BHP BILLITON YEELIRRIE DEVELOPMENT COMPANY PTY LTD

SOILS AND SOIL LANDSCAPES OF THE STUDY AREA

Prepared for

Landcare Holdings Pty Ltd

by

D. C. Blandford & Associates Pty Ltd
ABN 22 009 402 706
January, 2011

Cover Photo

Pedestalling occurring on the flanks of a low-relief aeolian dune along the Sandstone-Wiluna Road at the north-western end of the study area. The original bedding of the dune is apparent in the pedestal, formed by the fragment of calcrete protecting the sand below it from the kinetic energy of raindrop impact. The pedestal is approximately 2.5 cm in height.

Photography: D.C.Blandford

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The soil inspection pits were excavated by Mr Stewart Ridgway of Ridgway Backhoe & Contracting. Further, Mr Ridgway also assisted with sampling and provided general assistance in the field. Dr Carolyn Ringrose and Mr Cheyne Jowett, both of Western Botanical, also provided assistance in the field during the field programme.

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1.0 EXECUTIVE SUMMARY

The study area is located approximately 630 km north-east of Perth and 70 km south south-west of the town of Wiluna. This location places the study area in the Eastern Goldfields Province of the Yilgarn Block within the Western Shield Area. The scope of this study addressed the central portion of the Ministerial Temporary Reserve (TR70/6899) (MTR), an area of approximately 464 km^2.

The Yeelirrie deposit is contained within calcretes formed within a major trunk valley of the Lake Miranda palaeo drainage system, the remnants of which are now seen as a low-gradient drainage system, comprising a series of salt lakes stretching from Yeelirrie south and east to a point approximately 200 km north-east of Kalgoorlie. The study area is divided into three soil landscapes, the Sand Plain System, the Playa System, and the Central Calcrete System (Calcrete System). The trunk valley is bounded by granitoid breakaways, which make up a fourth soil landscape, the Granite Breakaway System, the area of which was outside the scope of this study. The breakaways are a prominent feature in the landscape, and are characterised by a well-developed pallid zone, dominated by kaolinitic material. Close to the breakaways, drainage lines are incised, but as distance down slope increases, the channelized flow decreases as water passes from surface flow to sheet flow and then to sub-surface flow.

The sand plain grades into the central floor of the valley, which is occupied by the remaining two soil landscapes. The Playa System of depressions (playas), flats, and scald areas, forms a peripheral zone to the Calcrete System, which in most areas forms a reverse landscape. Superimposed onto this framework are contemporary drainage systems.

The soil profiles at 41 sites were inspected and described during the study, using pits excavated to refusal or to a maximum depth of approximately five metres. The soils of the study area are complex, in both their profile stratigraphy and in their material characteristics within profiles. Field evidence indicates periods of intense pluvial activity and periods of prolonged aridity. The presence of pans, secondary precipitation of carbonates and sulphates, and the degree of competence and induration of many of the soil materials is evidence of long periods of geomorphic stability in the physical environment. Isolated occurrences of high ranking smectite clays, within the Calcrete System, infers that these clays are remnants of a back swamp/lagoonal environment that involved deposition of clay size sediment under a low energy palaeo environment.

Of the 41 sites examined, 35 profiles exhibit different stratigraphic, textural, and structural characteristics, indicating that at least 35 soil profiles have differing soil moisture regimes and accordingly will have differing tolerances and responses to soil moisture related stress. Some locations within the study area contain soil profiles with up to seven definable soil horizons, where the horizons are stratigraphic rather than pedologic. Further, 25 sites exhibited a hiatus or break in the stratigraphic record. This break in the record adds to the complexity of the profile system and its ability to store and transport soil water within the soil-vegetation system. Many of the soils contain a well-developed fabric indicating that they have good soil moisture retention capabilities in the pre-disturbance condition.

In general terms, the Yeelirrie soils have low physical and chemical fertility. Dispersive soils are present, and pH ranges from a low of 4.2 to a high of 8.4. Surface soil infiltration rates range from zero mm/h to a high of 756 mm/h.

Because of the age of the soils, profiles contain well indurated soil materials, a condition resulting in good soil water retention in the undisturbed state. This level of induration, the extent of fabric development, the presence of dispersive soils, the presence of high sub-surface permeability ferricrete horizons, and poor chemical fertility, are the key characteristics of the study area soils.

2.0 INTRODUCTION

D. C. Blandford & Associates Pty Ltd was engaged by URS Australia on behalf of BHP Billiton Yeelirrie Development Company Pty Ltd to conduct a soil and soil landscapes survey as part of the Environmental Review and Management Programme (ERMP) studies for the Proposed Yeelirrie Development (project).

2.1 LOCATION

The project is located approximately 630 km north-east of Perth, and locally is 70 km south south-west of the town of Wiluna, and approximately 63 km almost due west of the Mt Keith mining operations (Figure 1). The study area relates to the central portion of the Ministerial Temporary Reserve (TR70/6899) (MTR), an area of approximately 464 km^2, as outlined in Figure 2. The general morphotectonic-geological setting places the study area in the Eastern Goldfields Province of the Yilgarn Block within the Western Shield Area and at the northern end of the Yilgarn Plateau, a major geomorphological division of Western Australia (Wyrwoll & Glover, 1989).

2.2 SCALES OF TIME AND SPACE

The Yeelirrie uranium deposit (deposit) is contained within calcretes formed within a major trunk valley of the Lake Miranda palaeo drainage system, one of an extensive series of ancient drainage systems that generally flowed to the south-east. The remnants of these ancient systems are now seen as a low-gradient drainage system, comprising a series of salt lakes stretching from Yeelirrie south and east to a point approximately two hundred kilometres north-east of Kalgoorlie.

Scales of time for the study area are dominated by its location within the Yilgarn Plateau. Accordingly, the area is part of the ancient western shield, and locally, the basement granitoid rocks, exposed in the surrounding 'breakaways' have been dated at 2.6 billion years (Wylie and Doyle, 2006). Butt *et al.* (1977) suggest that the calcrete deposits formed during periods of increasing aridity during the Pliocene, and accordingly, we can apply an age of approximately 5 million years to the base of the calcretes.

2.3 PHYSICAL FRAMEWORK

The catchment area, taken as that extending from the north-west interfluve to approximately 10 km downstream from the Yeelirrie homestead, is approximately 6,810 km^2 (Boon Eow *pers. com.*) This area is generally bounded by granitoid breakaways, which represent the weathering, and erosion front that is advancing into the laterite duricrust of the so called "old plateau". These breakaways, which are a prominent feature in the landscape, are characterised by a well developed pallid zone, dominated by kaolinitic material.

The breakaways lead into small, discontinuous areas of coarse-grained foot slope deposits that are often incised by small surface drainage lines. These have been generated by localised storm event runoff from the surface of the 'new plateau, and immediate surroundings. Quartz dominates the mineralogy of the foot-slope deposits. Below these outwash sediments lies an extensive colluvial/alluvial plain grading down to the central floor of the valley. Because the sediment making up the colluvial/alluvial plain has been derived from the old lateritic plateau, ferricrete, in various forms, is present in most profiles. Sands tend to dominate the profile but their gritty characteristic, and wide range in particle size distribution, gives evidence of their colluvial/alluvial origins.

Two distinct systems can be recognised in the central floor of the valley. A system of depressions (playas), flats, and scald areas, forms a peripheral system to the central calcretes, which in most areas forms a reverse landscape. The surface expression of the calcrete is discontinuous in space.

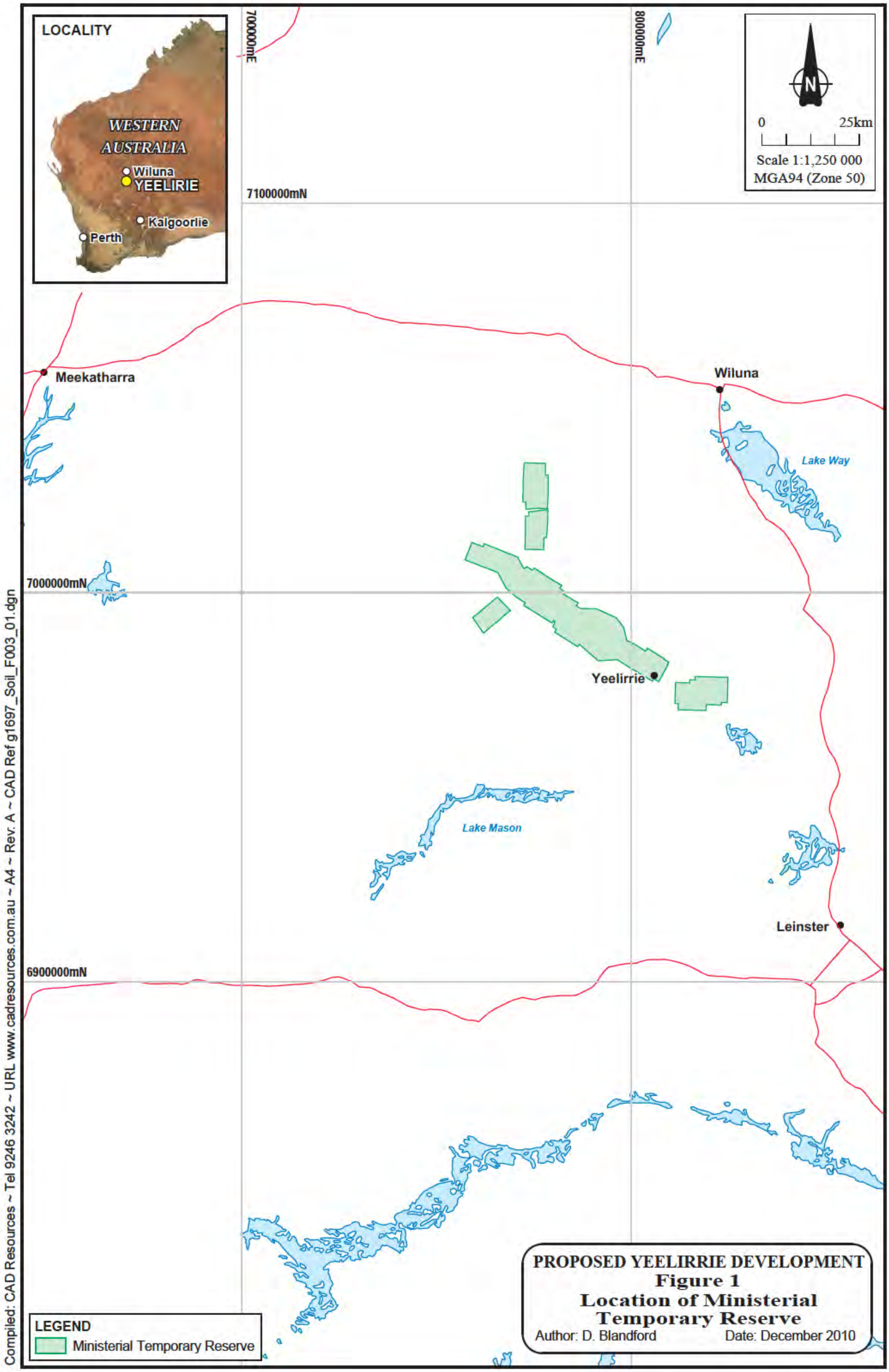
Superimposed onto this framework are contemporary drainage systems. Close to the breakaways, drainage lines are incised, but as distance down slope increases, the channelized flow decreases as water passes to sheet flow, some of which then passes to sub-surface flow. The surface drainage system is characterised by extensive outwash fans.

2.4 OBJECTIVES

The objective of this survey was to identify the major soil types and their associated soil landscapes occurring within the study area, and to define soil and soil profile characteristics. A further objective was to identify vegetation communities present at each soil inspection site with soil profile characteristics, to help develop an understanding of the soil-landscape-vegetation system present.

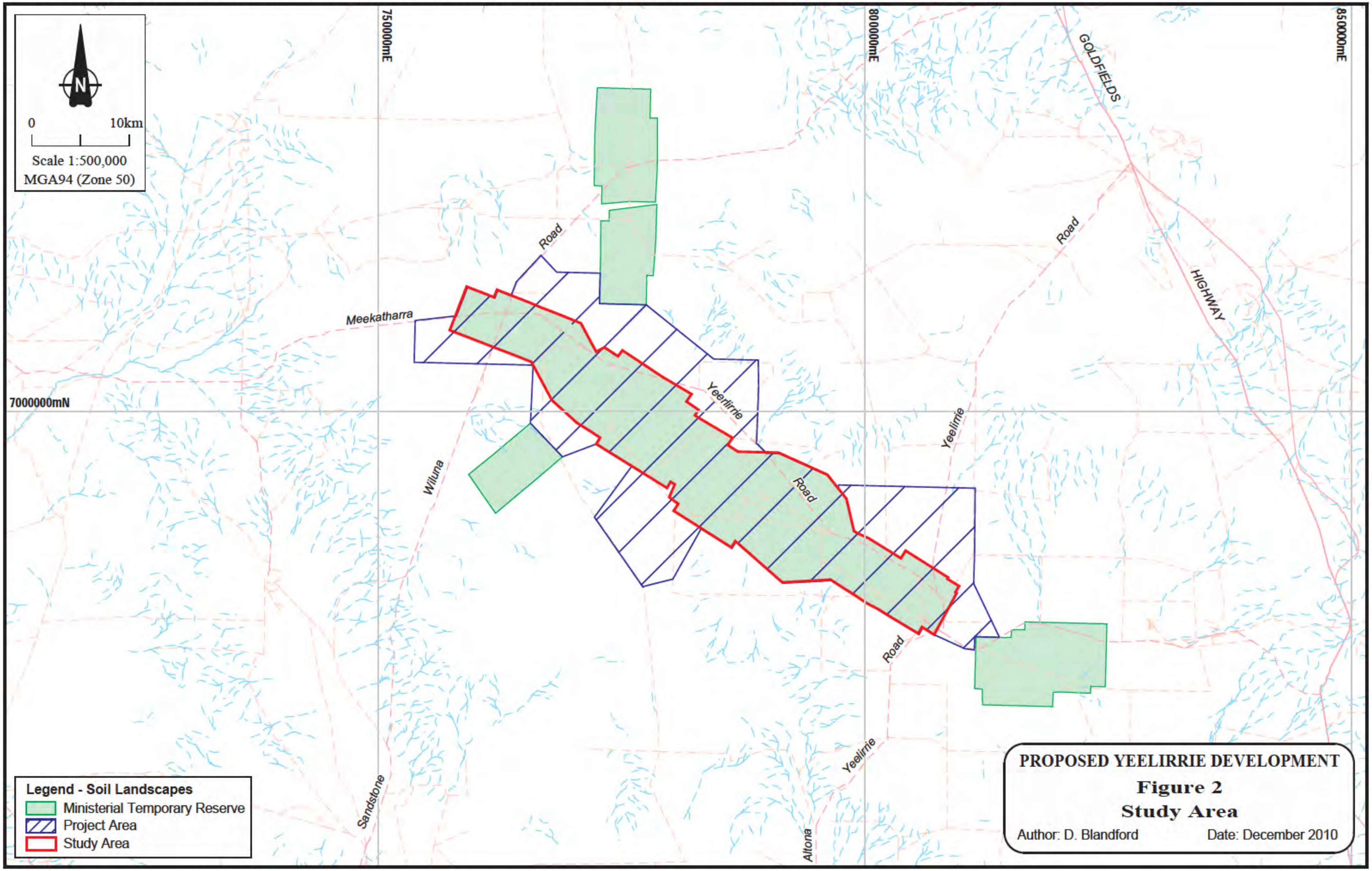
The size of the study area (464 km^2), together with the high degree of spatial variability of soil types occurring, indicated that it was not practical to map the soils at this scale. Accordingly, a soil landscape approach was adopted, in which soil types were grouped according to gross characteristics (e.g. upper profiles dominated by sand, profiles dominated by massive or weathered calcrete, and profiles dominated by strongly indurated hardpans just below the surface). Soil landscapes provide a broad grouping of soil profiles according to their major physical characteristics, which have been developed according to their position in the landscape as influenced by climate, and parent material over time. The soil landscape approach allows the relative significance of the functioning components of the landscape to be assessed as a whole in terms of the inter-relationship of geology, landform, soils, hydrology, and vegetation. The understanding of this functioning system provides the information needed to effectively establish the environmental management programs required to implement rehabilitation strategies and mine closure planning.

This survey was conducted in accordance with the *Guidance for the Assessment of Environmental Factors. Rehabilitation of Terrestrial Ecosystems No. 6* (2006), and accordingly provides baseline data on soils and soil landscapes that can be used to predict permanent changes to soils, landforms and consequent impacts on biodiversity.



PROPOSED YEELIRRIE DEVELOPMENT
Figure 1
Location of Ministerial Temporary Reserve
Author: D. Blandford Date: December 2010

Author: D. Blandford ~ Drawn: CAD Resources ~ Tel 9246 3242 ~ URL www.cadresources.com.au ~ Dec 2010 ~ A4 ~ Rev: A ~ CAD Ref g1697_Soils_F003_06_A4.dgn



PROPOSED YEELIRRIE DEVELOPMENT

Figure 2

Study Area

Author: D. Blandford Date: December 2010

2.5 DEFINITIONS AND COMMENTARY

The following terms, which are used throughout this report, are documented below.

LANDSCAPE

"Landscape is a concept encompassing physical, biological, and social components. In the context of my reports, it comprises a collection of landforms, (and hence landform elements) which have been formed within a geo-tectonic framework as modified by climate over time, and on which drainage systems and vegetation patterns have become established".

The bio-physical characteristics of landscapes are time dependent. Accordingly, many of the landforms, making up the landscapes of the northern-goldfields, are ancient and reflect the millions of years of weathering and erosion that has occurred, within scales of time that has included climatic change caused, in part, by glacial and interglacial periods.

Landscapes cannot be viewed without some reference to scales in time and space. Hence, we talk about the continental landscape, or the landscape of the Goldfields, one dominated by truncated drainage systems with their associated salt lakes, and the remnants of erosion resistant banded iron formations forming prominent hills and ranges, often protruding from a flat featureless plain.

The "Landscape" is what we see when we look at the land. It is different things to different people. In the context of this report, the landscape comprises a range of landforms, and landform elements.

LAND FORM (Landform)

"Landform is the term applied to the multitude of surface features that make up the surface of the earth and includes large-scale features such as mountain ranges, as well as small-scale features such debris slopes".

As with landscape, it is necessary to include a definition of scale when defining landform, and the level of detail provided is a function of the type and purpose of the survey.

There are usually four identifiable scales in space that are invoked in the application of functional geomorphology, or process geomorphology. These are micro-scale landforms (*eg. a pool system in a stream*); meso-scale landforms (*eg. a valley glacier*); macro-scale landforms (*eg. river floodplain*); and mega-scale landforms (*eg. major drainage basins*). Yeelirrie was investigated at the macro-scale wherein the exogenic processes included the regional climate, a medium-term climate change (glacial/interglacial cycles), and regional vegetation change. Accordingly the landforms at Yeelirrie, at the scale of investigation, are the granitoid breakaways, the colluvial/alluvial plain, the playas, and the calcrete.

The scale of these landforms is such that each has its own system which links with other, adjacent systems. The playa system for example, is linked closely with the calcrete system.

Each of the four major landforms can be further sub-divided into landform elements if appropriate.

SOIL LANDSCAPES

The relationship of Australian soils to vegetation and climate has been recognised for many years (Prescott, 1931, 1944), and to parent material Brewer (1954). Forty seven Great Soil Groups were recognised on the Australian continent (Stephens, 1956), and Stephens uses geomorphologic relationships to relate soils to past and present climates, landform (including age), vegetation where applicable, groundwater levels, parent material, and the length of time available for pedogenesis (Stephens, 1961).

Soils are a function of their parent material, and accordingly, are a function of their position within landforms, and therefore, within any given landscape. One of the major characteristics of soil formation in Australia is that the continent has undergone very limited uplift and so there has been limited dissection. In addition, climatic influence during Plio-Pleistocene-Holocene time has diminished, resulting in preservation of Tertiary land surfaces. This has left soil profiles with characteristics that reflect past climates and surface processes rather than contemporary climates characterised by the onset of aridity.

