 0.06 m. It is frequently calcareous with <2% nodular carbonate. Field pH is 6–8.

The **upper subsoil** (B21) is a red or brown, medium clay to medium heavy clay with strong lenticular structure. It is frequently calcareous with <2% nodular carbonate. Field pH is 7–8.5.

The **lower subsoil** (B22) is a red or brown, medium clay to heavy clay with strong lenticular structure. It is frequently calcareous with 10–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (B3, BC, C) is normally present below 0.5–0.9 m. Substrate material is partially altered basalt which is typically brown or grey and frequently calcareous. Field pH is 8–9.5.

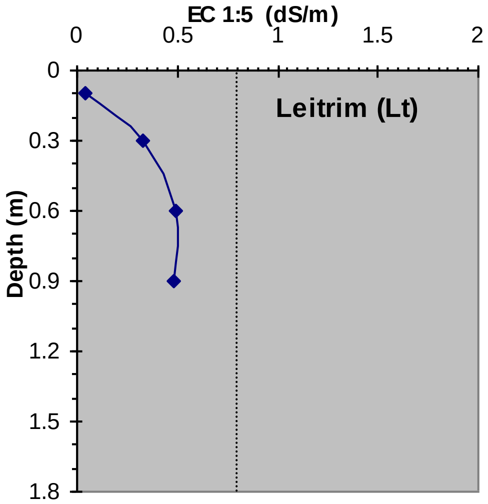
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.6	1.7	0.13	30	-	-	-	-	-	21	11
alkaline	moderate	high	high	-	-	-	-	-	very high	high

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are high. Comparison with the Battery (Bx) soil suggests most other nutrients would be moderate with the exception of calcium (Ca) and magnesium (Mg) which are high to very high. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P), calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Leitrim (Lt) soil. The profile salinity curve does not reach equilibrium (typical salt bulge is not developed) indicating significant drainage normally moves below the profile. Comparison with the Indicus (Id) soil suggests sodicity levels within the lower subsoil (ESP <10–15) are below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	-	**0.95**	-	-	**110**	-

Typically, PAWC levels for the Leitrim (Lt) soil are only moderate (approximately 110 mm) because mean ERD is <1.0 m. ERD is defined simply by the depth to weathered basalt. Restrictions to rooting depth are absent in the profile itself. Where deeper profiles occur (ERD >1.0 m), maximum PAWC levels, similar to those of the Indicus (Id) soil (130–150 mm) are achieved on a regular basis. The combination of high clay content and strong fine structure in the Leitrim (Lt) soil minimises deep drainage and evaporation losses, while strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available, but data from representative profile 9076 in Appendices 3 and 6 may be useful as a guide.

Physical Characteristics and Subsoil Chemistry

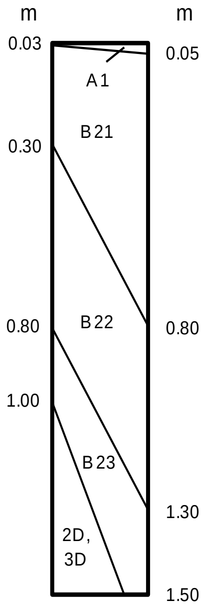
Interpretations and descriptions of the physical characteristics and chemistry of the Leitrim (Lt) soil are unavailable, but are probably comparable with those presented for the Indicus (Id) soil.

LINDSAY (Ld)

Concept: A strongly self-mulching, alkaline, black cracking clay over recent alluvuim on level flood plains. Eucalypt vegetation.
Aust. Soil Classification: Black (or occasionally Grey) Vertosol.
Great Soil Group: Black earth; occasionally grey clay.
Principal Profile Form: Ug5.15, 5.16, 5.17; occasionally Ug5.24, 5.28.
Geology: Quaternary alluvium (Qa).
Landform: Low lying, extensive, level flood plains and backplains along major rivers. Flooded by low to high velocity events, depending on flood plain position. ARI ranges from more frequent than 1 in 2 years down to 1 in 10 years. Occasionally on alluvial plains along upper and lower tributaries in catchments developed from basalt (Tb) or other labile sediments (Pw, TQa_b). Slopes <1% on flood plains, occasionally up to 2% on alluvial plains.
Vegetation Associations: Coolibah (VA11); occasionally Queensland bluegrass downs (VA28).
Microrelief: Occasionally weakly developed, indistinct normal gilgai VI 0.05–0.15 m, HI 5–8 m.
Runoff: Very slow (or occasionally slow).
Permeability. Slow (or occasionally very slow).
Drainage: Moderately well drained (or occasionally poorly to imperfectly drained).
Surface Features: Cracking with a coarse (2 to 5 mm), strongly (or occasionally moderately) self-mulching surface. Where gilgaied, mounds frequently have finer surface structure (<2 mm) and <2 to 20% free carbonate nodules. A weak surface seal with a well developed flake frequently forms after rain.

Representative Profiles: **9028, 9029, 9104**

Typical Profile



Soil Description – Non-gilgaied/mound profile

The **surface soil** (A1) is a black, light medium clay to medium heavy clay with strong, coarse granular structure. Depths typically range from 0.03 to 0.05 m. Field pH is 7–9.5.

The **upper subsoil** (B21) is a black, medium heavy clay to heavy clay with moderate or strong lenticular structure. It is frequently calcareous with <2–10% soft or nodular carbonate. Field pH is 8–9.5.

The **lower subsoil** (B22, B23) is a black or brown, medium heavy clay to heavy clay with strong, coarse lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Buried alluvial layers (2D, 3D) are sometimes present from 1.0–>1.5 m. Buried materials are typically a brown or grey, coarse sand to heavy clay with massive or weak to strong blocky or lenticular structure. They are frequently calcareous with <2–20% soft or nodular carbonate. Field pH is 9–9.5.

Soil Description – Depression profile

Depression profiles have similar horizons, depths and morphology to non-gilgaied or mound profiles.

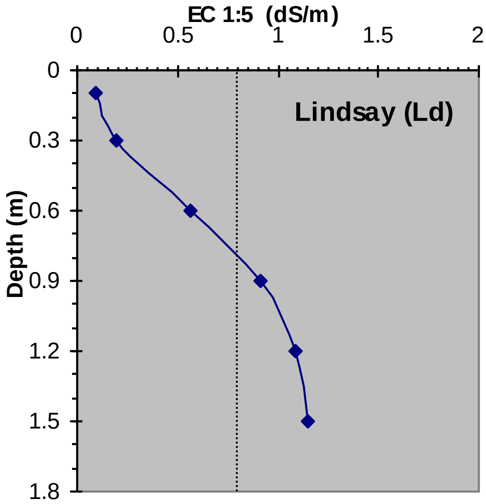
Surface Soil Fertility[1]

Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	8.4	0.95	0.06	24	1.01	23	14	1.9	0.50	39	29
	alkaline	low	moderate	high	very high	-	moderate	moderate	low	very high	very high
dep.	8.6	1.0	0.05	24	1.44	22	15	1.7	0.47	-	-
	strongly alkaline	low	moderate	high	very high	-	moderate	moderate	low	-	-

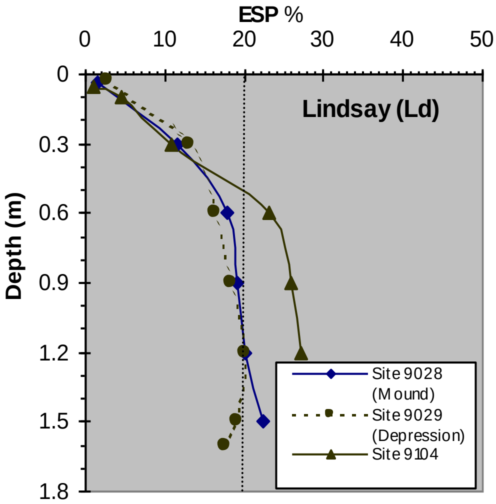
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility between gilgai components (non-gilgaied/mound versus depression) were not observed. Typically, nitrogen (Total N) levels are moderate and phosphorus (Bicarb. P) levels are high, irrespective of gilgai component. Most other nutrients are moderate to very high with similar levels on both gilgai components. The exception is zinc (Zn) which is low throughout. Elevated phosphorus (Bicarb. P) and potassium (K) levels reflect the young age and recent alluvial origins of this soil. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.75–0.85 m in the Lindsay (Ld) soil. The profile salinity curve reaches equilibrium between 1.2 and 1.5 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below about 0.6–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.44	**0.84**	1.24	96	**140**	184

Typically, PAWC levels for the Lindsay (Ld) soil are high (approximately 140 mm) even though mean ERD is only about 0.85 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Where deeper profiles occur (ERD >0.85 m), maximum PAWC levels (140–185 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9028, 9029 and 9104 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is relatively uniform (55–70%) throughout the profile. Clay contents in buried alluvial layers range from 10 to 45%, often with significant coarse sand (>60%). CEC/Clay% ratios in the profile are 0.65–1.1 and indicate the clay fraction varies from mixed mineralogy with a high proportion of montmorillonite through to almost purely montmorillonitic (depending on sediment source). Measured dispersion (R1 ratio) in the surface soil and upper subsoil is low (0.4–0.6), but gradually increases to moderate or high levels (0.75–0.9) because of high to very high sodicity levels (ESP >15). Moderate to high Total K levels throughout the profile reflect the young age and recent alluvial origins of this soil. Detailed physical data from representative profiles 9028, 9029 and 9104 are presented in Appendix 3.

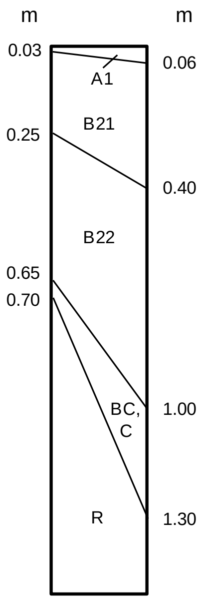
Laboratory pH is similar to field pH (see profile description). CEC levels are very high (40–70 meq/100 g) throughout the profile, but vary from moderate to high (15–45 meq/100 g) in buried alluvial layers depending on the nature of the buried material. Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while either calcium (Ca) or magnesium (Mg) may be dominant or co-dominant in the lower subsoil. Profiles are non-sodic (ESP <5) in the surface soil and immediate upper subsoil, but gradually increase to strongly or extremely sodic (ESP 17–27) at depth. Detailed chemical data from representative profiles 9028, 9029 and 9104 are presented in Appendix 3.

MAY (My)

Concept: A strongly self-mulching, alkaline, black cracking clay over fresh basalt from 0.65–1.0 m. Eucalypt vegetation or open downs.
Aust. Soil Classification: Black Vertosol.
Great Soil Group: Black earth.
Principal Profile Form: Ug5.12; occasionally Ug5.14, 5.16.
Geology: Fresh Tertiary basalt (Tb).
Landform: Gently undulating plains and rises associated with basalt flows near May Downs, Tiny Downs and in the Barmount area. Mostly broad gentle ridges with long sideslopes. Slopes 0.5 to 3%.
Vegetation Associations: Gum-topped bloodwood (VA16) or Queensland bluegrass downs (VA28); occasionally Mountain coolibah (VA19) or Coolibah (VA11) on lower footslopes adjacent to alluvium.
Microrelief: Occasionally weakly developed linear gilgai VI <0.1 m, HI 5–8 m.
Runoff: Slow (or occasionally moderately rapid).
Permeability: Slow.
Drainage: Moderately well drained.
Surface Features: Cracking with a coarse (2 to 10 mm), strongly self-mulching surface. Where gilgaied, mounds have finer structure (<2 to 5 mm) and <2 to 10% free carbonate nodules. Occasionally <2 to 10% silcrete or ferruginised siltstone gravels 6 to 60 mm and <2% basalt rocks 60 to 200 mm.

Representative Profiles: **9089, 9090**

Typical Profile



Soil Description – Non-gilgaied/mound profile

The **surface soil** (A1) is a black, medium clay to heavy clay with strong, coarse granular structure. Depths typically range from 0.03 to 0.06 m. Field pH is 7–9.

The **upper subsoil** (B21) is a black, medium heavy clay to heavy clay with moderate to strong, lenticular or blocky structure. It is frequently calcareous with <2–10% nodular carbonate. Field pH is 7–9.5.

The **lower subsoil** (B22) is a black, medium heavy clay to heavy clay with strong, coarse lenticular structure. It is normally calcareous with 2–20% nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (BC, C) is normally present below 0.65–1.0 m. Substrate material is fresh basalt. Typically it is brown or grey and frequently calcareous. Field pH is 8–9.5.

Soil Description – Depression profile

Depression profiles generally have similar horizons, depths and morphology, but differ in colour and pH in the upper profile. The A1 and B21 horizons are usually darker, non-calcareous and have a field pH of only 6–7.

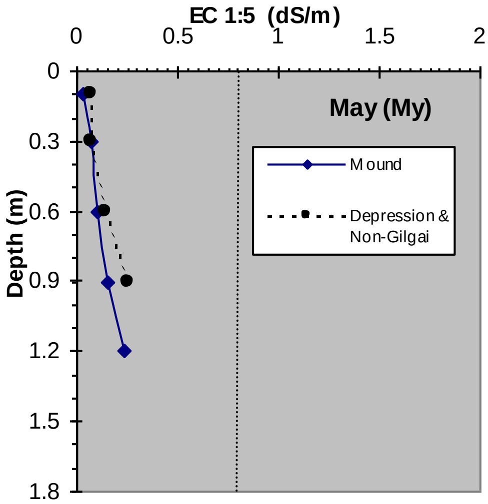
Surface Soil Fertility[1]

Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	7.7	0.99	0.06	6	0.38	18	19	1.3	0.35	41	29
	alkaline	low	moderate	low	moderate	-	moderate	moderate	low	very high	very high
dep.	7.4	0.98	0.06	9	0.36	32	42	1.9	0.39	36	31
	neutral	low	moderate	low	moderate	-	moderate	moderate	low	very high	very high

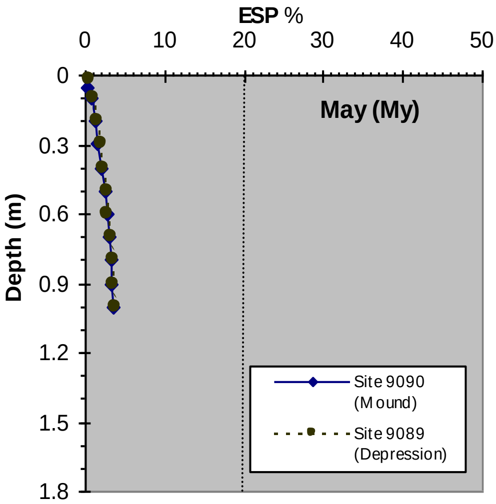
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility between gilgai components (non-gilgaied/mound versus depression) were not observed. Typically, nitrogen (Total N) levels are moderate and phosphorus (Bicarb. P) levels are low, irrespective of gilgai component. Most other nutrients are moderate to very high with similar levels on both gilgai components. The exception is zinc (Zn) which is low throughout. Elevated calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data ($EC_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the May (My) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Weathered substrate is normally present somewhere below 0.65–1.0 m and contributes to slight increases in salinity levels at depth. Sodicity levels within the profile (ESP <3.5) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.66	**0.88**	1.11	100	**133**	166

Typically, PAWC levels for the May (My) soil are high (approximately 135 mm) even though mean ERD is <0.9 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is defined simply by the depth to weathered basalt. Restrictions to rooting depth are absent in the profile itself. Where deeper profiles occur (ERD >0.9 m), maximum PAWC levels (135–165 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9089 and 9090 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (65–75%) throughout the profile, but decreases in the underlying weathered substrate (30–60%), where appreciable weathered rock (coarse sand, fine sand and silt) is present. CEC/Clay% ratios in the profile are 1.1–1.25 and indicate the clay fraction is entirely montmorillonitic. Ratios in the underlying substrate (1.4–2.7) are typical of weathered basaltic material. Measured dispersion (R1 ratio) in the profile is low (0.25–0.5) throughout, because of very high exchangeable calcium (Ca) values and low sodicity levels (ESP <6). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9089 and 9090 are presented in Appendix 3.

Subsoil Chemistry

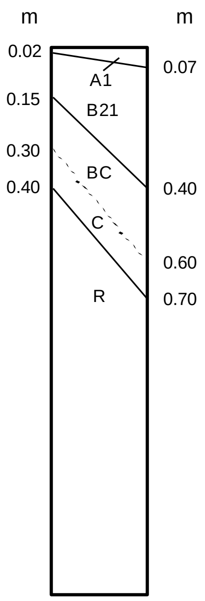
Laboratory pH is similar to field pH (see profile description). CEC levels are very high (70–88 meq/100 g) throughout the profile and also in the underlying weathered substrate. While the levels of calcium (Ca) and magnesium (Mg) are both very high, the relative dominance of the two cations down the profile is not consistent. In general, the two are either co-dominant or magnesium (Mg) is slightly more dominant. Profiles (including the underlying weathered substrate) are non-sodic throughout (ESP <3.5). Detailed chemical data from representative profiles 9089 and 9090 are presented in Appendix 3.

MAY SHALLOW PHASE (MySp)

Concept: A shallow, stony version of the May (My) soil over fresh basalt from 0.15–0.4 m. Eucalypt vegetation.
Aust. Soil Classification: Black Vertosol.
Great Soil Group: Black earth.
Principal Profile Form: Ug5.12.
Geology: Fresh Tertiary basalt (Tb).
Landform: Gently undulating plains and rises associated with basalt flows near May Downs, Tiny Downs and in the Barmount area. Restricted to occasional rocky slopes and crests. Slopes 0.5 to 3%, occasionally up to 5%.
Vegetation Associations: Gum-topped bloodwood (VA16); occasionally Queensland bluegrass downs (VA28) or Ironbark–bloodwood–ghost gum (VA43).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Slow.
Drainage: Moderately well drained.
Surface Features: Cracking with a coarse (2 to 10 mm), strongly self-mulching surface. Occasionally <2 to 50% basalt rocks 60 to 200 mm.

Representative Profile: **9064**

Typical Profile



Soil Description

The **surface soil** (A1) is a black, medium clay to heavy clay with strong, coarse granular structure. Depths typically range from 0.02 to 0.07 m. Field pH is 7–9.5.

The **subsoil** (B21) is a black, medium heavy clay to heavy clay with moderate to strong, blocky or lenticular structure. Field pH is 7.5–9.5.

Weathered **substrate** (BC, C) is normally present below 0.15–0.4 m. Substrate material is fresh basalt. Typically it is brown or grey and frequently calcareous. Field pH is 8–9.5.

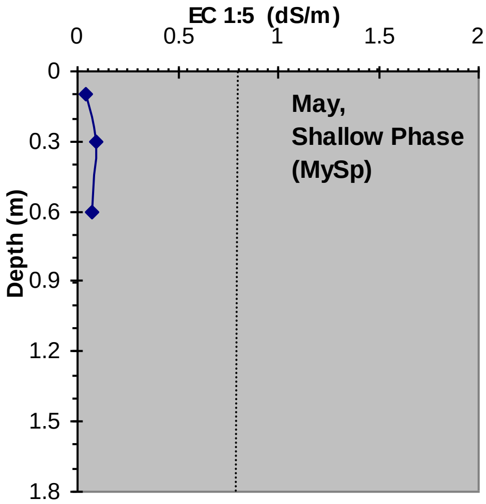
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)	(meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.5	1.1	0.07	11	1.10	18	12	1.8	0.46	58	25
neutral	low	moderate	moderate	very high	-	moderate	moderate	low	very high	very high

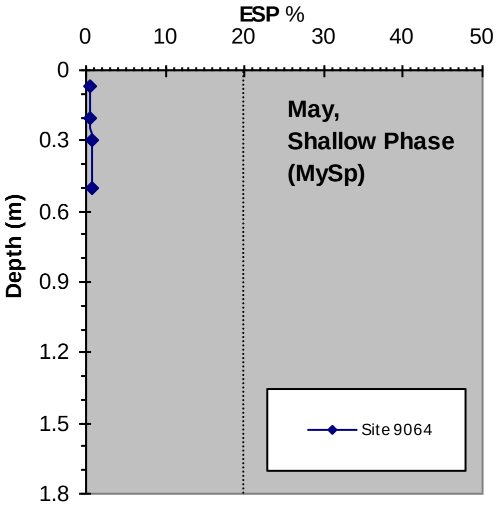
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are moderate. Most other nutrients are moderate to very high with the exception of zinc (Zn) which is low. Elevated calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the May shallow phase (MySp) soil. The profile salinity curve is in equilibrium throughout (salt bulge is not developed) indicating significant drainage normally moves below the profile. Sodicity levels within the profile (ESP <1) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**
	0.35	**0.44**	0.53	59	**78**	98

Typically, PAWC levels for the May shallow phase (MySp) soil are low (approximately 80 mm) because mean ERD is <0.45 m. It is restricted by the presence of weathered basalt at relatively shallow depths in most profiles. Restrictions to rooting depth are generally absent in the profile itself. Where deeper profiles occur (ERD >0.45 m), maximum PAWC levels (80–100 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9064 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (65–75%) throughout the profile, but decreases in the underlying weathered substrate (20–50%), where appreciable weathered rock (coarse sand, fine sand and silt) is present. CEC/Clay% ratios in the profile are 1.3–1.4 and indicate the clay fraction is entirely montmorillonitic. Ratios in the underlying substrate (1.7–3.5) are typical of weathered basaltic material. Measured dispersion (R1 ratio) in the profile is low (0.4–0.5) throughout, because of very high exchangeable calcium (Ca) values and low sodicity levels (ESP <6). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9064 are presented in Appendix 3.

Subsoil Chemistry

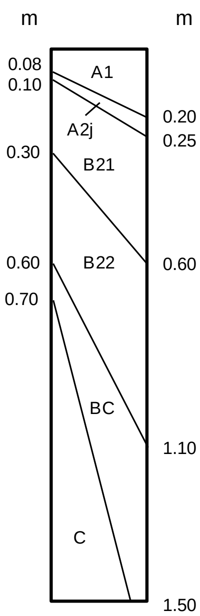
Laboratory pH is similar to field pH (see profile description). CEC levels are very high (65–95 meq/100 g) throughout the profile and also in the underlying weathered substrate. While the levels of calcium (Ca) and magnesium (Mg) are both very high, calcium (Ca) is consistently the dominant cation. Profiles (including the underlying weathered substrate) are non-sodic throughout (ESP <1). Detailed chemical data from representative profile 9064 are presented in Appendix 3.

MAYFAIR (Mf)

Concept: A hard setting, loamy or clay loamy surfaced, sporadically bleached, alkaline, brown or red, non-sodic texture contrast soil over unconsolidated, calcareous sediments from 0.6–1.1 m. Eucalypt vegetation.
Aust. Soil Classification: Brown or Red Chromosol.
Great Soil Group: Solodic soil, no suitable group.
Principal Profile Form: Db1.33, Dr2.13, Db1.13, Dy2.33; occasionally Db2.23, 2.33, Dy3.33.
Geology: Unconsolidated calcareous Tertiary–Quaternary sediments (TQa_b). Mainly relict alluvial deposits sourced from basaltic or andesitic landscapes in the Isaac–Connors and Mackenzie River catchments. Fine grained basaltic-derived sediment, clay, marl, gravel beds and sand lenses.
Landform: Gently undulating plains and low rises. Slopes mostly 1 to 3%, occasionally <1% on plains.
Vegetation Associations: Silver-leaved ironbark (VA17) or Poplar box (VA20); occasionally Narrow-leaved ironbark (VA12), Poplar box–ironbark (VA34) or Mountain coolibah (VA19).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Very slow to slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Hard setting. Frequently <2 to 10% silcrete or quartz gravels 6 to 60 mm.

Representative Profile: **9058**

Typical Profile



Soil Description

The **surface soil** (A1, A2j) is a brown or black, sandy loam to sandy clay loam with massive structure. Depths typically range from 0.1 to 0.25 m. A sporadically bleached layer is frequently developed immediately above the clay subsoil. Field pH is 6–7.

The **upper subsoil** (B21) is a brown or red, light medium clay to medium heavy clay (frequently sandy) with moderate or strong blocky structure. Field pH is 6–7, increasing to 8.5 with depth.

The **lower subsoil** (B22) is a brown or red, light medium clay to medium heavy clay (frequently sandy) with moderate or strong blocky structure. It is frequently calcareous and manganiferous with 2–50% soft or nodular carbonate and 2–20% manganese veins. Field pH is 8.5–9.5.

Substrate material (BC, C) is normally present below 0.6–1.1 m and consists of marl or unconsolidated, calcareous, fine sandy clay sediments. Field pH is 9–9.5.

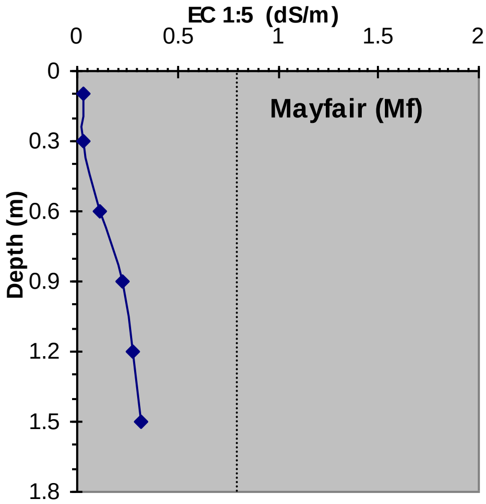
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.5	0.86	0.05	5	0.23	23	12	0.41	0.23	5.1	2.8
acid	low	moderate	very low	low	-	moderate	moderate	low	high	moderate

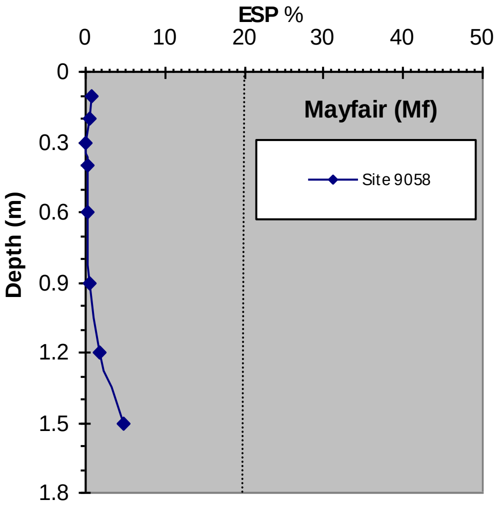
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are very low. Most other nutrients are low to moderate with the exception of calcium (Ca) which is borderline moderate–high. The phosphorus infertility of the Mayfair (Mf) soil reflects its leached, permeable (non-sodic) nature and the low phosphorus status of the underlying unconsolidated sediments. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Mayfair (Mf) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Sodicity levels in the subsoil (ESP <6) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.50	**1.01**	1.52	67	**113**	159

Typically, PAWC levels for the Mayfair (Mf) soil are only moderate (approximately 115 mm) even though mean ERD is around 1.0 m. Restrictions to rooting depth are generally absent, although unconsolidated substrate material (sand, gravel, basaltic sediments) often occurs below 1.0 m. Even where deeper profiles occur (ERD >1.0 m), maximum PAWC levels (115–160 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, loamy or clay loamy surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9058 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (15–25%) and the subsoil (35–45%), while high levels of fine sand (>60%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the subsoil are 0.7–0.9 and indicate the clay fraction is dominantly montmorillonitic. Ratios in the underlying unconsolidated substrate (1.05–1.1) indicate the material from which the soil has developed is of basaltic origins. Measured dispersion (R1 ratio) is low (0.3–0.5) throughout the subsoil (and underlying substrate) because of high to very high exchangeable calcium (Ca) values and low sodicity levels (ESP <6). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9058 are presented in Appendix 3.

Subsoil Chemistry

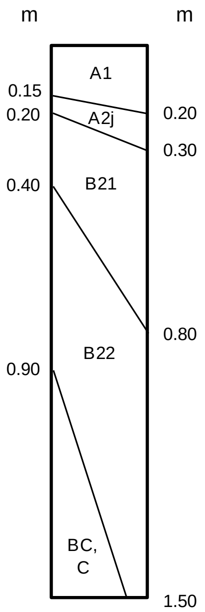
Laboratory pH is similar to field pH (see profile description). CEC levels are low (10 meq/100 g) in the surface soil and moderate to high (20–35 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while magnesium (Mg) becomes either co-dominant or dominant at depth. Profiles (including the underlying unconsolidated substrate) are typically non-sodic (ESP <6) throughout. Detailed chemical data from representative profile 9058 are presented in Appendix 3.

MAYFAIR SANDY SURFACE VARIANT (MfSv)

Concept: A sandy surfaced, sporadically bleached, alkaline, mottled, brown or grey, sodic texture contrast soil with coarse columnar structure over unconsolidated, calcareous sediments below 0.9–>1.5 m. (Sandy surfaced, sodic version of the Mayfair (Mf) soil). Eucalypt vegetation.
Aust. Soil Classification: Brown or Grey Sodosol.
Great Soil Group: Solodized solonetz.
Principal Profile Form: Dy5.33, Db2.33, 4.33; occasionally Db2.43, Dy5.43, 2.33, 3.23.
Geology: Unconsolidated calcareous Tertiary–Quaternary sediments (TQa_b). Mainly relict alluvial deposits sourced from basaltic or andesitic landscapes in the Isaac–Connors and Mackenzie River catchments. Fine grained basaltic-derived sediment, clay, marl, gravel beds and sand lenses.
Landform: Gently undulating plains and low rises. Slopes mostly 1 to 3%, occasionally <1% on plains.
Vegetation Associations: Poplar box (VA20) or Poplar box–ironbark (VA34); occasionally Ironbark–bloodwood–ghost gum (VA43).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Very slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Soft, firm or hard setting.

Representative Profiles: **Not sampled** (see sites 9001 and 9020 from the Foxleigh (Fx) soil).

Typical Profile



Soil Description

The **surface soil** (A1, A2j) is a black or brown, sand or loamy sand with massive structure. Depths typically range from 0.2 to 0.3 m. A sporadically bleached layer is normally developed immediately above the clay subsoil. Field pH is 6–6.5.

The **upper subsoil** (B21) is a mottled, brown or grey, sandy light clay to sandy light medium clay with moderate or strong, coarse columnar structure. Field pH is 6–7, increasing to 8.5 with depth.

The **lower subsoil** (B22) is a mottled, brown, sandy light clay to sandy light medium clay with weak to moderate blocky or polyhedral structure. It is normally calcareous with 10–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Substrate material (BC, C) is often present below 0.9–>1.5 m and consists of marl or unconsolidated, calcareous, sandy clay sediments. Field pH is 8.5–9.5.

