# WALLABY ENVIRONMENTAL REVIEW

## THE SOILS AND LANDFORMS
## OF THE WALLABY PROJECT AREA

Prepared for

Placer (Granny Smith) Pty Limited

by

**D. C. Blandford & Associates Pty Ltd**
**ACN 009 402 706**

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# 1.0 EXECUTIVE SUMMARY AND RECOMMENDATIONS

## EXECUTIVE SUMMARY

The Wallaby Project Area lies in the Eastern Goldfields Province of the Yilgarn Block within the Western Shield, a major but general morphotectonic-geological division of Western Australia.

The landforms of the Project Area are dominated by four major groups including erosional remnants of the Archaean Yilgarn Plateau, colluvial outwash plains, dune fields, and playa/salt pan drainage systems associated, in part, with the Lake Carey palaeoriver.

The term 'pan' (salt pan) is applied to all small basins (nominally <100 m across), that are generally devoid of vegetation, with or without a salt crust on the surface, that occur within the Project Area and that have clearly defined boundaries to the level surface of the pan. The term playa is confined to the Lake Carey system and is defined here as a fluvio-lacustrine endoreic basin, comprising shallow groundwater, surface features that are shaped by both aeolian and fluvial processes, and a significant depth of sediments including evaporites and material of fluvio-alluvial origin, through which protrude erosion remnants of Archaean age forming islands within the playa sediment. The Lake Carey playa has a local catchment area of 5,020 $km^2$ and a surface area of 884 $km^2$.

The playa surface contains local depressions, which vary in area up to several square kilometres, islands, sand banks, and saline flats.

In the northern areas of the playa, erosion remnants (Archaean) are present on Kevin Island East and West where they form low rounded hills. Elsewhere, there is a complex network of ridges (erosion remnants) that now tend to form the 'backbone' of many of the islands.

The soils of the outwash plains, which are characterised by great variability in depth, texture, and structure, are generally classified as Gradational Soils (Gn1.13, Gn2.13) and are characterised by an increase in clay content with depth. Uniform textured soils also occur as major profile forms. As a general rule, the surface soils are sandy in nature and range in textural grades from sand through loamy sand, fine sandy loams to loam, fine sandy.

The soils of the hills and ranges are dominated by shallow skeletal soils (Uc1.23, Um1.43) and are classified as lithosols.

The soils of the dune fields are typically moderately acid siliceous sands (Uc1.23).

The soils (sediments) of the Lake Carey playa are dominated by sediment in the size range clays to coarse silt/fine sand. At a depth of 30 cm below the surface, clays and silts make up approximately 80% of particle size.

Clay pan soils are a very diverse group of soils as both texture and structure are a function of pedologic prehistory as well as contemporary pedo-geomorphic processes. The soils are typically fine textured, moderately alkaline (pH 8.5), and non-calcareous.

Although the soils of the Wallaby Project Area are complex in both texture and structural form, making it difficult to predict the behaviour of specific soil material, the soils of the Wallaby Project Area are a potential resource for use in environmental management. What is important is that the constraints of particular soils are understood and that soil material is not used beyond its capability.

The term topsoil should be abandoned in favour of using the term 'surface soil' where field evidence suggests that up to 0.5 m of soil material is available for use in environmental management programmes such as rehabilitation of structural outslopes.

The soils of the Wallaby Project Area are highly erodible. The sandy and earthy fabrics of the soil mass, the poor coherence of the soil in the moist state, the particle size distribution generally dominated by material in the silt/sand range, and in some areas the presence of well-sorted sands, means that detachment thresholds and maximum non-scour velocities are in the range of 0.15 to 0.3 m/s. The presence of dispersible clays within the soil material also increases the erodibility of a given soil by several orders of magnitude.