Accordingly, the Great Soil Groups can be related to climate, parent material, topography, age of the land surface, and vegetation. These elements are also used to define ‘landscape’ and so, for any given scale, it is possible to define the soils present. The greater the area defined in the landscape, the more complex the soil relationships. Even at the macro-scale of the Yeelirrie survey, the geomorphic prehistory has dictated a very complex relationship, and one that is best considered in terms of the soils that are present in each of the three landforms present.

Thus, each landform present at Yeelirrie has a suite of soils, and as that landform is part of the “Yeelirrie Landscape”, the soil landscapes of Yeelirrie represent the soils present within each landform.

“Soil landscapes are defined as those landform elements making up the local landscape that comprise a suite of soils with similar characteristics. Any given soil landscape may contain a range of definable soils, all with similar characteristics, but which may vary in profile or horizon morphology”.

3.0 METHOD

3.1 LITERATURE REVIEW

There are no soils data available at a scale appropriate for this investigation. Churchward (1977) described the soils, landforms, and regolith of the Sandstone–Mt Keith area, and the study area is covered by the AgWest (1994, 1998) land system mapping. Again, this latter work, although extensive, lacked the detail necessary to develop an understanding of system dynamics as well as meeting the requirements to develop environmental management programmes.

Much broader scale mapping has been carried out that includes the study area but the scales are inappropriate for the level of detail required (Atlas of Australian Soils, 1968; Stephens, 1961; Northcote *et al.,* 1975; Stace *et al.,* 1968; McKenzie *et al.,* 2004).

3.2 FIELD PROGRAMME

The field programme comprised an initial reconnaissance survey to define access, establish a "feel" for the land, including the identification of process-response systems operating, set preliminary targets, identify inspection and sampling sites, and to assess timing requirements.

Sites were selected on their being representative of the soil landscapes within the MTR or that contained features, such as, overlying vegetation changes, and changes in micro-topography, and therefore warranted closer inspection and description.

The soil profiles at 41 sites were inspected and described. Pits were excavated to refusal or to a maximum depth of approximately 5 m. The inspection trench was accessed for only the first 1.4 m depth and samples were taken from the wall of the trench for laboratory analysis. After this depth, any samples required were taken using the bucket on the backhoe. Once sampling and description were complete, the excavation was backfilled and the surface soil and available vegetation respread over the surface.

As a general rule, the following profile characteristics were noted:

- overall pedologic organization;
- horizonation due to colour change;
- horizonation due to textural change;
- the presence and nature of pans, ferricrete zones, non-ferricrete gravels;
- the nature of horizon boundaries;
- soil texture;
- soil structure; and
- soil fabric.

When present, the following features were also noted:

- the presence of plant roots, including depth;
- the presence of palaeosols;
- the presence of moist zones, seepage, or free water in the profile;
- indicators of geomorphic pre-history; and
- the presence of relict palaeo drainage systems.

In addition to the physical characteristics listed above, a number of horizons within selected profiles were sampled for chemical analysis. The key chemical analyses included, pH, EC, TSS, organic carbon and a range of indicative nutrients, which included, boron, calcium, cadmium, cobalt, copper, iron, potassium, magnesium, manganese, molybdenum, sodium, arsenic, lead and selenium. The Mehlich No. 3 analysis was used for multi-element soil extraction.

In addition to chemical analyses, a laboratory particle size distribution analysis was carried out on selected samples using the full hydrometer technique to define the percentage of gravel, sand, silt and clay present.

Each profile was photographed where possible, including an image of the associated vegetation at that site.

3.3 LIMITATIONS

Limitations to the scope of this study were as follows.

First, the study area was confined to the central (46,426 ha) section of the MTR, which excludes the satellite tenements, and the distal parts of the trunk valley catchment above the resource. These distal areas included:

- the granite breakaways and their associated soils and landforms; and
- the extensive surface drainage, vegetation and soil landscape characteristics between the granite breakaways and the boundary of the MTR;

areas deemed as being major contributors to the characteristics of soils within the study area.

Second, the proponent also requested that soil inspection pits were only located along existing station or mining operation tracks. Accordingly, no investigations were carried out where access tracks did not exist, which limited our ability to fully define soil profile characteristics of the Calcrete and Playa Systems.

4.0 SOIL LANDSCAPES OF THE STUDY AREA

4.1 INTRODUCTION

As discussed above in Section 2.4 Objective, it is not appropriate to try to map the soils of the study area. There are a number of reasons for this but the mains ones are size of the area, complexity of landform evolution, and hence potential complexity of soil types, and geomorphic pre-history. Further, there is little, if any, value in defining detailed soil characteristics and boundaries. There is however, value in understanding the soil resources of an area at the landscape scale to allow an understanding of soil landscape systems and the relationship between these systems, vegetation, and hydrology.

Accordingly, the soil resources of the study area have been defined using a soil landscape approach, where the major landscape units are identified and the characteristics of soils from representative positions within each landscape are defined. The only boundaries considered in this approach are topographic or process derived.

Within the study area three soil landscapes have been recognised. While we have attempted to simplify the position in space of each of these landscapes; local structural, lithologic, and topographic variations, results in a range of process-response systems operating and hence a range of soil-vegetation-hydrological associations. Each soil landscape gives rise to a suite of soils with distinctive characteristics, but with at times, indistinct boundaries. We do not intend to pursue detail past the level of this primary association. Soil Landscapes of the study area, excluding the granite breakaways, are shown in Figure 3.

4.2 SOIL LANDSCAPES

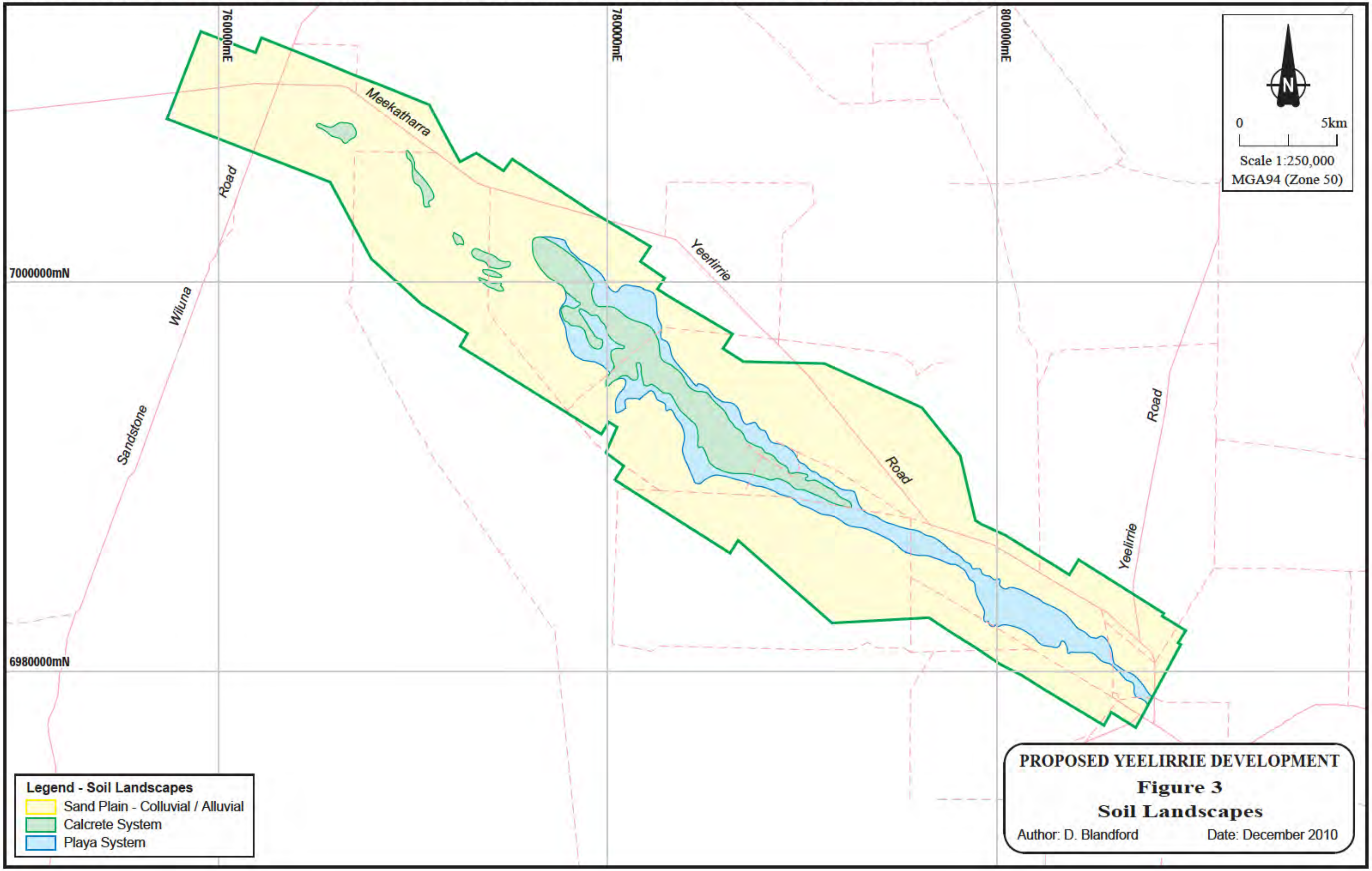
4.2.1 The Colluvial/Alluvial Sand Plain System

This is an extensive soil landscape that extends from the central valley to the granite breakaway country. Surface gradients are very low and while the total valley side slope has an overall angle of approximately 3.5 per cent (northern side) and 5 per cent (southern side), the lower surface of the plain is generally around 0.3 to 0.4 per cent. Nowhere within this soil landscape is there a constancy of soil profile characteristics. This has been brought about by the age of the system (>5 million years), and the impacts of climatic change overprinting process-response systems. The system is everywhere underlain by weathering granitoids, with the saprolite zone ranging in thickness from tens of centimetres to zero. The surface of the plain is intruded by the granitoid bedrock at isolated locations, where it forms very low relief 'granite' rises.

The 'sands' of the sand plain, which rarely show single grain fabric in the undisturbed state, but rather a variously developed earthy fabric, tend to contain a range of grain sizes from fine sand to fine gravel, with some gravel reaching 5 cm in size. These 'sands' also demonstrate varying degrees of induration, a characteristic, which indicates, among other things, high soil moisture retention at varying depths below the surface.

Ferricrete, in a range of types, is ubiquitous throughout the sand plain soils and the thickness of ferricrete horizons ranges from a low of 0.25 m to a maximum thickness of 1.0 m. The most complex profile examined during the survey occurred in this soil landscape where the profile contained seven clearly defined soil horizons. The nature of the ferricrete present ranges from a true ferricrete gravel with well sorted and well rounded gravels to 35 mm in diameter, to ferricrete that is in the form of secondary cementation. Elsewhere, the ferricrete is typified by massive, recemented forms.

Author: D. Blandford ~ Drawn: CAD Resources ~ Tel 9246 3242 ~ URL www.cadresources.com.au ~ Dec 2010 ~ A4 ~ Rev: A ~ CAD Ref g1697_Soils_F003_02_A4.dgn



PROPOSED YEELIRRIE DEVELOPMENT

Figure 3

Soil Landscapes

Author: D. Blandford   Date: December 2010

Many profiles in this soil landscape also display a hiatus (gap in the record) in the stratigraphic horizonation, indicating extensive periods of erosion of the pre-existing profile structure. The plain is also characterised by drainage systems originating in the bounding breakaway country. However, few of these surface systems reach the central valley due to dissemination of surface flow, and low volume runoff entering the groundwater system.

The sand plain soil landscape comprises the following units: the plain itself, drainage lines, outwash fans, aeolian dunes, and low relief 'granite' rises, each with its associated soils.

Surface characteristics of the sand plain soil landscape are shown in Plates 1 to 3 below.

Plate 1: Typical sand plain soil landscape terrain north of the Meekatharra-Yeelirrie Road towards the north-western end of the study area.

Plate 2: Sand plain country north of the Meekatharra-Yeelirrie Road towards the south-eastern end of the study area.

Plate 3: Typical sand plain country just north of the Meekatharra-Yeelirrie Road at Site Y20. This site is the start of Transect B, shown as Figure 6.

4.2.2 The Playa System

The Playa System is a key component of the overall surface system operating within the study area, in that not only is this system a transition zone from the Sand Plain System to the Calcrete System, but also a major conduit for surface runoff moving down the valley.

This is a highly variable soil landscape, which, in many ways, reflects a complex interaction between the sand plain and central valley drainage. It is also a system that includes peripheral calcrete influence.

The Playa System comprises the following units: depressions (shallow), flats with scalds, and flats with sink holes. The depressions, or true playas (as defined in this report), are low relief, shallow structures, often no more than 0.5 m deep, at times with a slightly raised rim, and varying in diameter from tens of metres to hundreds of metres. Flats with scalds are essentially areas devoid of vegetation where wind erosion is the major degradation factor. These flats tend to temporarily pond water.

The Playa System is an important soil landscape in that the system is now the major drainage focus for surface runoff along the valley floor. Complexity in this soil landscape rises from the fact that there is no continuity in the interconnectedness of the depressions, nor is there any obvious preferred route of surface runoff along the valley floor. At the valley scale, the surface discharge conduit passes both sides of the Calcrete System, which, as a reverse landscape, provides a topographic high relative to the adjoining Playa System.

It is most likely that uplift of the Western Shield was responsible for a significant reduction in valley gradients, slowing the discharge, and limiting the energy available for erosion and maintenance of formalised discharge patterns. The soils of this system often show a complex stratigraphy due to a highly varied geomorphic pre-history.

Some profiles contain silty clays at depth below the surface, which is usually a platy sandy loam. Gypsum is also present is some profiles as either crystal growths or as a massive, structureless material. Surface characteristics of the Playa System soil landscape are set out in Plates 4 to 6 below.

Plate 4: A typical playa in the playa soil landscape. This structure, which is only slightly depressed below the surrounding terrain, has a complex stratigraphy. The surface is a loam, fine sandy (Lfsy) displaying post compaction deflocculation [E_c 3(3,4)], which greatly reduces rainfall infiltration. This surface horizon overlies a strongly indurated, massive and strongly calcareous horizon which, in turn, overlies a strongly calcareous horizon containing nodules of carbonate in a finer matrix. At a depth of 1.4 m below the surface, a platy calcrete/gypcrete is present where calcium carbonate and calcium sulphate have cemented ancient sediments. The carbonates are finely disseminated in part with the gypsum forming the main cementing agent. The white material to the left of the pit is the platy calcrete/gypcrete, which is from 1.7 m below the surface.

Plate 5: This playa at Site Y23 also displays a complex stratigraphy. A massive silty clay loam (SiCL), which is present at 0.7 m below the surface and is 0.7 m thick, also contains abundant $CaSO_4$ (Gypsum) in both massive and crystalline forms. This horizon overlies 1.2 m of ferruginised sediment with gypsum, which in turn overlies calcrete at 2.6 m below the surface. Gypsum, which occurs as nodules and crystals is also present in this last horizon.

Plate 6: A well-developed playa within the Playa System. The presence of ponding, which is characteristic of these depression playas, may be due to dispersion reducing the surface infiltration rate, or to a greatly reduced permeability due to induration of the surface. The surface sand (A) around the *Muehlenbeckia florulenta* (R.Graham *pers com.*) is a highly mobile material and is not the topsoil.
Photo: (Western Botanical).

4.2.3 The Central Calcrete System (Calcrete System)

This soil landscape, which occupies the central zone of the valley floor, generally comprises outcropping calcrete in its various forms. This soil landscape is quite variable, and four units can be recognised: calcrete rises, depressions, flats, and clay flats. Each of these units has a distinctive soil stratigraphy.

The calcrete rises are expressed as discrete areas of outcropping but weathered calcrete. The weathered material is generally present as a discontinuous surface lag gravel. The calcrete rises are characterised by a thin veneer of residual soil overlying massive to platy calcrete.

The surface of the calcrete may still contain ‘flats’ where sediment is retained on the structure and where it generally forms a thin veneer of sandy loams to loam, fine sandy. Elsewhere, highly distinctive clay flats are present where the clays tend to be high ranking, self-mulching, and display seasonal cracking.

In some areas, solution of the underlying calcretes has resulted in collapse of the surface, forming small-scale pseudo-karstic topography, while in other areas, low relief depressions are present. These tend not to be filled with sediment but are more typically small scale hollows in the surface, probably the result of differential collapse of underlying solution cavities.

The Calcrete System generally provides a topographic high, relative to the adjacent Playa System. While at the broader scale, this tends to cause water shedding from this soil landscape, areas with depressions tend to concentrate meteoric input, hence adding to the soil water store of the system.

The surface characteristics of the Calcrete System are set out in Plates 7 to 10 below.

Plate 7: Site Y30 is typical of a clay flat within the Calcrete System. Here, 0.7 m of self-mulching, medium to light medium, strongly pedal clay, overlies a nodular light medium clay with carbonates to 1.0 m which in turn overlies 0.6 m of gritty sandy clay. Weathering granite occurs at 1.6 m below the surface. The abrupt boundaries between horizons suggest that the horizonation is stratigraphic rather than pedologic.

Plate 8: Calcrete rises are characterised by a surface lag of weathered calcrete overlying a stony loam, fine sandy (Lfsy) overlying a carbonate rubble in an Lfsy matrix. Platy, strongly laminated calcrete occurs, at this location, at 0.45 m below ground level.

Plate 9: Small scale pseudo-karstic topography along transect A. These small-scale collapse structures are most likely caused by solution cavities developing in the underlying calcrete. This location is immediately north of Site Y4 where the calcrete occurs at 0.2 m below the surface.

Plate 10: A large depression caused by collapse into solution cavities in calcrete at the same location as Plate 9 above.

4.2.4 The Granite Breakaway System

The granite soil landscape system was not investigated in any detail during this survey as the area was outside the scope of the study. However, a brief reconnaissance survey to the breakaway country to put the physical framework together allowed identification of three key units and a highly variable transition zone to the sand plain. The system units are the breakaway plateau surface, the breakaway itself, and a foot slope. No attempt is made here to define soils contained with this system and soil landscape.

The surface characteristics are shown in Plates 11 to 13.

Plate 11: Overview of the breakaway system north of the central valley.

Plate 12: Detail of the pallid zone within the granite breakaway. Structural orientation is still apparent in the kaolinitic dominant mass.

Plate 13: General overview of foot slopes showing the coarse and stony nature of the surface. The breakaway is to the left in this image.

5.0 SOILS OF THE STUDY AREA

5.1 INTRODUCTION

The soil profiles at 41 sites were inspected and described during the initial survey, using pits excavated to refusal or to a maximum depth of approximately 5 m. The nature of the landscape, and a lack of well incised drainage lines limited opportunistic sampling and assessment of profiles along other than well-defined access tracks and roads. Table 1 summarises site soil data, and the location of soil inspection sites is given in Figure 4.