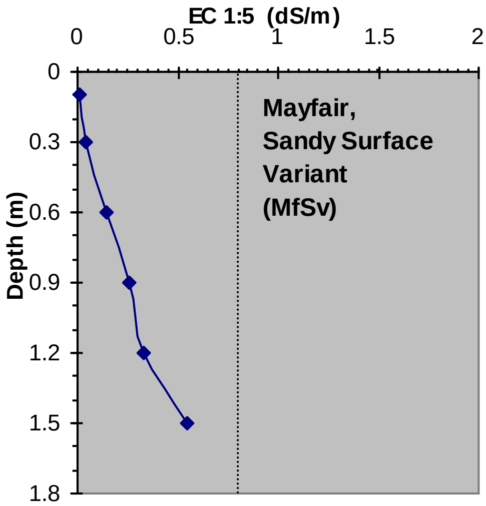
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.4	0.65	0.04	4	0.20	27	16	0.38	0.09	2.9	1.3
acid	low	low	very low	very low	-	moderate	moderate	very low	moderate	moderate

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are low while phosphorus (Bicarb. P) levels are very low. Most other nutrients are moderate with the exception of potassium (K) and zinc (Zn) which are very low. The phosphorus infertility of the Mayfair sandy surface variant (MfSv) soil reflects its leached sandy nature and the low phosphorus status of the underlying unconsolidated sediments. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data ($EC_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Mayfair sandy surface variant (MfSv) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Comparison with the Foxleigh (Fx) soil suggests critical sodicity levels (ESP >20) are likely in the subsoil, but will be substrate dependent and vary in depth.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.11	**0.35**	0.73	14	**46**	78

Typically, PAWC levels for the Mayfair sandy surface variant (MfSv) soil are low (approximately 45 mm) because mean ERD is only 0.35 m. It is restricted by physical limitations and reduced permeability in the upper subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.35 m), maximum PAWC levels are only 45–80 mm and are subject to significant evaporation and lateral drainage losses because of the highly permeable nature of the surface horizons. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available, but data from representative profiles 9001 and 9020 in Appendices 3 and 6 may be useful as a guide.

Physical Characteristics and Subsoil Chemistry

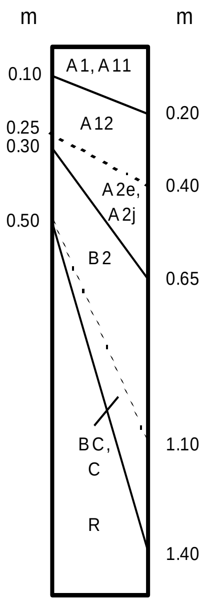
Interpretations and descriptions of the physical characteristics and chemistry of the Mayfair sandy surface variant (MfSv) soil are unavailable, but are probably comparable with those presented for the Foxleigh (Fx) soil.

MAYWIN (Mw)

Concept: A shallow, sporadically bleached, acid, sand to clay loam (0.25–0.5 m) on steeper slopes grading to a moderately deep, sandy to clay loamy surfaced, conspicuously or sporadically bleached, acid, mottled, grey texture contrast soil on gentler slopes over partially altered quartzose or micaceous sandstone, siltstone or shale from 0.5–1.1 m. Eucalypt vegetation.
Aust. Soil Classification: Grey (or occasionally Brown or Red) Kurosol; Leptic Tenosol.
Great Soil Group: Soloth, red podzolic soil, no suitable group.
Principal Profile Form: Dy5.41, 5.31, Dr2.31, 5.31, Dy3.41, 5.11, Db2.31, 2.11, Uc5.21, 6.14, Um6.23.
Geology: Sandstones and fine grained marine sedimentary rocks of the Back Creek Group (Pb) partially altered by Tertiary deep weathering. Mainly quartzose sandstone, micaceous sandstone, siltstone and shale.
Landform: Gently undulating rises to rolling low hills and occasional plateaus at the southern end of the Cherwell Range. Slopes 1 to 10%, occasionally up to 15%.
Vegetation Associations: Eucalypts with shrubby teatree (VA13), Narrow-leaved ironbark (VA12), Lemon-scented gum (VA31) or Queensland peppermint (VA25).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: **Loam -** moderate to high.
Texture contrast - very slow to slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Soft, firm or hard setting. Occasionally 2 to 10% sandstone outcrop.

Representative Profiles: **9042, 9043, 9044**

Typical Profile



Soil Description – Texture contrast profile

The **surface soil** (A1, A11, A12, A2e, A2j) is a black, brown or grey, loamy sand to sandy clay loam with massive structure. Depths typically range from 0.3 to 0.65 m. A conspicuously or sporadically bleached layer is normally developed immediately above the clay subsoil. Field pH is 5.5–6.

The **subsoil** (B2) is a mottled, grey, sandy light medium clay to sandy medium heavy clay with moderate blocky or polyhedral structure. Field pH is 5.5–6.5.

Weathered **substrate** (BC, C) is normally present from 0.5–1.1 m. Substrate material may be partially altered and ranges from quartzose or micaceous sandstone to siltstone or shale. Field pH is 5–6.

Soil Description – Sand or loam profile

In steeper areas, subsoils are not developed and profiles are mostly shallow sands or loams. The **surface soil** (A11, A12, A2j) is a black or brown, sandy loam to clay loam (frequently fine sandy) with massive or weak to moderate polyhedral structure. Depths typically range from 0.25 to 0.5 m. A sporadically bleached layer is frequently developed immediately above the underlying substrate. Field pH is 5–6.

Weathered **substrate** (BC, C) is normally present below 0.25–0.5 m and is the same as for texture contrast profiles.

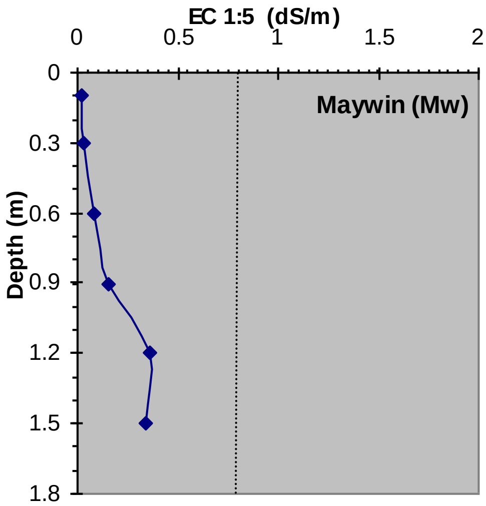
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.2	1.5	0.08	3	0.72	89	7	0.19	0.72	1.0	0.64
strongly acid	low	moderate	very low	mod-high	-	moderate	low	moderate	low	low

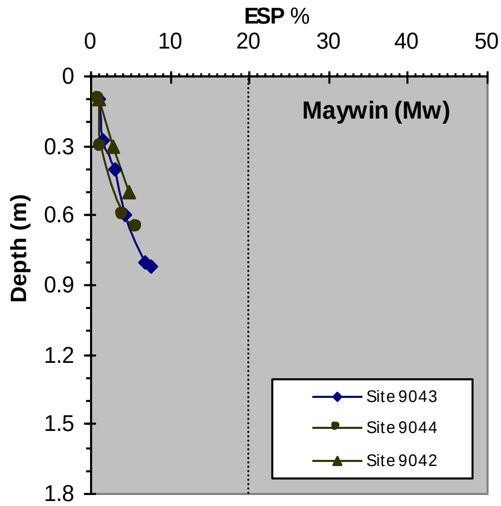
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are very low. Most other nutrients are low to moderate with the exception of potassium (K) which is moderate to high. The infertility of the Maywin (Mw) soil reflects its age, leached nature and the low nutrient status of the underlying partially altered sedimentary rocks. Elevated potassium (K) levels indicate much of the substrate material is micaceous. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Maywin (Mw) soil. The profile salinity curve reaches equilibrium between 1.1 and 1.3 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.5–1.1 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Sodicity levels within the profile (ESP <6) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.24	**0.57**	0.90	34	**58**	83

Typically, PAWC levels for the Maywin (Mw) soil are low (approximately 60 mm) because mean ERD is <0.6 m. It is restricted by the presence of hard sandstone, siltstone or shale with a pH <5.5. Even where deeper profiles occur (ERD >0.6 m), maximum PAWC levels are only 60–85 mm and are subject to significant evaporation, lateral drainage and runoff because of elevation, slope and the permeable nature of the surface horizons. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9042, 9043 and 9044 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content in shallow loam profiles is relatively uniform or gradational (15–30%), while in texture contrast profiles it increases significantly between the surface soil (10–20%) and the subsoil (40–65%). High levels of fine sand (60–70%) in the surface soil are responsible for its predominantly hard setting nature. CEC/Clay% ratios in the subsoil are 0.15–0.2 and indicate the clay fraction is predominantly kaolinitic. Measured dispersion (R1 ratio) in the subsoil is typically low (0.45–0.6) and reflects the non-sodic (ESP <6), acidic, kaolinitic nature of the subsoil. High to very high Total K levels in the soil profile reflect similar levels in the underlying predominantly micaceous substrate and confirm soil development has been *in situ*. Detailed physical data from representative profiles 9042, 9043 and 9044 are presented in Appendix 3.

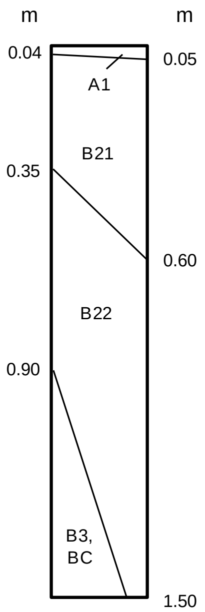
Laboratory pH is similar to field pH (see profile description). CEC levels are very low (3–5 meq/100 g) in the surface soil and only increase to low levels (8–11 meq/100 g) in the subsoil. Calcium (Ca) and magnesium (Mg) are normally present in very low to moderate levels (<0.5–5 meq/100 g). Calcium (Ca) is dominant only in the immediate surface soil, while magnesium (Mg) dominates the remainder of the profile and the underlying substrate. Profiles are typically non-sodic (ESP <6) throughout. Detailed chemical data from representative profiles 9042, 9043 and 9044 are presented in Appendix 3.

MERION (Mr)

Concept: A hard setting, firm pedal or weakly self-mulching, acid, black, saline, sodic cracking clay over reticulite or partially altered, fine grained sandstone or siltstone below 0.9–>1.5 m. Eucalypt vegetation.
Aust. Soil Classification: Black (or occasionally Brown or Red) Vertosol.
Great Soil Group: No suitable group; occasionally brown clay or red clay.
Principal Profile Form: Ug5.13, 5.15, 5.32.
Geology: Fine grained sedimentary rocks altered by Tertiary deep weathering (Td, Ta). Substrate is reticulite or partially altered, fine grained sandstone or siltstone.
Landform: Level to gently undulating pediments and footslopes that have developed on soft, argillaceous deeply weathered sediments exposed at the base of Tertiary plateaus following scarp retreat. Slopes 0.5 to 1.5%.
Vegetation Associations: Yapunyah (VA24); occasionally Gum-topped box (VA18) or Poplar box–ironbark (VA34).
Microrelief: Occasionally weakly developed normal gilgai VI 0.05–0.1 m, HI 8–10 m; frequently with a prominent shelf and indistinct mounds and depressions.
Runoff: Slow to moderately rapid.
Permeability: Very slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Cracking with a hard setting, firm pedal or weakly self-mulching surface. Frequently 2 to 10% silcrete, sandstone or siltstone gravels 6 to 60 mm.

Representative Profile: **9038**

Typical Profile



Soil Description

The **surface soil** (A1) is a black, light medium clay to medium clay with weak to moderate blocky or granular structure. Depths typically range from 0.04 to 0.05 m. Field pH is 5–6.

The **upper subsoil** (B21) is a black, medium heavy clay with moderate or strong blocky structure. Field pH is 4.5–6.5.

The **lower subsoil** (B22) is a black, medium clay to heavy clay with moderate or strong, coarse lenticular structure. Field pH is 4.5–6.5.

Weathered **substrate** (B3, BC) is often present below 0.9–>1.5 m. Substrate material is reticulite or partially altered, fine grained sandstone or siltstone. In deep profiles (>1.5 m) acid clay continues at depth.

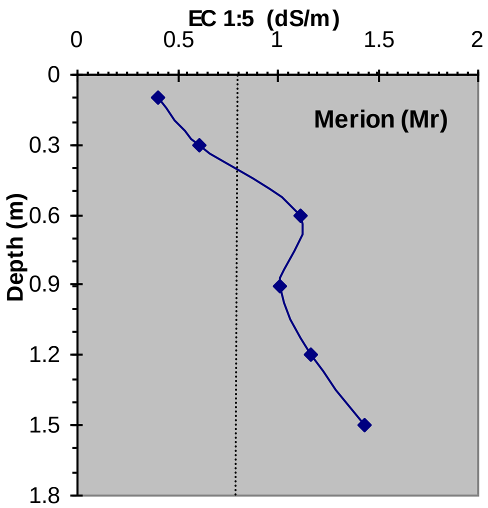
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.0	1.4	0.08	24	0.30		7	1.2	1.4	4.7	14
strongly acid	low	moderate	high	low	-	moderate	moderate	moderate	moderate	high

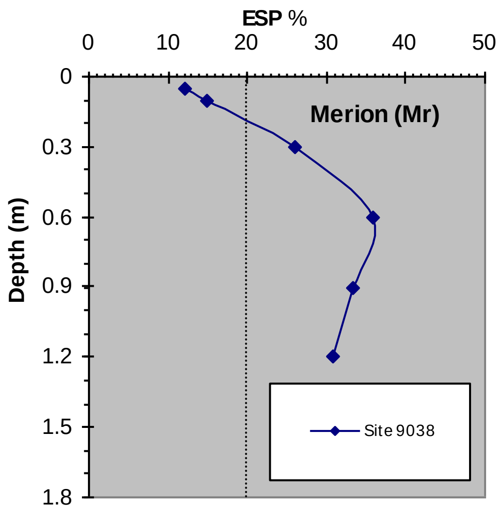
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are high. Most other nutrients are low to moderate with the exception of magnesium (Mg) which is high. Elevated magnesium (Mg) levels are derived directly from the underlying partially altered Tertiary rocks (i.e. basal layers of the deeply weathered profile) from which this soil is developed. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.2–0.4 m in the Merion (Mr) soil. The profile salinity curve reaches equilibrium between 0.5 and 0.7 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.9–>1.5 m and contributes to increased salinity levels at depth. Critical sodicity levels (ESP >20) typically occur within the upper 0.2 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.06	**0.19**	0.32	42	**70**	99

Typically, PAWC levels for the Merion (Mr) soil are low (approximately 70 mm) because mean ERD is <0.2 m. It is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the upper subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.2 m), maximum PAWC levels (70–100 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, clay surface; surface sealing and dispersive behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9038 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content gradually increases from 50–60% in the surface soil and upper subsoil to 70–75% in the lower subsoil. CEC/Clay% ratios in the profile are consistently 0.3–0.4 and indicate the clay fraction is of mixed mineralogy with significant kaolinite and illite. Measured dispersion (R1 ratio) in the surface soil and immediate upper subsoil is low (0.45–0.6), but increases to moderate or high levels (0.8–0.85) at depth. The interaction of very high sodicity levels (ESP >25) and very high EC levels (EC >1.5 dS/m) counteract each other and limit potential dispersion. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. High Total S levels throughout the profile are probably indicative of footslope seepage from adjacent elevated Tertiary plateaus. Detailed physical data from representative profile 9038 are presented in Appendix 3.

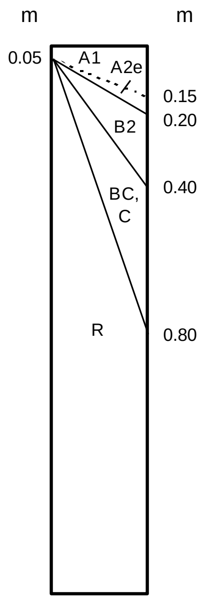
Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are moderate (19–25 meq/100 g) throughout the profile. Magnesium (Mg) is the dominant cation in the profile with levels up to 100 times greater than calcium (Ca). Levels of calcium (Ca) are mostly very low (<0.5 meq/100 g), while sodium (Na) is sub-dominant to magnesium (Mg). Profiles are typically sodic (ESP 6–15) in the surface soil and immediate upper subsoil, increasing rapidly to extremely sodic levels (ESP 25–35) in the remainder of the profile. Detailed chemical data from representative profile 9038 are presented in Appendix 3.

MIDDLEMOUNT (Mi)

Concept:	A shallow, rocky, hard setting, acid, loam to clay loam (0.05–0.15 m) on steeper slopes grading to a moderately deep, loamy or clay loamy surfaced, neutral, brown or red, non-sodic gradational or texture contrast soil on gentler slopes over syenite (or equivalent) from 0.4 m. Eucalypt vegetation.
Aust. Soil Classification:	Leptic Rudosol; Orthic Tenosol; Brown or Red Dermosol; Brown or Red Chromosol.
Great Soil Group:	Lithosol, red podzolic soil, no suitable group.
Principal Profile Form:	Uc1.43, Um1.44, 2.12, 6.42, Dr2.12, Db1.42.
Geology:	Acid to intermediate intrusives (Ki). Most commonly syenite or trachysyenite.
Landform:	Gently undulating rises to steep hills. Mostly isolated, elongate, north-west trending intrusive structures aligned with the strike of the surrounding folded Permian sediments. Slopes 1 to 60%, occasionally >60% on steeper sideslopes.
Vegetation Associations:	Ironbark–bloodwood–ghost gum (VA43), Silver-leaved ironbark (VA17) or Narrow-leaved ironbark (VA12).
Microrelief:	Absent.
Runoff:	Moderately rapid to very rapid.
Permeability:	Moderate to high.
Drainage:	Moderately well drained to well drained.
Surface Features:	Hard setting with 10 to 90% syenite stones and boulders 0.06 to 2 m and 10 to >50% syenite outcrop.
Representative Profile:	**9097**

Typical Profile



Soil Description

The **surface soil** (A1, occasionally A2e) is a black, brown or red, sandy loam to sandy clay loam (frequently coarse sandy) with massive or weak to moderate polyhedral structure. Depths typically range from 0.05 to 0.2 m. A conspicuously bleached layer is sometimes present where clay subsoils are developed. Field pH is 5.5–6.5.

The **subsoil** (B2) where developed is a brown or red, light clay to light medium clay (frequently coarse sandy) with weak to strong polyhedral structure. Field pH is 6.5–7.

Weathered **substrate** (BC, C) is normally present from 0.05–0.4 m. Substrate material is syenite (or equivalent) with a field pH of 6.5–7.5

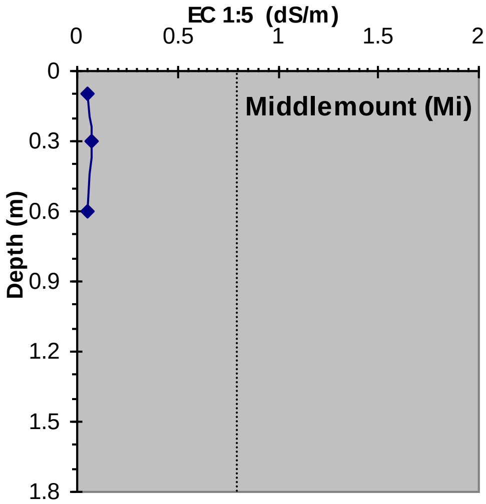
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.3	1.2	0.07	4	0.73	32	98	0.22	3.7	4.0	2.2
acid	low	moderate	very low	high	-	high	low	moderate	moderate	moderate

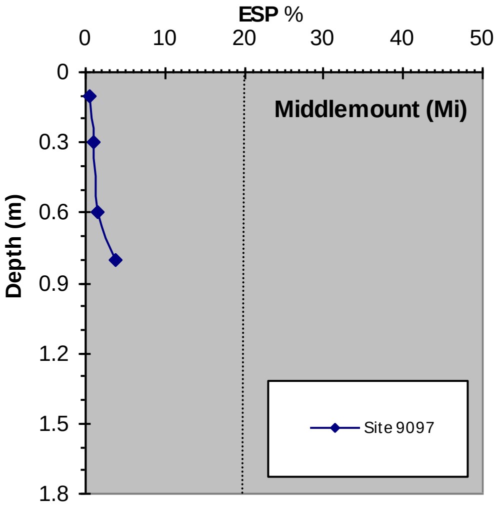
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are very low. Most other nutrients are moderate to high with the exception of copper (Cu) which is low. The combination of elevated potassium (K) levels and very low phosphorus (P) levels reflects the predominantly quartz–k feldspar mineralogy (i.e. low phosphorus status) of the underlying syenite parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the Middlemount (Mi) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Sodicity levels within the profile (ESP <2–4) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.11	**0.55**	0.99	23	**47**	72

Typically, PAWC levels for the Middlemount (Mi) soil are low (approximately 45 mm) because mean ERD is only 0.55 m. It is restricted by the presence of hard syenite (or equivalent) at shallow depths in most profiles. Even where deeper profiles occur (ERD >0.6 m), maximum PAWC levels are only 45–70 mm and are subject to significant evaporation, lateral drainage and runoff because of elevation, slope and the permeable nature of the soil. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9097 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content in shallow loam profiles is relatively uniform (15–25%), while in gradational or texture contrast profiles it increases from 15–25% in the surface soil to 30–35% in the subsoil. Significant coarse sand (>25%) derived from the underlying coarse grained substrate is usually present in the surface soil. CEC/Clay% ratios in the profile are 0.2–0.35 and indicate the clay fraction consists predominantly of kaolinite and illite. Measured dispersion (R1 ratio) in the subsoil (where developed) is low (0.35–0.4) and reflects the non-sodic (ESP <6), kaolinitic nature of the profile. Very high Total K levels in the soil profile reflect the predominantly quartz–k feldspar mineralogy of the underlying substrate and confirm soil development has been *in situ*. Detailed physical data from representative profile 9097 are presented in Appendix 3.

Subsoil Chemistry

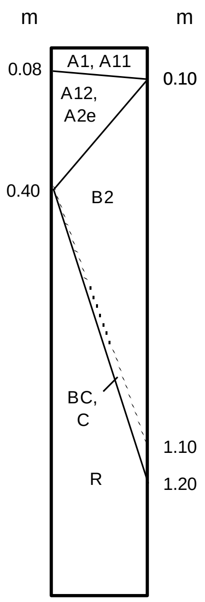
Laboratory pH is similar to field pH (see profile description). CEC levels are low (5–10 meq/100 g) in both the surface soil and subsoil (where developed). Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while magnesium (Mg) becomes co-dominant or dominant in the lower subsoil and underlying substrate. Profiles are non-sodic (ESP <2–4) throughout. Detailed chemical data from representative profile 9097 are presented in Appendix 3.

MIDDLEMOUNT COLLUVIAL VARIANT (MiCv)

Concept: A shallow, stony, conspicuously bleached, acid, sand to clay loam (<0.4 m) on steeper slopes grading to a moderately deep, sandy to clay loamy surfaced, conspicuously bleached, alkaline, grey or brown, sodic texture contrast soil or gradational soil on gentler slopes. Developed on colluvial material over syenite (or equivalent) from 0.4–1.1 m. Eucalypt vegetation.
Aust. Soil Classification: Leptic Rudosol; Orthic Tenosol; Grey or Brown Sodosol.
Great Soil Group: No suitable group, solodized solonetz.
Principal Profile Form: Uc5.23, Um5.22, Dy4.43.
Geology: Acid to intermediate intrusives (Ki). Most commonly syenite or trachysyenite.
Landform: Lower footslopes, pediments and colluvial aprons surrounding undulating to steep hills. Restricted to larger intrusive structures where significant colluvial deposition has occurred. Slopes 2 to 5%.
Vegetation Associations: Eucalypts with shrubby teatree (VA13) or Narrow-leaved ironbark (VA12).
Microrelief: Absent.
Runoff: Moderately rapid.
Permeability: Very slow to moderate.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Soft, firm or hard setting with 2 to 20% syenite rocks 60 to 600 mm and <2 to 10% syenite outcrop.

Representative Profiles: **Not sampled** (see site 9097 from the Middlemount (Mi) soil).

Typical Profile



Soil Description

The **surface soil** (A1, A11, A12, A2e) is a brown, black or grey, loamy sand to sandy clay loam with massive or weak polyhedral structure. Depths typically range from 0.1 to 0.4 m. A conspicuously bleached layer with 2–20% ferromanganiferous nodules is frequently developed either immediately above the underlying substrate or above the clay subsoil where present. Field pH is 6–6.5.

The **subsoil** (B2) where developed is a grey or brown, sandy clay loam to sandy light medium clay with massive or weak to strong blocky structure. It is often manganiferous with <2–10% manganese soft segregations. Field pH is 6–9.5.

Weathered **substrate** (BC, C) is normally present below 0.4–1.1 m. Substrate material is syenite (or equivalent). Field pH ranges from 6 to 9.5

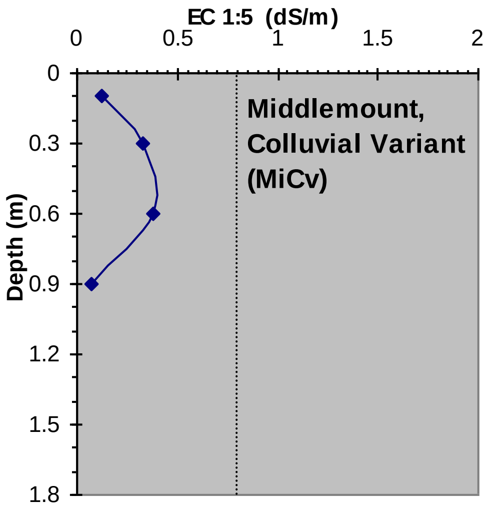
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.1	0.65	0.04	4	0.43	35	54	0.07	0.13	0.84	0.81
acid	low	low	very low	low-mod.	-	high	very low	very low	low	low

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are low while phosphorus (Bicarb. P) levels are very low. Most other nutrients are low to very low with the exception of manganese (Mn) which is high. The infertility of the Middlemount colluvial variant (MiCv) soil reflects its leached nature and the low nutrient status of the colluvial sediment from which it is developed. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data ($EC_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the Middlemount colluvial variant (MiCv) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant lateral drainage is probably occurring on the colluvial footslopes. Comparison with the Middlemount (Mi) soil suggests sodicity levels within the profile are likely to be well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.10	**0.57**	1.14	17	**53**	89

Typically, PAWC levels for the Middlemount colluvial variant (MiCv) soil are low (approximately 55 mm) because mean ERD is <0.6 m. It is restricted by the presence of hard syenite (or equivalent) at relatively shallow depths in most profiles. Even where deeper profiles occur (ERD >0.6 m), maximum PAWC levels are only 55–90 mm, and are subject to significant evaporation and lateral drainage losses because of the permeable nature of the surface horizons. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available.

Physical Characteristics and Subsoil Chemistry

Interpretations and descriptions of the physical characteristics and chemistry of the Middlemount colluvial variant (MiCv) soil are unavailable, but are probably comparable with those presented for the Middlemount (Mi) soil.

MT STUART (Ms)

Concept: A strongly self-mulching, alkaline, black cracking clay with linear or lattice gilgai (VI 0.05–0.15 m) over marl or labile, fine grained calcareous sedimentary rocks or feldspathic sandstone from 0.7–1.3 m. Eucalypt vegetation or open downs.

Aust. Soil Classification: **Mound:** Black (or occasionally Grey) Vertosol **Depression:** Black Vertosol

Great Soil Group: **Mound:** Black earth; occasionally grey clay **Depression:** Black earth

Principal Profile Form: **Mound:** Ug5.12, 5.14, 5.15, 5.16; occasionally Ug5.22 **Depression:** Ug5.12, 5.13

Geology: Sandstones, siltstones and mudstones of the Blackwater Group (Pw). Mostly feldspathic or calcareous freshwater sedimentary rocks (e.g. marl or calcareous siltstone and mudstone).

Landform: Gently undulating plains and rises. Slopes 0.5 to 2%, occasionally up to 3%.

Vegetation Associations: Ironbark–bloodwood–ghost gum (VA43), Mountain coolibah (VA19), *Bothriochloa* grassland (VA27) or Queensland bluegrass downs (VA28).

Microrelief: Linear or lattice gilgai VI 0.05–0.15 m, HI 7–10 m.

Runoff: Slow.

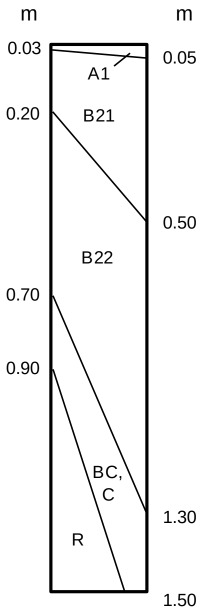
Permeability: Slow.

Drainage: Moderately well drained.

Surface Features: **Mound** - cracking with a fine (<2 mm), strongly self-mulching surface and 2 to 20% free carbonate nodules.
Depression - cracking with a coarse (2 to 5 mm), strongly self-mulching surface. Frequently 2 to 10% sandstone, siltstone or petrified wood fragments 6 to 60 mm.

Representative Profiles: **9023, 9024**

Typical Profile



Soil Description – Mound profile

The **surface soil** (A1) is a black or grey, light medium clay to medium heavy clay with strong granular structure. Depths typically range from 0.03 to 0.05 m. It is normally calcareous with <2–10% nodular carbonate. Field pH is 8–9.5.

The **upper subsoil** (B21) is a black, medium heavy clay with moderate to strong, blocky or lenticular structure. It is normally calcareous with 2–10% nodular carbonate. Field pH is 8.5–9.5

The **lower subsoil** (B22) is a black, medium heavy clay to heavy clay with strong, coarse lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (BC, C) is normally present below 0.7–1.3 m. Substrate material is typically labile and calcareous. It includes marl, calcareous siltstone or mudstone and feldspathic sandstone. Field pH is 8–9.5

Soil Description – Depression profile

Depression profiles generally have similar horizons, depths and morphology, but differ in the colour, structure and pH of the upper profile. The A1 and B21 horizons are usually darker, with coarser surface structure and a range in field pH from 6–9.5.