TABLE 1

Summary: Soil Profile Inspection Sites

Site Number (Y)	Soil Landscape	Comments
1	Sand Plain System	1.2 m sand, EF, over 0.5 m Fe gravel
2	Sand Plain System	Sand to 3.0 m with EF at depth, calcrete at 3.6 m
3	Sand Plain System	Sand to 0.8 m over Fe gravel, WR to 1.25 m
4	Calcrete System	Sand to 0.2 m over massive calcrete
5	Sand Plain System	Sand to 1.9 m over ferricrete
6	Sand Plain System	Sand to 0.8 m over ferricrete gravel over mass. Fe.
7	Sand Plain System	Sand to 0.3 m over gravel over weathering granite
8	Sand Plain System	Sand to 0.6 m over ferricrete gravel over granite
9	Sand Plain System	Sand to 0.6 m over Fe gravel, mass Fe, granite 1.4 m
10	Sand Plain System	Sand to 1.2 m over gravels over Si pan at 2.9 m
11	Sand Plain System	Sand to 0.2 m over gravel over granite at 0.9 m
12	Sand Plain System	Sand to 1 m over weathering granite
13	Sand Plain System	Sand to 1.4 m over qtz rubble over granite at 1.8 m
14	Sand Plain (next to calcrete)	Sand to 0.5 m over hard pan, ferruginised
15	Calcrete System	Lfsy to 0.4 m over platy, laminated calcrete

Table 1 (continued)

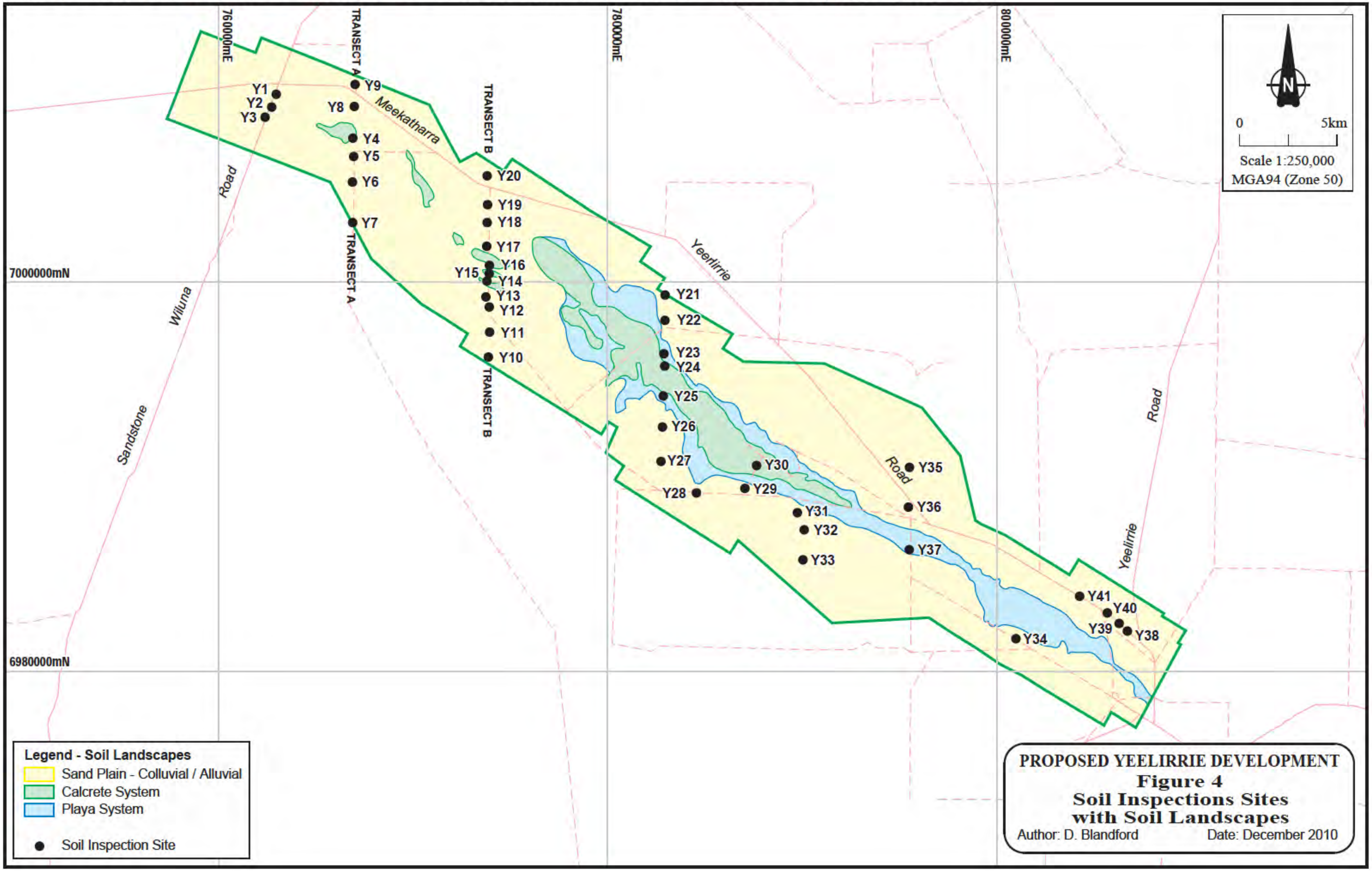
Summary: Soil Profile inspection Sites

Site Number (Y)	Soil Landscape	Comments
16	Calcrete System	Lfsy to 0.4 m over calcrete
17	Sand Plain System	Sand to 1.4 m over gravel over carb. rubble at 2.1 m
18	Sand Plain System	Sand to 1.2 m over gravel over granite
19	Sand Plain System	Sand to 1.7 m over granite
20	Sand Plain System	Sand to 1.6 m over gravels over sap granite
21	Sand Plain System	Sand to 1.8 m over gravels of carb., Fe, indurated
22	Sand Plain System	Sand to 1 m over gravel over indur. sediment
23	Playa System	Thin sand over indur. sand over SiCL over calcrete
24	Calcrete System	Lfsy to 0.1 m over massive calcrete
25	Playa System	Indur. platy sed. over carb.: enriched nodular sed.
26	Sand Plain (granite rise)	Sand to 0.1 m over indur sed. over granite
27	Sand Plain System	Sand to 1.5 m over saprolitic granite
28	Sand Plain System	Sand to 0.9 m over saprolitic granite
29	Sand Plain System	Sand to 0.7m over saprolitic granite
30	Calcrete System	Clay flat L/MC to 1m over SC over granite at 1.6 m
31	Sand Plain System	Sand over strongly indurated platy sediment
32	Sand Plain System	Sand to 1.4 m over indurated platy sediment
33	Sand Plain System	Sand to 0.9 m over platy indurated sediment
34	Sand Plain System	Sand with gravels to 1.4m over indurated sediment
35	Sand Plain System	Sand to 1.2 m over saprolitic granite at 1.6m
36	Sand Plain System	Sand to 1.0 m over pseudo gravels
37	Playa System	Sand to 0.2 m over indur. massive sed. over gravel
38	Sand Plain System	Lfsy to 0.4 m over earthy pan
39	Sand Plain System	LS to 0.2 m over indurated sed. over mass. cal. sed.
40	Sand Plain System	LS to 0.4 m over massive calcrete, globular
41	Sand Plain System	Sand to 1.4 m over Fe gravels over cal. seds.

Note: The following definitions apply to abbreviations used in Table 1 and are defined in full in the Glossary of Technical Terms:

EF	earthy fabric
Fe	ferricrete
WR	well rounded
Mass	massive
Si	silica
Qtz	quartz
Carb	carbonate
Sap	saprolite, saprolitic
Indur	indurated (hardened)
L/MC	light to medium clay
SC	sandy clay
Lfsy	loam, fine sandy (a soil texture)
Sed	sediment (unable to be identified in the field)
Cal	calcareous
Pseudo	iron oxide cemented carapace with sediment core
LS	loamy sand (soil texture)

Author: D. Blandford ~ Drawn: CAD Resources ~ Tel 9246 3242 ~ URL www.cadresources.com.au ~ Dec 2010 ~ A4 ~ Rev: A ~ CAD Ref g1697_Soils_F003_03_A4.dgn



PROPOSED YEELIRRIE DEVELOPMENT

Figure 4

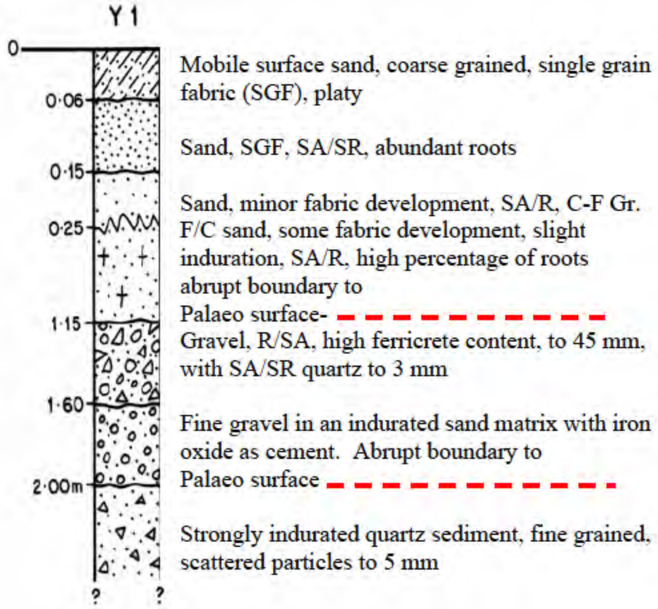
Soil Inspections Sites with Soil Landscapes

Author: D. Blandford Date: December 2010

5.2 THE SOILS OF THE STUDY AREA

SITE Y1: Sand Plain System

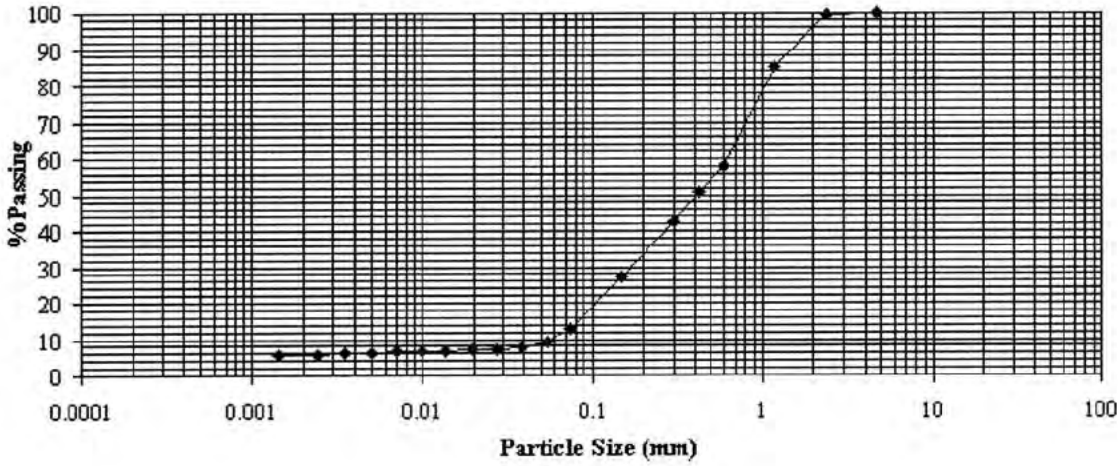
7009619N
0762887E



Summary:

Sample Depth: 0.5 m

Sand (6% Clay), with fabric development: non-saline: strongly sodic (ESP 30.8%), extremely acid (pH 4.2), very low organic carbon (0.1%); deficient in K-Mg-Mn-P-Zn

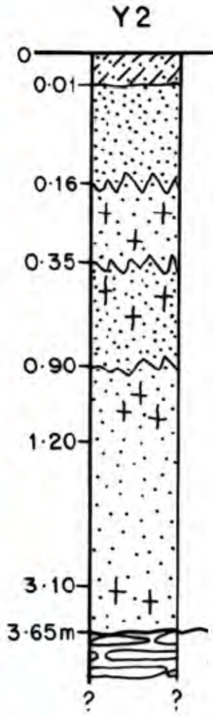


Site Y1 Vegetation:

Triodia basedowii hummock grassland with low Myrtaceous heath of *Enekbatus eremaeus* and *E. cryptandroides* and emergent shrubs of *Acacia effusifolia* (SAHS community). [Rebecca Graham].

SITE Y2 Sand Plain System

7008967 N
0762660 E



Mobile sand, SGF, fines to 2 mm
Surface sand, fine-grained, isolated grains to 2 mm, SA/SR, SGF

Fine sand, fabric development, SA/SR, isolated grains to 2 mm

Fine sand, fabric development, SA/SR, indurated, roots to 1.2 m

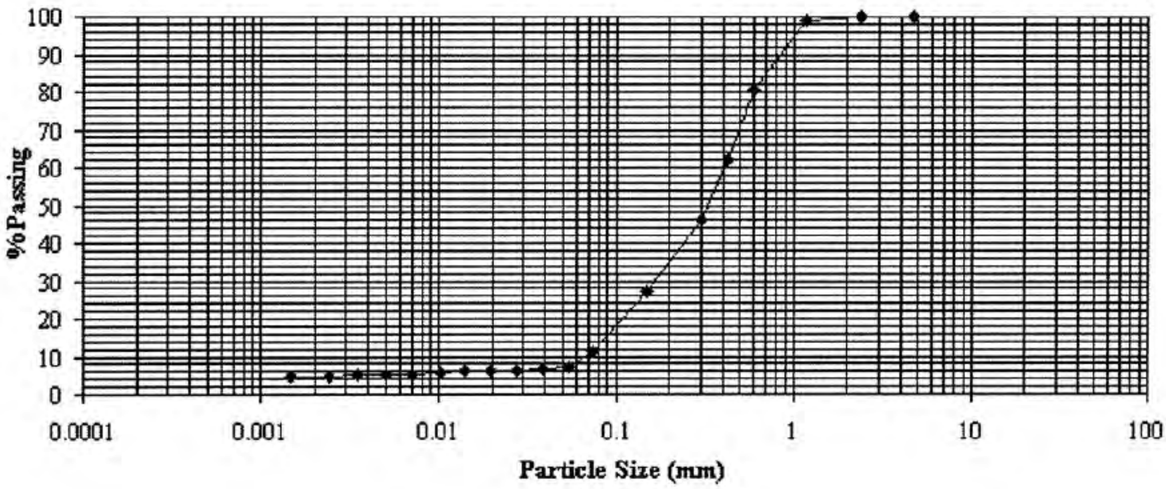
Fine sands increasing to 2 m, indurated, with strong fabric development

Hiatus
Calcrete, massive

Summary:

Sample Depth: 0.95 m

Indurated fine sand (26% Fine sand) with fabric development: non-saline: non-sodic: very strongly acid (pH 4.7): extremely low organic carbon (0.08%): deficient in B-Cu-Mg-Mn-P

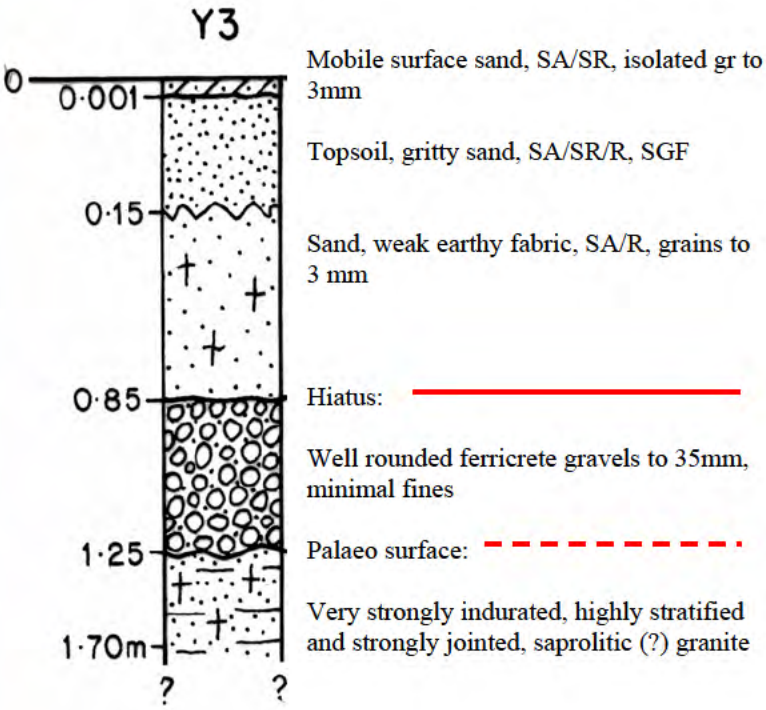


Site Y2 Vegetation:

Callitris columellaris and *Hakea francisiana* tall shrubland with *Eucalyptus leptopoda* subsp. *elevata* mallee over scattered shrubs of *Bertya dimerostigma* and *Micromyrtus flaviflora* over *Triodia basedowii* hummock grassland (SDSH community) [Rebecca Graham].

SITE Y3 Sand Plain System

7008442 N
0762391 E

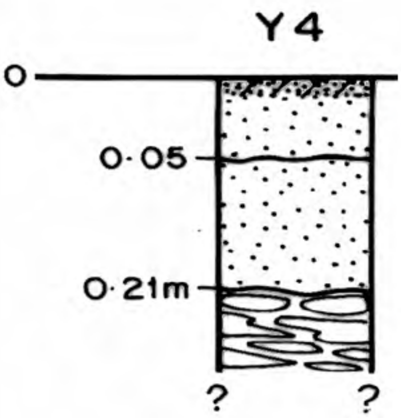


Site Y3 Vegetation:

Callitris columellaris and *Hakea francisiana* tall shrubland with *Eucalyptus leptopoda* subsp. *elevata* mallee over scattered shrubs of *Bertya dimerostigma* and *Micromyrtus flaviflora* over *Triodia basedowii* hummock grassland (SDSH community) [Rebecca Graham].

SITE Y4 Calcrete System

7007428 N
0766987 E



Mobile surface sand, SGF
Gritty, fine sandy loam (FSL)

Dark reddish brown (2.5YR 3/6) FSL, earthy

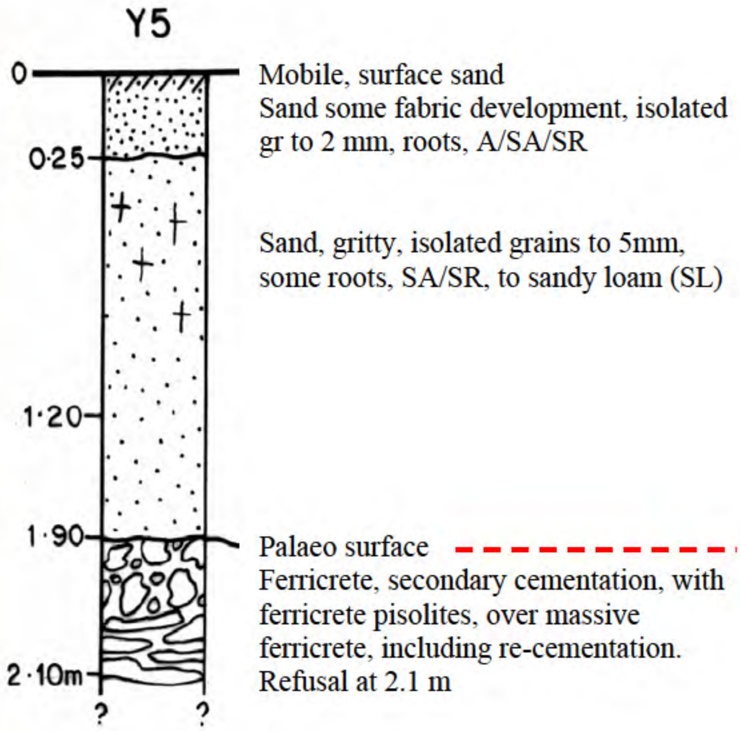
Massive calcrete

Site 4 Vegetation:

Acacia aneura (several varieties) tall open shrubland over *Ptilotus obovatus* (typical Goldfields form) scattered low shrubs over *Triodia basedowii* scattered hummock grasses (PLAPoS community). [Rebecca Graham].

SITE Y5 Sand Plain System

7006431 N
0766957 E



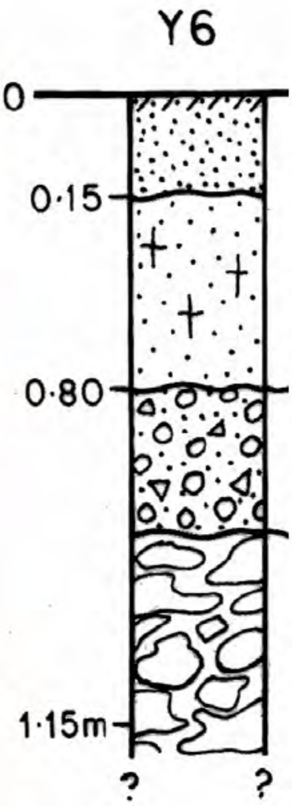
Site Y5 Vegetation:

Triodia basedowii hummock grassland with *Acacia effusifolia* open shrubland (SAWS community). [Rebecca Graham].