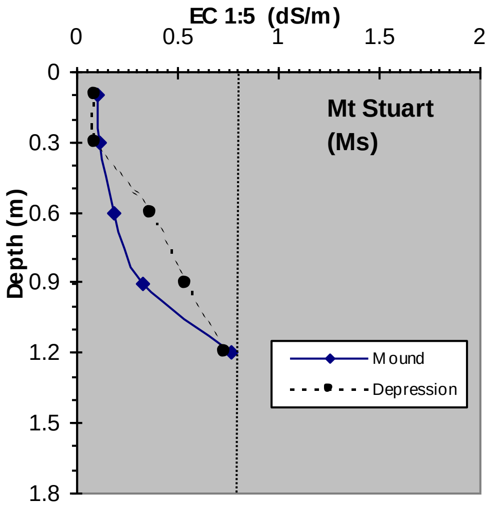
Surface Soil Fertility[1]

Gilgai comp.	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)	(meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
mound	8.5	1.4	0.09	4	0.57	9	4	0.71	0.29	-	-
	alkaline	low	high	very low	high	-	moderate	moderate	very low	-	-
dep.	8.5	1.9	0.14	8	1.19	9	4	0.94	0.31	-	-
	alkaline	moderate	high	low	very high	-	moderate	moderate	low	-	-

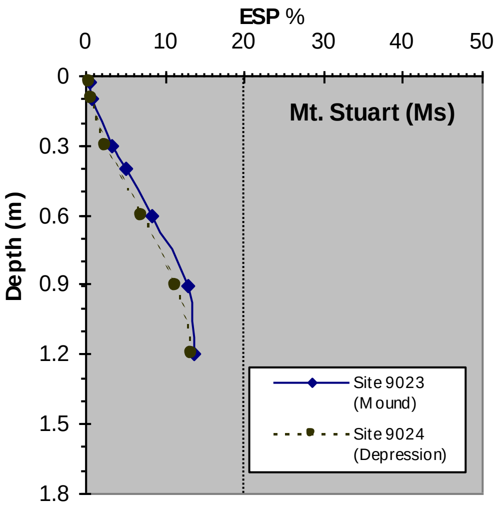
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (mounds and depressions). Typically, nitrogen (Total N) levels are high irrespective of gilgai component while phosphorus (Bicarb. P) levels increase from very low on mounds to low in depressions. Absolute differences in phosphorus (Bicarb. P) fertility between components are significant with levels doubling in depressions. Most other nutrients are moderate to very high with similar levels on both gilgai components. Comparison with the Ternallum (Tn) soil suggests calcium (Ca) and magnesium (Mg) levels would be high to very high throughout. The exceptions are potassium (K) which is higher in depressions and zinc (Zn) which is low in depressions and very low on mounds. The low phosphorus fertility of the Mt Stuart (Ms) soil reflects the low phosphorus status of the underlying labile, calcareous sedimentary rocks. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the Mt Stuart (Ms) soil. The profile salinity curves for mounds and depressions are similar. Neither curve reaches equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profiles. Weathered substrate is normally present somewhere below 0.7–1.3 m and contributes to increased salinity levels at depth. Sodicity levels within the profile (ESP <6–13) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.81	**1.06**	1.32	133	**145**	158

Typically, PAWC levels for the Mt Stuart (Ms) soil are high (approximately 145 mm) with a mean ERD of about 1.1 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is defined simply by the depth to weathered sandstone, siltstone or shale. Restrictions to rooting depth are absent in the profile itself. Where deeper profiles occur (ERD >1.1 m), maximum PAWC levels (145–160 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9023 and 9024 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (55–65%) throughout the profile, but decreases in the underlying substrate (<35%). CEC/Clay% ratios in the profile are 0.85–1.0 and indicate the clay fraction is predominantly montmorillonitic. Measured dispersion (R1 ratio) in the profile is low (0.3–0.55) throughout because of very high levels of exchangeable calcium (Ca) and only low to moderate sodicity levels (ESP mostly <10). Moderate to high Total K levels in the profile reflect similar levels in the underlying substrate and confirm soil development has been *in situ*. Detailed physical data from representative profiles 9023 and 9024 are presented in Appendix 3.

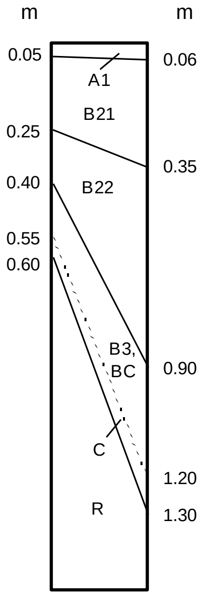
Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are very high (50–60 meq/100 g) throughout the profile. Calcium (Ca) is the dominant cation and is mostly present in levels 5–15 times higher than magnesium (Mg). Profiles are non-sodic (ESP <6) in the surface soil and upper subsoil, but gradually become sodic at depth (ESP 7–13). Detailed chemical data from representative profiles 9023 and 9024 are presented in Appendix 3.

NINEMILE (Nm)

Concept:	A weakly to strongly self-mulching, alkaline, red or brown cracking clay over partially altered basalt from 0.4–0.9 m. Eucalypt vegetation.
Aust. Soil Classification:	Red or Brown Vertosol.
Great Soil Group:	Red clay, brown clay.
Principal Profile Form:	Ug5.37, 5.32.
Geology:	Partially altered Tertiary basalt (Tb_a).
Landform:	Gently undulating plains and rises associated with partially altered basalt flows near May Downs, Tiny Downs and in the Barmount area. Slopes 1 to 3%.
Vegetation Associations:	Silver-leaved ironbark (VA17) or Ironbark–bloodwood–ghost gum (VA43).
Microrelief:	Occasionally linear gilgai VI 0.05–0.2 m, HI 10 m.
Runoff:	Slow.
Permeability:	Slow.
Drainage:	Moderately well drained.
Surface Features:	Cracking with a coarse (2 to 5 mm), weakly to strongly self-mulching surface. Where gilgaied, mounds have a fine (<2 mm), moderately to strongly self-mulching surface (usually in thin strips), frequently with <2 to 10% free carbonate nodules.
Representative Profiles:	**Not sampled** (see sites 9089 and 9090 from the May (My) soil).

Typical Profile



Soil Description

The **surface soil** (A1) is a brown, medium clay to medium heavy clay with strong, coarse granular structure. Depths typically range from 0.05 to 0.06 m. It is normally calcareous with <2% nodular carbonate. Field pH is 8–9.5.

The **upper subsoil** (B21) is a red or brown, medium heavy clay to heavy clay with strong lenticular structure. It is normally calcareous with <2% soft carbonate. Field pH is 8.5–9.5.

The **lower subsoil** (B22) is a red or brown, medium heavy clay to heavy clay with strong, coarse lenticular structure. It is normally calcareous with 2–10% soft carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (B3, BC, C) is normally present below 0.4–0.9 m. Substrate material is partially altered basalt which is typically brown and frequently calcareous. Field pH is 8–9.5.

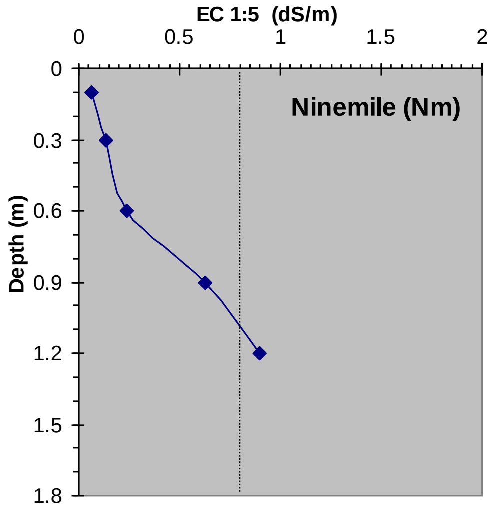
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.6	1.1	0.08	19	0.65	22	15	1.4	0.35	34	23
alkaline	low	moderate	high	high	-	moderate	moderate	low	very high	very high

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are high. Most other nutrients are moderate to very high with the exception of zinc (Zn) which is low. Elevated phosphorus (Bicarb. P), calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 1.0 m in the Ninemile (Nm) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Weathered substrate is normally present somewhere below 0.4–0.9 m and contributes to increased salinity levels at depth. Comparison with the May (My) soil suggests sodicity levels within the profile are likely to be well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.85	**1.02**	1.20	59	**122**	186

Typically, PAWC levels for the Ninemile (Nm) soil are moderate (approximately 120 mm) because mean ERD is only 1.0 m. ERD is defined simply by the depth to weathered basalt. Restrictions to rooting depth are generally absent in the profile, although high salinity levels (EC >0.8 dS/m) are present in the underlying weathered substrate. Where deeper profiles occur (ERD >1.0 m), maximum PAWC levels (120–185 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available, but data from representative profiles 9089 and 9090 in Appendices 3 and 6 may be useful as a guide.

Physical Characteristics and Subsoil Chemistry

Interpretations and descriptions of the physical characteristics and chemistry of the Ninemile (Nm) soil are unavailable, but are probably comparable with those presented for the May (My) soil.

NORWICH (Nw)

Concept: A weakly to strongly self-mulching, alkaline, grey or black cracking clay with normal (VI 0.1–0.3 m) or melonhole (VI 0.3–0.8 m) gilgai over unconsolidated, calcareous sediments below 1.1–>1.5 m. Brigalow vegetation.

Aust. Soil Classification: Grey or Black Vertosol.

Great Soil Group: Grey clay, black earth.

Principal Profile Form: Ug5.24, 5.28, 5.16; occasionally Ug5.13, 5.15.

Geology: Unconsolidated calcareous Tertiary–Quaternary sediments (TQa_b). Mainly relict alluvial deposits sourced from basaltic or andesitic landscapes in the Isaac–Connors and Mackenzie River catchments. Fine grained basaltic-derived sediment, clay, marl, gravel beds and sand lenses.

Landform: Level to gently undulating plains. Slopes 0.5 to 1.5%, occasionally up to 2%.

Vegetation Associations: Brigalow (VA1) or Brigalow with shrubs (VA8).

Microrelief: Normal gilgai VI 0.1–0.3 m, HI 8–10 m or melonhole gilgai VI 0.3–0.8 m, HI 10–15 m. Areas with normal gilgai frequently have a prominent shelf and indistinct mounds and depressions.

Runoff: Slow on mounds and shelves; no runoff in depressions.

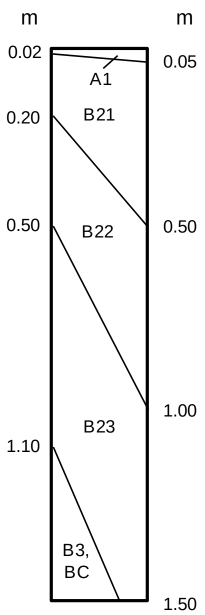
Permeability: Slow.

Drainage: Moderately well drained.

Surface Features: **Mound** - cracking with a fine (<2 mm), moderately to strongly self-mulching surface and <2 to 20% free carbonate nodules.
Shelf - cracking with a fine (<2 mm), weakly to strongly self-mulching surface.
Depression - cracking with a fine or coarse (<2 to 5 mm), moderately to strongly self-mulching surface.
Frequently <2 to 10% silcrete or water worn quartz and sandstone gravels 6 to 60 mm. A weak surface seal with a well developed flake and thin sandy veneer forms after rain.

Representative Profile: **9112**

Typical Profile



Soil Description – Mound/shelf profile

The **surface soil** (A1) is a black, light medium clay to medium clay with moderate to strong blocky or granular structure. Depths typically range from 0.02 to 0.05 m. It is frequently calcareous with <2–10% nodular carbonate. Field pH is 7–9.5.

The **upper subsoil** (B21, B22) is a grey or black, medium clay to medium heavy clay with strong blocky or lenticular structure. It is normally calcareous with 2–50% soft or nodular carbonate. Field pH is 8.5–9.5

The **lower subsoil** (B23) is a grey, medium clay to heavy clay with moderate or strong, coarse lenticular structure. It is frequently calcareous with <2–10% soft or nodular carbonate in the upper part of the horizon, but grades to non-calcareous at depth. Field pH is 8.5–9.5, decreasing to <6 where substrate is absent.

Substrate material (B3, BC) is sometimes present below 1.1–>1.5 m. Where present, it typically consists of unconsolidated, calcareous, fine sandy clay sediments with a field pH of 8.5–9.5. In deep profiles (>1.5 m) acid clay continues at depth.

Soil Description – Depression profile

Depression profiles generally have similar horizons, depths and morphology, but with coarser surface structure.

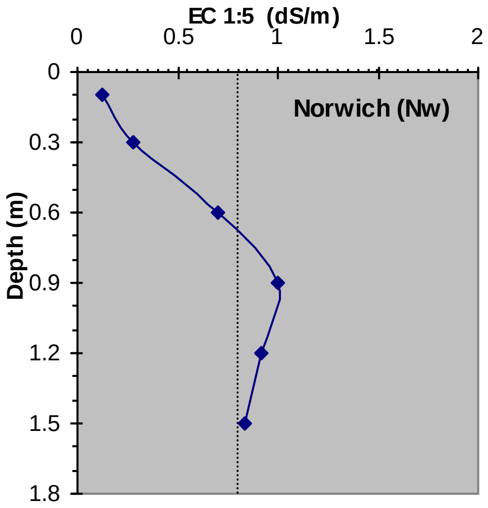
Surface Soil Fertility[1]

Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	8.5	1.1	0.09	14	0.17	14	7	0.60	0.17	21	8.5
	alkaline	low	high	moderate	low	-	moderate	moderate	very low	very high	high
dep.	7.6	1.4	0.11	46	0.31	29	19	1.0	0.59	22	6.9
	alkaline	low	high	very high	moderate	-	moderate	moderate	low	very high	high

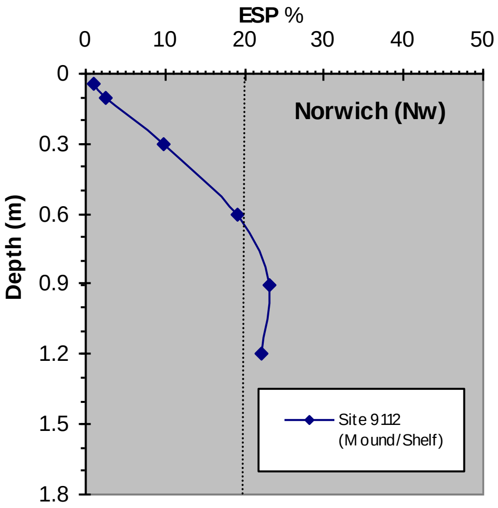
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (non-gilgaied/mound versus depression). Typically, nitrogen (Total N) levels are high irrespective of gilgai component, while phosphorus (Bicarb. P) levels increase from moderate on mounds and non-gilgaied areas to very high in depressions. Absolute differences in phosphorus (Bicarb. P) fertility between components are significant with levels more than three times higher in depressions. Most other nutrients are moderate to very high with similar levels on both gilgai components. The exceptions are potassium (K) which is low on mounds and zinc (Zn) which is low in depressions and very low on mounds. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P), calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying calcareous, basaltic-derived, unconsolidated sediments. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.65–0.85 m in the Norwich (Nw) soil. The profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below about 0.6–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.47	**0.87**	1.27	107	**143**	179

Typically, PAWC levels for the Norwich (Nw) soil are high (approximately 140 mm) even though mean ERD is only about 0.85 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is restricted by high salinity levels (EC >0.8 dS/m) as well physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.9 m), maximum PAWC levels (140–180 mm) are rarely achieved on a regular basis because of restricted infiltration (surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9112 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content gradually increases between the surface soil (40–45%) and the subsoil (45–55%), while significant levels of coarse sand (20%) and fine sand (30%) in the surface soil promote surface sealing behaviour. CEC/Clay% ratios in the profile are 0.7–0.85 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (i.e. derived from basaltic sediments). Measured dispersion (R1 ratio) is low (0.3–0.5) in the surface soil and upper subsoil, but increases to high levels (0.9–0.95) in the lower subsoil because of high to very high sodicity levels (ESP 15–25). Detailed physical data from representative profile 9112 are presented in Appendix 3.

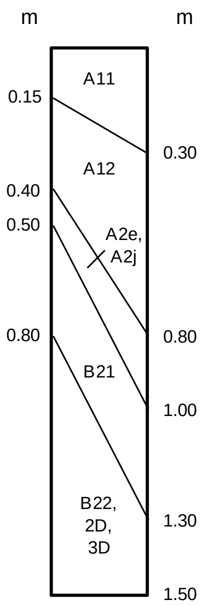
Laboratory pH is similar to field pH (see profile description). CEC levels are high (30–40 meq/100 g) throughout the profile. Calcium (Ca) is the dominant cation only in the surface soil, while magnesium (Mg) is dominant throughout the subsoil. Profiles are non-sodic (ESP <3) in the surface soil, but become sodic (ESP <10) in the upper subsoil and strongly to extremely sodic (ESP 15–25) in the lower subsoil. Detailed chemical data from representative profile 9112 are presented in Appendix 3.

PARROT (Pr)

Concept: A thick (0.5–1.0 m), sandy surfaced, conspicuously or sporadically bleached, acid to alkaline, mottled, brown texture contrast soil over recent alluvium on alluvial plains and levees. Eucalypt vegetation.
Aust. Soil Classification: Brown (or occasionally Grey) Chromosol; Brown (or occasionally Grey) Sodosol.
Great Soil Group: Solodic soil, solodized solonetz, soloth.
Principal Profile Form: Dy5.32, 5.33, 5.42, 5.43, 3.33, 3.43, 4.43, Db4.32, 4.43, 2.32, 3.33; occasionally Dy5.41,3.31, 3.41, Db2.31.
Geology: Quaternary alluvium (Qa).
Landform: Level to gently undulating, elevated levees, sand ridges and sandy alluvial plains on upper and lower tributaries or occasionally on flood plain terraces; often in lower landscape positions adjacent to the Booroondarra (Bn) soil. Flooded in lower lying parts by short duration, high velocity events. ARI is less frequent than 1 in 10 years. Slopes 0.5 to 1.0%.
Vegetation Associations: Poplar box (VA20) or Poplar box–bloodwood–Moreton Bay ash (VA33).
Microrelief: Absent.
Runoff: Slow.
Permeability: Very slow to slow.
Drainage: Imperfectly drained to moderately well drained.
Surface Features: Loose to hard setting.

Representative Profile: **9013**

Typical Profile



Soil Description

The **surface soil** (A11, A12, A2e, A2j) is a brown, sand or loamy sand with massive structure. Depths typically range from 0.5 to 1.0 m. A conspicuously or sporadically bleached layer with 2–10% ferromanganiferous nodules is normally developed immediately above the clay subsoil. Field pH is 5.5–7.5.

The **upper subsoil** (B21) is a mottled, brown, sandy light clay to sandy medium clay (frequently fine sandy) with moderate prismatic or blocky structure. It is frequently manganiferous with <2–10% manganese soft segregations. Field pH is 6–9.

The **lower subsoil** (B22) is a mottled, brown, sandy clay loam to sandy light medium clay with weak blocky structure. It is frequently manganiferous with 2–20% manganese soft segregations. Field pH is 6–9.

Buried alluvial layers (2D, 3D) are sometimes present below 0.8–1.3 m. Buried materials range from loamy sand to medium heavy clay. They are typically brown and mottled with massive or weak to strong blocky, polyhedral or lenticular structure. Field pH is 6–9.

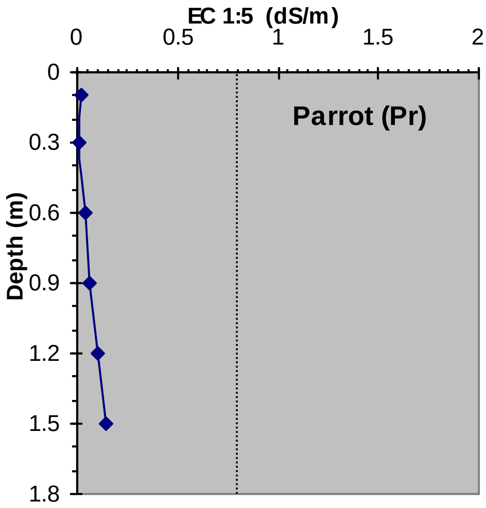
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.6	0.60	0.03	9	0.28	14	26	0.34	0.14	2.8	0.89
neutral	low	very low	low	very low	-	moderate	moderate	very low	moderate	low

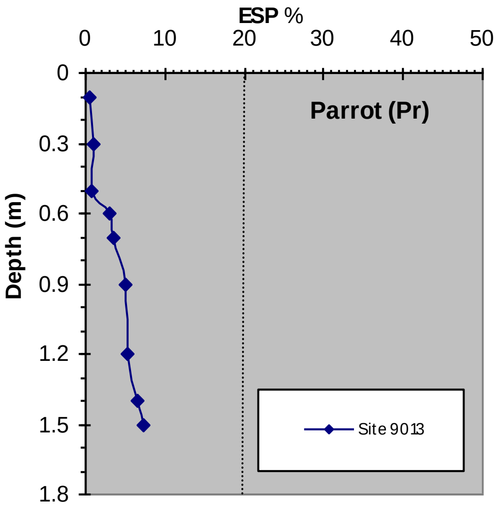
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are very low while phosphorus (Bicarb. P) levels are low. Most other nutrients are low to moderate with the exception of potassium (K) and zinc (Zn) which are very low. The lower fertility of the Parrot (Pr) soil compared with other alluvial soils reflects its leached sandy nature and possible relict age compared with adjacent younger alluvium. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the upper 1.5 m of the Parrot (Pr) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Sodicity levels in the subsoil are normally low (ESP <6), and are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.98	**1.33**	1.67	58	**78**	98

Typically, PAWC levels for the Parrot (Pr) soil are low (approximately 80 mm) even though mean ERD is almost 1.35 m. Restrictions to rooting depth are generally absent. Maximum PAWC levels (80–100 mm) are rarely achieved on a regular basis however, because profiles are permeable and subject to continued deep (or lateral) drainage and evaporation losses over time. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9013 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (<10%) and the subsoil (30–40%), while variation in the levels of fine sand and coarse sand in the surface soil is responsible for a range of surface conditions from loose to hard setting. CEC/Clay% ratios in the subsoil are 0.6–0.75 and indicate the clay fraction is predominantly of mixed mineralogy. Measured dispersion (R1 ratio) in the subsoil is mostly moderate (0.65–0.7) and reflects low sodicity levels (ESP <6) in the majority of profiles. High dispersion levels (>0.9) occur in some buried layers because of low clay contents. High Total K levels in the profile reflect the alluvial origins of this soil. Detailed physical data from representative profile 9013 are presented in Appendix 3.

Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are low (5–8 meq/100 g) in the surface soil and moderate (20–25 meq/100 g) in the subsoil. Levels in buried alluvial layers are mostly low (10–15 meq/100 g) because of low clay content. Calcium (Ca) is the dominant cation within the profile, although significant magnesium (Mg) may be present in the subsoil. While most profiles are non-sodic throughout (ESP <6), some become sodic to strongly sodic (ESP 6–20) in the lower subsoil. Detailed chemical data from representative profile 9013 are presented in Appendix 3.

PICARDY (Pc)

Concept: A strongly self-mulching, alkaline, black cracking clay, frequently with weakly developed linear, lattice or normal gilgai (VI 0.05–0.1 m), over unconsolidated, calcareous sediments below 0.8–>1.5 m. Brigalow vegetation.

Aust. Soil Classification: Black Vertosol.

Great Soil Group: Black earth.

Principal Profile Form: Ug5.15, 5.12, 5.13, 5.14, 5.16.

Geology: Unconsolidated calcareous Tertiary–Quaternary sediments (TQa_b). Mainly relict alluvial deposits sourced from basaltic or andesitic landscapes in the Isaac–Connors and Mackenzie River catchments. Fine grained basaltic-derived sediment, clay, marl, secondary carbonate deposits, gravel beds and sand lenses.

Landform: Level to gently undulating, elevated plains and low rises. Occurs mainly on upper slopes and crests on broad gentle ridges or as gently undulating, elevated plains. Slopes mostly 1 to 3%, occasionally <1% on plains and up to 4% on sideslopes.

Vegetation Associations: Brigalow with shrubs (VA8) or Brigalow (VA1); occasionally Belah (VA9).

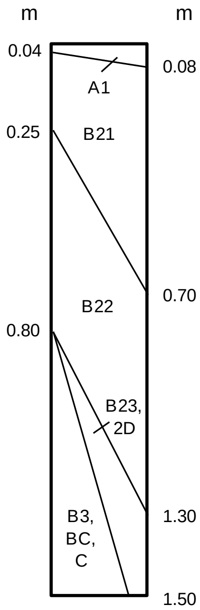
Microrelief: Frequently weakly developed linear, lattice or normal gilgai VI 0.05–0.1 m, HI 5–12 m; occasionally non-gilgaied.

Runoff: Slow. **Permeability:** Slow. **Drainage:** Moderately well drained.

Surface Features: Cracking with a fine (<2 mm), strongly self-mulching surface. Where gilgaied, mounds are very fine (<1 to 2 mm) with 2 to 20% free carbonate nodules; while depressions are coarser (<2 to 5 mm) and appear darker and more cracked. Occasionally <2 to 10% water worn quartz and sandstone gravels 6 to 60 mm.

Representative Profiles: **9030, 9032**

Typical Profile



Soil Description – Non-gilgaied/mound profile

The **surface soil** (A1) is a black, light medium clay to medium clay with strong, fine granular structure. Depths typically range from 0.04 to 0.08 m. It is frequently calcareous with <2–10% nodular carbonate. Field pH is 8–9.5.

The **upper subsoil** (B21) is a black, medium clay to heavy clay with strong lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5

The **lower subsoil** (B22) is a black, medium heavy clay to heavy clay with strong, coarse lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Substrate material (B3, BC, C, 2D) is normally present below 0.8–>1.5 m. Typically, it consists of unconsolidated, calcareous, fine sandy clay sediments, marl, gravel beds, sand lenses or strongly structured, acid clay layers. Field pH is 8.5–9.5, except in acid clay layers which are 5.5–6.5. In deep profiles (>1.5 m) the clay fraction of the lower subsoil continues at depth, often becoming brown or grey.

Soil Description – Depression profile

Depression profiles generally have similar horizons, depths and morphology, but with coarser structure in the surface soil and upper subsoil.

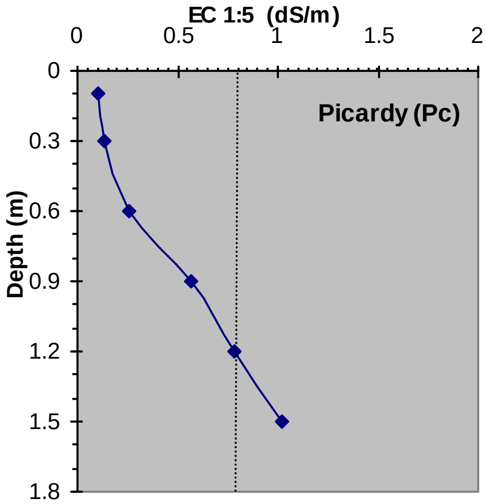
Surface Soil Fertility[1]

Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	8.0	1.6	0.12	17	0.55	20	16	0.95	0.38	32	12
	alkaline	moderate	high	high	high	-	moderate	moderate	low	very high	high
dep.	8.0	1.6	0.13	24	0.64	19	29	0.85	0.36	23	15
	alkaline	moderate	high	high	high	-	moderate	moderate	low	very high	high

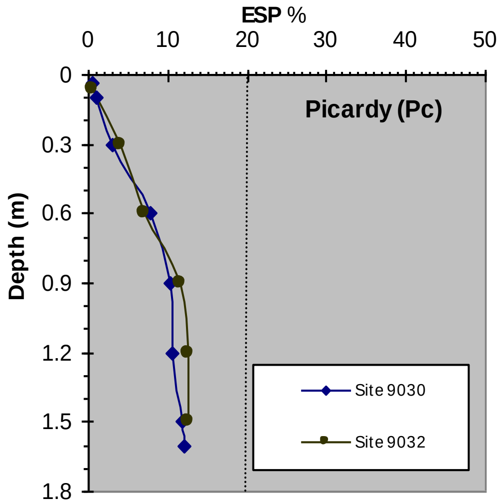
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility between gilgai components (non-gilgaied/mound versus depression) were not observed. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are high, irrespective of gilgai component. Most other nutrients are moderate to very high with similar levels on both gilgai components. The exception is zinc (Zn) which is low throughout. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P), calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying calcareous, basaltic-derived, unconsolidated sediments. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 1.05–1.25 m in the Picardy (Pc) soil. The profile salinity curve reaches an indistinct equilibrium between 1.1 and 1.3 m (salt bulge becomes constant) indicating the probable depth of long term wetting normally associated with this soil. Unconsolidated substrate is normally present somewhere below 0.8–>1.5 m and contributes to increased salinity levels at depth. Sodicity levels in the subsoil (ESP <6–13) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.75	**1.04**	1.32	128	**151**	175

Typically, PAWC levels for the Picardy (Pc) soil are very high (approximately 150 mm) even though mean ERD is only 1.05 m. Significant differences in ERD or PAWC between gilgai components were not observed. Restrictions to rooting depth are generally absent in the profile, although high salinity levels (EC >0.8 dS/m) are often present in the underlying unconsolidated sediments (basaltic sediments, acid clay layers). Maximum PAWC levels (150–175 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9030 and 9032 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is relatively uniform (60–70%) throughout, although self-mulching surface horizons may have slightly lower clay contents (55–65%). Clay contents in the underlying unconsolidated substrate are normally <45%. CEC/Clay% ratios in the profile are 0.75–1.2 and indicate the clay fraction is predominantly montmorillonitic. Ratios in the underlying unconsolidated substrate are consistently >1.0 and indicate the material from which the soil has developed is of basaltic origins. Measured dispersion (R1 ratio) in the profile is low (0.35–0.6) throughout because of very high levels of exchangeable calcium (Ca) and only low to moderate levels of sodicity (ESP <10) in the lower subsoil. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9030 and 9032 are presented in Appendix 3.

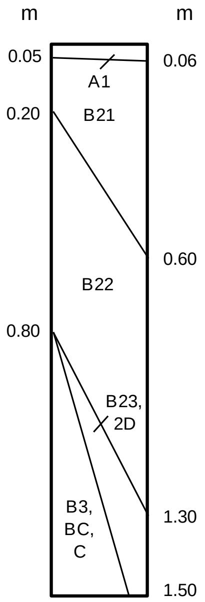
Laboratory pH is similar to field pH (see profile description). CEC levels are very high (45–80 meq/100 g) throughout the profile and also in the substrate below (>60 meq/100 g). Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while either calcium (Ca) or magnesium (Mg) may be dominant or co-dominant in the lower subsoil and substrate. Profiles are non-sodic (ESP <6) in the surface soil and upper subsoil, but become sodic (ESP <13) in the lower subsoil and substrate. Detailed chemical data from representative profiles 9030 and 9032 are presented in Appendix 3.