SITE Y6 Sand Plain System

7005170 N
0766946 E

I_r-756mm/h (surface infiltration rate)



Laminated, platy, mobile surface sand

Sand, earthy fabric, SA/SR, isolated gr to 2 mm

Gritty sand, earthy fabric, isolated gr to 5 mm, massive

Ferricrete/quartz gravel in a sand matrix

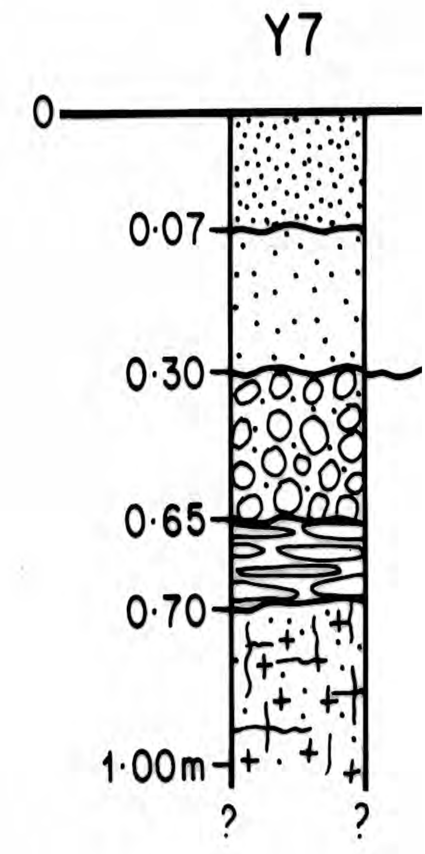
Massive ferricrete, refusal at 1.15 m impeding layer

Site Y6 Vegetation:

Triodia basedowii hummock grassland with *Acacia effusifolia* open shrubland and occasional *Eucalyptus* sp. (SAWS community) [Rebecca Graham].

SITE Y7 Sand Plain System

7003020 N
0766915 E



Surface horizon of platy sand, SA/SR, over

Earthy fabric, sandy loam (SL), massive, isolated grains to 3 mm
Hiatus:

Ferricrete gravel, coarse, A/R, with contained pisolitic zones

Saprolitic granite, platy,

Weathering granite, with quartz veins, feldspar, mica

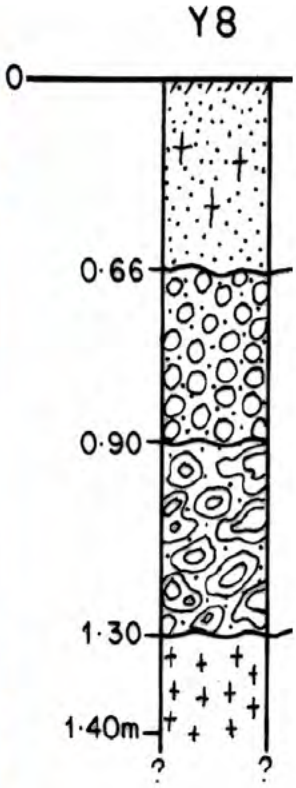
Refusal

Site Y7 Vegetation:

Triodia basedowii hummock grassland with *Acacia effusifolia* and *Eremophila forrestii* subsp. *forrestii* open shrubland and *Eucalyptus kingsmillii* scattered mallee (SAMA community). [Rebecca Graham].

SITE Y8 Sand Plain System

7008989 N
0767015 E



Mobile surface layer of sand, Gritty to 3 mm, sand, earthy fabric, massive, minor post compaction deflocculation in surface crust [3(1)]

Hiatus:

Weathering ferricrete gravels to 20 mm in sand matrix, abundant roots,

Weathering massive ferricrete, roots

Hiatus:

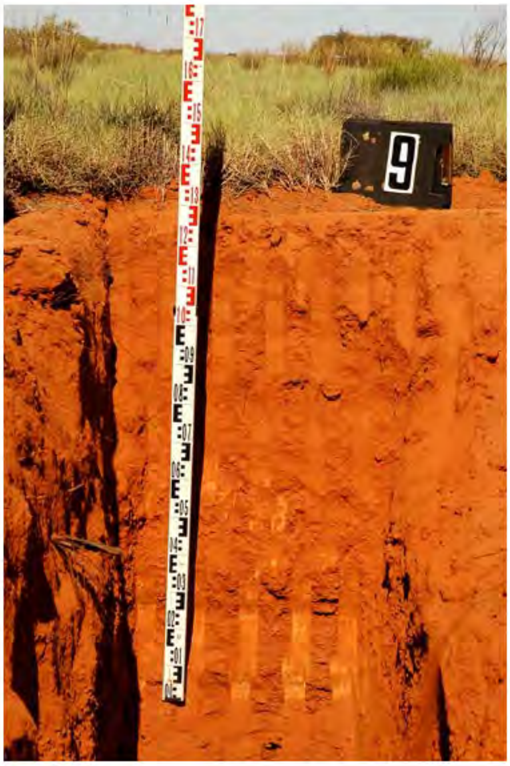
Weathering granite, high moisture content, quartz, feldspar, manganese in veins

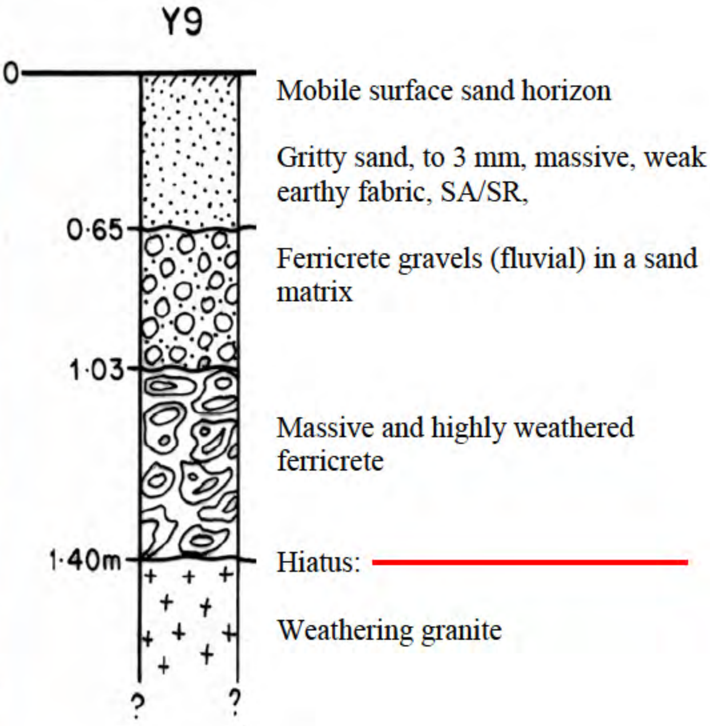
Site Y8 Vegetation:

Triodia basedowii hummock grassland with *Leptosema chambersii*, *Euryomyrtus inflata*, *Prostanthera wilkieana*, and *Keraudrenia velutina* ssp. *elliptica* low scattered shrubs (SASP community) [Rebecca Graham].

SITE Y9 Sand Plain System

7010268 N
0767036 E



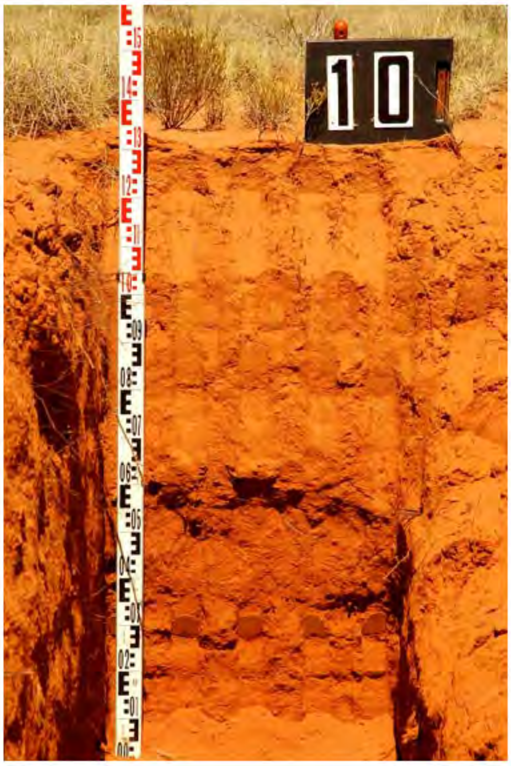


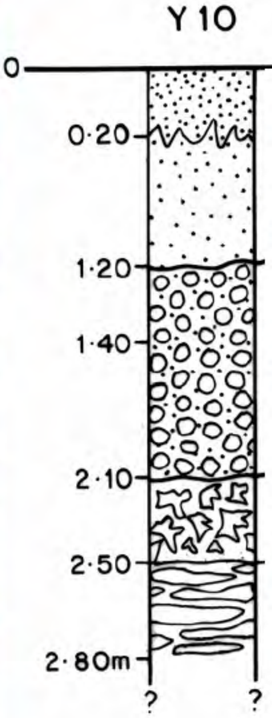
Site Y9 Vegetation

Triodia basedowii hummock grassland with *Leptosema chambersii* and *Prostanthera wilkieana* low scattered shrubs and *Eucalyptus kingsmillii* scattered mallee (SAMA community).
[Rebecca Graham].

SITE Y10 Sand Plain System

6996179 N
0773842 E





Surface sand, massive, earthy fabric, SA/SR, over

Gritty loamy sand, earthy fabric, massive, roots, over

Ferricrete gravel, pisolitic to medium gravel, 2-20 mm, <1%<75μm, over

Hiatus

Si dominated sediment, well rounded qtz grains, carbonate free, silica masses sharp/hard, over

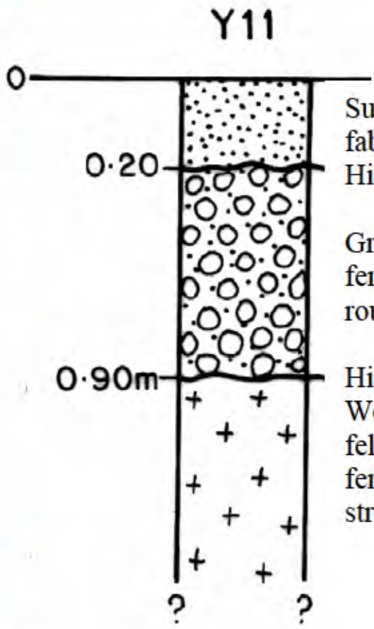
Silica pan, high carbonate content, with secondary Si cementation

Site Y10 Vegetation:

Triodia basedowii hummock grassland with *Acacia effusifolia* tall open shrubland and *Eucalyptus kingsmillii* scattered mallee (SAMA community).
[Rebecca Graham].

SITE Y11　　Sand Plain System

6997463 N
0773860 E



Surface sand, massive, SGF, weak fabric development, SA/SR

Hiatus

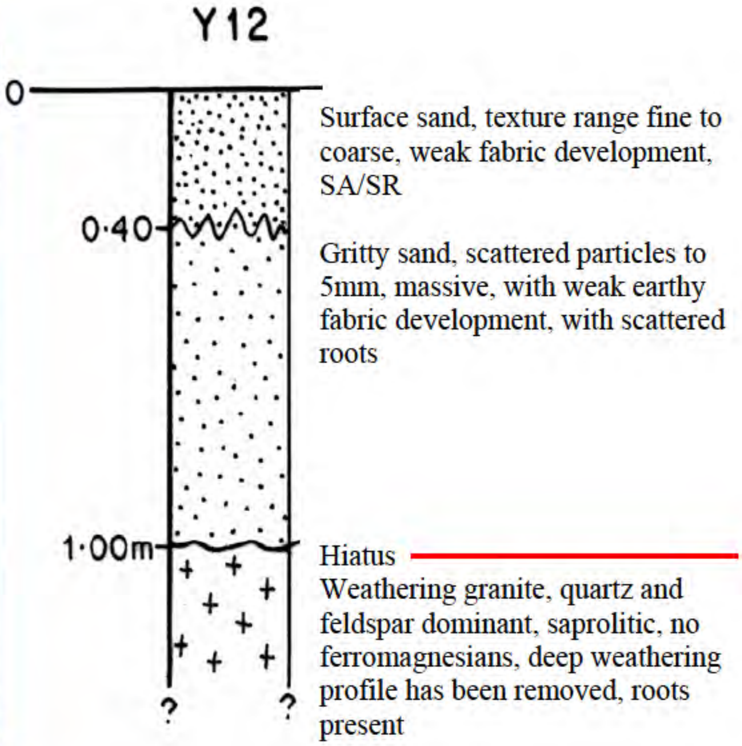
Gravel and sediment galls with ferruginous cement, hard, well rounded, in a fine sand matrix

Hiatus

Weathering granite, quartz and feldspar (?aplite), no ferromagnesians, strongly platy

SITE Y12 Sand Plain System

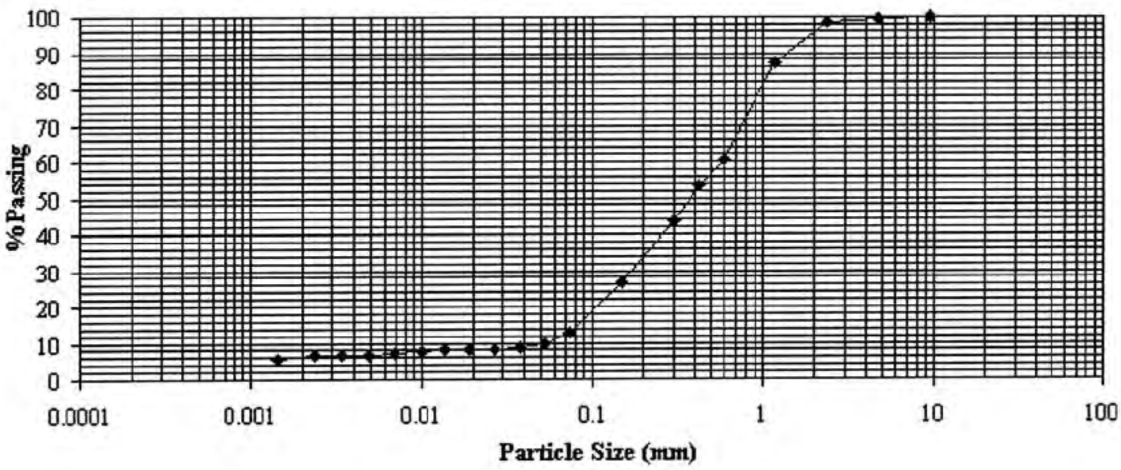
6998701 N
0773878 E

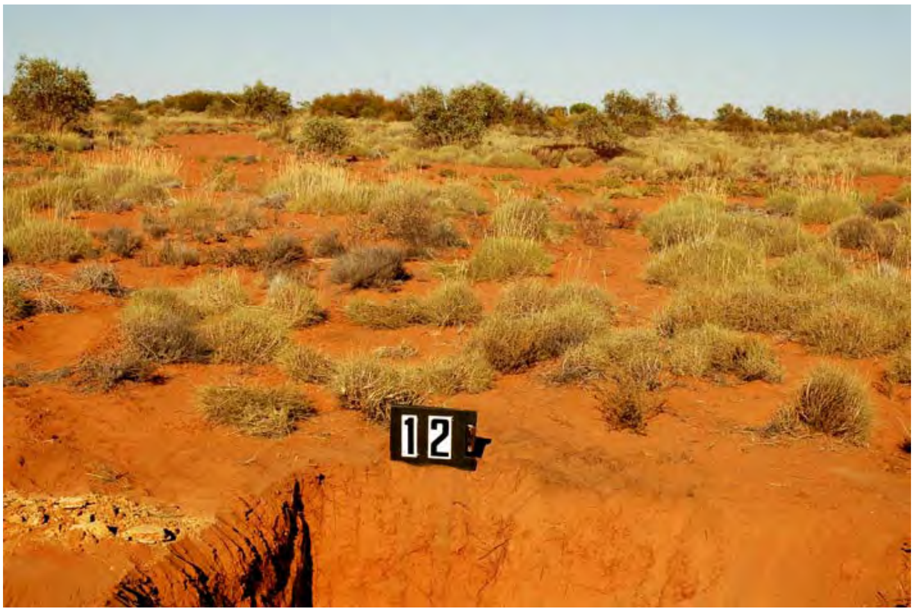


Summary:

Sample depth 0.6 m

Gritty sand (6% clay) with earthy fabric: moderately acid (pH 5.1): non-saline (<1mS/m): non-sodic: extremely low organic carbon (0.09%): deficient in B-Cu-Mg-Mn-P-S.



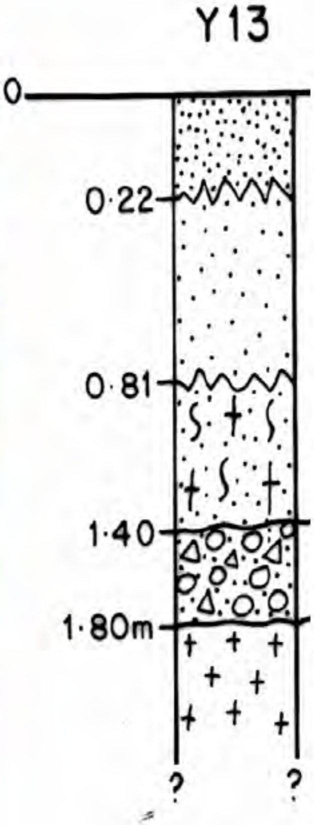


Site Y12 Vegetation:

Triodia basedowii hummock grassland with *Leptosema chambersii* and *Keraudrenia velutina* ssp. *elliptica* low scattered shrubs and *Eucalyptus kingsmillii* scattered mallee (SAMA community). [Rebecca Graham].

SITE Y13 Sand Plain System

6999230 N
0773844 E



Surface sand to loamy sand, massive, weak fabric development, SA/SR

Gritty fine sandy loam (FSL), massive, some fabric development, roots to 0.8 mbgl (metres below ground level), SA/SR

Indurated, massive fine sandy clay loam (FSCL), fine roots to 1.4 mbgl

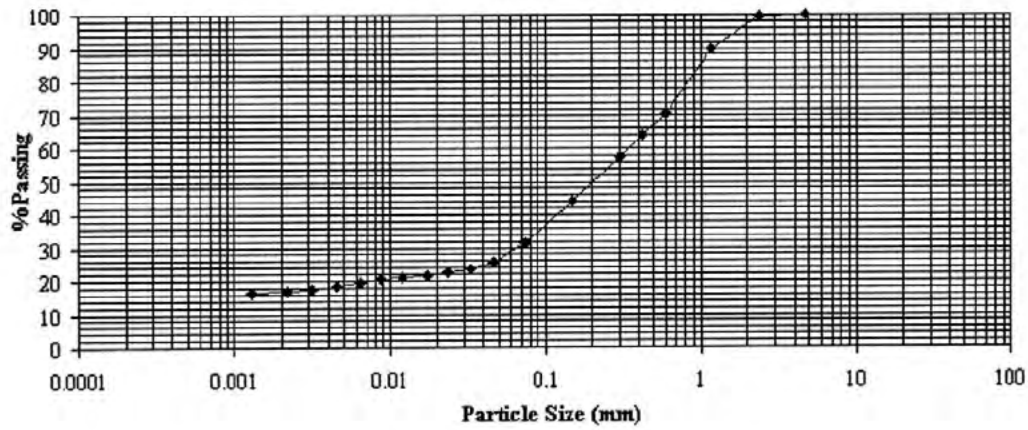
Hiatus

Quartz rubble with pisolitic gravel in a sandy loam matrix

Saprolitic granite, no ferromagnesians

Summary:
Sample depth 0.8-1.5 m

Indurated FSCL (16.5% Clay; 11% Silt; 20% Fine sand): moderately acid (pH 5.3): non-saline: non-sodic, extremely low organic carbon (0.08%): deficient in Zn-P.