PICARDY SURFACE SEAL PHASE (PcXp)

Concept: A strongly self-mulching, cracking clay similar to the Picardy (Pc) soil but with a lower clay content, increased sand fraction, less basaltic influence and normal or lattice gilgai (VI 0.1–0.3 m). A weak surface seal and thin sandy veneer form after rain. Brigalow vegetation.
Aust. Soil Classification: Black Vertosol.
Great Soil Group: Black earth.
Principal Profile Form: Ug5.16, 5.12, 5.13, 5.14, 5.15.
Geology: Unconsolidated calcareous Tertiary–Quaternary sediments (TQa_b). Mainly relict alluvial deposits sourced from basaltic or andesitic landscapes in the Isaac–Connors and Mackenzie River catchments. Fine grained basaltic-derived sediment, clay, marl, gravel beds and sand lenses.
Landform: Level to very gently undulating, elevated plains. Slopes <0.5 to 1%, occasionally up to 2%.
Vegetation Associations: Brigalow with shrubs (VA8); occasionally Brigalow (VA1).
Microrelief: Normal or lattice gilgai VI 0.1–0.3 m, HI 8–12 m.
Runoff: Slow on mounds; very slow or no runoff in depressions.
Permeability: Slow.
Drainage: Moderately well drained.
Surface Features: **Mound** - cracking with a fine (<1 to 2 mm), strongly self-mulching surface and frequently 2 to 20% free carbonate nodules.
Depression - cracking with a fine to coarse (<2 to 5 mm), strongly self-mulching surface; usually thinner (0.03 to 0.05 m) than on mounds and without free carbonate nodules. Occasionally <2 to 10% waterworn quartz or sandstone gravels 6 to 20 mm. A weak surface seal with a well developed flake and a thin sandy veneer forms after rain.

Representative Profiles: **9026, 9027**

Typical Profile



Soil Description – Mound profile

The **surface soil** (A1) is a black, light medium clay to medium clay with strong granular structure. Depths typically range from 0.05 to 0.06 m. It is frequently calcareous with <2–10% nodular carbonate. Field pH is 7–9.5.

The **upper subsoil** (B21) is a black, medium clay to heavy clay with strong lenticular structure. It is normally calcareous with <2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

The **lower subsoil** (B22, B23) is a black, medium heavy clay to heavy clay with strong, coarse lenticular structure. It is normally calcareous with 2–50% soft or nodular carbonate. Field pH is 8.5–9.5.

Substrate material (B3, BC, C, 2D) is normally present below 0.8–>1.5 m. Typically, it consists of unconsolidated, calcareous, fine sandy clay sediments, marl, gravel beds, sand lenses or strongly structured, acid clay layers. Field pH is 8–9.5, except in acid clay layers which are 5–7. In deep profiles (>1.5 m) the the clay fraction of the lower subsoil continues at depth, often becoming brown or grey.

Soil Description – Depression profile

Depression profiles generally have similar horizons, depths and morphology, but differ in the colour, structure and pH of the surface soil. The A1 horizon is usually thinner, darker, coarser, non-calcareous and has a lower pH compared with mound profiles.

Surface Soil Fertility[1]

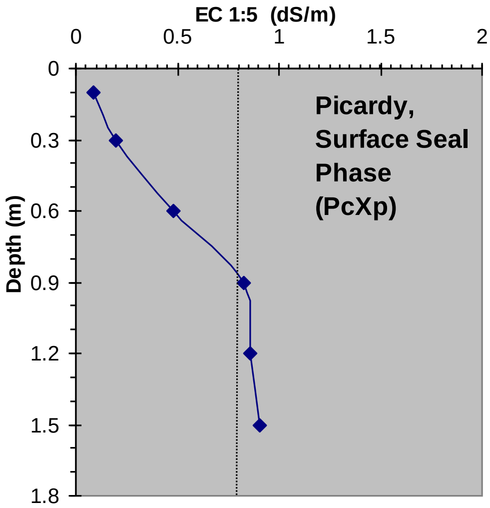
Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	8.2	1.4	0.11	17	0.40	26	21	1.0	0.36	35	12
	alkaline	low	high	high	moderate	-	moderate	moderate	low	very high	high
dep.	7.2	1.4	0.09	28	0.31	57	41	1.8	0.65	23	12
	neutral	low	high	high	moderate	-	moderate	moderate	low	very high	high

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

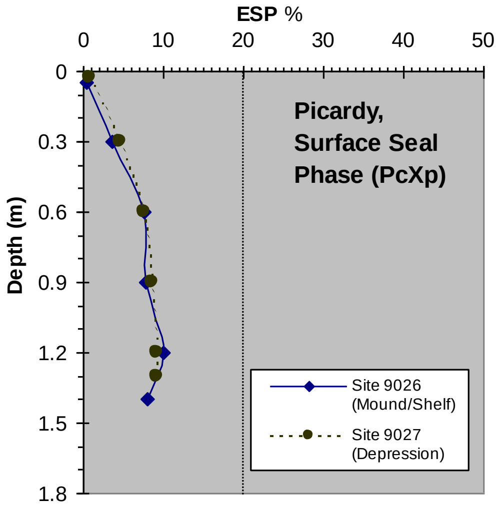
Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility between gilgai components (non-gilgaied/mound versus depression) were not observed.

Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are high, irrespective of gilgai component. Most other nutrients are moderate to very high with similar levels on both gilgai components. The exception is zinc (Zn) which is low throughout. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P), calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying calcareous, basaltic-derived, unconsolidated sediments. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.8–0.9 m in the Picardy surface seal phase (PcXp) soil. The profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Unconsolidated substrate is normally present somewhere below 0.8–>1.5 m and contributes to the development of the salt bulge because of restricted subsoil drainage, as well as slight increases in salinity levels at depth. Sodicity levels in the subsoil (ESP <6–10) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.40	**0.78**	1.17	106	**139**	173

Typically, PAWC levels for the Picardy surface seal phase (PcXp) soil are high (approximately 140 mm) even though mean ERD is only 0.8 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is restricted by high salinity levels (EC >0.8 dS/m) in the subsoil. Where deeper profiles occur (ERD >0.8 m), maximum PAWC levels (140–175 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. Weak surface sealing behaviour however, means runoff losses are slightly higher and infiltration rates slightly slower when compared with the Picardy (Pc) soil. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9026 and 9027 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

While the Picardy surface seal phase (PcXp) soil is morphologically similar to the Picardy (Pc) soil, laboratory analyses indicate there are slight but significant differences between the two soils, particularly in terms of particle size distribution, cation exchange capacity, clay mineralogy and sediment source. The Picardy surface seal phase (PcXp) soil has a lower cation exchange capacity, approximately 10% less clay through the profile and 10–15% more coarse sand in the surface soil. In addition, Total K levels and clay activity ratios in the subsoil are significantly lower indicating potential differences in sediment source, increased mixing of sediments during deposition, less basaltic influence and the presence of predominantly mixed mineralogy rather than montmorillonitic clays. Following rain a weak seal forms on the surface of the soil that is characterised by a well developed flake or weak crust and a thin sandy surface veneer. Differences in infiltration rate, plant available water capacity and ameliorative response to compaction are predicted with long term cultivation when compared with the Picardy (Pc) soil. Detailed physical and chemical data from representative profiles 9026 and 9027 are presented in Appendix 3.

POMEGRANATE (Pg)

Concept: A hard setting, gravelly, alkaline, brown, sodic cracking to non-cracking clay, frequently with normal or shallow melonhole gilgai (VI 0.2–0.5 m), over unconsolidated sediments on valley floors and pediments below Tertiary plateaus. Brigalow vegetation.

Aust. Soil Classification: Brown Vertosol; Brown Dermosol.

Great Soil Group: Brown clay.

Principal Profile Form: Ug5.34, Uf6.31; occasionally Ug5.35, Uf6.34.

Geology: Unconsolidated Tertiary–Quaternary sediments (TQa) associated with reworked Tertiary clay and local colluvium on pediments, plains and valley floors below Tertiary plateaus. Clay and gravel material deposited locally following plateau dissection and scarp retreat. Occasionally overlying reticulite or petroreticulite on footslopes and pediments.

Landform: Level to gently undulating plains and lower footlslopes below Tertiary plateaus; particularly surrounding the Junee tablelands. Slopes 0.5 to 3%.

Vegetation Associations: Brigalow (VA1); occasionally Brigalow–Dawson gum (VA5).

Microrelief: Either non-gilgaied (50%) or with normal gilgai or shallow melonhole gilgai (50%), VI 0.2–0.5 m, HI 8–15 m. In gilgaied areas, a prominent shelf with indistinct mounds and depressions is normally present.

Runoff: Slow on mounds, shelves and non-gilgaied areas; very slow or no runoff in depressions.

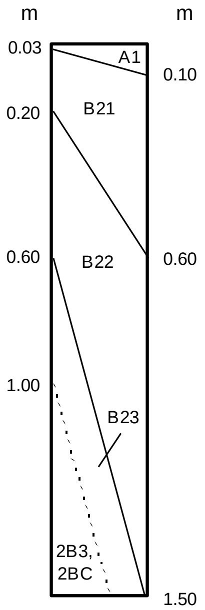
Permeability: Very slow to slow.

Drainage: Moderately well drained.

Surface Features: Frequently cracking with a hard setting or occasionally firm pedal to fine (<2 mm), weakly self-mulching surface. Variation between gilgai components is minimal. Frequently 2 to 20% and occasionally 20 to 50% silcrete or ferruginised siltstone and sandstone gravels 6 to 60 mm.

Representative Profiles: **9062, 9114**

Typical Profile



Soil Description – Non-gilgaied/mound/shelf profile

The **surface soil** (A1) is a gravelly, brown, fine sandy light clay to fine sandy medium clay with moderate or strong blocky structure. Depths typically range from 0.03 to 0.1 m. Field pH is 6–8.

The **upper subsoil** (B21) is a brown, medium clay to medium heavy clay (frequently fine sandy) with moderate blocky or lenticular structure. It is occasionally calcareous with 2–10% soft or nodular carbonate. Field pH is 8–9.5

The **lower subsoil** (B22, B23) is a brown, medium clay to medium heavy clay (frequently fine sandy) with weak to strong, coarse lenticular structure grading to polyhedral at depth. It is occasionally calcareous with 2–10% soft carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (2B3, 2BC) is sometimes present below 1.0–>1.5 m. Substrate material is brown, mottled, reticulite or petroreticulite. Field pH is 5–9.5

Soil Description – Depression profile

Depression profiles generally have similar horizons, depths and morphology, but are non-calcareous and acid throughout. Field pH is typically <6.5.

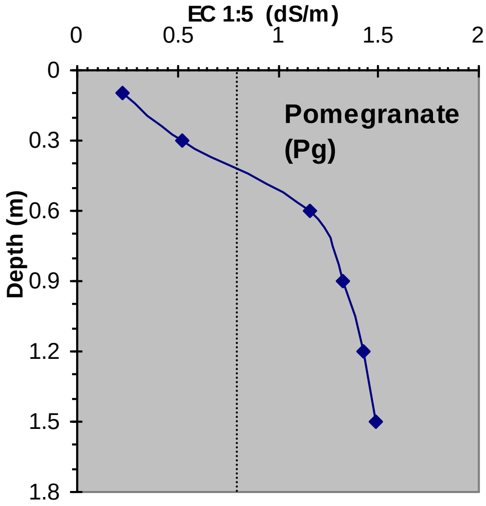
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.9	1.4	0.10	21	0.32	42	26	2.0	1.3	7.4	6.8
neutral	low	high	high	moderate	-	moderate	moderate	moderate	high	high

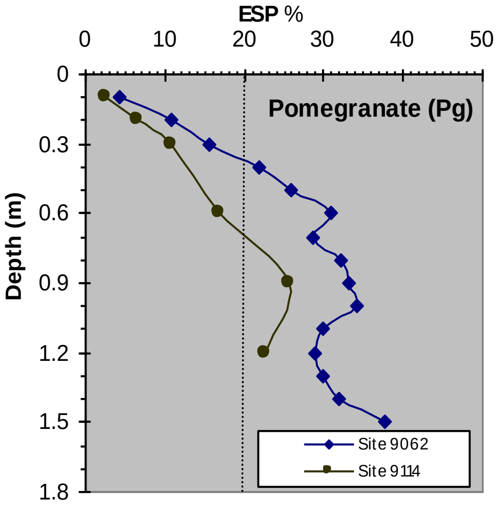
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are high. Most other nutrients are moderate to high. High nitrogen (Total N) levels are associated with the presence of brigalow scrub. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.35–0.55 m in the Pomegranate (Pg) soil. The profile salinity curve reaches equilibrium between 0.6 and 0.9 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.08	**0.57**	1.06	56	**97**	138

Typically, PAWC levels for the Pomegranate (Pg) soil are moderate (approximately 100 mm) because mean ERD is only about 0.55 m. It is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.6 m), maximum PAWC levels (100–140 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9062 and 9114 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases gradually between the surface soil (35–45%) and the subsoil (45–55%), while significant levels of fine sand (30–35%) and silt (>15%) in the surface soil promote surface sealing and hard setting behaviour. CEC/Clay% ratios in the profile are 0.4–0.55 and indicate the clay fraction is predominantly of mixed mineralogy. Measured dispersion (R1 ratio) in the surface soil is low (0.45–0.6), but increases to moderate levels (0.65–0.8) in the upper subsoil and high levels (0.8–0.95) at depth, because of increasing sodicity (ESP 6–15 increasing to >20). Detailed physical data from representative profiles 9062 and 9114 are presented in Appendix 3.

Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are mostly moderate (20–25 meq/100 g) throughout the profile. Calcium (Ca) is the dominant cation in the surface soil, while magnesium (Mg) is dominant throughout the subsoil. Profiles are non-sodic (ESP 2–6) in the immediate surface soil, but become sodic (ESP 6–15) in the upper subsoil and increase from strongly sodic (ESP 15–20) to extremely sodic (25–40) at depth. Detailed chemical data from representative profiles 9062 and 9114 are presented in Appendix 3.

POMEGRANATE MELONHOLE PHASE (PgMp)

Concept: A strongly developed melonhole gilgai complex (VI 0.6–1.5 m) with:

- a firm pedal, gravelly, alkaline, brown, sodic cracking clay on mounds; and
- a hard setting, firm pedal or weakly self-mulching, gravelly, acid, brown or grey, sodic cracking clay in depressions;

over reworked, acid Tertiary clay from 0.7–>1.5 m or unconsolidated sediments on valley floors and pediments below Tertiary plateaus. Brigalow vegetation.

Aust. Soil Classification: **Mound:** Brown Vertosol **Depression:** Brown or Grey Vertosol

Great Soil Group: **Mound:** Brown clay **Depression:** Brown clay, grey clay

Principal Profile Form: **Mound:** Ug5.34; occasionally 5.35 **Depression:** Ug5.34, 5.24

Geology: Unconsolidated Tertiary–Quaternary sediments (TQa) associated with reworked Tertiary clay and local colluvium on pediments, plains and valley floors below Tertiary plateaus. Clay and gravel material deposited locally following plateau dissection and scarp retreat.

Landform: Level to very gently undulating plains and lower footslopes below Tertiary plateaus; particularly surrounding the Junee tablelands. Slopes <0.5 to 1%, occasionally up to 3%.

Vegetation Associations: Brigalow (VA1); occasionally Brigalow with shrubs (VA8).

Microrelief: Strongly developed melonhole gilgai VI 0.6–1.5 m, HI 10–40 m; occasionally with a prominent shelf.

Runoff: Slow on mounds; very slow or no runoff in depressions.

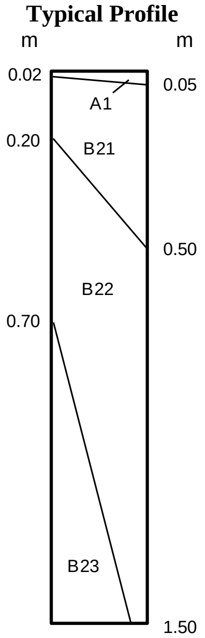
Permeability: Very slow.

Drainage: Moderately well drained on mounds; poorly to imperfectly drained in depressions.

Surface Features: **Mound** - cracking with a firm pedal surface; occasionally hard setting or weakly to moderately self-mulching with <2 to 10% free carbonate nodules.
Depression - cracking with a hard setting, firm pedal or coarse (>2 mm), weakly self-mulching surface.
Frequently 2 to 20% and occasionally 20 to 50% silcrete or ferruginised sandstone and siltstone gravels 6 to 60 mm.

Representative Profiles: **9060, 9061**

Typical Profile



Soil Description – Mound profile

The **surface soil** (A1) is a brown, fine sandy light medium clay to fine sandy medium clay with moderate blocky structure. Depths typically range from 0.02 to 0.05 m. Field pH is 6–7.

The **upper subsoil** (B21) is a brown, medium clay to medium heavy clay (frequently fine sandy) with moderate or strong lenticular structure. It is occasionally calcareous with 2–10% soft or nodular carbonate. Field pH is 8–9.5, although acid subsoils with a pH of 6–7 sometimes occur.

The **lower subsoil** (B22, B23) is a brown, medium clay to medium heavy clay (frequently fine sandy) with weak to strong, coarse lenticular structure grading to polyhedral at depth. It is occasionally calcareous with 2–20% soft or nodular carbonate in the upper part, grading to non-calcareous at depth. Field pH is 5–9.5, but generally decreases with depth.

Soil Description – Depression profile

Depression profiles have similar horizons, texture and structure but differ significantly in terms of colour and pH. Profiles may be either brown or grey and are typically non-calcareous and acid throughout. Field pH is 5.5–6.5 in the upper profile, decreasing to <5 at depth.

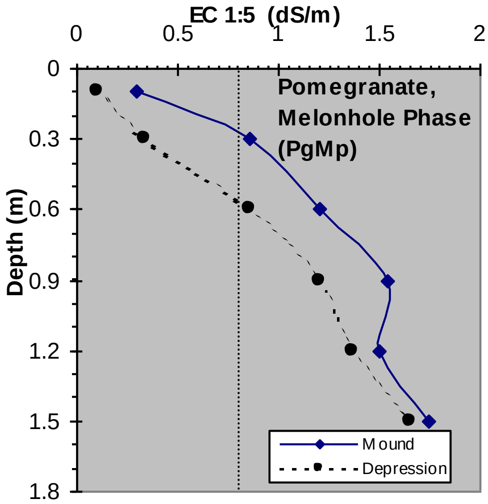
Surface Soil Fertility[1]

Gilgai comp.	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
mound	6.8	1.5	0.11	18	0.39	51	27	1.4	0.83	11	9.4
	neutral	low	high	high	moderate	-	moderate	moderate	moderate	high	high
dep.	6.3	1.2	0.09	44	0.48	121	35	2.4	1.4	8.6	6.7
	acid	low	high	very high	moderate	-	moderate	moderate	moderate	high	high

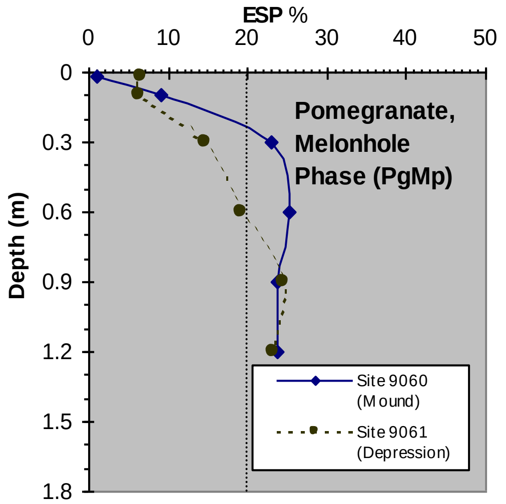
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (mounds and depressions). Typically, nitrogen (Total N) levels are high irrespective of gilgai component, while phosphorus (Bicarb. P) levels increase from high on mounds to very high in depressions. Absolute differences in phosphorus fertility between components are significant with levels more than doubling in depressions. Most other nutrients are moderate to high with similar levels on both gilgai components. High nitrogen (Total N) levels are associated with the presence of brigalow scrub. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

The Pomegranate melonhole phase (PgMp) soil normally has significant salinity (EC >0.8 dS/m) developed by 0.25–0.35 m on mounds and 0.6–0.85 m in depressions. The mound profile salinity curve reaches an indistinct equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the probable depth of long term wetting normally associated with mound profiles. The depression curve in contrast does not reach equilibrium (salt bulge is not developed) suggesting significant drainage moves below depressions. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil, on mounds, and in the lower subsoil (below 0.6–>1.5 m) in depressions.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
mound	0.08	**0.24**	0.40	38	**68**	99
dep.	0.32	**0.87**	1.42	81	**124**	167

Typically, PAWC levels for the Pomegranate melonhole phase (PgMp) soil are low (approximately 70 mm) on mounds and moderate (approximately 125 mm) in depressions. Mean ERD on mounds is only 0.25 m, compared with 0.85 m in depressions. In both cases, ERD is restricted by high salinity levels (EC >0.8 dS/m), as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Regular seasonal ponding in depressions has resulted in significant leaching and a downward movement of the salt bulge. Even where deeper mound profiles occur (ERD >0.25 m), maximum PAWC levels (70–100 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface; surface sealing and dispersive behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9060 and 9061 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is relatively uniform (50–65%) throughout both mound and depression profiles, although thin surface horizons with only 35–45% clay are often developed on mounds. Significant fine sand (20–40%) and silt (15–20%) in the surface soil of both gilgai components promote surface sealing behaviour. CEC/Clay% ratios in both gilgai components are 0.3–0.55 and indicate the clay fraction is predominantly of mixed mineralogy. Measured dispersion (R1 ratio) in the surface soil is mostly low (0.45–0.6), while in the upper subsoil it ranges from moderate to high (0.7–0.85), irrespective of gilgai component. Dispersion (R1 ratio) in the lower subsoil is mostly high (0.9–0.95). Detailed physical data from representative profiles 9060 and 9061 are presented in Appendix 3.

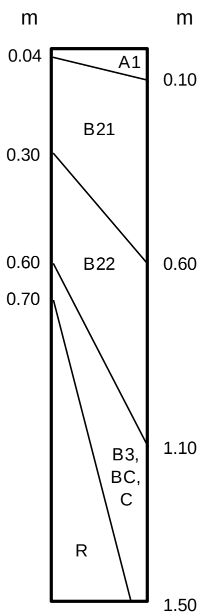
Laboratory pH is similar to field pH (see profile description). CEC levels are mostly moderate (15–25 meq/100 g) throughout the profile, irrespective of gilgai component. Magnesium (Mg) is the dominant cation throughout both mound and depression profiles, and is often present in levels 5–10 times higher than calcium (Ca) in the lower subsoil. Mound profiles are typically non-sodic (ESP <3) in the immediate surface soil, but increase dramatically to extremely sodic levels (ESP 20–25) in the upper and lower subsoils. Depression profiles are also non-sodic (ESP 6) in the surface soil, but increase more gradually becoming sodic (ESP 6–15) in the upper subsoil and extremely sodic (ESP 20–25) only at depth. Detailed chemical data from representative profiles 9060 and 9061 are presented in Appendix 3.

POMEGRANATE SHALLOW PHASE (PgSp)

Concept:	A moderately deep, very hard setting, gravelly, acid to alkaline, strongly sodic version of the Pomegranate (Pg) soil, developed on colluvium over deeply weathered sediments from 0.6–1.1 m, on pediments and footslopes below Tertiary plateaus. Brigalow vegetation.
Aust. Soil Classification:	Brown Dermosol; Brown Vertosol.
Great Soil Group:	Brown clay.
Principal Profile Form:	Uf6.31, Ug5.34, 5.35.
Geology:	Unconsolidated Tertiary–Quaternary sediments (TQa) derived from local colluvium, that overlie deeply weathered sediments on pediments and footslopes below Tertiary plateaus. Clay and gravel overlying reticulite or petroreticulite.
Landform:	Gently undulating pediments and footslopes immediately below Tertiary plateaus and dissected plateau remnants. Often as distinct pediment slopes that fan out and form a characteristic apron around adjacent plateaus or residuals. Slopes 0.5 to 2%.
Vegetation Associations:	Brigalow–yapunyah (VA40); occasionally Brigalow (VA1).
Microrelief:	Absent.
Runoff:	Slow.
Permeability:	Very slow.
Drainage:	Moderately well drained to imperfectly drained.
Surface Features:	Non-cracking to cracking and very hard setting with 10 to 20% silcrete or ferruginised sandstone and siltstone gravels 6 to 60 mm.

Representative Profile: **9099**

Typical Profile



Soil Description

The **surface soil** (A1) is a brown, fine sandy light clay to fine sandy light medium clay with weak or moderate blocky structure. Depths typically range from 0.04 to 0.1 m. Field pH is 6–7.

The **upper subsoil** (B21) is a brown, fine sandy medium clay to fine sandy medium heavy clay with moderate blocky or lenticular structure. Field pH is 5–9.5.

The **lower subsoil** (B22) is a brown, fine sandy medium clay to fine sandy medium heavy clay with moderate or strong polyhedral structure. Field pH is 5–9.5.

Weathered **substrate** (B3, BC, C) is normally present below 0.6–1.1 m. Substrate material is grey, mottled, reticulite or petroreticulite. Field pH is 5–9.

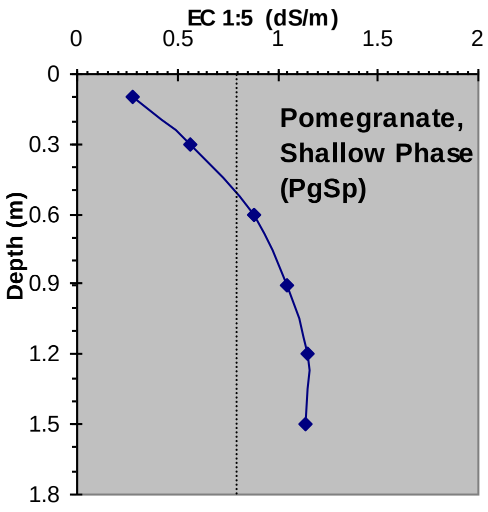
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.5	1.4	0.10	16	0.27	61	10	1.7	1.1	3.4	8.5
acid	low	high	high	low	-	moderate	moderate	moderate	moderate	high

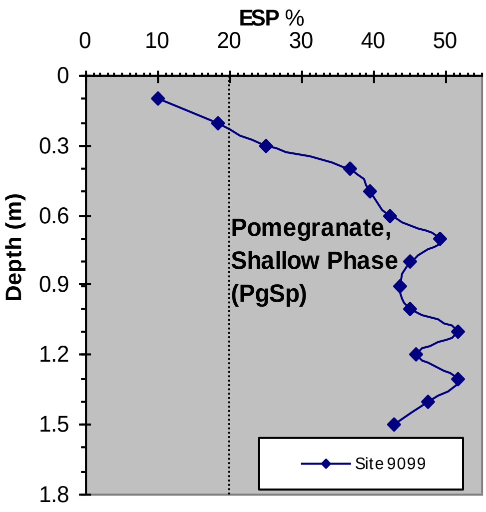
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are high. Most other nutrients are low to moderate with the exception of magnesium (Mg) which is high. Elevated magnesium (Mg) levels are derived directly from the underlying deeply weathered Tertiary substrate (i.e. basal layers of the deeply weathered profile). Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.55 m in the Pomegranate shallow phase (PgSp) soil. The profile salinity curve reaches an indistinct equilibrium between 0.6 and 0.9 m (salt bulge becomes constant) indicating the probable depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.6–1.1 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.00	**0.54**	1.08	50	**99**	148

Typically, PAWC levels for the Pomegranate shallow phase (PgSp) soil are only moderate (approximately 100 mm) because mean ERD is <0.55 m. It is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.55 m), maximum PAWC levels (100–150 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface; surface sealing and dispersive behaviour) and excessive runoff (elevated, sloping landforms). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9099 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is relatively uniform (45–50%) throughout the profile. Significant levels of fine sand (30%) and silt (15%) in the surface soil promote surface sealing and hard setting behaviour. CEC/Clay% ratios in the profile are 0.3–0.4 and indicate the clay fraction is predominantly of mixed mineralogy (i.e. kaolinitic Tertiary clay with significant colluvial influence). Measured dispersion (R1 ratio) is moderate (0.7) in the surface soil and very high (>0.95) throughout the remainder of the profile, because of consistently very high sodicity levels (ESP 20–55). Detailed physical data from representative profile 9099 are presented in Appendix 3.

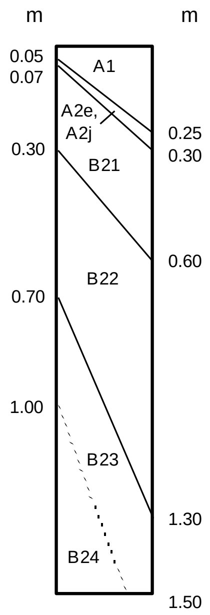
Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are moderate (15–20 meq/100 g) in the surface soil and upper subsoil where colluvial influences are strongest, decreasing to low levels (10–15 meq/100 g) at depth because of the underlying deeply weathered Tertiary substrate. Magnesium (Mg) is the dominant cation in the upper profile, while sodium (Na) is dominant in the lower subsoil. Levels of magnesium (Mg) and sodium (Na) in the lower subsoil are up to 5–10 times higher than calcium (Ca). Typically profiles are sodic (ESP >10) in the surface soil and increase dramatically to extremely sodic levels (ESP 20–55) in both the upper and lower subsoil. Detailed chemical data from representative profile 9099 are presented in Appendix 3.

RACETRACK (Rt)

Concept:	A hard setting, clay loamy surfaced, conspicuously or sporadically bleached, alkaline, brown, sodic texture contrast soil with coarse columnar structure over unconsolidated sediments. Brigalow vegetation.
Aust. Soil Classification:	Brown (or occasionally Black or Grey) Sodosol.
Great Soil Group:	Solodic soil, solodized solonetz.
Principal Profile Form:	Db1.43, 1.33, Dy2.43, 2.33, Dd1.43, 1.33; occasionally Db1.13, Dy2.13, Db1.41, 1.31, Dy2.41, Db3.43, 3.33.
Geology:	Unconsolidated Tertiary–Quaternary sediments (TQa). Includes relict alluvial deposits and widespread reworked local colluvium. Sand, clay and gravel sourced from sedimentary landscapes in the Isaac–Connors and Mackenzie River catchments.
Landform:	Level to gently undulating plains. Slopes 0.5 to 3%.
Vegetation Associations:	Brigalow–Dawson gum (VA5); occasionally Brigalow (VA1), Dawson gum (VA10) or Brigalow–yapunyah (VA40).
Microrelief:	Absent.
Runoff:	Slow to moderately rapid.
Permeability:	Very slow.
Drainage:	Moderately well drained (or occasionally imperfectly drained).
Surface Features:	Hard setting. Frequently 2 to 20% silcrete or ferruginised siltstone and sandstone gravels 6 to 60 mm.
Representative Profiles:	**9003, 9007, 9019**

Typical Profile



Soil Description

The **surface soil** (A1, A2e, A2j) is a brown or black, sandy clay loam to clay loam (frequently fine sandy) with massive structure. Depths typically range from 0.05 to 0.3 m. A conspicuously or sporadically bleached layer is frequently developed immediately above the clay subsoil. Field pH is 6–7.

The **upper subsoil** (B21) is a brown, light medium clay to medium heavy clay (frequently fine sandy) with moderate or strong, coarse columnar structure. Field pH is 6–7, increasing to >8.5 with depth.

The **lower subsoil** (B22, B23, B24) is a brown or grey, light medium clay to medium heavy clay (frequently sandy or fine sandy) with moderate to strong blocky or polyhedral structure. It is frequently calcareous and manganiferous with 2–20% soft or nodular carbonate and 2–20% manganese veins. Field pH is 8.5–9.5.

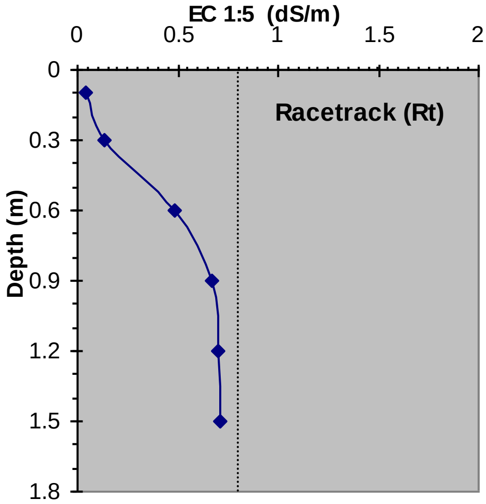
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.4	1.2	0.05	13	0.16	32	31	0.66	0.23	3.8	1.7
acid	low	moderate	moderate	low	-	moderate	moderate	low	moderate	moderate

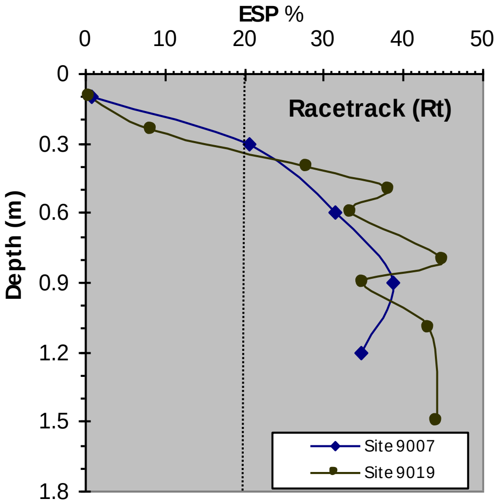
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are moderate. Most other nutrients are also moderate, with the exception of potassium (K) and zinc (Zn) which are low. Nitrogen (Total N) fertility is lower than expected for a brigalow scrub soil because of the significant eucalypt component normally associated in the upper storey (e.g. Dawson gum). Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Racetrack (Rt) soil. The profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.12	**0.70**	1.28	27	**74**	122

Typically, PAWC levels for the Racetrack (Rt) soil are low (approximately 75 mm) because mean ERD is only 0.7 m. It is restricted by physical limitations and reduced permeability in the upper subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.7 m), maximum PAWC levels (75–120 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9003, 9007 and 9019 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (15–30%) and the upper subsoil (35–45%), while in the lower subsoil clay content often decreases to between 25–35%. High levels of fine sand (45–65%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the subsoil are 0.4–0.55 and indicate the clay fraction is of mixed mineralogy. Measured dispersion (R1 ratio) in the upper subsoil ranges from moderate to high (0.7–0.85), but increases to very high levels (>0.99) in the lower subsoil, because of extreme sodicity (ESP >20). Detailed physical data from representative profiles 9003, 9007 and 9019 are presented in Appendix 3.

Subsoil Chemistry

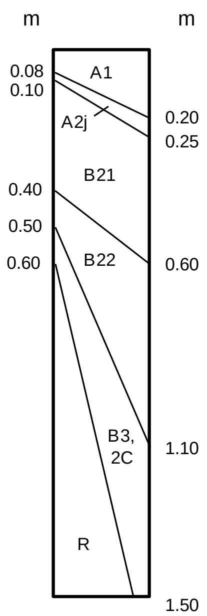
Laboratory pH is similar to field pH (see profile description). CEC levels are low (7–11 meq/100 g) in the surface soil and low to moderate (10–17 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil, while magnesium (Mg) and sodium (Na) are dominant in the subsoil. Profiles are typically extremely sodic (ESP 20–50) throughout the subsoil. Detailed chemical data from representative profiles 9003, 9007 and 9019 are presented in Appendix 3.

RACETRACK SHALLOW PHASE (RtSp)

Concept: A moderately deep, sporadically bleached, gravelly, neutral or alkaline version of the Racetrack (Rt) soil with blocky structure, developed on colluvium over deeply weathered sediments from 0.5–1.1 m, on pediments and footslopes below Tertiary plateaus. Brigalow vegetation.
Aust. Soil Classification: Brown (or occasionally Black or Grey) Sodosol.
Great Soil Group: Solodic soil.
Principal Profile Form: Db1.33, 1.13, Dd1.33, 1.13, Dy2.33; occasionally Db1.31, 1.32, 1.41, Dd1.42.
Geology: Unconsolidated Tertiary–Quaternary sediments (TQa) derived from local colluvium, that overlie deeply weathered sediments on pediments and footslopes below Tertiary plateaus. Sand, clay and gravel overlying reticulite or petroreticulite.
Landform: Gently undulating pediments and occasional rises below Tertiary plateaus. Slopes 1 to 3%, occasionally up to 5%.
Vegetation Associations: Brigalow–Dawson gum (VA5); occasionally Dawson gum (VA10) or Brigalow–yapunyah (VA40).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Very slow to slow.
Drainage: Moderately well drained.
Surface Features: Hard setting. Frequently 2 to 20% silcrete or ferruginised siltstone and sandstone gravels 6 to 60 mm.

Representative Profiles: **Not sampled** (see sites 9003, 9007 and 9019 from the Racetrack (Rt) soil).

Typical Profile



Soil Description

The **surface soil** (A1, A2j) is a brown or black, sandy clay loam to clay loam (frequently fine sandy) with massive to weak platy or blocky structure. Depths typically range from 0.1 to 0.25 m. A sporadically bleached layer is frequently developed immediately above the clay subsoil. Field pH is 6–7.

The **upper subsoil** (B21) is a brown, light medium clay to medium clay (frequently fine sandy) with moderate blocky structure. Field pH is 6–8.5, generally increasing with depth.

The **lower subsoil** (B22) is a brown, light medium clay to medium clay (frequently fine sandy) with moderate or strong blocky structure. It is frequently calcareous with 2–20% soft or nodular carbonate. Field pH is 7–9.5.

Weathered **substrate** (B3, 2C) is normally present below 0.5–1.1 m. Substrate material is grey, mottled, reticulite or petroreticulite. Field pH is 5–9.

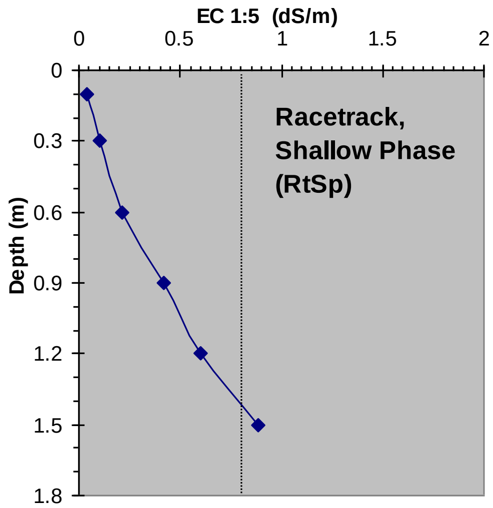
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.4	1.4	0.08	17	0.31	25	30	0.80	0.86	3.6	1.5
acid	low	moderate	high	moderate	-	moderate	moderate	moderate	moderate	moderate

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are high. Most other nutrients are present in moderate levels. Nitrogen (Total N) fertility is lower than expected for a brigalow scrub soil because of the significant eucalypt component normally associated in the upper storey (e.g. Dawson gum). Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is not normally present until about 1.4 m in the Racetrack shallow phase (RtSp) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Weathered substrate is normally present somewhere below 0.5–1.1 m and contributes to increased salinity levels at depth. Comparison with the Racetrack (Rt) soil suggests critical sodicity levels (ESP >20) are likely to occur within the upper 0.5 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**
	0.33	**0.70**	1.07	51	**88**	125

Typically, PAWC levels for the Racetrack shallow phase (RtSp) soil are borderline low to moderate (approximately 90 mm) because mean ERD is only 0.7 m. It is restricted by the presence of hard, deeply weathered substrate or physical limitations and reduced permeability in the lower subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.7 m), maximum PAWC levels (90–125 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy surface) and excessive runoff (elevated, sloping landforms). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available, but data from representative profiles 9003, 9007 and 9019 in Appendices 3 and 6 may be useful as a guide.

Physical Characteristics and Subsoil Chemistry

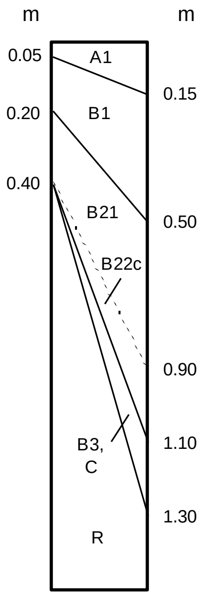
Interpretations and descriptions of the physical characteristics and chemistry of the Racetrack shallow phase (RtSp) soil are unavailable, but are probably comparable with those presented for the Racetrack (Rt) soil.

RED CLIFF (Rc)

Concept:	A shallow, hard setting, uniform, clay loamy surfaced, acid, red massive earth (<0.5 m) grading to a moderately deep, clay loamy surfaced, acid, red, structured gradational soil over deeply weathered sediments from 0.5–1.1 m. Eucalypt vegetation.
Aust. Soil Classification:	Red Kandosol; Red Dermosol.
Great Soil Group:	Red earth, no suitable group.
Principal Profile Form:	Um5.51, 5.52, Gn2.11, 3.11, 3.12, 4.11, 4.12, Uf6.21, 6.31.
Geology:	Fine grained sedimentary rocks altered by Tertiary deep weathering (Td, Ta). Substrate is reticulite or petroreticulite.
Landform:	Gently undulating to undulating rises associated with dissected Tertiary plateau remnants; occasionally gently undulating plains associated with eroded plateau margins. Distinct scarps often bound dissected remnants. Slopes <1 to 5%.
Vegetation Associations:	Narrow-leaved ironbark (VA12) or Ironbark–bloodwood–ghost gum (VA50); occasionally Bendee (VA30), Eucalypts with shrubby heath myrtle (VA14), Queensland peppermint (VA25) or Lancewood (VA3).
Microrelief:	Absent.
Runoff:	Slow to moderately rapid.
Permeability:	Moderate.
Drainage:	Moderately well drained to well drained.
Surface Features:	Hard setting. Frequently 2 to 20% ironstone gravels 6 to 20 mm. Occasionally 2 to 10% petroreticulite outcrop.

Representative Profile: **9082**

Typical Profile



Soil Description

The **surface soil** (A1, B1) is a red, brown or black, fine sandy clay loam to fine sandy light clay with massive or weak blocky structure. Depths typically range from 0.2 to 0.5 m. Field pH is 5–6.5.

The **upper subsoil** (B21) is a red, clay loam fine sandy to fine sandy light medium clay with massive or weak to moderate blocky or polyhedral structure. Field pH is 5–6.5.

The **lower subsoil** (B22c) is a red or brown, fine sandy light clay to fine sandy light medium clay with massive or weak to strong polyhedral structure. A ferruginous layer with 10–50% ferruginous nodules is normally developed. Field pH is 5–6.5.

Weathered **substrate** (B3, C) is normally present below the ferruginous layer from 0.4–1.1 m. Substrate material is grey or yellow, mottled, reticulite or petroreticulite. Field pH is <5.5.

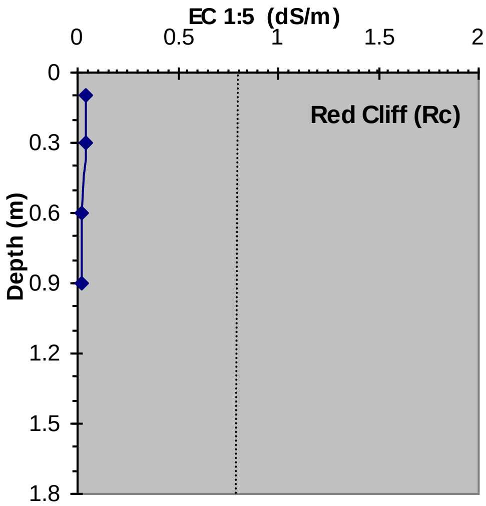
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.4	1.1	0.07	4	0.40	27	12	0.61	0.17	1.6	1.1
strongly acid	low	moderate	very low	moderate	-	moderate	moderate	very low	low	moderate

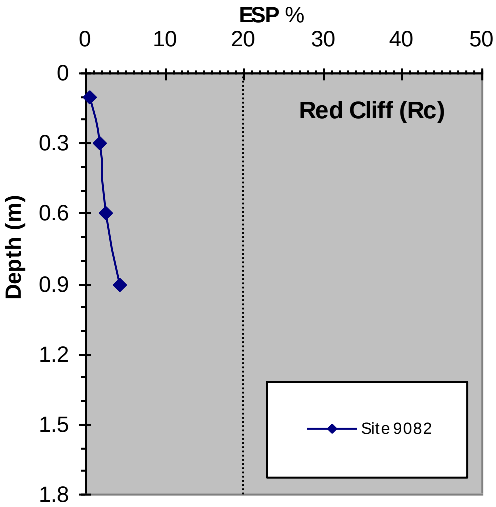
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are very low. Most other nutrients are moderate with the exception of calcium (Ca) which is low and zinc (Zn) which is very low. The phosphorus infertility of the Red Cliff (Rc) soil reflects its leached nature and the low phosphorus status of the underlying deeply weathered Tertiary substrate. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the Red Cliff (Rc) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Sodicity levels within the profile (ESP <4) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.19	**0.56**	0.94	42	**73**	104

Typically, PAWC levels for the Red Cliff (Rc) soil are low (approximately 75 mm) because mean ERD is <0.6 m. It is restricted by the presence of deeply weathered, acidic substrate at relatively shallow depths. Even where deeper profiles occur (ERD >0.6 m), maximum PAWC levels (75–105 mm) are rarely achieved on a regular basis because profiles are permeable and subject to continued deep drainage and evaporation losses over time. Elevated sloping landforms mean excessive runoff and lateral drainage are also significant. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9082 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is either relatively uniform (25–40%) throughout the profile or increases gradually between the surface soil (25–40%) and the subsoil (40–70%). Significant levels of fine sand (>40%) and silt (>15%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the profile are <0.15 and indicate the clay fraction is entirely kaolinitic. Measured dispersion (R1 ratio) is low (0.1–0.5) throughout the profile and reflects the non-sodic, acidic, kaolinitic nature of this soil. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9082 are presented in Appendix 3.

Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are low (6 meq/100 g) in the surface soil and low to very low (4–6 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while magnesium (Mg) is dominant at depth. Profiles are non-sodic (ESP <4) throughout. Detailed chemical data from representative profile 9082 are presented in Appendix 3.

RED HILL (Rh)

Concept: A hard setting, clay loamy surfaced, acid or neutral, red, structured gradational soil or non-cracking clay grading to a uniform or gradational, clay loamy surfaced, acid, red massive earth over deeply weathered basalt from 0.6–1.1 m. Eucalypt vegetation.

Aust. Soil Classification: Red Dermosol; Red Kandosol.

Great Soil Group: Red earth, no suitable group.

Principal Profile Form: Gn4.11, 4.13, 3.11; occasionally Uf6.21, Gn2.11, 2.12, Um5.51.

Geology: Basalt altered by Tertiary deep weathering (Tb_d). Substrate is reticulite or petroreticulite.

Landform: Gently undulating to undulating rises associated with dissected Tertiary plateau remnants; occasionally gently undulating plains associated with eroded plateau margins. Distinct scarps often bound dissected remnants. Slopes 1 to 5%.

Vegetation Associations: Narrow-leaved ironbark (VA12); occasionally Bendee (VA30), Ironbark–bloodwood–ghost gum (VA43) or Ironbark–bloodwood–ghost gum (VA50).

Microrelief: Absent.

Runoff: Slow to moderately rapid.

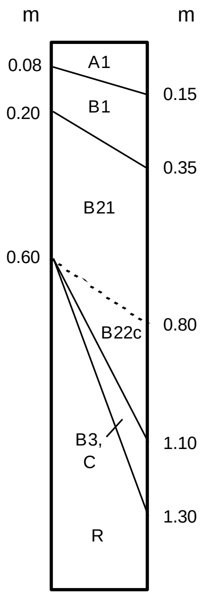
Permeability: Slow to moderate.

Drainage: Moderately well drained to well drained.

Surface Features: Hard setting. Frequently 10 to 20% ironstone gravels or petroreticulite fragments 6 to 60 mm. Occasionally 2 to 20% petroreticulite outcrop.

Representative Profiles: **Not sampled** (see site 9082 from the Red Cliff (Rc) soil).

Typical Profile



Soil Description

The **surface soil** (A1, B1) is a red, fine sandy clay loam to fine sandy light clay with massive to weak polyhedral or blocky structure. Depths typically range from 0.2 to 0.35 m. Field pH is 6–6.5.

The **upper subsoil** (B21) is a red, fine sandy light clay to fine sandy light medium clay with massive or weak to moderate polyhedral structure. Field pH is 5.5–7.

The **lower subsoil** (B22c) is a red, fine sandy light clay to fine sandy light medium clay with massive or weak to moderate polyhedral structure. A ferruginous layer with 2–20% ferruginous nodules or red kaolinitic clay nodules is normally developed. Field pH is 6–7.

Weathered **substrate** (B3, C) is normally present below the ferruginous layer from 0.6–1.1 m. Substrate material is red or brown, mottled, reticulite or petroreticulite. Field pH is 6–7.

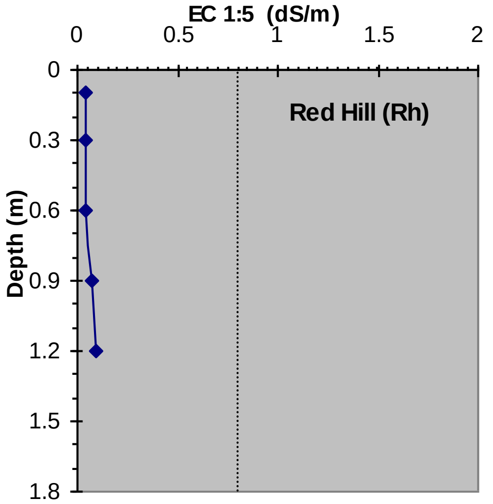
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)	(meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.7	1.2	0.07	9	0.45	18	57	1.0	0.29	4.4	1.5
acid	low	moderate	low	moderate	-	high	moderate	low	moderate	moderate

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are low. Most other nutrients are moderate, with the exception of manganese (Mn) which is high and zinc (Zn) which is low. Phosphorus (Bicarb. P) levels derived directly from the underlying, deeply weathered basalt are significantly higher than those of the equivalent Red Cliff (Rc) soil on deeply weathered Tertiary sediments. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data ($EC_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the Red Hill (Rh) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Comparison with the Red Cliff (Rc) soil suggests sodicity levels within the profile are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.25	**0.80**	1.35	51	**93**	135

Typically, PAWC levels for the Red Hill (Rh) soil are moderate (approximately 95 mm) with a mean ERD of about 0.8 m. It is restricted by the presence of deeply weathered, basaltic substrate at relatively shallow depths. Even where deeper profiles occur (ERD >0.8 m), maximum PAWC levels (95–135 mm) are rarely achieved on a regular basis because profiles are permeable and subject to continued deep drainage and evaporation losses over time. Elevated sloping landforms mean excessive runoff and lateral drainage are also significant. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available, but data from representative profile 9082 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

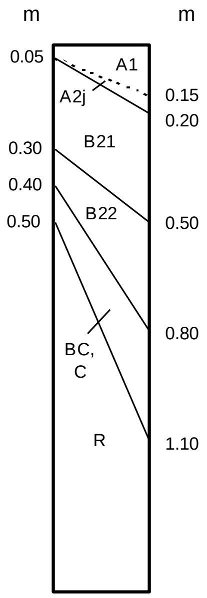
Interpretations and descriptions of the physical characteristics and chemistry of the Red Hill (Rh) soil are unavailable, but are probably comparable with those presented for the Red Cliff (Rc) soil.

RED-ONE (Rn)

Concept: A hard setting, loamy or clay loamy surfaced, alkaline, red, non-sodic texture contrast soil over lithic, feldspathic or calcareous sandstone, siltstone or shale from 0.4–0.8 m. Eucalypt vegetation.
Aust. Soil Classification: Red Chromosol.
Great Soil Group: No suitable group, red-brown earth.
Principal Profile Form: Dr2.12, 2.13, 2.33, 2.11, 2.23, 2.32.
Geology: Sandstones, siltstones and mudstones of the Blackwater Group (Pw). Mostly lithic, feldspathic or calcareous freshwater sedimentary rocks
Landform: Gently undulating plains and rises. Slopes 1 to 3%.
Vegetation Associations: Silver-leaved ironbark (VA17), Narrow-leaved ironbark (VA12) or Ironbark–bloodwood–ghost gum (VA43); occasionally Poplar box–ironbark (VA34) or Poplar box (VA20).
Microrelief: Absent.
Runoff: Slow or moderately rapid.
Permeability: Slow.
Drainage: Moderately well drained.
Surface Features: Hard setting. Frequently with 2 to 20% silcrete, petrified wood, sandstone or shale gravels 6 to 60 mm. Occasionally <2 to 10% stones 60 to 200 mm or <2 to 10% rock outcrop.

Representative Profiles: **9006, 9018**

Typical Profile



Soil Description

The **surface soil** (A1, A2j) is a brown, sandy loam to clay loam (frequently fine sandy) with massive or weak platy to blocky structure. Depths typically range from 0.05 to 0.2 m. A sporadically bleached layer is sometimes developed immediately above the clay subsoil. Field pH is 5.5–7.

The **upper subsoil** (B21) is a red, light medium clay to medium heavy clay with strong prismatic or blocky structure. Field pH is 5.5–7.

The **lower subsoil** (B22) is a red or brown, medium clay to medium heavy clay with moderate to strong blocky or lenticular structure. It is occasionally calcareous with 2–20% soft or nodular carbonate. Field pH is 7–9.5.

Weathered **substrate** (BC, C) is normally present below 0.4–0.8 m. Substrate material is labile sandstone, siltstone or shale that is often calcareous. Field pH is 7–9.5.

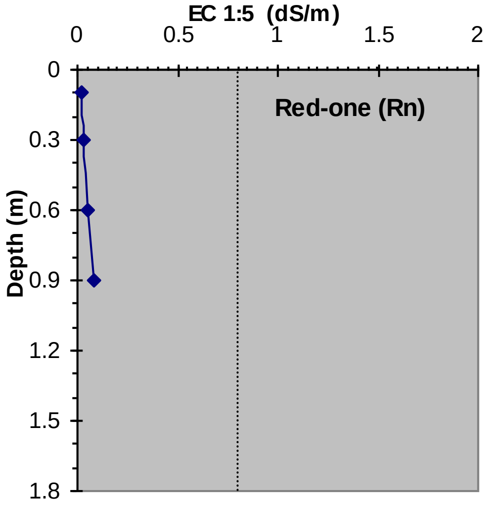
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.7	1.2	0.07	4	0.61	21	18	0.62	0.51	7.8	2.5
neutral	low	moderate	very low	high	-	moderate	moderate	moderate	high	moderate

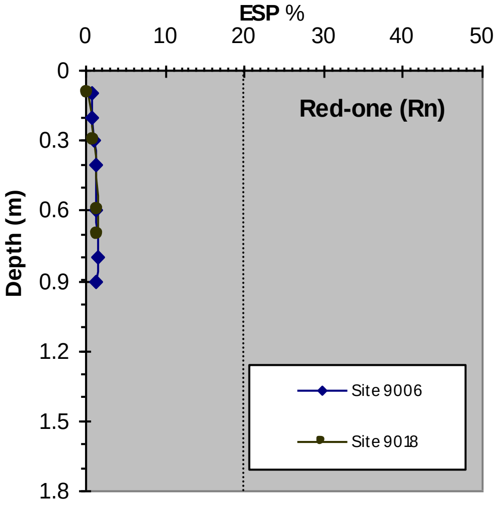
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are very low. Most other nutrients are moderate to high. The phosphorus infertility of the Red-one (Rn) soil reflects the low phosphorus status of the underlying labile sedimentary rocks. Elevated calcium (Ca) levels are derived directly from these same parent materials. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the Red-one (Rn) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Sodicity levels in the subsoil (ESP 1–2) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.37	**0.60**	0.83	55	**81**	106

Typically, PAWC levels for the Red-one (Rn) soil are low (approximately 80 mm) because mean ERD is only 0.6 m. ERD is defined simply by the depth to weathered sandstone, siltstone or shale. Restrictions to rooting depth are absent in the profile itself. Even where deeper profiles occur (ERD >0.6 m), maximum PAWC levels (80–105 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9006 and 9018 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (20–30%) and the subsoil (50–70%), while significant levels of fine sand (35–65%) and silt (>15%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the subsoil are 0.3–0.4 and indicate the clay fraction is of mixed mineralogy with a high proportion of kaolinite and illite. Measured dispersion (R1 ratio) in the subsoil is low throughout (0.2–0.4), because of high levels of exchangeable calcium (Ca) and low sodicity levels (ESP <6). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9006 and 9018 are presented in Appendix 3.

Subsoil Chemistry

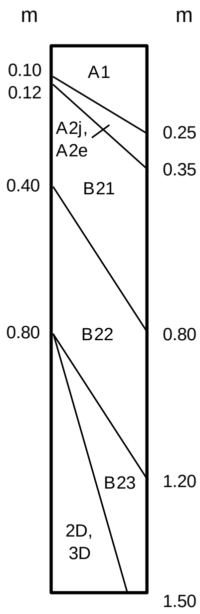
Laboratory pH is similar to field pH (see profile description). CEC levels are low (10–15 meq/100 g) in the surface soil and moderate to high (15–30 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation throughout the profile and is often 5–10 times higher than magnesium (Mg) in the subsoil. Profiles are non-sodic throughout (ESP <1.5). Detailed chemical data from representative profiles 9006 and 9018 are presented in Appendix 3.

ROPER (Rp)

Concept: A hard setting, sandy to clay loamy surfaced, sporadically or conspicuously bleached, alkaline, brown or black texture contrast soil over recent alluvium on alluvial plains and levees. Eucalypt vegetation.
Aust. Soil Classification: Brown or Black Chromosol; Brown or Black Sodosol.
Great Soil Group: Solodic soil; occasionally no suitable group, solodised solonetz.
Principal Profile Form: Dd1.33, 1.13, Db1.33, 1.13; occasionally Db1.43, 3.33, 3.43, Dd1.43, 3.13, 3.23, 3.33, Dy2.33, 2.43, 3.43, 5.43, Db1.11, 1.12, 1.31, 1.32, Dd1.12, Dy3.42.
Geology: Quaternary alluvium (Qa).
Landform: Slightly elevated levees and level alluvial plains on upper and lower tributaries; or occasionally elevated, terrace plains and relict levees on flood plains along major rivers. Flooded in lower lying parts. ARI is between 1 in 2 years and 1 in 10 years. Slopes <1%, occasionally up to 2 % on levees.
Vegetation Associations: Poplar box (VA20); occasionally Poplar box–bloodwood–Moreton Bay ash (VA33), Blue gum–mixed eucalypts (VA22) or Coolibah–mixed eucalypts (VA38).
Microrelief: Absent.
Runoff: Slow.
Permeability: Very slow to slow.
Drainage: Moderately well drained.
Surface Features: Hard setting or occasionally soft or firm.

Representative Profiles: **9012, 9106**

Typical Profile



Soil Description

The **surface soil** (A1, A2j, A2e) is a black or brown, loamy sand to clay loam fine sandy with massive or occasionally weak platy to blocky structure. Depths typically range from 0.1 to 0.35 m. A sporadically or conspicuously bleached layer is frequently developed immediately above the clay subsoil. Field pH is 6–7.

The **upper subsoil** (B21) is a brown or black, light medium clay to medium heavy clay (frequently sandy or fine sandy) with moderate to strong prismatic or blocky structure. Field pH is 6–8.5, generally increasing with depth.

The **lower subsoil** (B22, B23) is a brown, clay loam to medium clay (frequently sandy or fine sandy) with weak to strong blocky or polyhedral structure. It is frequently calcareous with 2–20% soft or nodular carbonate and is often mottled at depth. Field pH is 8.5–9.5.

Buried alluvial layers (2D, 3D) are often present from 0.8–>1.5 m. Buried materials are typically a brown, coarse sand to sandy medium clay with massive or weak to moderate blocky or polyhedral structure. Field pH is 6.5–9.5.

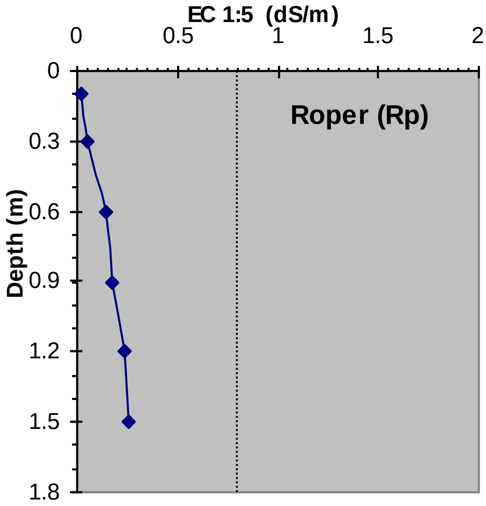
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.3	1.2	0.06	30	0.69	76	28	0.70	1.1	4.3	2.0
acid	low	moderate	high	mod-high	-	moderate	moderate	moderate	moderate	moderate

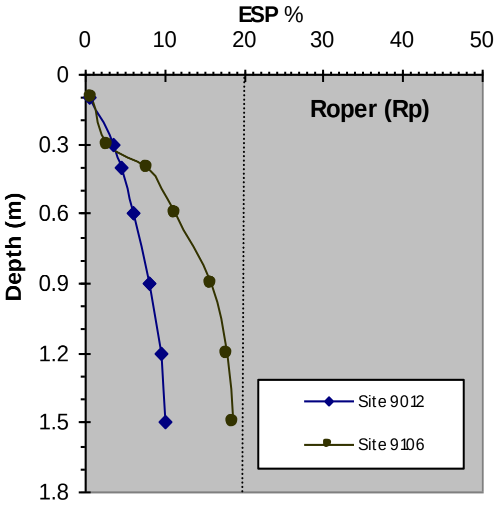
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are high. Most other nutrients are present in moderate levels. Elevated phosphorus (Bicarb. P) levels reflect the young age and recent alluvial origins of this soil. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Roper (Rp) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Critical sodicity levels (ESP >20) sometimes occur in the lower subsoil (below 1.2–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.64	**1.15**	1.66	69	**105**	141

Typically, PAWC levels for the Roper (Rp) soil are only moderate (approximately 105 mm) even though mean ERD is close to 1.2 m. Restrictions to rooting depth are generally absent, with the exception of buried alluvial layers (e.g. coarse sand, impermeable clay) or ESP levels close to 20 in the lower subsoil of some profiles. Even where deeper profiles (ERD >1.2 m) occur however, maximum PAWC levels (105–140 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, sandy to clay loamy surface; predominantly fine sandy). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9012 and 9106 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (15–25%) and the subsoil (30–50%), while high levels of fine sand (40–65%) and silt (>15%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the subsoil are 0.5–0.7 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (depending on sediment source). Measured dispersion (R1 ratio) in the subsoil ranges from low to moderate (0.55–0.8) and reflects subsoil sodicity levels that are mostly low to moderate (ESP <6–15). High levels of Total K throughout the profile reflect the young age and recent alluvial origins of this soil. Detailed physical data from representative profiles 9012 and 9106 are presented in Appendix 3.