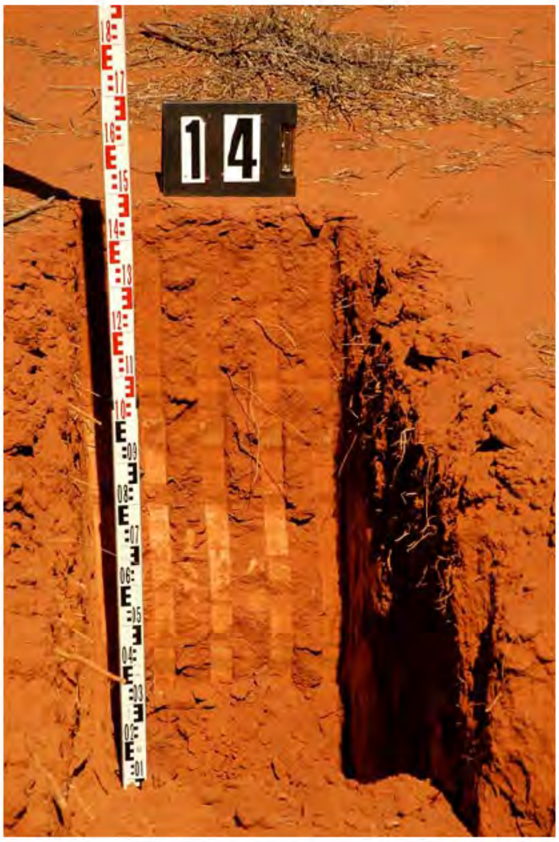


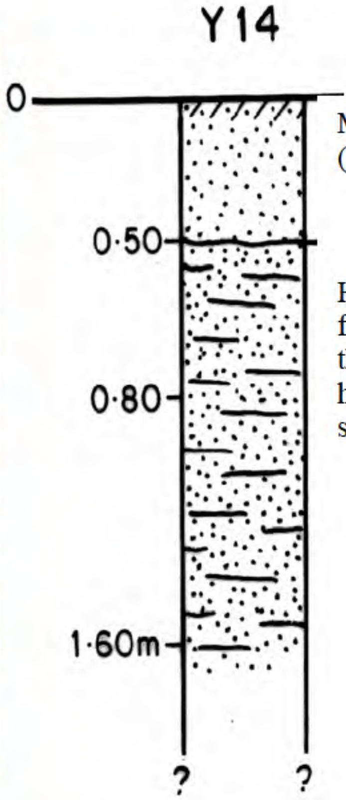
Site Y13 Vegetation:

Triodia basedowii hummock grassland with *Acacia effusifolia*, *Leptosema chambersii* and *Keraudrenia velutina* ssp. *elliptica* low scattered shrubs and *Eucalyptus kingsmillii* scattered mallee (SAMA community).
[Rebecca Graham].

SITE Y14 Sand Plain System

7000051 N
0773847 E





Mobile surface sand over sandy loam (SL), massive, SA/SR

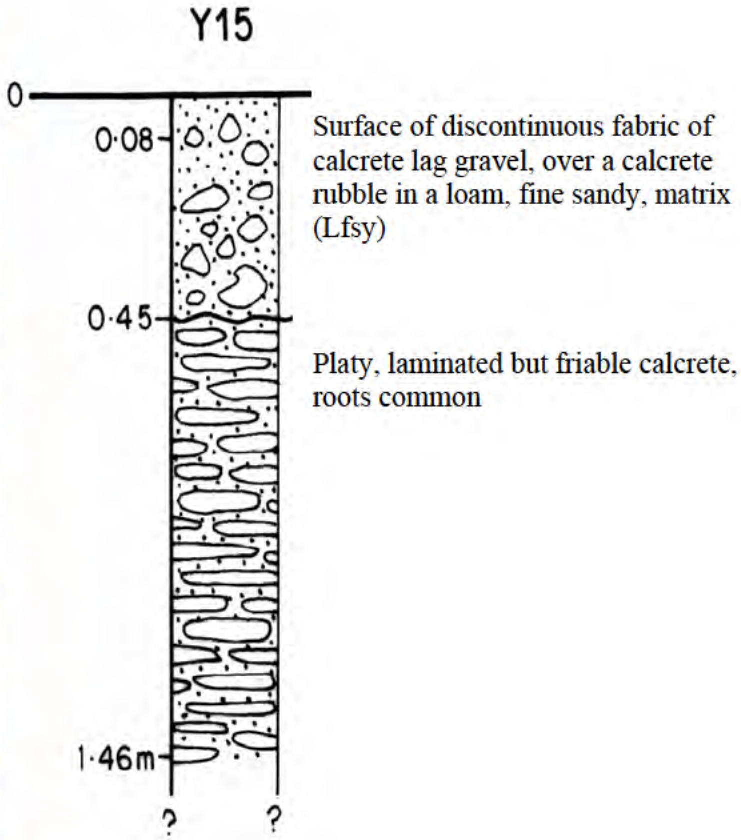
Hard pan, indurated, partly ferruginised sediment, massive, roots, this is an impeding layer but also has high moisture retention, platy structure, roots to 1.6 mbgl

Site Y14 Vegetation:

Acacia ayersiana and *A. aneura* tall open shrubland over *Ptilotus obovatus* (typical Goldfields form) low scattered shrubs (PLAPoS community). [Rebecca Graham].

SITE Y15 Calcrete System

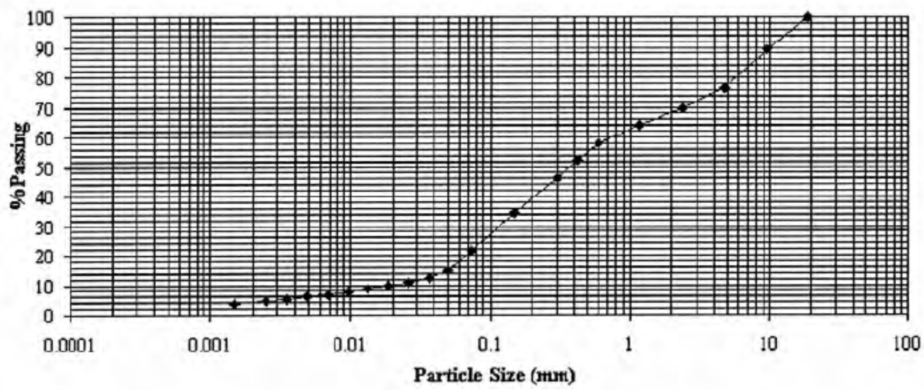
7000446 N
0773899 E



Summary:

Depth of sample: 0-0.3 m

Lfsy, (4%<2μm), pebbly (30% gravel): moderately alkaline (pH 8.0), non-saline: non-sodic: low organic carbon (0.54%): deficient in P-Zn.



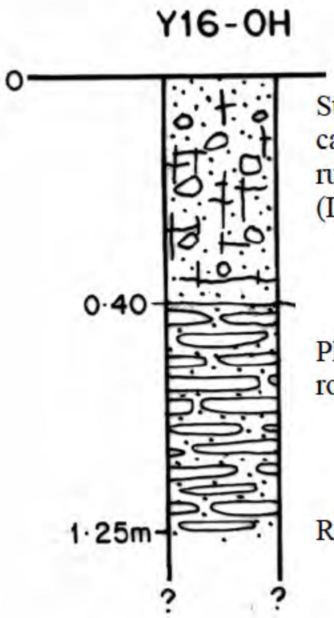
Site Y15 Vegetation:

Casuarina pauper open Woodland over *Templetonia incrassata* scattered shrubs over *Ptilotus obovatus* (typical Goldfields form) low scattered shrubs (CCpW community).
[Rebecca Graham].

SITE Y16 Calcrete System

7000851 N
0773901 E

Site Y16 is an observation hole. The profile characteristics are the same as for Y15. The surface horizon of Lfsy is 0.4m thick and the profile gave refusal at 1.25 m deep.



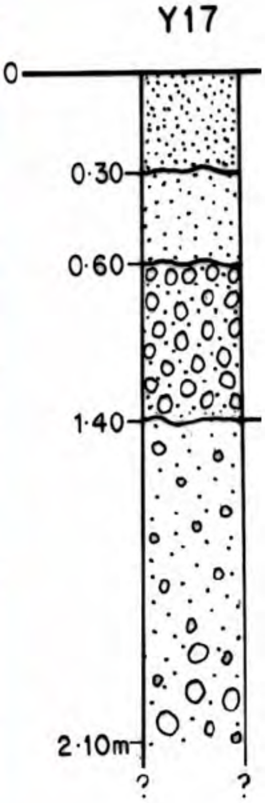
Surface of discontinuous fabric of calcrete lag gravel, over a calcrete rubble in a loam, fine sandy, matrix (Lfsy)

Platy, laminated but friable calcrete, roots common

Refusal

SITE Y17 Sand Plain System

7001836 N
0773871 E



Surface horizon of massive, Lfsy with weak fabric development, overlying a

Gritty fine sandy loam (FSL), with scattered grains to 5 mm, SA/SR, massive

Indurated pisolitic gravel in a sandy matrix, massive and competent, pseudo bedding

Indicated palaeo groundwater level

Carbonate coating on finer gravels, but not complete penetration

Larger carbonate pebbles in sand/gravel matrix

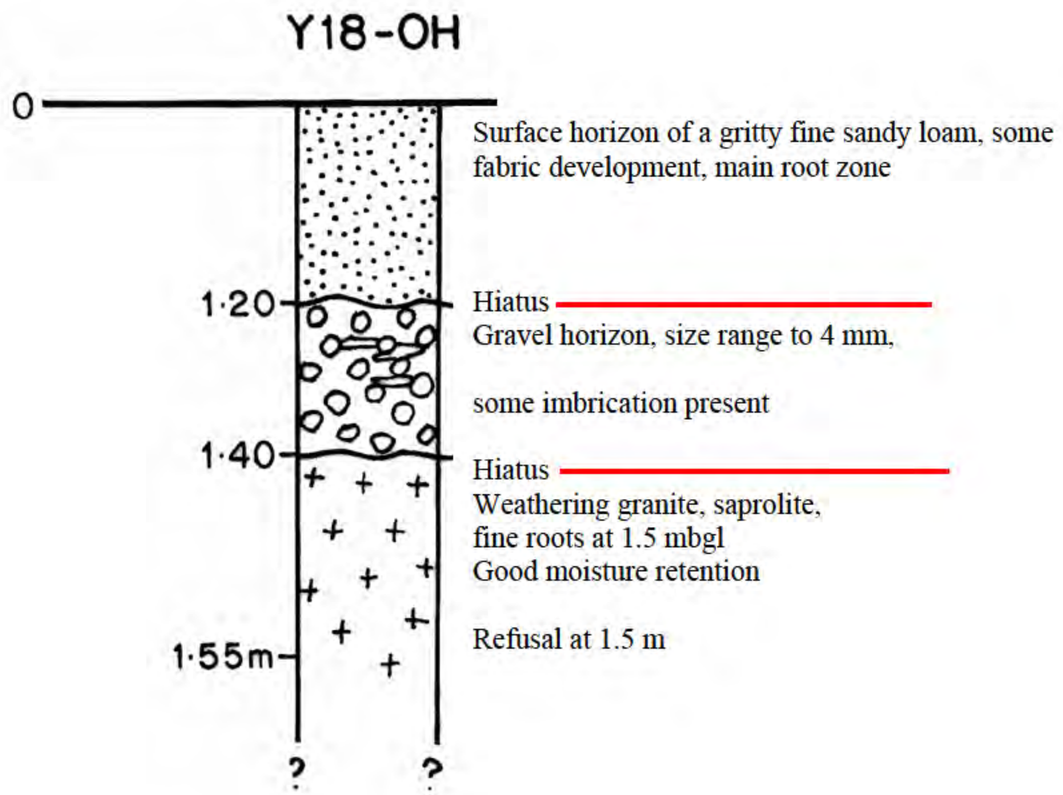
Site Y17 Vegetation:

Acacia ayersiana and *A. effusifolia* tall open shrubland over *Triodia basedowii* (SAMU community). [Rebecca Graham].

SITE Y18 Sand Plain System

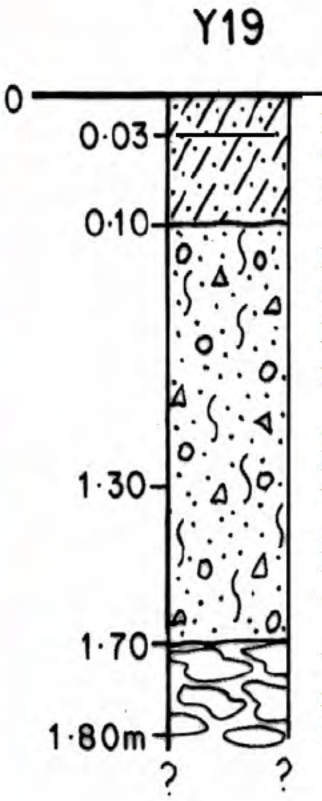
7003046 N
0773892 E

Site Y18 is an observation hole.



SISTE Y19 Sand Plain System

7003935 N
0773897 E



Mobile surface sand over Gritty, massive sand, indurated, earthy fabric

Massive, gravely sand, indurated, earthy fabric, particle size to 10 mm, A/SR,
Texture range sandy loam to a light sandy clay loam.
Ferricrete gravels highly weathered, roots to 1.3 mbgl, good soil moisture retention.
Ferricrete galls with rounded quartz and sand as core

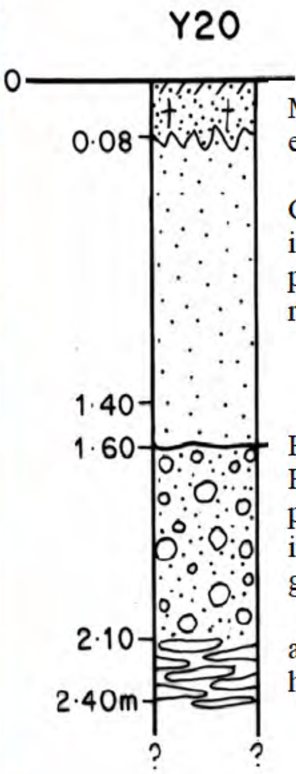
Weathered granite, high manganese, silica, and feldspar

Site Y19 Vegetation:

Triodia basedowii hummock grassland with *Acacia effusifolia*, *Leptosema chambersii* and *Keraudrenia velutina* ssp. *elliptica* low scattered shrubs and *Eucalyptus kingsmillii* scattered mallee (SAMA community). [Rebecca Graham].

SITE Y20 Sand Plain System

7005458 N
0773900 E



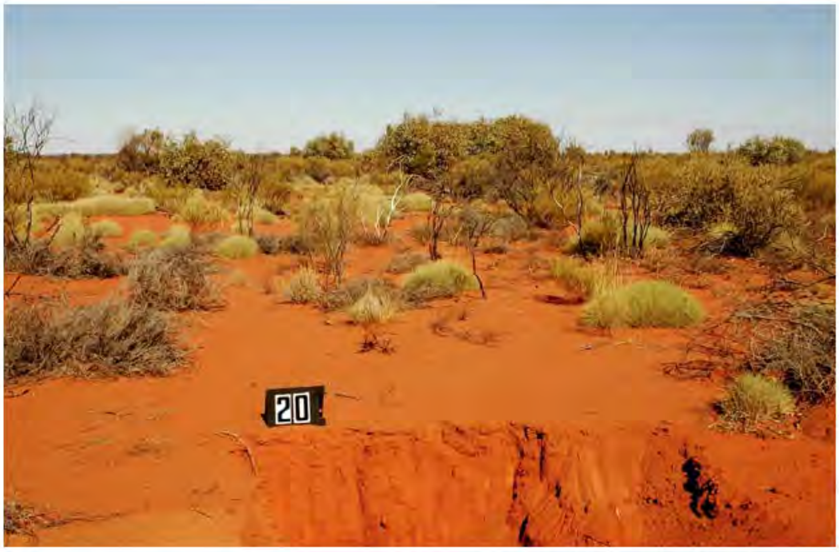
Mobile surface, gritty sandy loam, earthy fabric, platy

Gritty, massive sandy loam, some induration, earthy fabric, scattered particles to 3 mm, roots to 1.3 mbgl

Hiatus

Highly weathered ferricrete gravels, pisolitic to pebbles, range to 50 mm, in a sandy loam matrix, ferricrete galls, over

a platy ferricrete mass, indurated, high Mn content, roots to 2.4 mbgl

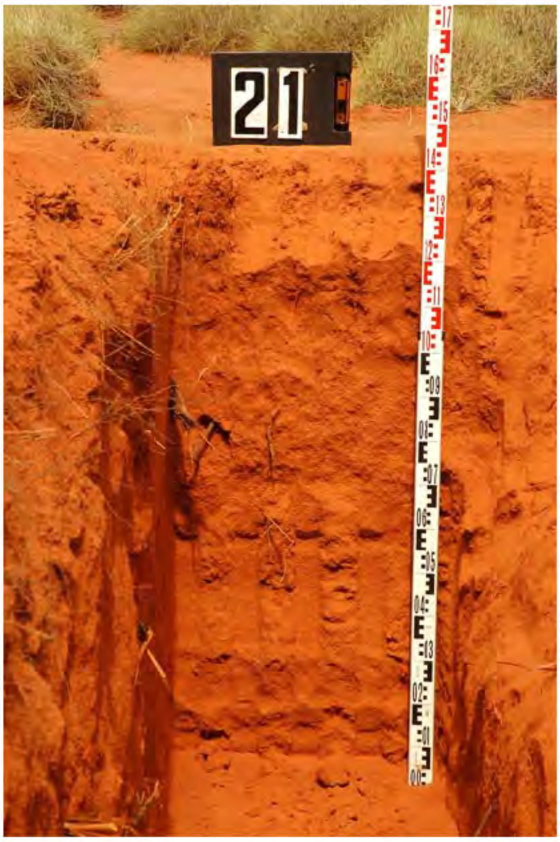


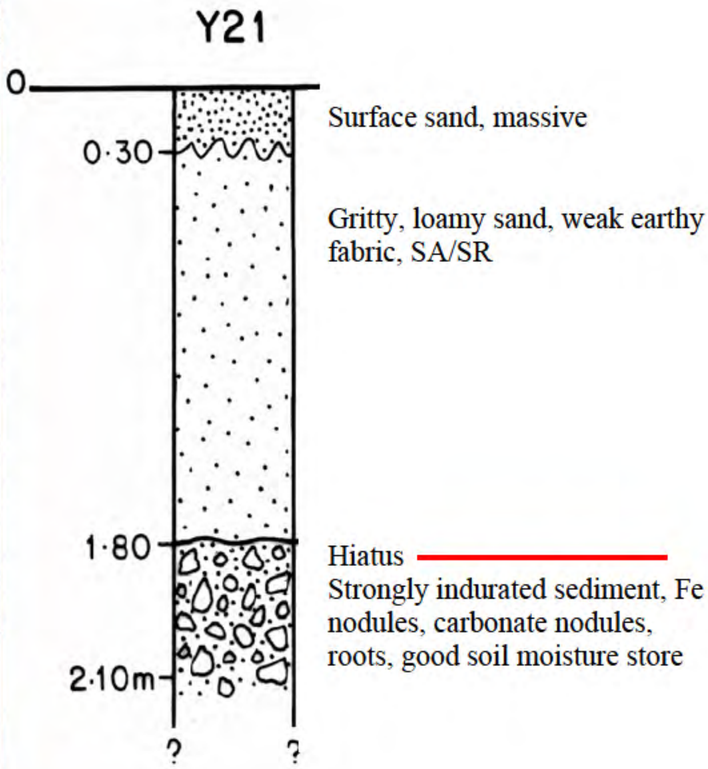
Site Y20 Vegetation:

Triodia basedowii hummock grassland with *Acacia effusifolia* scattered shrubs and *Eucalyptus kingsmillii* mallee (SAMA community).
[Rebecca Graham].

SITE Y21 Sand Plain System

6999397 N
0782904 E



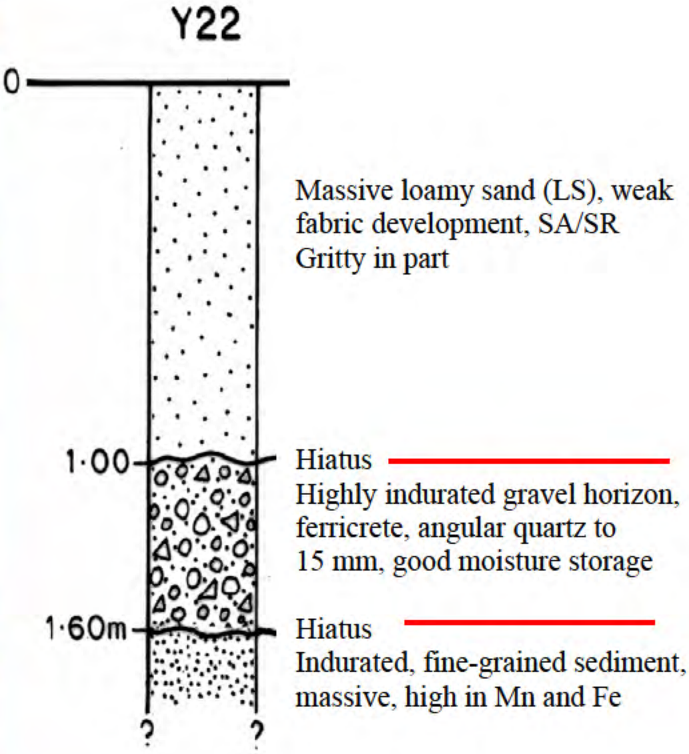


Site Y21 Vegetation:

Triodia basedowii hummock grassland with *Acacia effusifolia* open shrubland and *Eucalyptus kingsmillii* scattered mallee (SAMA community).
[Rebecca Graham].

SITE Y22 Sand Plain System

6998000 N
0782875 E

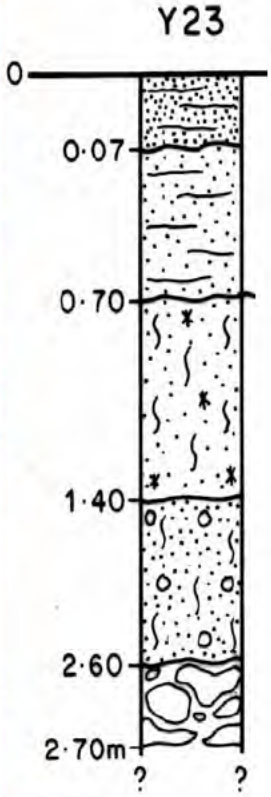


Site Y22 Vegetation:

Triodia basedowii hummock grassland with *Acacia effusifolia* tall shrubland (SAWS community). [Rebecca Graham].

SITE Y23 Playa System

6996234 N
0782862 E



Surface of massive, platy sandy loam

Massive & indurated, ferruginous loamy sand, Mn in fractures

Hiatus

Massive silty clay loam (SiCL), abundant $CaSO_4$ in massive and crystalline forms

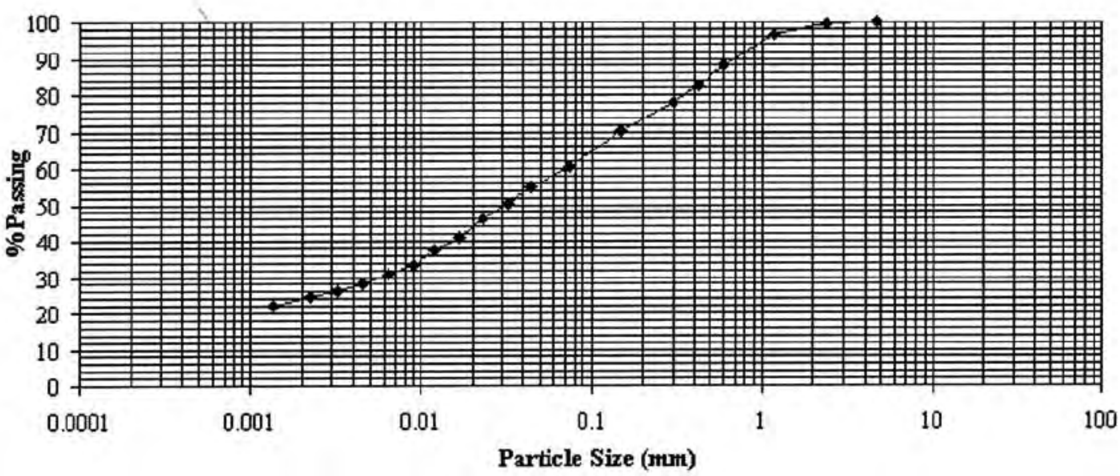
Hiatus

Indurated ferruginous sediment, scattered nodules of $CaSO_4$

Calcrete with $CaSO_4$ coating and nodules
Refusal at 2.7 m

Summary:
Sample depth 1.0 mbgl

Massive silty clay (22% Clay, 34% Silt): strongly alkaline (pH 8.4): saline (EC 370mS/m): extremely low organic carbon (0.09%): deficient in P-Zn.
Boron at toxic levels (>100 mg/kg).



Site Y23 Vegetation:

Unvegetated playa with fringing vegetation of *Acacia ayersiana*, *A. aneura* and *Melaleuca interioris* tall shrubland (PLAMI community).
[Rebecca Graham]

SITE Y24-OH Calcrete System

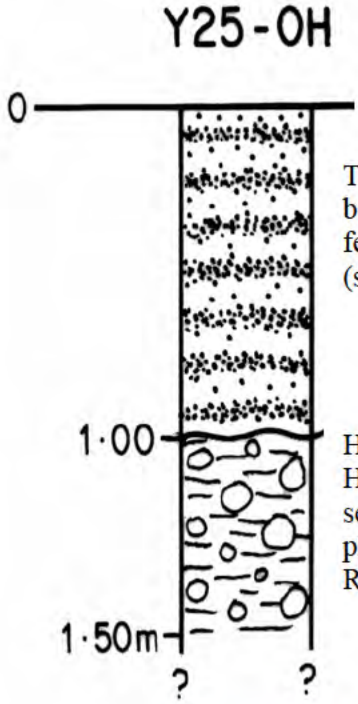
6995577 N
0782824 E

Site Y24 is an observation hole within the Calcrete System. It comprises a surface of 10 cm of a massive, carbonate rich, Lfsy over massive calcrete. The surface is characterised by a calcium carbonate lag gravel forming a discontinuous fabric.

SITE Y25 Playa System

6994078 N
0782795 E

Site Y25 is a scald area within the Playa System.



The surface 1.0 m is a strongly banded, highly indurated sediment, ferruginised, and with abundant Mn (see image below)

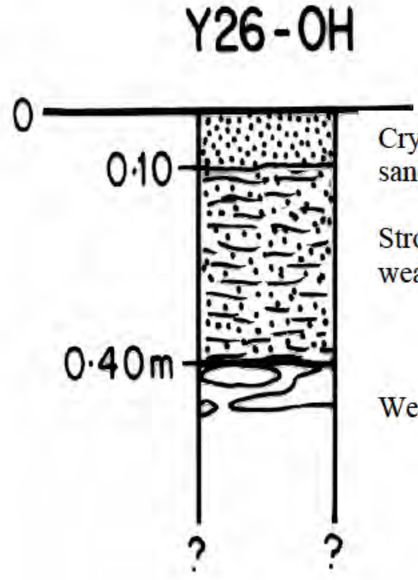
Hiatus

Highly laminated, platy, indurated sediment, $CaCO_3$ coating on particles plus carbonate nodules
Refusal at 1.5 mbgl

The surface at this site comprises very strongly indurated sediment, which is 1.0 m thick. The material behaves more as a weak rock than sediment. The fracture patterns along crude bedding planes are enhanced by removal from the profile. This zone is carbonate free, and profile characteristics suggests that this horizon was above groundwater penetration.

SITE Y26 Sand Plain System

6989450 N
0782751 E



Cryptogammic surface, thin veneer of massive sand over

Strongly indurated sediment (highly weathered ? granite) over

Weathered granite, competent

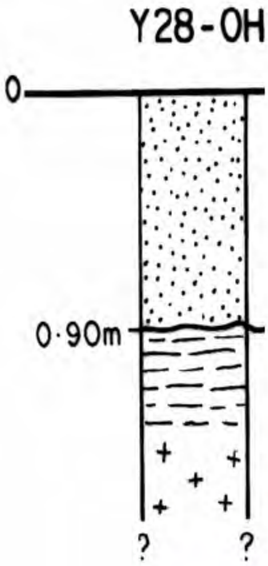
SITE Y27 Sand Plain System

6990783 N
0782743 E

Site Y27 is an observation hole comprising a massive, gritty, loamy sand SA/SR to 1.2 m, overlying a mottled sandy loam, massive, weak fabric development, roots at 1.3 mbgl,
overlying weathering granite at 1.5 mbgl.

SITE Y28 Sand Plain System

6989190 N
0784595 E



Massive loamy sand, fabric development, indurated, hard and competent, ferruginous, Mn present, $CaCO_3$ present as a coating and infill in veins, over

Hiatus

Earthy pan, with Fe and Mn, $CaCO_3$'s impeding layer, but good source of soil moisture. Penetration of roots (see image below)

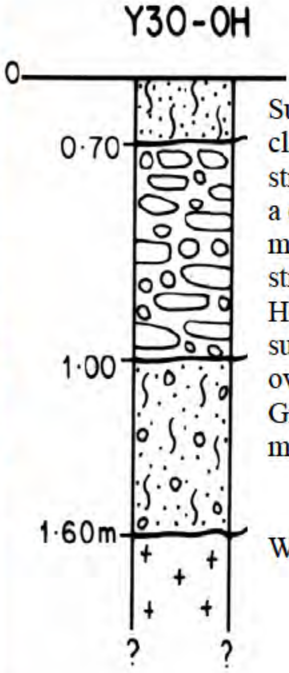
Plant roots penetrating the earthy hard pan at a depth of 0.9 m below the surface. This pan is an impeding layer but is also an excellent soil moisture store and was quite wet when first exposed. The pan contains well rounded quartz grains and is well indurated.

SITE Y29 Sand Plain System
6989448 N
0787032 E

Site Y29 is also an observation hole and is identical to Site Y28 above.

SITE Y30 Calcrete System

6990566 N
0787032 E



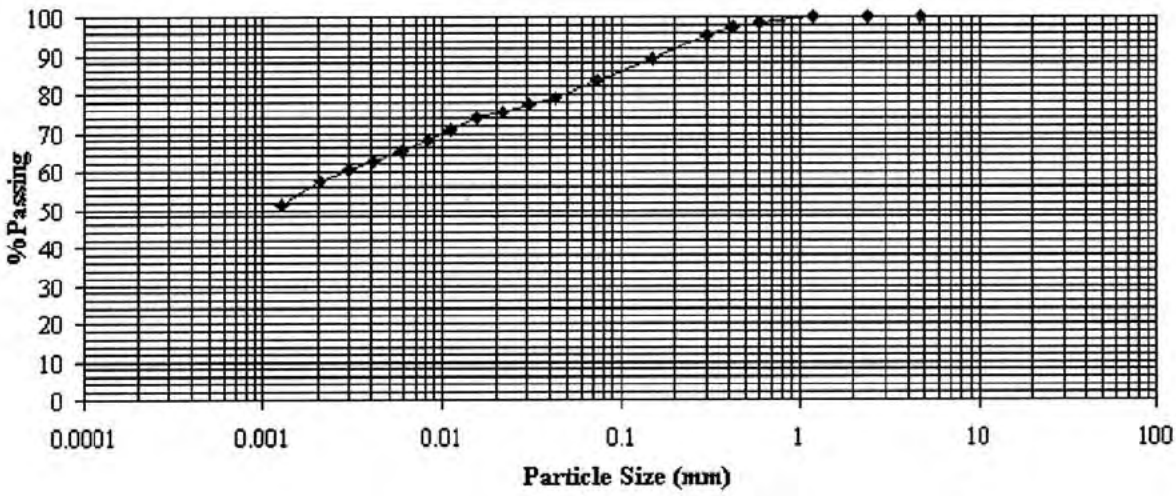
Surface of light to medium clay, very strong pedality with strong reaction to HCL, over a carbonate dominated light medium clay, nodular structure, weak reaction to HCL, (suggests calcium sulphate may also be present), over
Gritty, to 2 mm, sandy clay, massive, over

Weathering granite

Summary:

Depth of sample 0-0.2 m

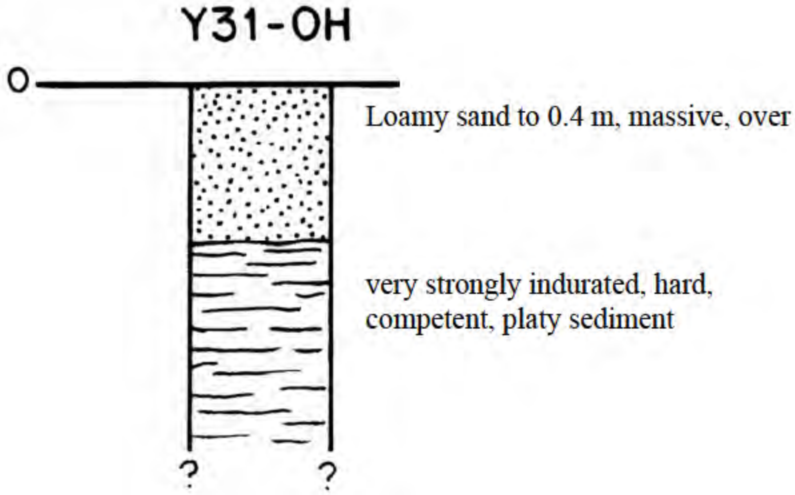
Strongly pedal light-medium clay (58%<2μm): moderately alkaline (pH 8.0): calcareous, low organic carbon (0.23%): deficient in P-Zn.
Boron at toxic levels (17 mg/kg).



SITE Y31 Sand Plain System

Observation Hole

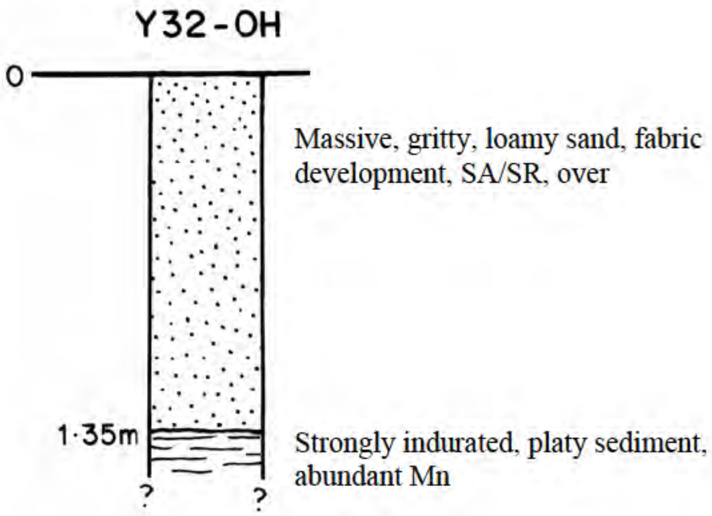
6988143 N
0789741 E



SITE Y32 Sand Plain System

Observation Hole

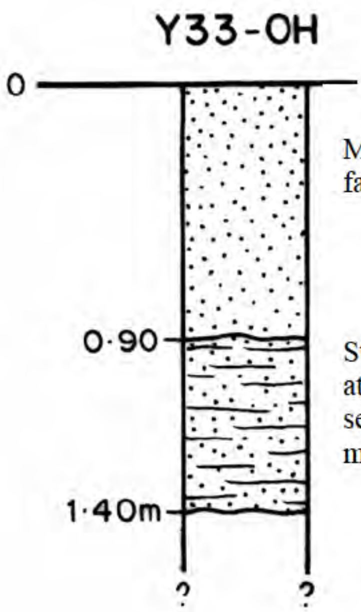
6987373 N
0790076 E



SITE Y33 Sand Plain System

Observation Hole

6985683 N
0790034 E



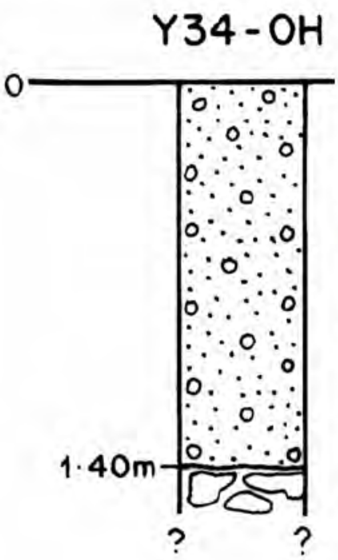
Massive, apedal, fine sandy loam, fabric development, over

Strongly indurated sediment, refusal at 1.4 mbgl in indurated, platy sediment with SA/SR quartz in fine matrix

SITE Y34 Sand Plain System

Observation Hole

6981906 N
0790034 E



A surface of mobile sand over a hard setting sandy loam (SL), indurated, fabric development

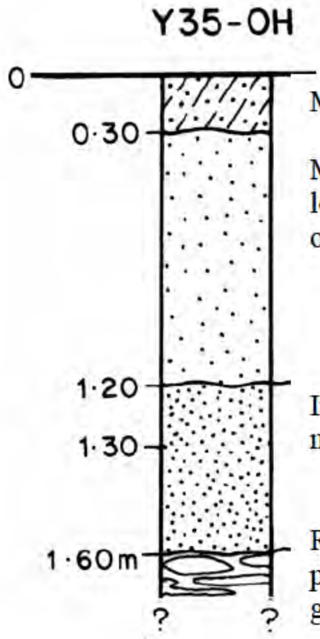
pseudo ferricrete nodules, gravels throughout the profile, over

Weathering (?) granite, good moisture retention

SITE Y35 Sand Plain System

Observation Hole

6990450 N
0795557 E



Mobile surface sand, massive, over

Massive, fabric development, sandy loam to loamy sand, SA/SR, over

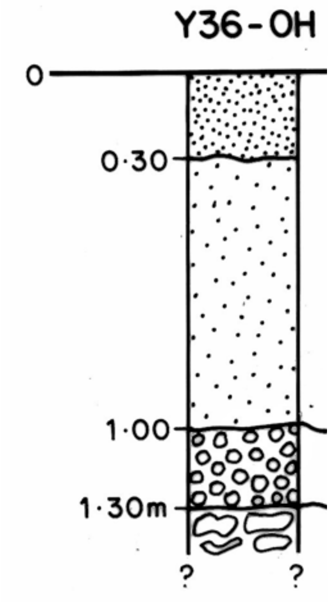
Indurated, fine sandy loam (FSL), massive, hard, Mn present, over

Refusal in platy, indurated, massive weathering (?) granite

SITE Y36 Sand Plain System

Observation Hole

6988402 N
0795538 E



Highly mobile surface sand, M/C, massive, over

Massive loamy sand, fabric development

Hiatus

Pseudo ferricrete gravels, nodules, and pisolites

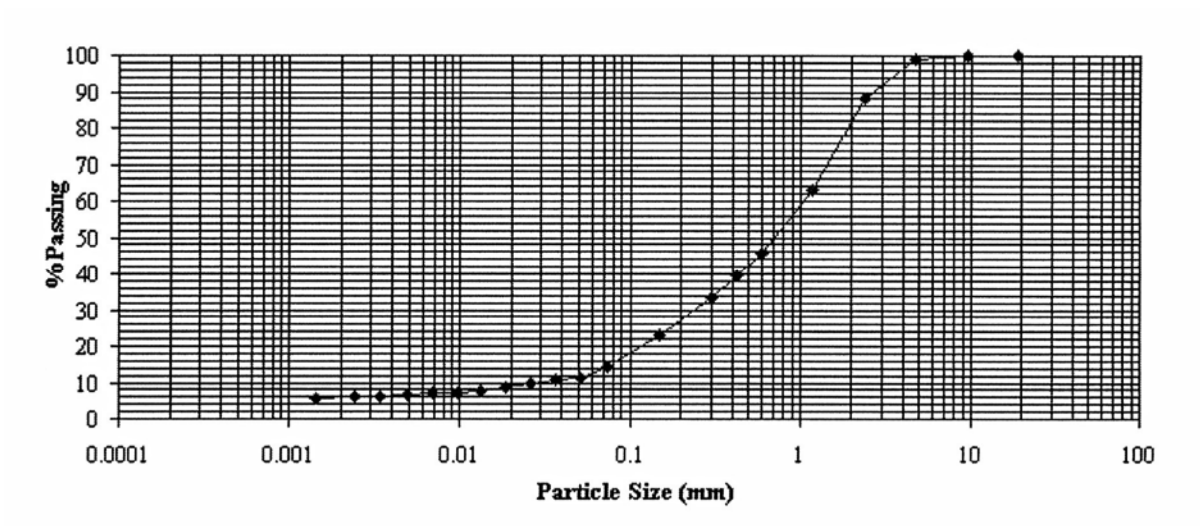
Hiatus

Refusal in highly indurated sediment

Summary:

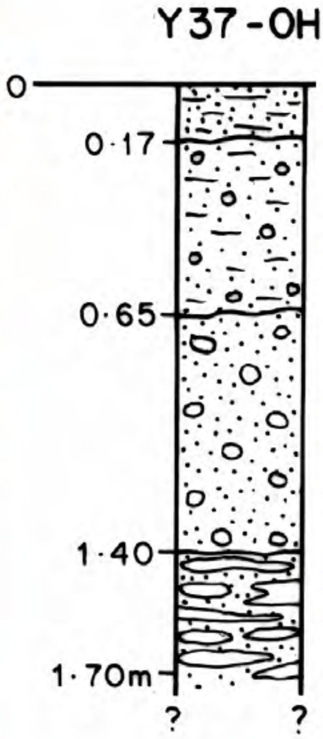
Depth of sample 1.0 m

Massive loamy sand (6%<2µm): slightly acid (pH6.4): non-saline: non-sodic low organic carbon (0.11%): deficient in P.