Subsoil Chemistry

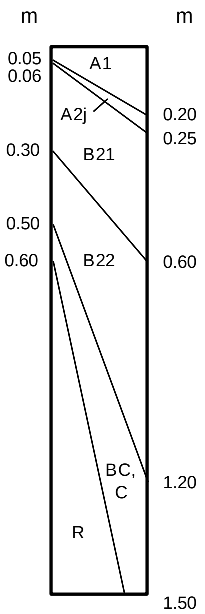
Laboratory pH is similar to field pH (see profile description). CEC levels are low (7–11 meq/100 g) in the surface soil and mostly moderate (15–25 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil, while either calcium (Ca) or magnesium (Mg) may be dominant or co-dominant in the subsoil (depending on sediment source). Profiles are typically non-sodic to sodic (ESP 3–12) in the upper subsoil and sodic (ESP 6–15) or strongly sodic (ESP 15–20) in the lower subsoil. Detailed chemical data from representative profiles 9012 and 9106 are presented in Appendix 3.

STATESCHOOL (Ss)

Concept: A hard setting, clay loamy surfaced, sporadically bleached, alkaline, brown or black, sodic texture contrast soil over labile sandstone, siltstone or shale from 0.5–1.2 m. Brigalow vegetation.
Aust. Soil Classification: Brown, Black (or occasionally Grey) Sodosol.
Great Soil Group: Solodic soil; occasionally solodised solonetz.
Principal Profile Form: Db1.13, 1.33, Dd1.33, 1.13, Db1.43, Dy2.13; occasionally Dy2.33, 4.13, 2.43, Db3.33, Dd1.43.
Geology: Sandstones, siltstones and mudstones of the Blackwater Group (Pw). Mostly lithic, feldspathic, micaceous or calcareous freshwater sedimentary rocks.
Landform: Gently undulating plains and rises. Slopes 0.5 to 3%.
Vegetation Associations: Brigalow–Dawson gum (VA5) or Brigalow (VA1); occasionally Dawson gum (VA10), Shrubby poplar box (VA7), Brigalow with shrubs (VA8) or Belah (VA9).
Microrelief: Absent.
Runoff: Slow to moderately rapid.
Permeability: Very slow to slow.
Drainage: Moderately well drained.
Surface Features: Hard setting. Frequently <2 to 50% silcrete, sandstone, siltstone and petrified wood gravel and rocks 20 to 200 mm. Occasionally <2 to 10% sandstone outcrop.

Representative Profiles: **9005, 9098, 9103**

Typical Profile



Soil Description

The **surface soil** (A1, A2j) is a black or brown, sandy clay loam to clay loam (frequently fine sandy) with massive or weak platy to blocky structure. Depths typically range from 0.05 to 0.25 m. A sporadically bleached layer is frequently developed immediately above the clay subsoil. Field pH is 6–7.

The **upper subsoil** (B21) is a brown or black, medium clay to medium heavy clay (frequently fine sandy) with moderate or strong blocky structure. Field pH is 8.5–9.5.

The **lower subsoil** (B22) is a brown, medium clay to medium heavy clay (frequently fine sandy) with moderate to strong blocky or lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (BC, C) is normally present below 0.5–1.2 m. Substrate material is labile sandstone, siltstone or shale that is often calcareous. Field pH is 8.5–9.5.

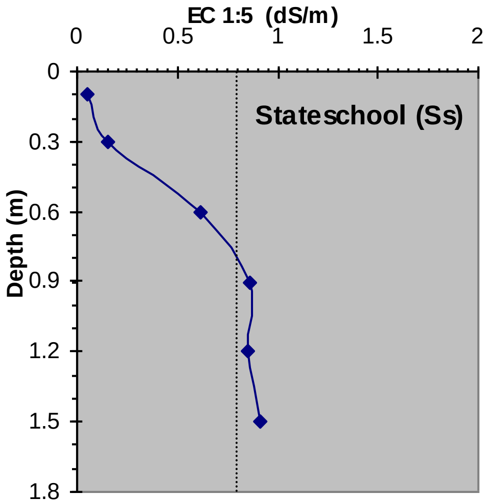
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.0	1.3	0.08	12	0.37	27	24	0.71	0.44	6.7	2.4
neutral	low	moderate	moderate	moderate	-	moderate	moderate	low	high	moderate

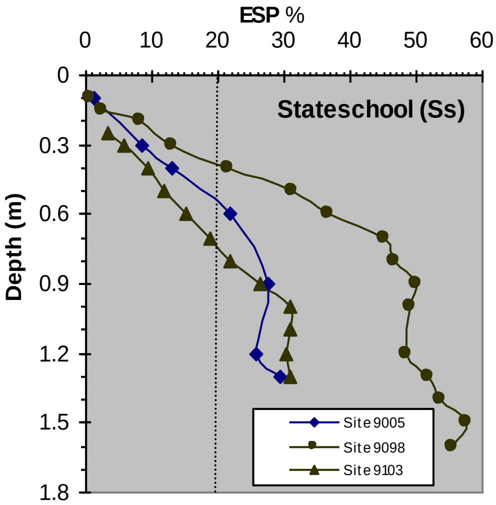
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are moderate. Most other nutrients are also moderate, with the exception of calcium (Ca) which is high and zinc (Zn) which is low. Nitrogen (Total N) fertility is lower than expected for a brigalow scrub soil because of the significant eucalypt component normally associated in the upper storey (e.g. Dawson gum). Elevated calcium (Ca) levels are derived directly from the underlying labile sedimentary rocks. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 0.7–0.8 m in the Stateschool (Ss) soil. The profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.5–1.2 m and contributes to the development of the salt bulge because of restricted subsoil drainage, as well as slight increases in salinity levels at depth. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.25	**0.69**	1.12	56	**96**	137

Typically, PAWC levels for the Stateschool (Ss) soil are only moderate (approximately 95 mm) because mean ERD is <0.7 m. It is restricted by high salinity levels (EC >0.8 dS/m) as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.7 m), maximum PAWC levels (95–135 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9005, 9098 and 9103 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (15–30%) and the subsoil (30–55%), while high levels of fine sand (45–65%) typically occur in the surface soil and promote hard setting behaviour. High levels of coarse sand (40–50%) throughout profile 9103 reflect the quartzose nature of the underlying substrate. CEC/Clay% ratios in the subsoil are 0.4–0.7 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (depending on the nature of the underlying substrate). Measured dispersion (R1 ratio) is only moderate (0.6–0.8) in the upper subsoil, but increases to high or very high levels (0.8–>0.95) in the lower subsoil because of high to very high sodicity levels (ESP 15–>50). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9005, 9098 and 9103 are presented in Appendix 3.

Subsoil Chemistry

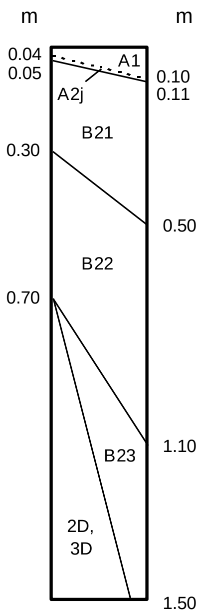
Laboratory pH is similar to field pH (see profile description). CEC levels are low to moderate (8–20 meq/100 g) in the surface soil and moderate to high (15–30 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil and immediate upper subsoil, while magnesium (Mg) is dominant at depth. Profiles are typically sodic (ESP 6–15) in the upper subsoil and strongly to extremely sodic (ESP 15–>50) in the lower subsoil and substrate. Detailed chemical data from representative profiles 9005, 9098 and 9103 are presented in Appendix 3.

STEPHENS (St)

Concept:	A hard setting, alkaline, black non-cracking clay grading to a thin (0.04–0.1 m), clay loamy surfaced, alkaline, black texture contrast soil over recent alluvium on levees and alluvial plains. Eucalypt vegetation.
Aust. Soil Classification:	Black (or occasionally Brown) Dermosol; Black (or occasionally Brown) Chromosol or Sodosol.
Great Soil Group:	No suitable group, solodic soil.
Principal Profile Form:	Uf6.32, 6.31, Dd1.13, 1.33, Db1.13, 1.33.
Geology:	Quaternary alluvium (Qa).
Landform:	Slightly elevated levees and backplain drainage areas on lower tributaries; or occasionally elevated, terrace plains and relict levees on flood plains along major rivers. Flooded in lower lying parts. ARI is between 1 in 2 years and 1 in 10 years. Slopes <1%, occasionally up to 2% on levees.
Vegetation Associations:	Poplar box (VA20); occasionally Blue gum–mixed eucalypts (VA22) or Coolibah–mixed eucalypts (VA38).
Microrelief:	Absent.
Runoff:	Slow.
Permeability:	Slow.
Drainage:	Moderately well drained.
Surface Features:	Hard setting.

Representative Profiles: **9025, 9108**

Typical Profile



Soil Description

The **surface soil** (A1, occasionally A2j) is a black, fine sandy clay loam to fine sandy light clay or silty light clay with massive or weak to moderate platy or blocky structure. Depths typically range from 0.04 to 0.1 m. A very thin sporadically bleached layer is sometimes developed immediately above the clay subsoil. Field pH is 6–7.

The **upper subsoil** (B21) is a black, light medium clay to medium heavy clay (frequently fine sandy) with moderate to strong blocky structure. Field pH is 6–8.5, increasing with depth.

The **lower subsoil** (B22, B23) is a black, brown or grey, light medium clay to medium clay (frequently fine sandy) with moderate to strong, prismatic or blocky structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 9–9.5.

Buried alluvial layers (2D, 3D) are often present from 0.7–>1.5 m. Buried materials are typically a black or brown, sandy clay loam to fine sandy medium clay with massive or weak to moderate prismatic or blocky structure. Field pH is 7–9.

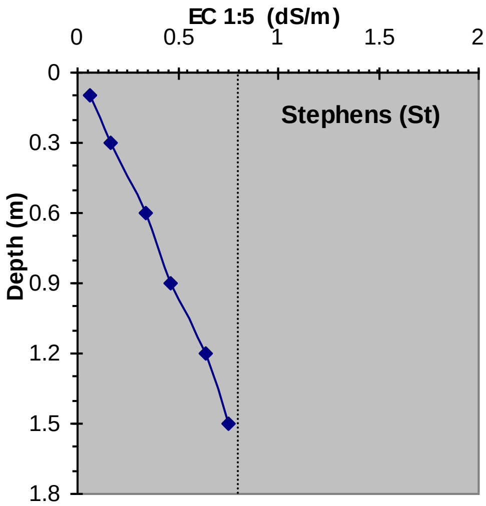
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.8	1.3	0.07	36	0.68	42	35	0.99	0.61	7.2	4.4
neutral	low	moderate	high	high	-	moderate	moderate	moderate	high	moderate

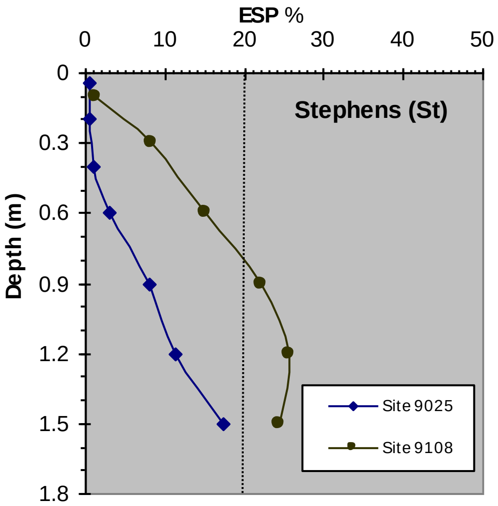
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, nitrogen (Total N) levels are moderate while phosphorus (Bicarb. P) levels are high. Most other nutrients are moderate with the exception of potassium (K) and calcium (Ca) which are high. Elevated phosphorus (Bicarb. P) and potassium (K) levels reflect the young age and recent alluvial origins of this soil. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Stephens (St) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below about 0.8–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.47	**1.00**	1.54	72	**116**	159

Typically, PAWC levels for the Stephens (St) soil are only moderate (approximately 115 mm) even though mean ERD is about 1.0 m. It is restricted by physical limitations and reduced permeability in the lower subsoil associated with ESP levels close to 20. Even where deeper profiles occur (ERD >1.0 m), maximum PAWC levels (115–160 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy or silty, clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9025 and 9108 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases gradually from 25–35% s in the immediate surface soil to 25–40% in the subsoil. High levels of fine sand (35–60%) and very high levels of silt (20–30%) in the surface soil promote hard setting and surface sealing behaviour. CEC/Clay% ratios in the profile are 0.55–1.0 and indicate the clay fraction is predominantly of mixed mineralogy with a high proportion of montmorillonite (depending on sediment source). Measured dispersion (R1 ratio) in the upper profile is mostly low to moderate (0.55–0.7), but increases to high to very high levels (0.8–0.99) in the lower subsoil because of moderate to very high sodicity levels (ESP 6–>25) (depending on sediment source). High levels of Total K throughout the profile reflect the young age and recent alluvial origins of this soil. Detailed physical data from representative profiles 9025 and 9108 are presented in Appendix 3.

Subsoil Chemistry

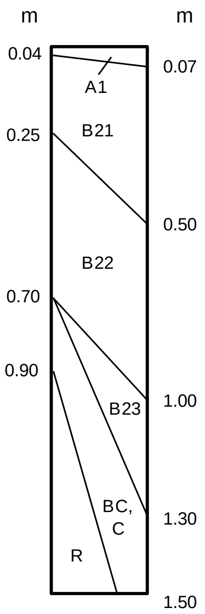
Laboratory pH is similar to field pH (see profile description). CEC levels are moderate (15–25 meq/100 g) throughout the profile (including most buried alluvial layers). Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while calcium (Ca) or magnesium (Mg) may be dominant or co-dominant in the lower subsoil (depending on sediment source). Sodicity in the profile is variable. It ranges from non-sodic (ESP <6) throughout in some profiles to others that are non-sodic (ESP <6) in the surface soil and upper subsoil increasing to strongly or extremely sodic (ESP 8–26) at depth. Detailed chemical data from representative profiles 9025 and 9108 are presented in Appendix 3.

TERNALLUM (Tn)

Concept: A strongly self-mulching, alkaline, black cracking clay over marl or labile, fine grained calcareous sedimentary rocks or feldspathic sandstone from 0.7–1.3 m. Brigalow vegetation.
Aust. Soil Classification: Black (or occasionally Grey) Vertosol.
Great Soil Group: Black earth; occasionally grey clay.
Principal Profile Form: Ug5.12, 5.13, 5.14, 5.11; occasionally Ug5.21, 5.22, 5.26.
Geology: Sandstones, siltstones and mudstones of the Blackwater Group (Pw). Mostly feldspathic or calcareous freshwater sedimentary rocks (eg marl or calcareous mudstone).
Landform: Gently undulating plains and rises. Slopes 0.5 to 3%.
Vegetation Associations: Brigalow with shrubs (VA8) or Brigalow (VA1); occasionally Belah (VA9).
Microrelief: Occasionally weakly developed linear or lattice gilgai VI <0.1 m, HI 8–10 m.
Runoff: Slow.
Permeability: Slow.
Drainage: Moderately well drained.
Surface Features: Cracking with a fine (<2 mm), strongly self-mulching surface. Where gilgaied, mounds are very fine (<1 to 2 mm) with 2 to 20% free carbonate nodules, while depressions have a coarser (2 to 5 mm) surface. Frequently 2 to 20% sandstone, siltstone or calcrete fragments 6 to 60 mm. Occasionally <2 to 20% sandstone or petrified wood rocks 60 to 200 mm.

Representative Profiles: **Not sampled** (see sites 9030 and 9032 from the Picardy (Pc) soil).

Typical Profile



Soil Description

The **surface soil** (A1) is a black, light medium clay to medium clay with strong, fine granular structure. Depths typically range from 0.04 to 0.07 m. It is normally calcareous with <2–10% nodular carbonate. Field pH is 7–9.

The **upper subsoil** (B21) is a black, medium clay to heavy clay with strong lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

The **lower subsoil** (B22, B23) is a black, grey or brown, medium heavy clay to heavy clay with strong, coarse lenticular structure. It is normally calcareous with 10–50% soft or nodular carbonate. Field pH is 8.5–9.5.

Weathered **substrate** (BC, C) is normally present below 0.7–1.3 m. Substrate material is typically labile and calcareous. It includes marl, calcareous siltstone or mudstone and feldspathic sandstone. Field pH is 8–9.5.

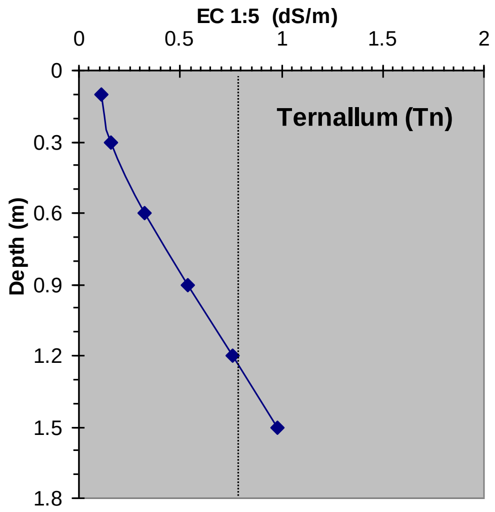
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
7.9	1.4	0.11	24						37	5.3
alkaline	low	high	high	-	-	-	-	-	very high	high

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are high. Comparison with the Tiny (Ty) soil suggests most other nutrients would be moderate to very high, with the exception of zinc (Zn) which is very low. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P), calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying labile, calcareous sedimentary rocks. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 1.1–1.3 m in the Ternallum (Tn) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Weathered substrate is normally present somewhere below 0.7–1.3 m and contributes to increased salinity levels at depth. Comparison with the Mt Stuart (Ms) and Tiny (Ty) soils suggests critical sodicity levels (ESP >20) are unlikely to occur within the profile.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.68	**1.00**	1.33	119	**145**	170

Typically, PAWC levels for the Ternallum (Tn) soil are high (approximately 145 mm) with a mean ERD of about 1.0 m. ERD is defined simply by the depth to weathered sandstone, siltstone or shale. Restrictions to rooting depth are generally absent in the profile, although high salinity levels (EC >0.8 dS/m) are often present in the underlying weathered substrate. Where deeper profiles occur (ERD >1.0 m), maximum PAWC levels (145–170 mm) are achieved on a regular basis because high clay content and strong fine structure minimise deep drainage and evaporation losses. In addition, strong cracking and self-mulching behaviour in the surface soil maximise infiltration and water entry. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5. Actual examples are not available, but data from representative profiles 9030 and 9032 in Appendices 3 and 6 may be useful as a guide.

Physical Characteristics and Subsoil Chemistry

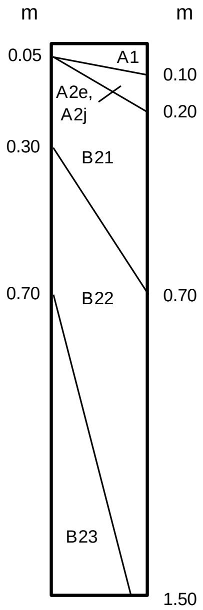
Interpretations and descriptions of the physical characteristics and chemistry of the Ternallum (Tn) soil are unavailable, but are probably comparable with those presented for the Picardy (Pc) soil.

THIRTEENMILE (Tt)

Concept: A hard setting, silty surfaced, conspicuously or sporadically bleached, acid to alkaline, mottled, grey or brown, sodic texture contrast soil to non-cracking clay over recent alluvium in seasonally flooded, closed depressions, swamps and backplains. Eucalypt vegetation.
Aust. Soil Classification: Grey or Brown Sodosol; Grey or Brown Dermosol.
Great Soil Group: Solodic, soloth, no suitable group, grey clay.
Principal Profile Form: Dy3.11, 3.12, 3.13, 3.41, 3.43, 5.43, Db4.12, Uf6.41; occasionally Ug5.24, 5.28.
Geology: Quaternary alluvium (Qa).
Landform: Locally drained, closed depressions and seasonal swamps on level alluvial plains of upper and lower tributaries; or slowly drained backplains on lower tributaries; or relict plains associated with unconsolidated Tertiary–Quaternary sediments (TQa) or occasionally internally drained, level, Tertiary (Td, Ta) plateaus. Flooded either from local drainage or from low velocity flood events in alluvial situations (e.g. backplains). ARI is more frequent than 1 in 2 years. Slopes <0.5%.
Vegetation Associations: Blue gum (VA21); occasionally Poplar box (VA20), Blue gum–mixed eucalypts (VA22), Swamp mahogany (VA49) or Sedges (VA29).
Microrelief: Absent.
Runoff: None or very slow.
Permeability: Very slow.
Drainage: Poorly drained to imperfectly drained.
Surface Features: Hard setting and occasionally cracking.

Representative Profile: **9101**

Typical Profile



Soil Description

The **surface soil** (A1, Aj, A2e, A2j) is a black or grey, fine sandy clay loam to silty clay loam or silty light clay with massive or weak to moderate blocky structure. Depths typically range from 0.05 to 0.2 m. A conspicuously or sporadically bleached layer is frequently developed immediately above the clay subsoil. Field pH is 5.5–6.

The **upper subsoil** (B21) is a mottled, grey or brown, light medium clay to medium clay (frequently fine sandy or silty) with moderate to strong blocky or lenticular structure. Field pH is 6–9.5.

The **lower subsoil** (B22, B23) is a mottled, grey or brown, sandy light clay to medium heavy clay with moderate blocky or lenticular structure grading to polyhedral at depth. It is normally manganiferous with 2–20% soft or nodular manganese. Field pH is 6–9.5.

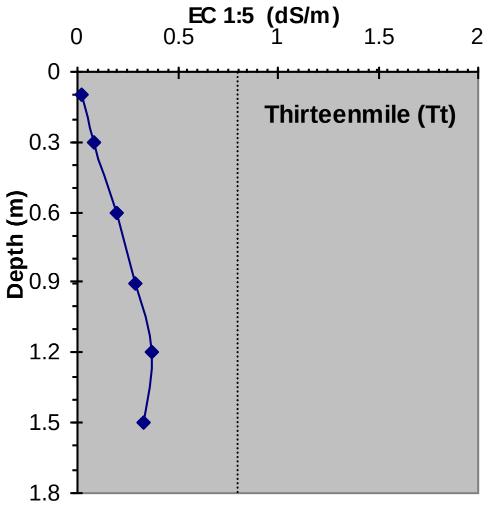
Surface Soil Fertility[1]

Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	6.1	1.3	0.07	8	0.46	108	9	0.65	0.22	3.0	1.37
	acid	low	moderate	low	moderate	-	moderate	moderate	low	moderate	moderate
dep.	4.5	1.5	0.12	23	-	-	-	-	-	2.4	1.6
	strongly acid	low	high	high	-	-	-	-	-	moderate	moderate

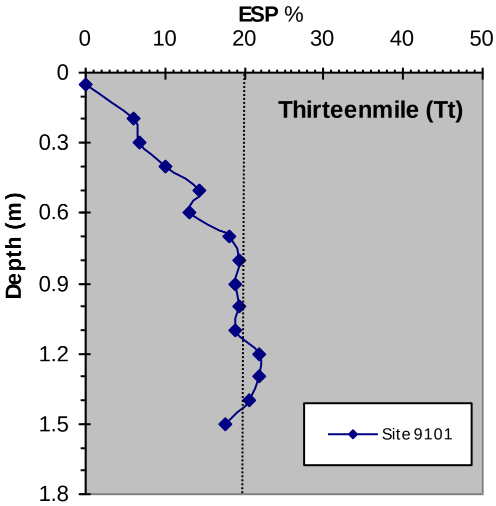
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were observed where gilgai components (non-gilgaied/mound and depression) were developed. Typically, nitrogen (Total N) levels increase from moderate on mounds and non-gilgaied areas to high in depressions. Phosphorus (Bicarb. P) levels follow a similar trend, increasing from low to high. Absolute differences are significant in both cases with levels almost 2–3 times higher in depressions. Most other nutrients are moderate with the exception of zinc (Zn) which is low. The phosphorus (Bicarb. P) fertility of the Thirteenmile (Tt) soil is largely determined by the nutrient status of the provenance areas from which the alluvium is sourced. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is generally not present in the upper 1.5 m of the Thirteenmile (Tt) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below about 0.7–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.35	**0.94**	1.53	58	**111**	164

Typically, PAWC levels for the Thirteenmile (Tt) soil are moderate (approximately 110 mm) with a mean ERD of about 0.95 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is restricted by physical limitations and reduced permeability in the lower subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.95 m), maximum PAWC levels (110–165 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy or silty, clay loamy to clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9101 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content increases significantly between the surface soil (20–35%) and the subsoil (30–50%), while high levels of fine sand (>60%) and silt (10–20%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the subsoil are 0.55–0.65 and indicate the clay fraction is predominantly of mixed mineralogy (depending on sediment source). Measured dispersion (R1 ratio) in the subsoil ranges from high to very high (0.85–0.99) because of relatively low clay contents and moderate to very high sodicity levels (ESP 6–25). Moderate levels of Total K throughout the profile reflect levels in the alluvial sediments from which the soil has developed. Detailed physical data from representative profile 9101 are presented in Appendix 3.

Subsoil Chemistry

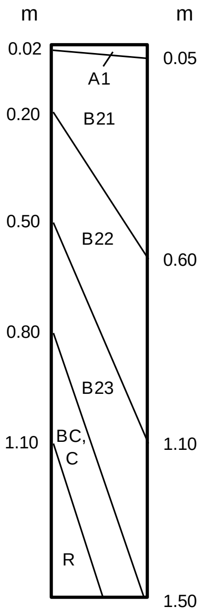
Laboratory pH is similar to field pH (see profile description). CEC levels are low (5–15 meq/100 g) in the surface soil and moderate (15–20 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation throughout the profile, although significant levels of both magnesium (Mg) and sodium (Na) occur at depth. Profiles are typically non-sodic (ESP <6) in the surface soil and upper subsoil, becoming strongly to extremely sodic (ESP 15–25) at depth. Detailed chemical data from representative profile 9101 are presented in Appendix 3.

TINY (Ty)

Concept: A firm pedal or weakly to strongly self-mulching, alkaline, black or grey cracking clay, frequently with normal gilgai (VI 0.1–0.3 m), over strongly structured, acid clay or labile sandstone, siltstone or shale from 0.5–1.1 m. Brigalow vegetation.
Aust. Soil Classification: Black or Grey Vertosol.
Great Soil Group: Black earth, grey clay.
Principal Profile Form: Ug5.16, 5.15, 5.12, 5.13, 5.14; occasionally Ug5.24, 5.22, 5.23.
Geology: Undifferentiated, fine grained sedimentary rocks of the Blackwater Group (Pw) and/or Back Creek Group (Pb). Includes lithic, feldspathic or calcareous freshwater sandstones, siltstones and shales folded and interbedded with fine grained marine sedimentary rocks.
Landform: Gently undulating plains and rises. Slopes 0.5 to 2%.
Vegetation Associations: Brigalow (VA1) or Brigalow with shrubs (VA8).
Microrelief: Either non-gilgaied (50%) or with normal gilgai (50%) VI 0.1–0.3 m, HI 7–25 m; occasionally with a prominent shelf.
Runoff: Slow on mounds and non-gilgaied areas; very slow or no runoff in depressions.
Permeability: Slow. **Drainage:** Moderately well drained.
Surface Features: **Non-gilgaied/mound -** cracking with a firm pedal or fine (<2 mm), weakly to strongly self-mulching surface; occasionally with <2 to 10% free carbonate nodules.
Depression - cracking with a fine or coarse (<2 to 5 mm), moderately to strongly self-mulching surface.
Frequently <2 to 20% silcrete or petrified wood gravels 6 to 60 mm and occasionally <2 to 10% sandstone, siltstone or petrified wood rocks 60 to 200 mm. A weak surface seal with a well developed flake and thin sandy veneer forms after rain.

Representative Profiles: **9055, 9056**

Typical Profile



Soil Description – Non-gilgaied/mound profile

The **surface soil** (A1) is a black, light medium clay to medium clay with moderate to strong blocky or granular structure. Depths typically range from 0.02 to 0.05 m. Field pH is 7–9.5.

The **upper subsoil** (B21, B22) is a black or grey, medium clay to medium heavy clay with strong blocky to lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

The **lower subsoil** (B23) is a mottled, grey, medium heavy clay to heavy clay with moderate or strong, coarse lenticular structure. It is sometimes calcareous in the upper part (2–20% soft or nodular carbonate), but grades quickly to non-calcareous with depth. Similarly, field pH is 8.5–9.5, in the upper part but decreases quickly to <6.5 where substrate is absent.

Weathered **substrate** (BC, C) is often present below 0.8–>1.5 m. Substrate material is typically labile sandstone, siltstone or shale. The nature of the underlying rocks varies significantly however, due to folding and interbedding, and includes a range of calcareous freshwater deposits through to fine grained marine sediments. Field pH ranges from 5–9.5, depending on substrate. In deep profiles (>1.5 m) strongly structured, acid clay continues at depth.

Soil Description – Depression profile

Depression profiles have similar horizons, depths and morphology to non-gilgaied or mound profiles.