SITE Y37 Playa System

6986232 N
0795496 E



Platy Lfsy, dispersion causing surface sealing, over

Strongly indurated, massive, calcareous sediment, platy, and strongly nodular, over

Strongly calcareous, nodules of carbonate, hard, massive, in a fine grained matrix, over

Platy calcrete but is sediment recemented with calcium sulphate, with framboidal carbonates

Site Y37 Vegetation:

Unvegetated playa with fringing vegetation of *Acacia ayersiana*, *A. aneura* and *Melaleuca interioris* tall shrubland (PLAMI community).
[Rebecca Graham].

SITE Y38 Sand Plain System

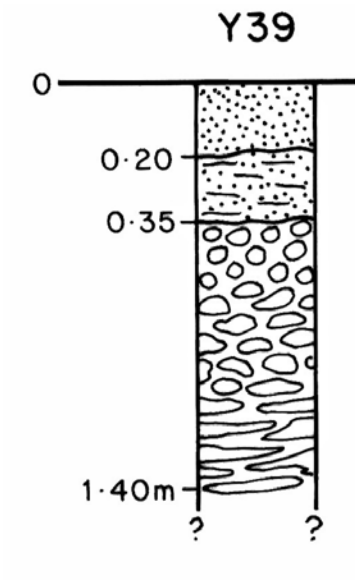
Site 38 is an observation Hole

6982062 N
0806272 E

The profile comprises 400 mm of massive Lfsy over an indurated earthy pan, very strongly cemented.

SITE Y39 Sand Plain System

6982458 N
0806272 E

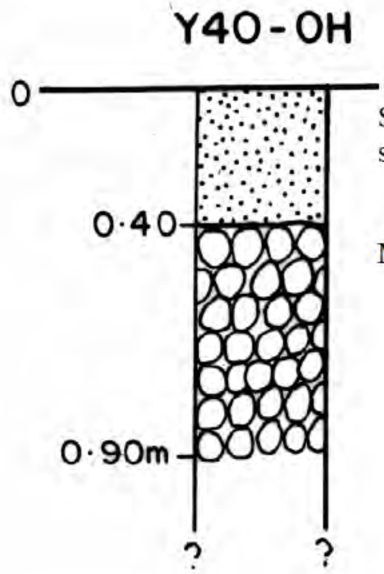


Platy surface, loamy sand, A/R, massive, over
Strongly indurated sediment, roots, carbonate present as coating on A/R sediment, massive,
good moisture retention, over

Indurated sediment, strongly calcareous, zone, platy, massive, with abundant Mn

SITE Y40 Sand Plain System

6982991 N
0805671 E



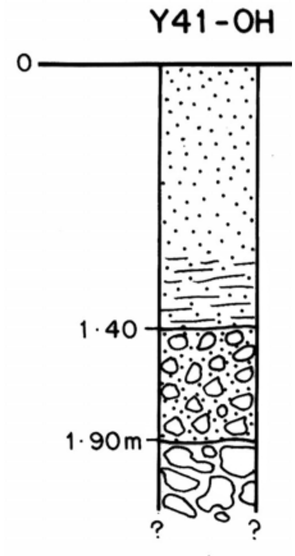
Surface of massive, SA/SR, loamy sand, over

Massive and globular calcrete

SITE Y41 Sand Plain System

Site Y41 is an Observation Hole

6983850 N
0804245 E



Massive sandy loam, with scattered particles to 4mm, gritty, SA/SR, major root zone to 0.4 m, induration increasing to 1.4 mbgl

Gritty indurated sediment, massive, over

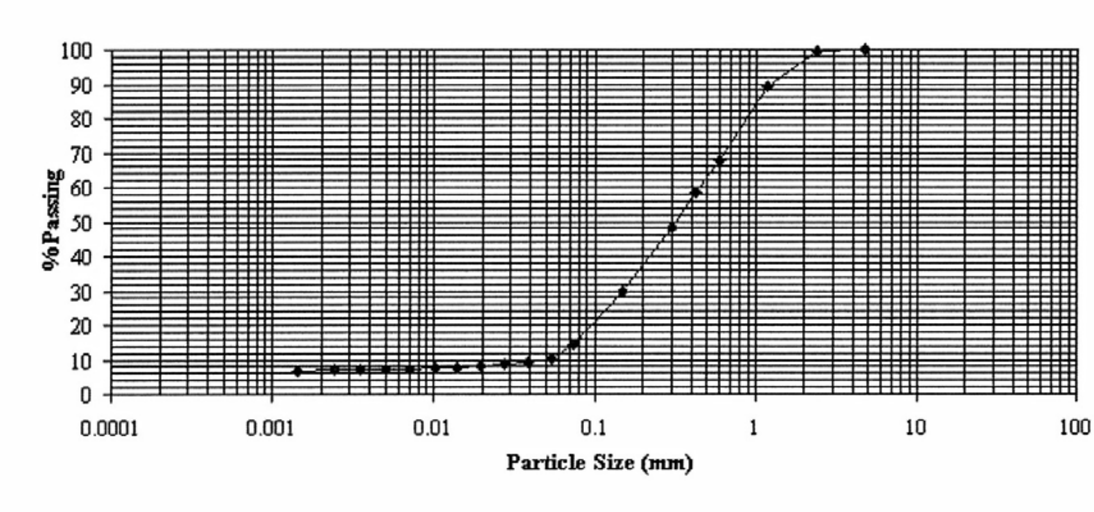
Pseudo ferricrete gravels in a gritty loamy sand matrix, over

Indurated sediment, strongly calcareous, with carbonate globules and nodules, coarse grained, some disseminated CO_3's

Summary:

Sample depth 0.3-0.4 m

Massive, gritty, loamy sand (6%<2μm): slightly acid (pH 5.7): non-saline: non-sodic extremely low organic carbon (0.08%): deficient in P-Zn.



Site Y41 Vegetation:

Triodia basedowii hummock grassland with *Hakea lorea* subsp. *lorea* scattered tall shrubs over *Acacia effusifolia* low open shrubland (SAWS community).
[Rebecca Graham].

6.0 RESULTS & DISCUSSION

6.1 INTRODUCTION

The soils within the study area are complex, in both their profile stratigraphy and in their material characteristics within profiles. Such complexity is born of soils and soil landscapes evolving over tens of thousands of years, during which, landscapes were subject to changing weather patterns and changing climates. Field evidence indicates periods of intense pluvial activity and periods of prolonged aridity.

The presence of pans, secondary precipitation of carbonates and sulphates, and the degree of competence and induration of many of the soil materials, is evidence of long periods of geomorphic stability in the physical environment. Isolated occurrences of high ranking smectite clays, within the Calcrete System, also infers that these clays are remnants of a back swamp/lagoonal environment that involved deposition of clay size sediment under a low energy palaeo environment.

Forty one profiles were examined within the study area. Of these, 35 profiles exhibit different stratigraphic, textural, and structural characteristics. This means that at least 35 soil profiles have differing soil moisture regimes and accordingly will have differing tolerances and responses to soil moisture related stress. These differing profiles will reflect, in part, changes in vegetation at varying scales in space. Some locations within the study area contain soil profiles containing up to seven definable soil horizons, where the horizons are stratigraphic rather than pedologic.

Of the 41 profiles examined in detail, 25 (60.9 per cent) exhibited a hiatus (break in the record). The evidence for the presence of a palaeo surface is compelling as the boundary between adjacent horizons is abrupt, with no sign of pedogenesis taking place. Further, the abrupt boundary is often between two materials, one of which was deposited under a high energy environment, such as a well sorted gravel deposit below a sand horizon. Both of these materials have very different detachment and transport thresholds in terms of their component particle size. This break in the record adds to the complexity of the profile system and its ability to store and transport soil water within the soil-vegetation system. Many of the soils contain a well developed fabric indicating that they have good soil moisture retention capabilities in the pre-disturbance condition.

As would be expected in the Yeelirrie environment, the chemical fertility of the soils is poor, and at best, physical fertility of all the soils is fragile in that the fundamental material making up most of the upper profile is a sand that, over the years, has become indurated (hardened), a process that has been aided by the breakdown of ancient lateritic debris and younger secondary ferricrete, forming iron oxides that have acted as cementing agents in the various sediments present.

In the undisturbed state, these indurated materials have good soil water retention capabilities and many sites have plant roots extending to depths of several metres below the surface.

Transect A (Figure 5), at the north-western end of the study area provides an ordered sequence of erosion-deposition episodes, reflected in a high degree of stratigraphic continuity along the transect, which covers a distance of seven kilometres. Ferricrete, present as either gravels or as massive, recemented material, is dominant in all but one of the sites along this transect. Saprolitic and unweathered granites are very close to the surface in three of the sites. The term granite is used loosely here as the Archaean basement in this area comprises a range of lithologies, and the term granitoids is more appropriate. Overall, ferricrete, occurring as gravel or as massive forms, is present in 41 per cent of sites inspected.

Further downstream, towards the south-east, the profiles exposed along Transect B (Figure 6), display a less ordered sequence of erosion-deposition episodes. While stratigraphic continuity can be recognised, the presence of the calcrete mass in the central valley, and its influence on the characteristics of the Playa System through modification of surface hydrology, becomes apparent. Downstream from Transect B, and within the limits of this survey, there is little stratigraphic continuity in profile morphology, indicating a complex association developed over a long period of time, and overprinted by climatic change.

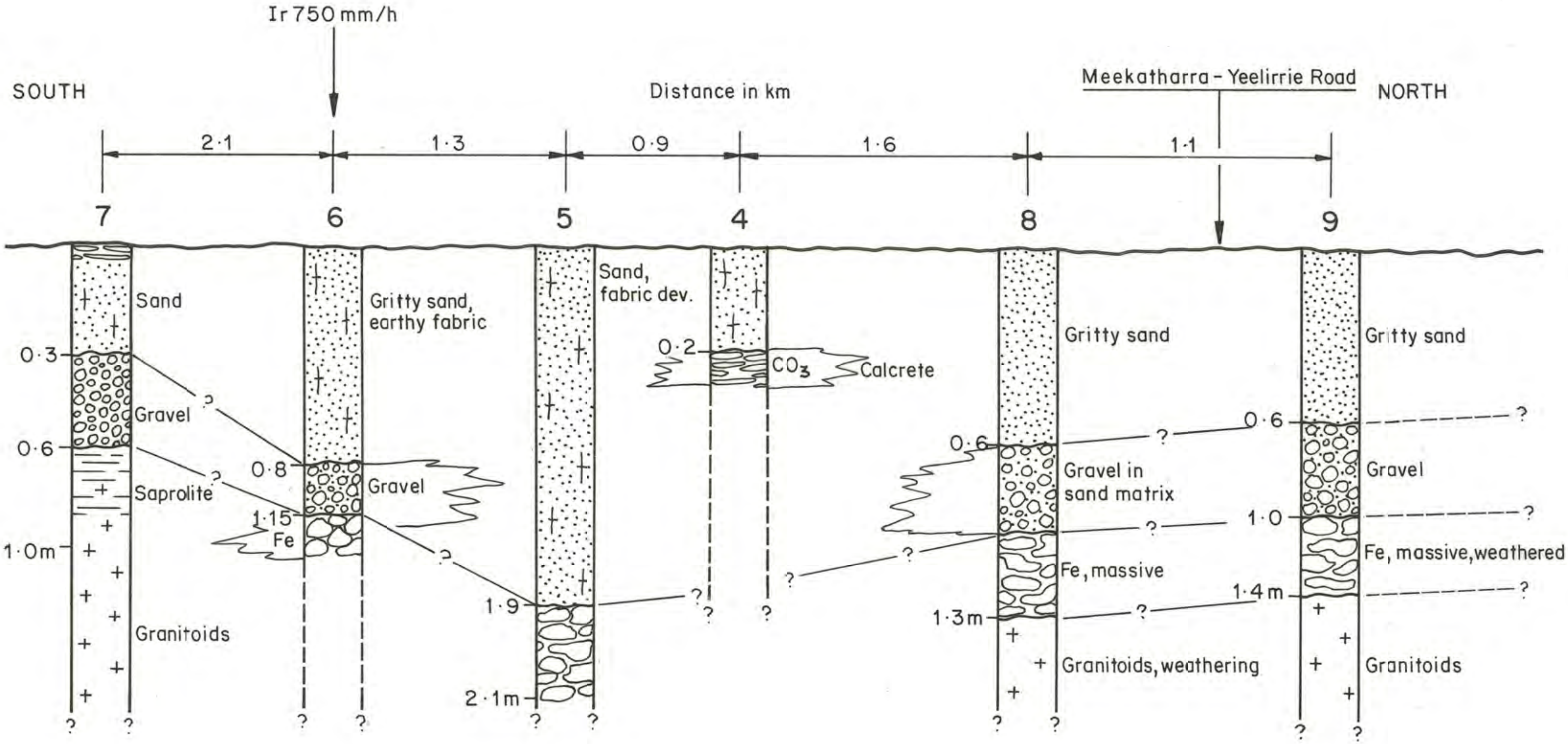
Complexity of landscape development is well illustrated by reference to Figure 4 showing the location of soil inspection sites in relation to soil landscapes expressed as a surface feature. At the south-eastern end of the study area, sites 38 to 41 parallel the long axis of the trunk valley and are outside the Playa System. However, sites 40 and 41 overlie calcrete, in various forms and at differing depths below the surface, 0.4 m and 1.4 m respectively. Site Y38 gave refusal at 0.4 m bgl at an indurated earthy pan. This pan was non-calcareous but it is possible that it overlies deeper calcrete materials. The field evidence suggests that Site Y38 was originally part of a more extensive Playa System and prolonged periods of aridity have resulted in deposition of sands, in the broadest sense, on-lapping the more extensive palaeo Playa System. On the southern side of the central valley, opposite Site Y41 at Site Y34, the profile is dominated by 1.4 m of indurated loamy sand with abundant pseudo ferricrete nodules to 32 mm wide and 50 mm long. This horizon overlies a very dark, highly weathered (?) granite, although field identification was difficult. The issue here is that profile morphology at Site Y34 characterises a high energy environment, which has, due to continuing aridity, no visible links to profile morphology across the central drainage line.

The lack of stratigraphic continuity in study area soils and profile morphology is well illustrated in the example discussed above. The presence of pseudo ferricrete gravels, here termed ‘galls’ by this author, raises questions of genesis, and while it is tempting to speculate on the processes leading their formation, such digression is beyond the scope of this report. Gall characteristics are shown in Plates 14 to 16 below.

Plate 14: A ferricrete gall showing an external carapace of iron oxide cemented polymodal, polymictic sediment comprising angular to rounded lithic fragments. The carapace itself has developed a patina and the surface of the internal cavity also displays what appears to be a solution precipitation surface. In this image, the internal cavity, which is approximately 12 mm wide, is filled with ‘soil’ comprising angular to subrounded particles in a matrix of fine/medium sand.
(*Photography: D.C.Blandford*)

Plate 15: The moisture retention capabilities of ferricrete galls is evidenced by a concentration of fine roots penetrating the gall through what appears to be a common opening at one end and accessing the finer sediment within the gall.
(*Photography: D.C.Blandford*)

Plate 16: Standard gall morphology showing, in this example, a well developed ‘opening’ at one end and the nature of the coating on the walls of the internal cavity.
(*Photography: D.C.Blandford*)

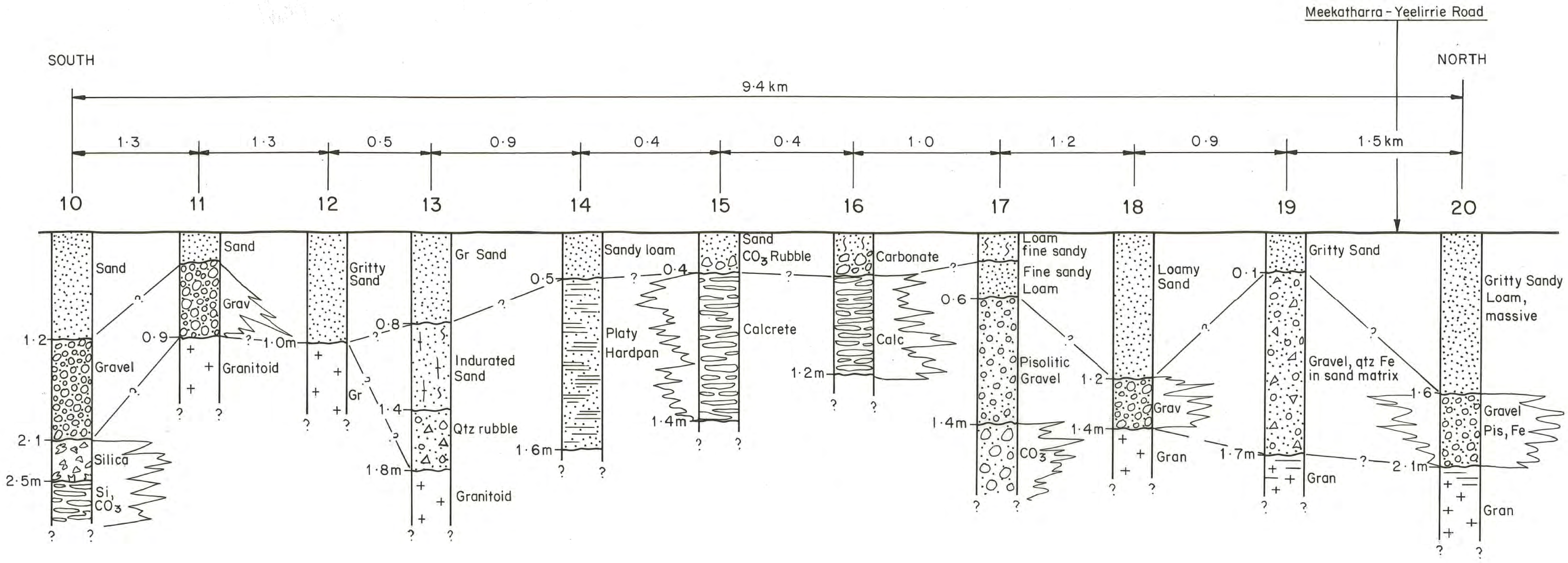


Note: Not to Scale

PROPOSED YEELIRRIE DEVELOPMENT

Figure 5
Transect A

Author: D. Blandford Date: December 2010



Note No to Sca e

PROPOSED YEEL RRIE DEVELOPMENT

F gure 6
Transect B

Au ho D Bla d o d Date D cembe 20 0

6.2 SOIL CHARACTERISTICS

6.2.1 Aggregate Stability and Dispersion

Dispersive soils are present within the study area. However, they are generally associated with the Playa System, and with scald areas at the interface of the Sand Plain and Playa Systems.

In simple terms, dispersion is the movement of clay from an aggregated state to one where the clays move freely into suspension. The ability of clays to disperse results from the cation exchange complex on the clays present being dominated by sodium ions (Na^+), allowing the clay component of the soil to move into suspension according to the chemistry of the percolating electrolyte. The Na^+ as an electrolyte (eg. Sodium chloride) will tend to cause flocculation while the sodium as an ion will result in dispersion. Over the years, there has been vigorous debate as to what actually constitutes a sodic soil. A soil is usually sodic if the sodium chloride is removed from the profile, that is, the Na^+ is present as an exchangeable cation in sufficient concentrations to cause dispersion. Popular terminology in Australia relates the exchangeable sodium percentage (ESP) of a soil to sodicity and a soil is said to be sodic if the ESP is 6 or greater. Northcote & Skene (1972) related this definition to the top metre of the soil profile. However, Richards (1954) defines a sodic soil as one having an ESP >15. This value is considered too high for Australian conditions given the widespread nature of dispersive A horizons in agricultural lands, a view supported by Loveday and Pyle (1973) on their work on dispersion and hydraulic conductivity.