Surface Soil Fertility[1]

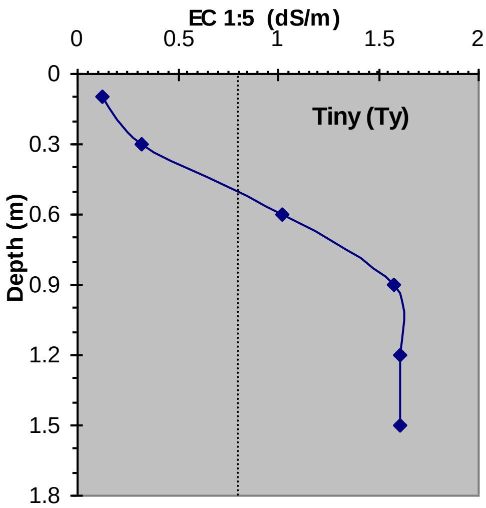
Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	8.0	1.2	0.08	12	0.28	19	19	1.2	0.26	24	8.5
	alkaline	low	moderate	moderate	low	-	moderate	moderate	very low	very high	high
dep.	7.6	1.3	0.10	18	0.31	30	43	1.7	0.61	26	10.0
	alkaline	low	high	high	moderate	-	moderate	moderate	low	very high	high

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

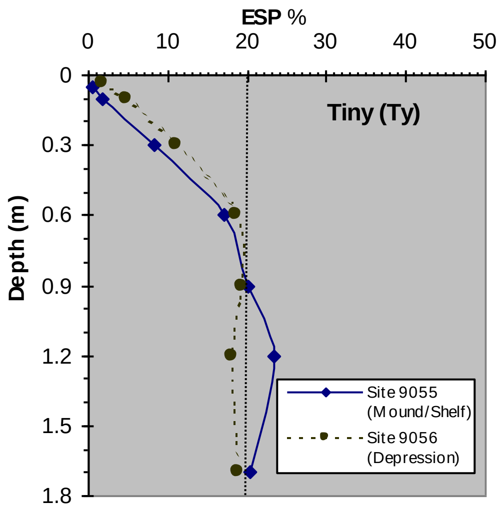
Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (non-gilgaied/mound versus depression). Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) increase from moderate on mounds and non-gilgaied areas to high in depressions. Most other nutrients are moderate to very high with similar levels on both gilgai components. The exception is zinc (Zn) which is low in depressions and very low on mounds. Moderate to high nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P), calcium

(Ca) and magnesium (Mg) levels are derived directly from the underlying labile sedimentary rocks. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by 0.45–0.65 m in the Tiny (Ty) soil. The profile salinity curve reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.8–>1.5 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Critical sodicity levels (ESP >20) typically occur in the lower subsoil (below about 0.6–>1.5 m).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.27	**0.64**	1.01	92	**121**	150

Typically, PAWC levels for the Tiny (Ty) soil are only moderate (approximately 120 mm) because mean ERD is <0.65 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is restricted by high salinity levels (EC >0.8 dS/m), as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.65 m), maximum PAWC levels (120–150 mm) are rarely achieved on a regular basis because of restricted infiltration (surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9055 and 9056 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content gradually increases between the surface soil (40–45%) and the subsoil (50–65%), while significant levels of fine sand (30–35%) and silt (15%) in the surface soil promote surface sealing behaviour. CEC/Clay% ratios in the profile are 0.7–0.9 and indicate the clay fraction is predominantly montmorillonitic. Measured dispersion (R1 ratio) is low (0.3–0.6) in the surface soil and upper subsoil, but increases to moderate or high levels (0.75–0.9) in the lower subsoil because of high to very high sodicity levels (ESP 15–25). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9055 and 9056 are presented in Appendix 3.

Laboratory pH is similar to field pH (see profile description). CEC levels are high (35–40 meq/100 g) in the surface soil and high to very high (35–50 meq/100 g) in the subsoil. Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while both calcium (Ca) and magnesium (Mg) are co-dominant in the lower subsoil. Profiles are non-sodic (ESP <6) in the surface soil and immediate upper subsoil, but gradually becomes strongly or extremely sodic (ESP 17–24) at depth. Detailed chemical data from representative profiles 9055 and 9056 are presented in Appendix 3.

TRALEE (Tl)

Concept: A hard setting, firm pedal or weakly to moderately self-mulching, alkaline, black, grey or brown cracking to non-cracking clay, frequently with normal (VI 0.1–0.3 m) or melonhole (VI 0.3–0.8 m) gilgai, over recent alluvium on alluvial plains. Brigalow vegetation.

Aust. Soil Classification: **Non-gilgaied/mound:** Black, Grey or Brown Vertosol or Dermosol
Depression: Black or Grey Vertosol

Great Soil Group: **Non-gilgaied/mound:** No suitable group, grey clay, brown clay
Depression: Grey clay

Principal Profile Form: **Non-gilgaied/mound:** Ug5.15, 5.16, 5.17, 5.24, 5.25, 5.28, 5.29, 5.34, Uf6.32, 6.33, 6.31
Depression: Ug5.24, 5.25, 5.16, 5.17

Geology: Quaternary alluvium (Qa).

Landform: Level alluvial plains on lower tributaries; or slightly elevated, terrace plains on flood plains along major rivers. Flooded in lower lying parts. ARI is between 1 in 2 years and 1 in 10 years. Slopes <0.5%, occasionally up to 1%.

Vegetation Associations: Brigalow (VA1); occasionally Brigalow–coolibah (VA6) or Brigalow with shrubs (VA8).

Microrelief: Either non-gilgaied (50%) or with normal gilgai (25%) VI 0.1–0.3 m, HI 6–15 m or melonhole gilgai (25%) VI 0.3–0.8 m, HI 10–20 m. Areas with normal gilgai frequently have a prominent shelf and indistinct mounds and depressions.

Runoff: Slow or very slow on mounds and non-gilgaied areas; no runoff in depressions.

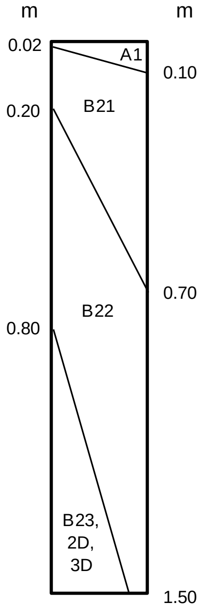
Permeability: Very slow to slow.

Drainage: Imperfectly to moderately well drained on mounds and non-gilgaied areas; poorly to imperfectly drained in depressions.

Surface Features: **Non-gilgaied -** frequently cracking with a hard setting, firm pedal or weakly self-mulching surface.
Mound - cracking with a hard setting, firm pedal or weakly to strongly self-mulching surface; occasionally with 2 to 10% free carbonate nodules.
Depression - cracking with a hard setting or coarse (2 to 5 mm), weakly to moderately self-mulching surface.

Representative Profiles: **9050, 9051, 9107, 9115**

Typical Profile



Soil Description – Non-gilgaied/mound profile

The **surface soil** (A1) is a black, light clay to medium clay (frequently fine sandy) with weak to strong blocky or granular structure. Depths typically range from 0.02 to 0.1 m. Field pH is 6–9.5.

The **upper subsoil** (B21) is a black, medium clay to medium heavy clay with moderate or strong blocky structure. It is frequently calcareous with 2–20% soft or nodular carbonate. Field pH is 6–9.5, increasing with depth.

The **lower subsoil** (B22, B23) is a grey or brown, light medium clay to medium heavy clay with moderate or strong, coarse lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

Buried alluvial layers (2D, 3D) are sometimes present from 0.8–>1.5 m. Buried materials are typically a mottled, brown or black coarse sand to medium heavy clay with massive or weak to strong blocky or lenticular structure. Field pH ranges from 6–9.5.

Soil Description – Depression profile

Depression profiles generally have similar horizons, texture and structure, but differ significantly in terms of colour, pH and surface soil thickness. Profiles may be either black or grey and are typically non-calcareous. Field pH ranges from 6.5 to 8.5 in the upper profile and 6 to 9.5 at depth. The surface soil (A1) in depressions is generally much thinner (0.02–0.03 m).

Surface Soil Fertility[1]

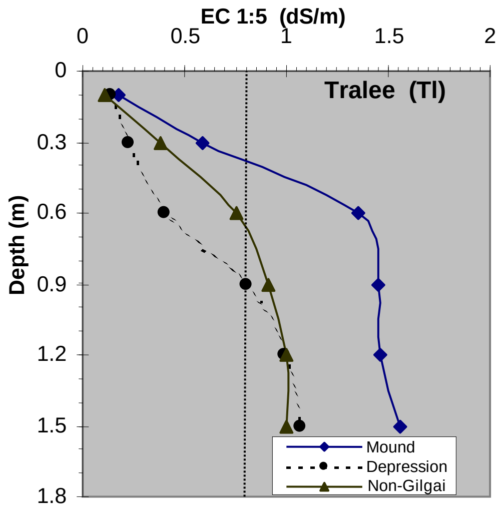
Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	7.4	1.6	0.11	39	0.53	37	16	1.4	1.1	13	8.0
	neutral	moderate	high	high	high	-	moderate	moderate	moderate	high	high
dep.	7.4	1.6	0.12	77	1.00	50	10	1.1	0.86	16	6.6
	neutral	moderate	high	very high	high	-	moderate	moderate	moderate	very high	high

Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

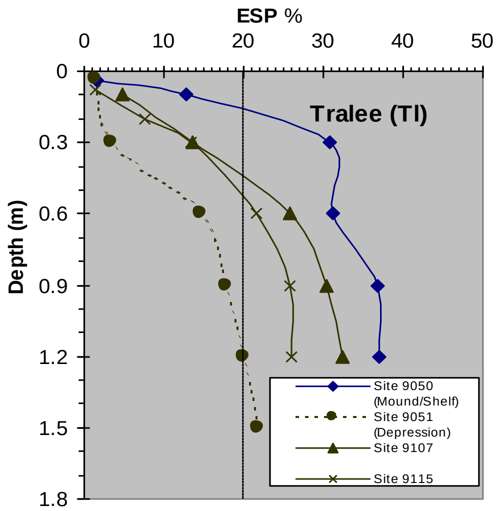
Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (non-gilgaied/mound versus depression). Typically, nitrogen (Total N) levels are high irrespective of gilgai component, while phosphorus (Bicarb. P) levels increase from high on mounds and non-gilgaied areas to very high in depressions. Absolute differences in phosphorus

(Bicarb. P) fertility between components are significant with levels almost doubling in depressions. Most other nutrients are moderate to high with similar levels on both gilgai components. High nitrogen (Total N) levels are associated with the presence of brigalow scrub, while elevated phosphorus (Bicarb. P) and potassium (K) levels reflect the young age and recent alluvial origins of this soil. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

The Tralee (Tl) soil normally has significant salinity (EC >0.8 dS/m) developed by 0.4–0.6 m on mounds and non-gilgaied areas and by 0.8–1.0 m in depressions. The mound and non-gilgaied profile salinity curves both reach equilibrium between 0.6 and 0.9 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with non-depression areas. The depression curve in contrast reaches equilibrium between 0.9 and 1.2 m (salt bulge becomes constant) suggesting significant leaching has occurred because of seasonal ponding. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil on mounds and non-gilgaied areas, and in the lower subsoil (below 0.6–>1.5 m) in depressions.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
mound	0.17	**0.57**	0.97	59	**99**	139
dep.	0.56	**0.99**	1.42	48	**106**	164

Typically, PAWC levels for the Tralee (Tl) soil are moderate on mounds and non-gilgaied areas (approximately 100 mm) and also moderate (approximately 110 mm) in depressions. Mean ERD on mounds and non-gilgaied areas is <0.6 m, compared with almost 1.0 m in depressions. In both cases, ERD is restricted by high salinity levels (EC >0.8 dS/m), as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Regular seasonal ponding in depressions has resulted in significant leaching and a downward movement of the salt bulge in most cases. Even where deeper non-gilgaied/mound profiles occur (ERD >0.6 m), maximum PAWC levels (100–140 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9050, 9051, 9107 and 9115 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is either relatively uniform (50–55%) throughout the profile or increases gradually between the surface soil (35–40%) and the subsoil (45–55%). Significant levels of fine sand (30%) and silt (15–35%) in the surface soil promote surface sealing behaviour. CEC/Clay% ratios in the profile are 0.5–0.6 and indicate the clay fraction is predominantly of mixed mineralogy (depending on sediment source). Measured dispersion (R1 ratio) in the surface soil and immediate upper subsoil is low (0.45–0.6), but gradually increases to moderate or high levels (0.7–0.9) because of high to very high sodicity levels (ESP 15–35) at depth. High Total K levels throughout the profile reflect the young age and recent alluvial origins of this soil. Detailed physical data from representative profiles 9050, 9051, 9107 and 9115 are presented in Appendix 3.

Laboratory pH is similar to field pH (see profile description). CEC levels are high (25–35 meq/100 g) throughout the profile. Calcium (Ca) is the dominant cation in the surface soil and upper subsoil, while either calcium (Ca) or magnesium (Mg) is dominant or co-dominant in the lower subsoil. Profiles are non-sodic (ESP <6) in the surface soil and immediate upper subsoil, but gradually become strongly or extremely sodic (ESP 15–35) at depth. Detailed chemical data from representative profiles 9050, 9051, 9107 and 9115 are presented in Appendix 3.

TURON (Tr)

Concept: A strongly developed melonhole gilgai complex (VI 0.7–1.5 m) with:

- a hard setting, firm pedal or weakly self-mulching, alkaline, grey or brown, sodic cracking clay on mounds; and
- a firm pedal or weakly self-mulching, acid, grey, sodic cracking clay in depressions;

over reworked, acid Tertiary clay from 0.6–>1.5 m. Brigalow vegetation.

Aust. Soil Classification: **Mound:** Grey, Brown (or occasionally Black) Vertosol **Depression:** Grey Vertosol

Great Soil Group: **Mound:** Grey clay, brown clay **Depression:** Grey clay

Principal Profile Form: **Mound:** Ug5.24, 5.25, 5.28, 5.29, 5.34, 5.35, 5.16 **Depression:** Ug5.24

Geology: Unconsolidated Tertiary–Quaternary sediments (TQa). Includes reworked Tertiary clay sheets, relict alluvial deposits and local colluvium. Mainly clay and gravel sourced from sedimentary landscapes in the Isaac–Connors and Mackenzie River catchments.

Landform: Level to very gently undulating plains. Slopes <0.5%, occasionally up to 1.5%.

Vegetation Associations: Brigalow (VA1), Blackwood (VA37) or Brigalow–blackwood (VA4); occasionally Brigalow with shrubs (VA8) or Belah (VA9).

Microrelief: Strongly developed melonhole gilgai VI 0.7–1.5 m, HI 10–35 m.

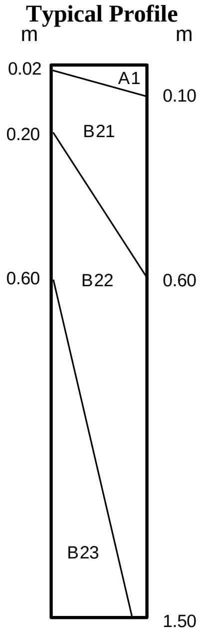
Runoff: Slow on mounds; no runoff in depressions. **Permeability:** Very slow.

Drainage: Imperfectly to moderately well drained on mounds; poorly to imperfectly drained in depressions.

Surface Features: **Mound** - cracking with a hard setting, firm pedal or weakly self-mulching surface. Frequently 2 to 10% silcrete gravels 6 to 60 mm.
Depression - cracking with a firm pedal to coarse (2 to 5 mm), weakly self-mulching surface; occasionally hard setting. Frequently 2 to 20% silcrete gravels 6 to 60 mm.

Representative Profiles: **9052, 9053, 9069, 9070, 9077, 9078**

Typical Profile



Soil Description – Mound profile

The **surface soil** (A1) is a grey, brown or black, light medium clay to medium clay (frequently fine sandy) with moderate or strong blocky or granular structure. Depths typically range from 0.02 to 0.1 m. Field pH is 6.5–8.5.

The **upper subsoil** (B21) is a grey or brown, medium heavy clay with moderate or strong blocky or lenticular structure. It is frequently calcareous with 2–20% soft or nodular carbonate. Field pH is 8.5–9.5.

The **lower subsoil** (B22, B23) is a grey or brown, medium clay to medium heavy clay with weak to strong, coarse lenticular structure. It is frequently mottled and manganiferous at depth with 2–10% manganese veins. Field pH in the upper part ranges from 5 to 9.5, but decreases quickly to <6.5 with depth.

Soil Description – Depression profile

Depression profiles have similar horizons, texture and structure but differ significantly in terms of colour, pH and surface soil thickness. They are typically grey, acid (pH <6.5) and non-calcareous, with significant fine sand recorded in field textures. The surface soil is usually thinner (0.02–0.04 m) and has coarser, blocky or granular structure.

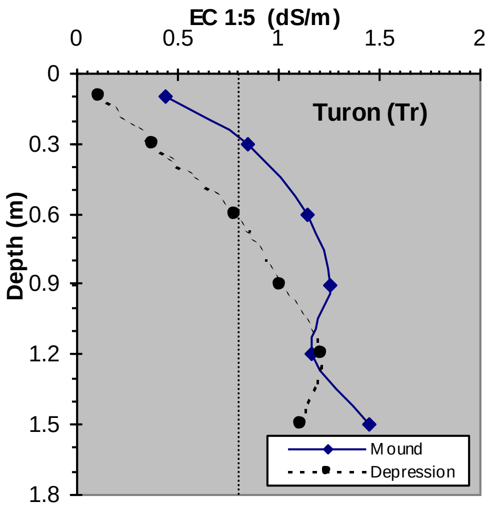
Surface Soil Fertility[1]

Gilgai comp.	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)	Extr. K (meq/100g)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
mound	7.3	1.6	0.10	10	0.41	39	17	1.1	0.49	13	10.5
	neutral	moderate	high	moderate	moderate	-	moderate	moderate	low	high	high
dep.	6.5	1.3	0.10	34	0.52	95	19	2.2	1.1	12	7.3
	acid	low	high	high	high	-	moderate	moderate	moderate	high	high

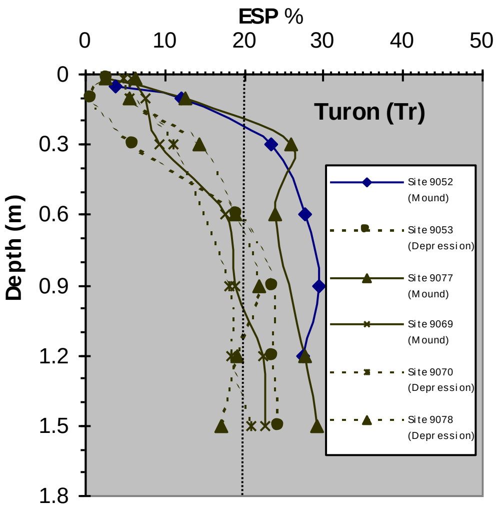
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (mounds and depressions). Typically, nitrogen (Total N) levels are high irrespective of gilgai component, while phosphorus (Bicarb. P) levels increase from moderate on mounds to high in depressions. Absolute differences in phosphorus (Bicarb. P) fertility between components are significant with levels more than three times higher in depressions. Most other nutrients are moderate to high with similar levels on both gilgai components. The exceptions are potassium (K) which is higher in depressions and zinc (Zn) which is lower on mounds. High nitrogen (Total N) levels are associated with the presence of brigalow scrub. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

The Turon (Tr) soil normally has significant salinity (EC >0.8 dS/m) developed by 0.2–0.45 m on mounds and 0.6–0.8 m in depressions. The mound profile salinity curve reaches equilibrium between 0.6 and 0.9 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with mound profiles. The depression curve in contrast reaches equilibrium between 1.1 and 1.3 m (salt bulge becomes constant) suggesting significant leaching has occurred because of seasonal ponding. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil on mounds and in the lower subsoil (below 0.6–>1.5 m) in depressions.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
mound	0.02	**0.47**	0.97	24	**72**	119
dep.	0.30	**0.79**	1.28	69	**117**	166

Typically, PAWC levels for the Turon (Tr) soil are low (approximately 70 mm) on mounds and moderate (approximately 120 mm) in depressions. Mean ERD on mounds is about 0.45 m, compared with almost 0.8 m in depressions. In both cases, ERD is restricted by high salinity levels (EC >0.8 dS/m), as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Regular seasonal ponding in depressions has resulted in significant leaching and a downward movement of the salt bulge. Even where deeper mound profiles occur (ERD >0.5 m), maximum PAWC levels (70–120 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface; surface sealing and dispersive behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9052, 9053, 9069, 9070, 9077 and 9078 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is relatively uniform (50–65%) throughout both mound and depression profiles, although thin surface horizons with only 40–50% clay are often developed on mounds. Significant fine sand (20–40%) and silt (10–20%) in the surface soil of both gilgai components promote surface sealing behaviour. CEC/Clay% ratios in both gilgai components are 0.35–0.6 and indicate the clay fraction is predominantly of mixed mineralogy. Measured dispersion (R1 ratio) in the surface soil is mostly low (0.4–0.55), while in the upper subsoil it ranges from moderate to high (0.6–0.95) (usually increasing with depth) irrespective of gilgai component. Dispersion (R1 ratio) in the lower subsoil is mostly very high (0.95–0.99). Detailed physical data from representative profiles 9052, 9053, 9069, 9070, 9077 and 9078 are presented in Appendix 3.

Laboratory pH is similar to field pH (see profile description). CEC levels are mostly moderate to high (20–30 meq/100 g) in the surface soil and upper subsoil and moderate (15–25 meq/100 g) in the lower subsoil, irrespective of gilgai component. Cation dominance is variable and calcium (Ca) or magnesium (Mg) may be dominant or co-dominant in either the surface soil or subsoil. The relative dominance of the cations varies with the source and nature of the underlying unconsolidated substrate. Profiles are typically non-sodic (ESP <6) in the immediate surface soil, increasing to sodic (ESP 6–15) in the upper subsoil, and strongly to extremely sodic (ESP 15–30) in the lower subsoil, irrespective of gilgai component. Detailed chemical data from representative profiles 9052, 9053, 9069, 9070, 9077 and 9078 are presented in Appendix 3.

WARWICK (Ww)

Concept: A normal or shallow melonhole gilgai complex (VI 0.25–0.5 m) with:

- a hard setting, firm pedal or weakly self-mulching, alkaline, grey or brown, sodic cracking clay on mounds and shelves; and
- a hard setting, firm pedal or weakly to moderately self-mulching, acid, grey, sodic cracking clay in depressions;

over reworked, acid Tertiary clay from 0.5–>1.5 m. Brigalow vegetation.

Aust. Soil Classification: **Mound:** Grey, Brown (or occasionally Black) Vertosol
Depression: Grey (or occasionally Black) Vertosol

Great Soil Group: **Mound:** Grey clay, brown clay
Depression: Grey clay

Principal Profile Form: **Mound:** Ug5.24, 5.25, 5.28, 5.29, 5.34, 5.35; occasionally Ug5.16
Depression: Ug5.24, 5.25, 5.16

Geology: Unconsolidated Tertiary–Quaternary sediments (TQa). Includes reworked Tertiary clay sheets, relict alluvial deposits and local colluvium. Mainly clay and gravel sourced from sedimentary landscapes in the Isaac–Connors and Mackenzie River catchments.

Landform: Level to gently undulating plains. Slopes <1%, occasionally up to 2%.

Vegetation Associations: Brigalow (VA1), Blackwood (VA37) or Brigalow–blackwood (VA4); occasionally Brigalow–Dawson gum (VA5).

Microrelief: Frequently normal or shallow melonhole gilgai VI 0.25–0.5 m, HI 8–25 m; occasionally non-gilgaied or with a prominent shelf.

Runoff: Slow on mounds and shelves; very slow or no runoff in depressions.

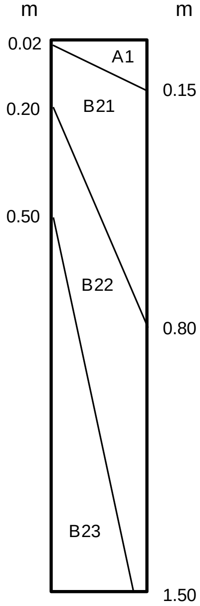
Permeability: Very slow.

Drainage: Imperfectly to moderately well drained on mounds and shelves; poorly to imperfectly drained in depressions.

Surface Features: **Mound/shelf -** cracking with a hard setting, firm pedal or weakly self-mulching surface. Frequently 2 to 20% silcrete gravels 6 to 60 mm.
Depression - cracking with a hard setting, firm pedal or weakly to moderately self-mulching surface. Frequently <2 to 10% silcrete gravels 6 to 60 mm.

Representative Profiles: **9048, 9049, 9067, 9068, 9113, 9117, 9118**

Typical Profile



Soil Description – Mound/shelf profile

The **surface soil** (A1) is a grey, brown or black, light medium clay to medium clay (frequently fine sandy) with moderate or strong blocky or granular structure. Depths typically range from 0.02 to 0.15 m. Field pH is 6–9.5.

The **upper subsoil** (B21) is a grey or brown, medium clay to medium heavy clay with moderate or strong blocky or lenticular structure. It is frequently calcareous with 2–10% soft or nodular carbonate. Field pH is 8–9.5.

The **lower subsoil** (B22, B23) is a grey or brown, medium clay to heavy clay with weak or moderate coarse lenticular structure grading to polyhedral at depth. It is frequently mottled in lower parts. Field pH is 4.5–6.5.

Soil Description – Depression profile

Depression profiles have similar horizons, texture and structure but differ significantly in terms of colour, pH and surface soil thickness. They are typically grey, acid (pH <6.5) and non-calcareous throughout, and have thinner surface horizons (0.03–0.05 m).

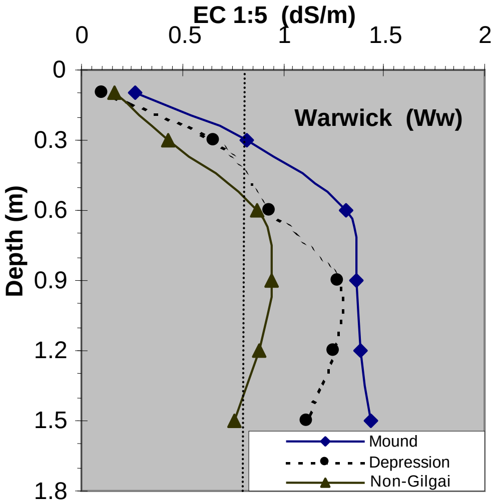
Surface Soil Fertility[1]

Gilgai comp.[3]	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
non-gilgaied	7.2	1.3	0.09	14	0.27	24	23	0.86	0.35	11	9.1
	neutral	low	high	moderate	low	-	moderate	moderate	low	high	high
dep.	6.4	1.3	0.09	29	0.26	76	78	1.4	0.89	9.3	8.2
	acid	low	high	high	low	-	high	moderate	moderate	high	high

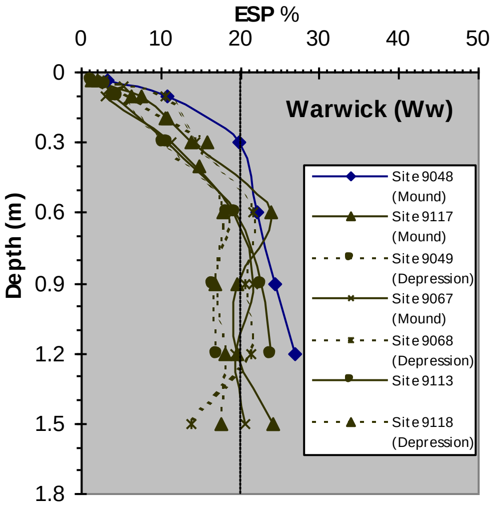
Notes:
1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.
3. Non-gilgaied data includes non-gilgaied areas as well as mound/shelf components.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (mounds and depressions). Typically, nitrogen (Total N) levels are high irrespective of gilgai component, while phosphorus (Bicarb. P) levels increase from moderate on mounds and non-gilgaied areas to high in depressions. Absolute differences in phosphorus (Bicarb. P) fertility between components are significant with levels more than doubling in depressions. Most other nutrients are moderate to high with similar levels on both gilgai components. The exceptions are potassium (K) which is low throughout and zinc (Zn) which is lower on mounds and non-gilgaied areas. High nitrogen (Total N) levels are associated with the presence of brigalow scrub. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

The Warwick (Ww) soil normally has significant salinity (EC >0.8 dS/m) developed by 0.3–0.5 m, irrespective of gilgai component. The mound and non-gilgaied profile salinity curves reach equilibrium between 0.6 and 0.8 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with non-depression areas. The depression profile in contrast reaches equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) suggesting only minor leaching has occurred because of seasonal ponding (i.e. depressions are relatively shallow). Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil on mounds and non-gilgaied areas, and in the lower subsoil (below 0.6–>1.5 m) in depressions.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.03	**0.42**	0.81	39	**83**	127

Typically, PAWC levels for the Warwick (Ww) soil are low (approximately 85 mm) because mean ERD is <0.5 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is restricted by high salinity levels (EC >0.8 dS/m), as well as physical limitations and reduced permeability in the subsoil associated with ESP levels >20. Even where deeper profiles occur (ERD >0.45 m), maximum PAWC levels (85–125 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface; surface sealing and dispersive behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9048, 9049, 9067, 9068, 9113, 9117 and 9118 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

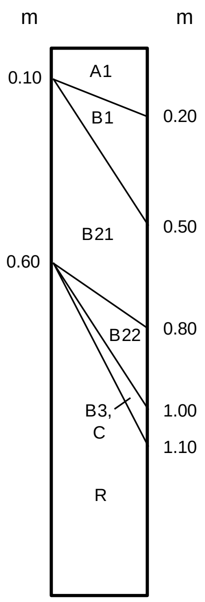
Clay content is relatively uniform (45–60%) throughout both mound and depression profiles, although thin surface horizons with only 35–45% clay are often developed. Significant fine sand (30–45%) and silt (10–15%) in the surface soil of both gilgai components promote surface sealing behaviour. CEC/Clay% ratios in both gilgai components are 0.3–0.6 and indicate the clay fraction is predominantly of mixed mineralogy. Measured dispersion (R1 ratio) in the surface soil is mostly low (0.35–0.6), while in the upper subsoil it ranges from moderate to high (0.6–0.9) (usually increasing with depth), irrespective of gilgai component. Dispersion (R1 ratio) in the lower subsoil is mostly high to very high (0.85–0.99). Detailed physical data from representative profiles 9048, 9049, 9067, 9068, 9113, 9117 and 9118 are presented in Appendix 3.

Laboratory pH is similar to field pH (see profile description). CEC levels are mostly moderate (15–25 meq/100 g) in the surface soil and moderate to high (15–35 meq/100 g) in the subsoil. Cation dominance is variable and calcium (Ca) or magnesium (Mg) may be dominant or co-dominant in either the surface soil or subsoil. The relative dominance of the cations varies with the source and nature of the underlying unconsolidated substrate. Profiles are typically non-sodic (ESP <6) in the immediate surface soil, increasing to sodic (ESP 6–15) in the upper subsoil, and strongly to extremely sodic (ESP 15–30) in the lower subsoil, irrespective of gilgai component. Detailed chemical data from representative profiles 9048, 9049, 9067, 9068, 9113, 9117 and 9118 are presented in Appendix 3.

WIETA (Wt)

Concept:	A hard setting, clay loamy surfaced, acid to alkaline, brown, structured gradational soil to non-cracking clay over deeply weathered sediments from 0.6–1.0 m. Eucalypt vegetation.
Aust. Soil Classification:	Brown Dermosol.
Great Soil Group:	Yellow earth, brown clay, no suitable group.
Principal Profile Form:	Uf6.31, Gn4.81, 3.72, 3.22, 2.21, 2.61; occasionally Gn4.83, 3.73, 2.32, 2.41.
Geology:	Fine grained sedimentary rocks altered by Tertiary deep weathering (Td, Ta). Substrate is reticulite or petroreticulite.
Landform:	Gently undulating plains and low rises that mark the final remnants following almost complete dissection of former Tertiary plateaus. Occasionally lower lying areas within intact plateaus or gently dissected and eroded plateau margins. Slopes 1 to 3%.
Vegetation Associations:	Poplar box (VA20), Poplar box–ironbark (VA34), Narrow-leaved ironbark (VA12) or Silver-leaved ironbark (VA17).
Microrelief:	Absent.
Runoff:	Slow to moderately rapid.
Permeability:	Very slow to moderate.
Drainage:	Imperfectly drained to moderately well drained.
Surface Features:	Hard setting. Frequently 2 to 10% silcrete gravels 6 to 20 mm. Occasionally 2 to 10% petroreticulite outcrop.
Representative Profile:	**9071**

Typical Profile



Soil Description

The **surface soil** (A1, B1) is a brown, fine sandy clay loam to fine sandy light medium clay with massive or weak to moderate platy or blocky structure. Depths typically range from 0.1 to 0.5 m. Field pH is 5.5–7.

The **subsoil** (B21, B22) is a brown, fine sandy light clay to fine sandy medium clay with weak to strong blocky, lenticular or polyhedral structure. It frequently becomes mottled and manganiferous (2–10% manganese soft segregations) with depth. Field pH ranges from 6 to 9.5.

Weathered **substrate** (B3, C) is normally present below 0.6–1.0 m. Substrate material is typically brown or grey, mottled, reticulite or petroreticulite. Field pH is 6–7.

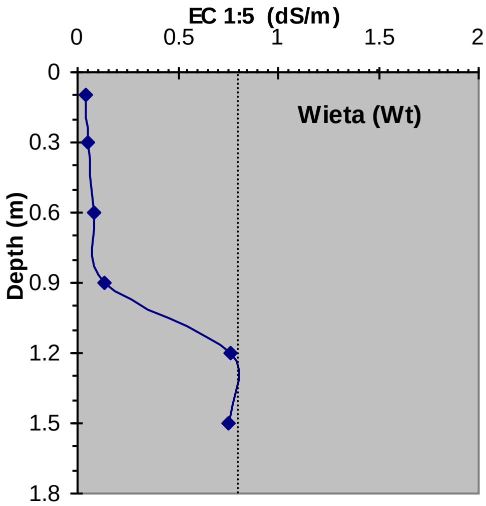
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
5.9	0.98	0.05	7	0.42	41	12	0.37	0.27	2.3	1.6
acid	low	low	low	moderate	-	moderate	moderate	low	moderate	moderate

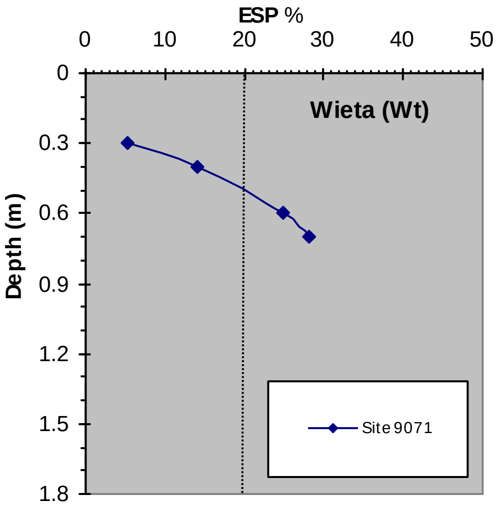
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are low. Most other nutrients are moderate with the exception of zinc (Zn) which is low. The relative infertility of the Wieta (Wt) soil reflects the low nutrient status of the underlying deeply weathered Tertiary substrate. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present by about 1.2 m in the Wieta (Wt) soil. The profile salinity curve reaches equilibrium between 1.1 and 1.3 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Weathered substrate is normally present somewhere below 0.6–1.0 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Critical sodicity levels (ESP >20) are often present in the kaolinitic substrate material underlying the profile.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.50	**0.81**	1.11	59	**91**	123

Typically, PAWC levels for the Wieta (Wt) soil are borderline low to moderate (approximately 90 mm) with a mean ERD of about 0.8 m. It is restricted by the presence of deeply weathered, strongly sodic, acidic substrate. Restrictions to rooting depth are generally absent in the profile, although high salinity levels (EC >0.8 dS/m) are often present in the underlying substrate. Even where deeper profiles occur (ERD >0.8 m), maximum PAWC levels (90–125 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy or clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9071 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content is either relatively uniform throughout the profile (25–40%) or increases gradually between the surface soil (25–40%) and the subsoil (40–60%). High levels of fine sand (50–60%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the profile are <0.15 throughout and indicate the clay fraction is entirely kaolinitic. Measured dispersion (R1 ratio) is low throughout the profile and reflects the acidic, kaolinitic nature of this soil. Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9071 are presented in Appendix 3.

Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are low to very low (4–7 meq/100 g) throughout, with magnesium (Mg) the dominant cation in the subsoil. Sodicity in the profile is variable. It is either non-sodic (ESP <6) throughout or non-sodic (ESP <6) in the surface soil and upper subsoil increasing to sodic (ESP 6–15) or extremely sodic (ESP >20) in the lower subsoil and underlying substrate in other profiles. Detailed chemical data from representative profile 9071 are presented in Appendix 3.

WINDEYERS HILL (Wy)

Concept: A hard setting, alkaline, brown or red non-cracking clay grading to a clay loamy surfaced, alkaline, brown or red, non-sodic texture contrast soil over partially altered basalt or strongly structured, basaltic clay from 0.5–>1.5m. Eucalypt vegetation.

Aust. Soil Classification: Brown or Red Dermosol; Brown or Red Chromosol.

Great Soil Group: Brown clay, no suitable group, solodic soil.

Principal Profile Form: Uf6.31; occasionally Db1.13, 1.33, 1.43, Dr2.12.

Geology: Partially altered Tertiary basalt (Tb_a).

Landform: Gently undulating pediments, colluvial footslopes and occasional rises associated with partially altered basalt flows exposed following scarp retreat of Tertiary plateaus in the Duaringa Basin. Slopes 0.5 to 3%, occasionally up to 5%.

Vegetation Associations: Ironbark–bloodwood–ghost gum (VA43), occasionally Narrow-leaved ironbark (VA12), Silver-leaved ironbark (VA17), Poplar box–ironbark (VA34) or Poplar box (VA20).

Microrelief: Absent.

Runoff: Slow to moderately rapid.

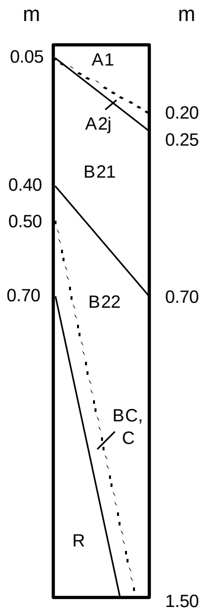
Permeability: Slow.

Drainage: Moderately well drained.

Surface Features: Hard setting or occasionally firm pedal. Frequently 2 to 20% silcrete gravels 6 to 60 mm.

Representative Profile: **9086**

Typical Profile



Soil Description

The **surface soil** (A1, occasionally A2j) is a black, fine sandy clay loam to fine sandy light medium clay with massive or weak to moderate blocky structure. Depths typically range from 0.05 to 0.20 m. Field pH is 6–7.

The **upper subsoil** (B21) is a brown or red, light medium clay to medium heavy clay with moderate to strong blocky or lenticular structure. Field pH is 6–9.5, increasing with depth.

The **lower subsoil** (B22) is a brown, medium heavy clay to heavy clay with moderate or strong, coarse lenticular structure. It is normally calcareous with 2–20% soft or nodular carbonate. Field pH is 8–9.5.

Weathered **substrate** (BC, C) is often present from 0.5–>1.5 m. Substrate material is partially altered basalt. Typically it is brown or grey with a field pH of 8–9.5. In deep profiles (>1.5 m), strongly structured, alkaline basaltic clay continues at depth.

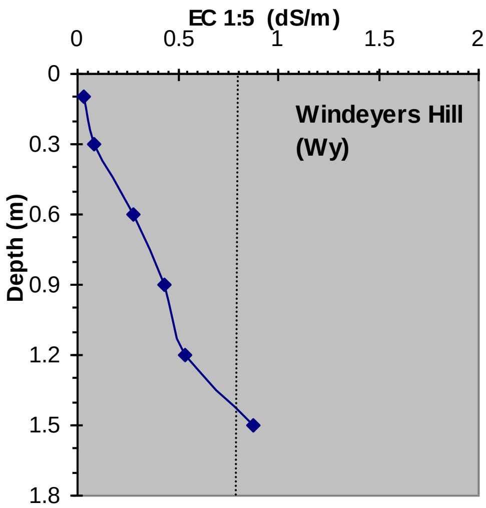
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.6	1.1	0.06	10	0.89	33	31	1.4	0.48	7.1	6.6
neutral	low	moderate	moderate	high	-	moderate	moderate	low	high	high

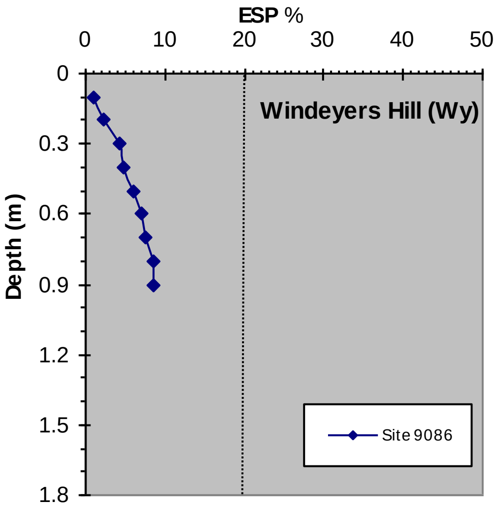
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are moderate. Most other nutrients are moderate to high with the exception of zinc (Zn) which is low. Elevated calcium (Ca) and magnesium (Mg) levels are derived directly from the underlying basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is normally present below about 1.4 m in the Windeyers Hill (Wy) soil. The profile salinity curve does not reach equilibrium (salt bulge is not developed) indicating significant drainage normally moves below the profile. Weathered substrate is normally present somewhere below 0.5–>1.5 m and contributes to increased salinity levels at depth. Sodicity levels in the subsoil (ESP <6–10) are well below critical levels (ESP >20).

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.47	**0.96**	1.45	71	**116**	160

Typically, PAWC levels for the Windeyers Hill (Wy) soil are moderate (approximately 115 mm) with a mean ERD of about 0.95 m. ERD is defined simply by the depth to weathered basalt. Restrictions to rooting depth are absent in the profile, although high salinity levels (EC >0.8 dS/m) are sometimes present in the underlying weathered substrate. Even where deeper profiles occur (ERD >0.95 m), maximum PAWC levels (115–160 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay loamy or clay surface). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profile 9086 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content gradually increases between the surface soil (30–45%) and the subsoil (45–65%), while significant levels of fine sand (30–40%) and silt (>15%) in the surface soil promote hard setting behaviour. CEC/Clay% ratios in the profile are 0.5–0.7 and indicate the clay fraction is of mixed mineralogy with a high proportion of montmorillonite (i.e. basaltic clay with significant colluvial influence). Measured dispersion (R1 ratio) in the profile is low (0.3–0.6) throughout because of high levels of exchangeable calcium (Ca) and subsoil sodicity levels that are only low to moderate (ESP <8). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profile 9086 are presented in Appendix 3.

Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are moderate (20–25 meq/100 g) in the surface soil and high (30–40 meq/100 g) in the subsoil and weathered substrate. Calcium (Ca) and magnesium (Mg) are co-dominant in the surface soil and upper subsoil, while magnesium (Mg) is the dominant cation at depth. Profiles are either non-sodic (ESP <6) throughout or are non-sodic in the surface soil and upper subsoil and gradually become sodic (ESP 6–10) at depth. Detailed chemical data from representative profile 9086 are presented in Appendix 3.

WINDEYERS HILL MELONHOLE PHASE (WyMp)

Concept: A lattice or shallow melonhole gilgai complex (VI 0.3–0.5 m) with:

- a hard setting, firm pedal or weakly self-mulching, alkaline, brown non-cracking to cracking clay on mounds and shelves; and
- a hard setting, firm pedal or weakly self-mulching, acid, grey cracking clay in depressions;

over acid, basaltic clay from 0.6–1.1 m. Eucalypt vegetation.

Aust. Soil Classification: **Mound/shelf:** Brown Dermosol; Brown Vertosol **Depression:** Grey (or occasionally Brown) Vertosol

Great Soil Group: **Mound/shelf:** Brown clay **Depression:** Grey clay

Principal Profile Form: **Mound/shelf:** Uf6.31, Ug5.34, 5.35 **Depression:** Ug5.25, 5.29

Geology: Partially altered Tertiary basalt (Tb_a).

Landform: Lower slopes of gently undulating pediments associated with partially altered basalt flows exposed following scarp retreat of Tertiary plateaus in the Duaringa Basin. Slopes <1%.

Vegetation Associations: Narrow-leaved ironbark (VA12) or Ironbark–bloodwood–ghost gum (VA43); locally in depressions Sedges (VA29).

Microrelief: Lattice gilgai or shallow melonhole gilgai VI 0.3–0.5 m, HI 20–30 m; frequently with a prominent shelf, indistinct mounds and well developed depressions.

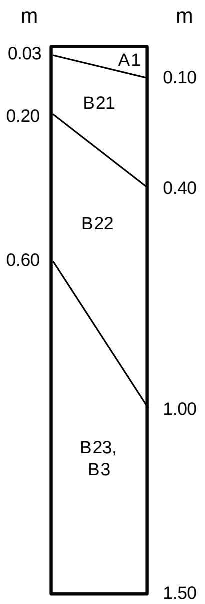
Runoff: Slow on mounds and shelves; no runoff in depressions. **Permeability:** Slow.

Drainage: Moderately well drained on mounds and shelves; imperfectly drained in depressions.

Surface Features: **Mound -** cracking with a fine (<2 mm), weakly to moderately self-mulching surface.
Shelf - frequently cracking with a hard setting or firm pedal surface.
Depression - cracking with a hard setting to weakly self-mulching surface.
Frequently 2 to 10% silcrete gravels 6 to 60 mm, mainly on shelves and mounds.

Representative Profiles: **9087, 9088**

Typical Profile



Soil Description – Mound/shelf profile

The **surface soil** (A1) is a brown, light medium clay (frequently fine sandy) with moderate to strong blocky or granular structure. Depths typically range from 0.03 to 0.1 m. Field pH is 6–7.

The **upper subsoil** (B21, B22) is a brown, medium clay to heavy clay (frequently fine sandy) with moderate or strong blocky structure grading to strong lenticular. It is normally calcareous with 2–10% soft or nodular carbonate. Field pH is 8–9.5.

The **lower subsoil** (B23, B3) is a mottled, grey or brown, medium heavy clay to heavy clay with moderate or strong, coarse lenticular structure. Field pH is 8–9.5 in upper parts, decreasing to 5–6 at depth.

Acid, basaltic clay is normally present below 0.6–1.0 m and continues well past 1.5 m. Weathered basalt substrate is not usually seen.

Soil Description – Depression profile

Depression profiles have similar horizons, texture and structure but differ significantly in terms of colour, pH and surface soil thickness. They are predominantly grey and mottled (except for immediate surface horizons (A1, B21)) and are typically acid (pH 4.5–6) and non-calcareous throughout. The surface soil is usually thinner (0.03–0.04 m) and has coarser blocky or granular structure.

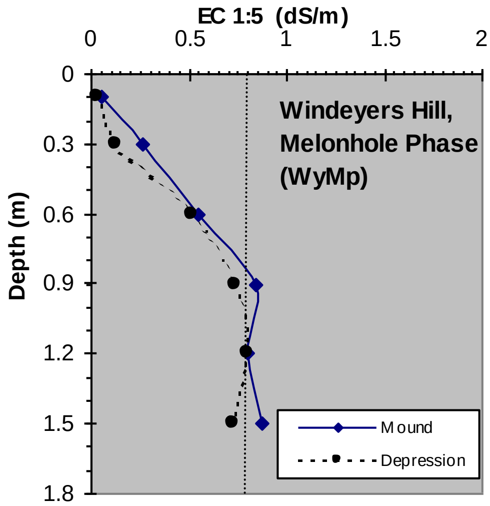
Surface Soil Fertility[1]

Gilgai comp.	pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
				Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
mound	6.6	0.76	0.05	5	0.17	15	27	0.86	0.14	4.8	7.5
	neutral	low	moderate	very low	low	-	moderate	moderate	very low	moderate	high
dep.	6.5	1.3	0.08	16	0.19	84	85	1.8	0.61	5.8	7.9
	acid	low	moderate	high	low	-	high	moderate	moderate	high	high

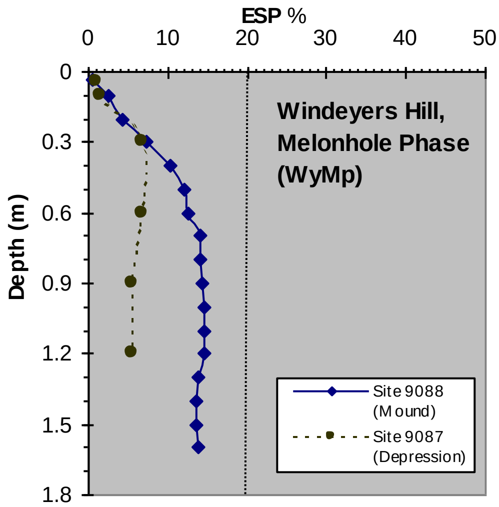
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Significant differences in fertility were consistently observed between gilgai components (mounds and depressions). Typically, nitrogen (Total N) levels are moderate irrespective of gilgai component, while phosphorus (Bicarb. P) levels increase from very low on mounds to high in depressions. Absolute differences in phosphorus (Bicarb. P) fertility between components are significant with levels more than three times higher in depressions. Most other nutrients are moderate to high with similar levels on both gilgai components. The exceptions are potassium (K) which is low throughout, manganese (Mn) which is higher in depressions and zinc (Zn) which is very low on mounds. Elevated magnesium (Mg) levels are derived directly from the underlying partially altered, basaltic parent material. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

The Windeyers Hill melonhole phase (WyMp) soil normally has significant salinity (EC >0.8 dS/m) developed by 0.65–0.85 m, irrespective of gilgai component. Both mound and depression profile salinity curves reach equilibrium between 0.8 and 1.0 m (salt bulge becomes constant) indicating the depth of long term wetting normally associated with this soil. Acid basaltic clay is normally present below 0.6–1.0 m and contributes to the development of the salt bulge because of restricted subsoil drainage. Sodicity levels in the subsoil (ESP 6–15) are normally below critical levels (ESP >20), irrespective of gilgai component.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.40	**0.63**	0.86	82	**112**	142

Typically, PAWC levels for the Windeyers Hill melonhole phase (WyMp) soil are moderate (approximately 110 mm) with a mean ERD of about 0.65 m. Significant differences in ERD or PAWC between gilgai components were not observed. ERD is restricted by high salinity levels (EC >0.8 dS/m) in the subsoil. Even where deeper profiles occur (ERD >0.65 m), maximum PAWC levels (110–140 mm) are rarely achieved on a regular basis because of restricted infiltration (hard setting, fine sandy, clay surface; surface sealing behaviour). The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9087 and 9088 are presented in Appendices 3 and 6.

Physical Characteristics and Subsoil Chemistry

Clay content is relatively uniform (50–55%) throughout both mound and depression profiles, although thin surface horizons with only 40–45% clay are normally developed. Significant fine sand (20–40%) and silt (15–30%) in the surface soil of both gilgai components promote surface sealing behaviour. CEC/Clay% ratios in both gilgai components are 0.3–0.55 and indicate the clay fraction is predominantly of mixed mineralogy (i.e. altered basaltic clay with considerable colluvial/depositional influence). Measured dispersion (R1 ratio) in the surface soil and upper subsoil is low (0.4–0.6) irrespective of gilgai component, but increases to moderate levels (0.6–0.8) in the lower subsoil of mound profiles because of increasing sodicity (ESP 6–15). Total K in the soil profile reflects levels in the underlying altered basaltic clay substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9087 and 9088 are presented in Appendix 3.

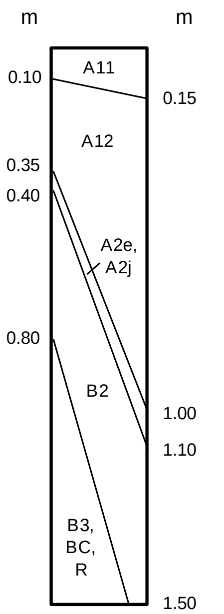
Laboratory pH is similar to field pH (see profile description). CEC levels are high (25–30 meq/100 g) throughout mound profiles, and low to moderate (10–20 meq/100 g) in depression profiles. Magnesium (Mg) is the dominant cation in the profile, irrespective of gilgai component. Mound profiles are non-sodic (ESP <6) in the surface soil and immediate upper subsoil, but gradually become sodic (ESP 6–15) with depth. Depression profiles are typically non-sodic (ESP <6) throughout. Detailed chemical data from representative profiles 9087 and 9088 are presented in Appendix 3.

WYNDHAM (Wm)

Concept: A deep, soft or loose, acid, brown or yellow uniform sand (>1.1 m) grading to a thick (0.4–1.1 m), sandy surfaced, conspicuously bleached, acid to alkaline, mottled, grey, sodic texture contrast soil with coarse columnar structure over ferricrete or deeply weathered sediments below 0.8–>1.5m. Eucalypt vegetation.
Aust. Soil Classification: Orthic Tenosol; Grey Sodosol.
Great Soil Group: Siliceous sand, earthy sand, soloth, solodic.
Principal Profile Form: Uc5.11, 5.21, 5.22, Gn2.21, Dy3.41, 5.31, 5.41, 3.43, 5.43.
Geology: Fine grained sedimentary rocks altered by Tertiary deep weathering (Ta). Substrate is reticulite, petroreticulite or ferricrete.
Landform: Level to gently undulating intact Tertiary plateaus bounded by distinct scarps. Slopes 0.5 to 1.0%.
Vegetation Associations: Eucalypts with shrubby teatree (VA13), Narrow-leaved ironbark (VA12), Ironbark–bloodwood–ghost gum (VA50) or Long-fruited bloodwood (VA15); occasionally Queensland peppermint (VA25).
Microrelief: Absent.
Runoff: Very slow to slow.
Permeability: **Sand -** high.
Texture contrast - very slow
Drainage: **Sand -** moderately well drained to well drained.
Texture contrast - imperfectly drained.
Surface Features: Soft or loose; occasionally firm to hard setting.

Representative Profiles: **9008, 9046**

Typical Profile



Soil Description

The **surface soil** (A11, A12, A2e, A2j) is a brown, sand or loamy sand with massive structure. Depths typically range from 0.4 to 1.1 m in texture contrast profiles to >1.5 m in deep sand profiles. A conspicuously (or sometimes sporadically) bleached layer with 10–>50% ferromanganiferous nodules is normally developed above clay subsoils. Field pH is 5.5–6.5.

The **subsoil** (B2) in texture contrast profiles is a mottled, grey, sandy light medium clay with moderate to strong, coarse columnar structure. It is frequently ferruginous with 2–20% ferromanganiferous nodules. Field pH ranges from 6–9. In deep sand profiles, an acid (pH 5.5–6.5), brown or yellow, sandy loam with massive structure is normally developed in the lower part of the profile.

Weathered **substrate** (B3, BC) is normally present from 0.8–>1.5 m in texture contrast profiles. Substrate material is brown, mottled, reticulite or petroreticulite with a field pH of 6–9. Deep sand profiles, in contrast, are underlain by a ferricrete layer with 20–90% cemented ironstone nodules, usually from 1.1–>1.5 m. Field pH is 5.5–6.5. Weathered substrate appears to lie immediately below this layer.

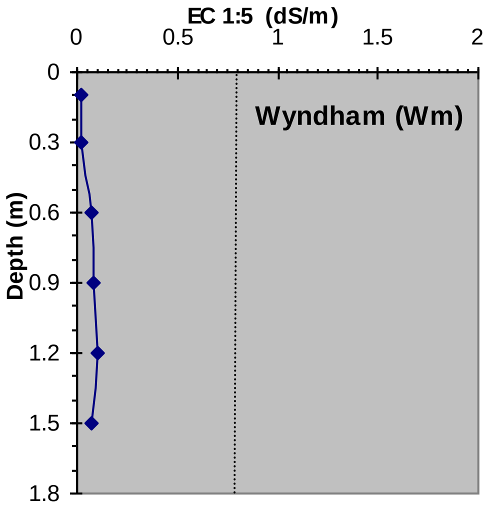
Surface Soil Fertility[1]

pH (1:5)	Org. C (%)	Tot. N (%)	Extr. P	Acid Extr. K (meq/100g)	DTPA Extr. Micronutrients				Exchangeable Cations [2]	
			Bicarb. (mg/kg)		Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ca (meq/100g)	Mg (meq/100g)
6.0	0.56	0.03	2	0.10	33	7	0.12	0.11	1.3	0.53
acid	low	very low	very low	very low	-	moderate	low	very low	low	low

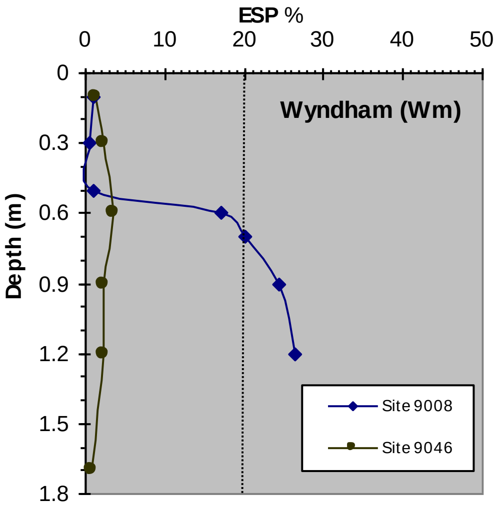
Notes: 1. Air dry (@ 40 C) mean fertility data (0–0.1 m bulk surface samples).
2. CEC/alcoholic cations @ pH 8.5 or ECEC/aqueous cations @ pH 7 depending on surface soil pH.

Mean fertility data for the major soil nutrients measured in the surface soil (0–0.1 m) are summarised in the table above. Typically, the levels of both nitrogen (Total N) and phosphorus (Bicarb. P) are very low. Most other nutrients are also low to very low with the exception of manganese (Mn) which is moderate. The infertility of the Wyndham (Wm) soil reflects its leached sandy nature and the low nutrient status of the underlying deeply weathered Tertiary substrate. Further detail, including ranges (min., max.) and sample counts, is presented in Appendix 4.

Salinity and Sodicity



Mean salinity data (EC $_{1:5}$) down the profile.



Typical sodicity levels (ESP) down the profile.

Significant salinity (EC >0.8 dS/m) is not present in the upper 1.5 m of the Wyndham (Wm) soil. The profile salinity curve is in equilibrium throughout indicating significant leaching and deep drainage normally occur. Critical sodicity levels (ESP >20) typically occur within the upper 0.5 m of the subsoil in texture contrast profiles.

Effective Rooting Depth (ERD) and Plant Available Water Capacity (PAWC)

Mean ERD and PAWC values calculated from individual field site data are presented below. The criteria used for determining ERD and PAWC are presented in Appendix 8.

Gilgai Component	Effective Rooting Depth (m)			PAWC (mm)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
	0.41	**0.90**	1.39	48	**67**	85

Typically, PAWC levels for the Wyndham (Wm) soil are low (approximately 65 mm) even though mean ERD is about 0.9 m. In texture contrast profiles ERD is restricted by physical limitations and reduced permeability in the subsoil associated with ESP levels >20. In deep sand profiles, restrictions to rooting depth are generally absent. Even where deeper profiles (texture contrast or sand) occur (ERD >0.9 m), maximum PAWC levels are only 65–85 mm and are subject to significant evaporation and deep or lateral drainage losses because of the highly permeable nature of the surface horizons. The amount of water stored in each 0.1 m increment down the profile is listed in Appendix 5, while actual examples from representative profiles 9008 and 9046 are presented in Appendices 3 and 6.

Physical Characteristics

Clay content in texture contrast profiles increases significantly between the surface soil (5–10%) and the subsoil (30–40%), while in deep sand profiles clay content is <10% throughout. Significant levels of coarse sand (25–35%) and fine sand (55–65%) in the surface soil are responsible for its soft or loose surface condition. CEC/Clay% ratios in the subsoil of texture contrast profiles are 0.3–0.55 and indicate the clay fraction is predominantly of mixed mineralogy. Measured dispersion (R1 ratio) in the clay subsoil is high (0.85–0.95) because of high to very high sodicity levels (ESP 15–25). Total K in the soil profile reflects levels in the underlying substrate and confirms soil development has been *in situ*. Detailed physical data from representative profiles 9008 and 9046 are presented in Appendix 3.

Subsoil Chemistry

Laboratory pH is similar to field pH (see profile description). CEC levels are very low (1–4 meq/100 g) in the surface soil (and deep sand profiles) and low to moderate (10–20 meq/100 g) in the clay subsoil. Calcium (Ca) is the dominant cation in the surface soil of texture contrast profiles and throughout deep sand profiles, while magnesium (Mg) is dominant in the clay subsoil and underlying substrate (often up to 10 times higher than calcium (Ca)). Sodicity only occurs in the clay subsoil of texture contrast profiles, which are typically strongly to extremely sodic (ESP 15–30). Detailed chemical data from representative profiles 9008 and 9046 are presented in Appendix 3.

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