In addition to the well-recognised impacts of clay dispersion on soil structure and consequent adverse effects on plant germination, rainfall infiltration, and surface erosion, when the ESP passes 15, soils are regarded as crossing the tunnelling susceptibility threshold. Tunnelling is a form of earthwork failure and is readily observed in poorly constructed farm dams and on waste dumps constructed of dispersive clays. Tunnelling itself is a very complex process and is dependent on variables such as clay content, soil density and moisture content, and characteristics of the electrolyte (see Rosewell, 1970). Ritchie (1963) set a limit of 30 per cent dispersion of the <5μm soil particles and soils with a dispersion percentage >30 are susceptible to tunnelling. These soils present major management issues for landform and soil profile reconstruction. This author agrees with these findings and the dispersion percentage, when used in conjunction with other parameters including ESP and clay content, provide definitive parameters for profile reconstruction. The process of dispersion induced tunnelling is insidious, is often occurring below the surface, and may not be apparent until slope failure occurs in the form of exposure of extensive tunnel networks through massive gully development.

The above discussion relates to spontaneous dispersion and such dispersion is a function of soil aggregates with an aggregate stability class of 1 or 2 (Emerson, 1967).

However, the input of energy to soil aggregates not displaying spontaneous dispersion may result in aggregate breakdown and subsequent dispersion. Such energy inputs can be provided by the removal, transport, and replacement of soil material by mining or earth moving machinery, or by the kinetic energy of raindrop impact. Such a process, defined here as post-compaction deflocculation (PCD), was investigated by Aitchison *et al.* (1963) in relation to the failure of earth dams. While post compaction deflocculation results in aggregate stability moving from a semi-stable condition to a dispersive state, clay dispersion, and the associated impacts, may not be manifest for some time after energy has been applied. Further, the material dispersing may be below the surface soil and so the development of tunnels, or the development of zones of reduced permeability may not be readily apparent. Dispersion due to post compaction deflocculation in surface soils from a playa within the Playa System is shown in Plate 17 below, with the surface of the playa shown in Plate 18.

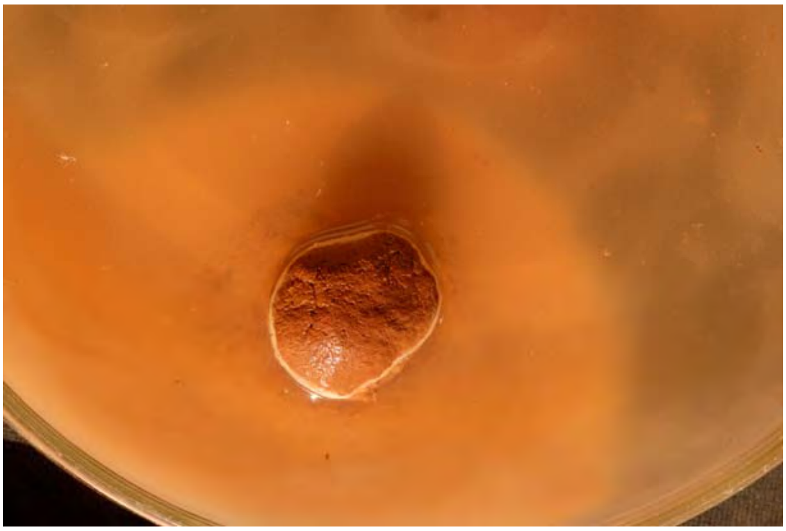


Plate 17: Post compaction deflocculation in surface soils at Site Y37.

Plate 18: The playa at Site Y37 showing the 'compacted' and hard surface, almost certainly due to post compaction deflocculation caused by the kinetic energy of raindrop impact on the bare playa surface.

When dispersion occurs at or near the surface, and the dispersed clays are allowed to dry *in situ*, they will set hard. This hard, fine-grained layer will result in differential permeability. Vertical permeability will be greatly reduced resulting in increased horizontal permeability or in water ponding at the depth of the dispersed clay layer. If dispersion occurs at the surface, accelerated runoff will occur due to decreased infiltration, and evaporation rates will increase, resulting in a reduction of effective rainfall. Because of these mechanisms, the Playa System has a complex surface, and near surface hydrology.

6.2.2 Surface Infiltration Rates

Surface infiltration rates were measured at two locations using a constant head infiltrometer. These were Site Y24 and Site Y6.

Site Y6, which is located along Transect A, gave an infiltration rate of 756 mm/hr. This rate is regarded as normal for a surface sand comprising 0.15 m of sand over 0.65 m of gritty sand.

Site Y24, which is a scald area within the Calcrete System, comprises a surface soil of loam, fine sandy, over massive calcrete. The surface texture of Lfsy is fine-grained and such a texture will result in decreased infiltration rates.

Elsewhere, a number of playas gave zero infiltration, due to dispersion of surface sediments, or due to the surface soils being an exhumed palaeo hardpan.

The range of surface infiltration rates from zero to 756 mm/h is considered normal, by this author, for the Yeelirrie environment.

6.2.3 Soil Chemistry

Soil Chemistry was investigated at nine sites to assess the trend in soil chemical status. A summary of the key parameters is given in Table 2 and the results are given in full in Appendix I.

TABLE 2

Summary of Key Parameters

Site (Y)	Depth [m]	pH	EC [mS/m]	TSS [% Salt]	Org C [%]	Soil Landscape
1	0.5	4.2	2.0	0.006	0.1	Sand Plain
2	0.95	4.7	1.0	0.003	0.08	Sand Plain
12	0.6	5.1	<1	<0.001	0.09	Sand Plain
13	0.8-1.5	5.3	11.0	0.035	0.08	Sand Plain
15	0.0-0.3	8.0	11.0	0.035	0.54	Calcrete System
23	1.0	8.4	370	1.184	0.09	Playa System
30	0.0-0.2	8.0	270	0.864	0.23	Calcrete System
36	1.0	6.4	11.0	0.035	0.11	Sand Plain
41	0.3-0.4	5.7	2.0	0.006	0.08	Sand Plain

7.0 BIBLIOGRAPHY

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8.0 GLOSSARY OF TECHNICAL TERMS

Aeolian:
Derived from the action of wind, including the detachment, transport and deposition of sediment and soils.

Calcareous:
Containing calcium carbonate ($CaCO_3$).

Calcrete:
A pan occurring at or below the surface of the soil, that is dominated by calcium carbonate, usually forming a hard, compact mass. Typically found in arid and semi-arid environments.

Carbonate:
In this document, the presence of calcium carbonate in a range of forms.

Dispersion:
The ability of clay to move into suspension due to the dominance of sodium ions on the exchange complex, and according to the electrolyte content of the water.

Duricrust:
A hard, erosion resistant material formed at the surface of the regolith and usually referred to by the dominant mineralogy, *eg*, a ferricrete duricrust.

Earthy fabric:
A term used to describe the fabric of a soil mass where single grains are not the dominant feature but the soil presents as a coherent mass, but with a non-metallic lustre from porous soil aggregates

Ferricrete:
Ferricrete is a term used for a collection of iron minerals that includes the more common iron oxides hematite, goethite, lepidocrocite, ferrihydrite, maghemite, and jarosite and which may occur in various combinations. The form taken by the ferricrete mass is dependent on its method of formation, and may range from massive forms with minimal structure but in which pisolitic influence is present, to secondary cementation of iron-rich erosion debris, pisolites, and quartz grains. Both forms of ferricrete are hard and erosion resistant materials and may occur on the surface or within the regolith.

Gilgai:
A term applied to a surface feature of soils where the type of clay present, *eg.* montmorillonite, results in high volume expansion and contraction, resulting in local micro-relief of up to 0.5metres.

Granitoid:
A term applied to igneous plutonic rocks that include the suite of minerals that typically occur in alkali-feldspar granite, granite, granodiorite, and tonalite.

Gypsum:
A mineral, calcium sulphate ($CaSO_4$) which is present in the Yeelirrie soils as crystals or as structureless masses.

Indurated:
Literally, hardened.

Kaolinitic:
Dominated by the kaolin group of clay minerals, typified by their 1:1 lattice and low shrink/swell characteristics.

Karst/karstic:
Pertaining to characteristic sink hole features, generally resulting from the development of solution cavities or differential weathering.

Light to Medium clay:
A soil texture under the Northcote system, defined by the resistance to shearing.

Lithology:
Literally, rock type.

Loamy sand:
A soil texture under the Northcote system..

Loam, fine sandy:
A soil texture under the Northcote soil classification system.

Massive:
Without obvious structural form, or without pedological development.

Palaeosols:
Ancient soils.

Pallid zone:
The upper zone of weathering in granite terrane where the development of the zone is often associated with prior lateritisation and deep weathering, and where the pallid zone is dominated by clays belonging to the kaolinite group. The pallid zone, which may extend to depths of many tens of metres, usually contains evidence of structural orientation in the parent rock material.

Patina:
A thin zone, measured in mm, of weathered material forming an outside skin on an existing surface. The patina is often lighter in colour due to oxidation of the component minerals present.

Pedestalling:
The development of a small structure (pedestal) formed when a rock fragment protects the underlying soil from raindrop impact, resulting, over time, in the erosion of soil around the fragment.

Pedologic:
Pertaining to processes within the soil profile.

Polymictic:
Comprising a range of different rock types or lithologies

Polymodal:
Comprising a range of different rock or particle sizes.

Playa:
Derived from the Spanish word for ‘beach’ and is used here to define a low lying depression, capable of holding water for extended periods of time due to restricted infiltration rates of the surface. The surface soils may be high in clays or may be the exposed remnants of an ancient profile where the surface now forms an indurated, highly stratified material, resistant to rainfall penetration, and accordingly to vegetation establishment. Playas occupy, and form, local topographic lows, usually lack surface outflow points, and generally have flat surfaces on which evaporation greatly exceeds meteoric input.

Quartz:
A mineral, silicon dioxide (SiO_2).

Reverse landscape:
A landscape where the current surface, was at one time, buried beneath younger sediments and has been exhumed by erosion of the younger sediment, often resulting in the older material being topographically higher than the surrounding soils.

Sandy clay:
A soil texture under the Northcote system of soil classification.

Saprolite, saprolitic:
The term applied to chemically weathered rock in which the original rock structure can still be identified. The saprolites present in the study area at Yeelirrie still contain typical granite characteristics.

Silica:
Literally, silicon dioxide (SiO_2). Occurs in the study area as quartz grains from the mechanical weathering of granitoid rocks and as irregular masses from precipitation of silica within the soil profile.

Smectites:
A family of clay minerals that includes clays with a 2:1 lattice structure such as montmorillonite. These clays are generally clays that demonstrate shrink/swell characteristics and typically crack when dry.

Well-rounded:
A term used to describe the 'sphericity' of a soil particle. Used as an indicator of abrasion due to transport by water.

9.0 APPENDIX

Soil Chemistry Data.

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Mark Matthews SGS Australia
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Report on 9 samples of soil: Yeelirrie Uranium Project

Received on 25/05/2009

CCWA	Client ID	Client Description
08A0646 / 001	09-MT-6342	09-MT-6342 Yeelirrie Y1 -0.5m
08A0646/002	09-MT-6343	09-MT-6343 Yeelirrie Y2-0.95m
08A0646/003	09-MT-6344	09-MT-6344 Yeelirrie Y12-0.6m
08A0646 / 004	09-MT-6345	09-MT-6345 Yeelirrie Y13 0.80-1.50m
08A0646/005	09-MT-6346	09-MT-6346 Yeelirrie Y15 0.0-0.30m
08A0646/006	09-MT-6347	09-MT-6347 Yeelirrie Y23-1.0m
08A0646/007	09-MT-6348	09-MT-6348 Yeelirrie Y30 0.0-0.20m
08A0646/008	09-MT-6349	09-MT-6349 Yeelirrie Y36-1.0m
08A0646 / 009	09-MT-6350	09-MT-6350 Yeelirrie Y41 0.3-0.4m

CCWA ID			001	002	003	004
Client ID			09-MT-6342	09-MT-6343	09-MT-6344	09-MT-6345
Analyte	**Method**	**Unit**				
EC	(1:5)	mS/m	2	1	<1	11
pH	(CaCl2)		4.2	4.7	5.1	5.3
OrgC	(W/B)	%	0.1	0.08	0.09	
	0.08					
B	(M3)	mg/kg	0.5	0.1	<0.1	0.6
Ca	(M3)	mg/kg	18	73	82	190
Cd	(M3)	mg/kg	<0.01	<0.01	<0.01	
	<0.01					
Co	(M3)	mg/kg	0.03	0.14	0.06	
	0.97					
Cu	(M3)	mg/kg	0.2	<0.1	<0.1	0.8
Fe	(M3)	mg/kg	16	9	10	14
K	(M3)	mg/kg	26	34	42	68
Mg	(M3)	mg/kg	<10	12	20	
	120					
Mn	(M3)	mg/kg	0.8	0.8	0.3	6.6
Mo	(M3)	mg/kg	<0.01	<0.01	<0.01	
	<0.01					
Na	(M3)	mg/kg	16	<1	1	18

Analyte	**Method**	**Unit**				
As	(M3)	mg/kg	<0.1	<0.1	<0.1	<0.1
Pb	(M3)	mg/kg	0.3	0.2	0.2	0.6
Se	(M3)	mg/kg	<0.1	0.1	<0.1	<0.1

CCWAID			005	006	007	008
Client ID			09-MT-6346	09-MT-6347	09-MT-6348	09-MT-6349
Analyte	**Method**	**Unit**				
EC	(1:5)	mS/m	11	370	270	11
pH	(CaCl2)		8	8.4	8	6.4
OrgC	(W/B)	%	0.54	0.09	0.23	0.11
B	(M3)	mg/kg	0.7	>100	17	1.6
Ca	(M3)	mg/kg	>5000	2300	>5000	280
Cd	(M3)	mg/kg	<0.01	<0.01	<0.01	<0.01
Co	(M3)	mg/kg	0.08	0.90	0.12	2.4
Cu	(M3)	mg/kg	0.2	0.4	0.3	0.7
Fe	(M3)	mg/kg	4	38	59	20
K	(M3)	mg/kg	240	>500	400	81
Mg	(M3)	mg/kg	380	890	>1000	140
Mn	(M3)	mg/kg	8.8	30	14	33
Mo	(M3)	mg/kg	<0.01	<0.01	<0.01	<0.01
Na	(M3)	mg/kg	13	>1000	84	3
Ni	(M3)	mg/kg	0.1	0.6	0.2	0.3
P	(M3)	mg/kg	12	2	10	<1
S	(M3)	mg/kg	17	>250	>250	66
Zn	(M3)	mg/kg	0.7	0.2	0.1	1.1
As	(M3)	mg/kg	0.1	0.1	0.5	<0.1
Pb	(M3)	mg/kg	0.2	1.7	1	0.8
Se	(M3)	mg/kg	0.2	0.2	0.1	<0.1

CCWA ID			009
Client ID			09-MT-6350
Analyte	**Method**	**Unit**	
EC	(1:5)	mS/m	2
pH	(CaCl2)		5.7
OrgC	(W/B)	%	0.08
B	(M3)	mg/kg	0.3
Ca	(M3)	mg/kg	180

Analyte	Method	Unit	
K	(M3)	mg/kg	52
Mg	(M3)	mg/kg	50
Mn	(M3)	mg/kg	11
Mo	(M3)	mg/kg	<0.01
Na	(M3)	mg/kg	1
Ni	(M3)	mg/kg	0.1
P	(M3)	mg/kg	<1
S	(M3)	mg/kg	5
Zn	(M3)	mg/kg	0.4
As	(M3)	mg/kg	<0.1
Pb	(M3)	mg/kg	0.5
Se	(M3)	mg/kg	0.2

Analyte	Method	Description
As	(M3)	Arsenic, As extracted by Mehlich No 3 - method S42
B	(M3)	Boron,B extracted by Mehlich No 3 - method S42
Ca	(M3)	Calcium,Ca extracted by Mehlich No 3 - method S42
Cd	(M3)	Cadmium,Cd extracted by Mehlich No 3 - method S42
Co	(M3)	Cobalt,Co extracted by Mehlich No 3 - method S42
Cu	(M3)	Copper.Cu extracted by Mehlich No 3 - method S42
EC	(1:5)	Electrical conductivity (1:5) at 25 deg C by method S02
Fe	(M3)	Iron, Fe extracted by Mehlich No 3 - method S42
K	(M3)	Potassium, K extracted by Mehlich No 3 - method S42
Mg	(M3)	Magnesium, Mg extracted by Mehlich No 3 - method S42
Mn	(M3)	Manganese, Mn extracted by Mehlich No 3 - method S42
Mo	(M3)	Molybdenum, Mo extracted by Mehlich No 3 - method S42
Na	(M3)	Sodium, Na extracted by Mehlich No 3 - method S42
Ni	(M3)	Nickel, Ni extracted by Mehlich No 3 - method S42
OrgC	(W/B)	Organic Carbon C, Walkley and Black method S09.
P	(M3)	Phosphorus, P extracted by Mehlich No 3 - method S42
Pb	(M3)	Lead, Pb extracted by Mehlich No 3 - method S42
pH	(CaCl2)	pH (1:5) in 0.01 M CaCl2 by method S03
S	(M3)	Sulphur, S extracted by Mehlich No 3 - method S42
Se	(M3)	Selenium, Se extracted by Mehlich No 3 - method S42
Zn	(M3)	Zinc, Zn extracted by Mehlich No 3 - method S42

The results apply only to samples as received. This report may only be reproduced in full.

Unless otherwise advised, the samples in this job will be disposed of after a holding period of 1 month from the report date shown below.

Multi-Element Soil Extraction Universal Extractants (Mehlich No.3)

The Mehlich No.3 Test is a alternate soil test using universal extractants for multi-elemental analysis. Results obtained using the Mehlich 3 extractant are highly correlated with the standard "single element" soil tests currently used for a wide range of Western Australian soil types. The test provides information on the amount of plant-available nutrients including phosphorus, potassium, sulphur, calcium, magnesium, sodium, boron, cobalt, copper, iron, manganese and zinc, in the soil. It is also capable of measuring concentrations of toxic metals such as cadmium and nickel

Peter McCafferty
Chief
Natural Resources Chemistry - 29/06/2009

08A646_001-009

Calculation of TSS fromEC Results

EC		**TSS**
Lab No	**(1:5)**	
mS/m		**%salt**
08A0646/001	2	0.006
08A0646/002	1	0.003
08A0646/003	<1	<0.001
08A0646/004	11	0.035
08A0646/005	11	0.035
08A0646/006	370	1.184
08A0646/007	270	0.864
08A0646/008	11	0.035
08A0646/009	2	0.006

TSS (%salt) = EC x 0.0032

08A646_001-009

Calculation of Cation Exchange Properties from Mehlich-3 Results

Lab No	**Ca(M3)**	**Mg (M3)**	**Na (M3)**	**K (M3)**
mg/kg		mg/kg	mg/kg	mg/kg
08A0646/001	18	0	16	26
08A0646/002	73	12	0	34
08A0646/003	82	20	1	42
08A0646/004	190	120	18	68
08A0646/005	**Calcareous**			
08A0646/006	**Saline**			
08A0646/007	**Calcareous**			
08A0646/008	280	140	3	81
08A0646/009	180	50	1	52

Lab No	**Ca (M3)**	**Mg (exch)**	**Na (exch)**	**K (exch)**	**Sum**	**ESP**
08A0646/001	O09	0.00	0.07	0.07	O2	30.8
08A0646/002	0.36	0.10	0.00	0.09	0.6	n/a
08A0646/003	0.41	0.16	0.00	0.11	0.7	0.6
08A0646/004	0.95	0.99	0.08	0.17	2.2	3.6
08A0646/005	**Calcareous**					
08A0646/006	**Saline**					
08A0646/007	**Calcareous**					
08A0646/008	1.40	1.15	0.01	0.21	2.8	0.5
08A0646/009	0.90	0.41	0.00	0.13	1.4	0.3

Provided the soil samples are non-saline and either moderately acidic to neutral, cation exchange properties can be calculated from results for Ca, Mg, Na and K measured by the Mehlich-3 procedure.

The sum of the concentrations of the basic cations provides a reasonable estimate of the Effective Cation Exchange Capacity (ECEC). The ratio of the calculated concentration of exchangeable sodium to ECEC is a measure of the Exchangeable Sodium Percentage (ESP).