Many of the soils are strongly flocculated. Soils with this characteristic tend to behave as a fine gravel or coarse sand, and so soils that are highly flocculated can also be highly erodible As a general rule, the surface soils of the Wallaby Project Area are non-saline, however, there is a potential increase in salinity with depth with ranges from 150 mg/kg at a depth of 10 cm to 15,000 mg/kg at a depth of 65 cm.

## RECOMMENDATIONS

The soils of the Wallaby Project Area exhibit a high degree of variability in soil profile characteristics. This variability is in keeping with the polygenetic nature of the soils.

No specific soil landscape is recommended for use in rehabilitation programmes as there is variability within soil groups both spatially across the area, vertically in terms of soil chemistry, and vertically in terms of soil texture.

The soils of the Wallaby Project Area should be defined in terms of a 'resource' for the Wallaby Project and the term 'surface soil' used to identify soils that have a potential role in Project environmental management.

Once the specific infrastructural requirements have been determined, it is recommended that the value of the underlying soils be determined, in the first instance, on the characteristics identified in this report, and then with a follow-up re-assessment of specific soils if they are found to differ from the predicted behaviour.

Of particular concern is the presence of sodium-dominated clays within an overall profile form that contains strongly flocculated clays. These two end-points of aggregate stability require different management techniques and their joint use in rehabilitation programmes will cause conflict in programme results. It is strongly recommended that particular attention be given to aggregate stability of the soils proposed for use in the rehabilitation programme, particularly when selecting soil material for use on the outslopes of waste rock dumps, tailing storage facilities, or other works requiring the application of a growth medium.

The particle size distribution data generated during this investigation indicate that the surface soils, which are dominated by the sand fraction of textures, may be usefully graded with the primary conglomerate waste to develop an outslope material that is able to form the functions of a seed bed while resisting the kinetic energy of raindrop impact and overland flow. The determination of such a course of action (mixing material types) can only be made when the nature of the conglomerate waste is confirmed following blasting and dumping.

The highly flocculated nature of Project Area soils, and the dominance of the sand–size fraction, indicates that the soils will tend to 'break down' (texturally) with repeated handling. Once a soil has been identified for use in the rehabilitation programme, the handling of the material should be kept to a minimum so that the textural, and structural, integrity of the material is maintained.

# 2.0 INTRODUCTION

## 2.1 AIMS OF THE SURVEY

The primary aim of this soil and landform survey is to describe the physical framework of the Wallaby Project Area as defined by the soils present, their position in the landscape, the major landforms occurring, and the relationship of soil/landform associations with proposed Project infrastructure.

The secondary aim of the programme is to define the management requirements to maximise benefits from the use of soil resources, and to minimise potential impacts on Project Area soils.

A full soil survey (and consequent production of a soil map) of the Project Area has not been carried out. Rather the soils have been investigated and described in relation to their contribution to the physical framework, and accordingly the soils are defined as typical of component landforms and landscape position.

The physical characteristics of the soil types present are described so that management requirements can be developed. Soil chemistry has been investigated to a lesser degree but to the level necessary to define constraints and opportunities for management.

## 2.2 METHODS

A reconnaissance survey was carried out over the Project Area to define the range of soil types and landforms present. This preliminary survey was then followed by a series of traverses to identify surface features within broad landform groupings.

The preliminary surveys were then followed by a detailed sampling and identification programme that involved:

- identification of proposed Project infrastructural components and their location;
- identification of the landforms present;
- identification of soil types present;
- soil profile investigation by hand auger to a maximum depth of 0.7 m;
- soil sampling using a hand auger; and
- description of profiles exposed in pits and trenches excavated as part of the orebody drilling programme.

In addition to the soil investigation programme, landforms were defined using standard geomorphological description of form and process. Slopes were defined using an optical clinometer, and both Brunton and Prismatic compasses. The landforms of the Lake Carey playa were defined from air photo interpretation, stereoscopy, and limited helicopter survey.

Soil infiltration data were determined by the use of a constant-head infiltrometer at sites considered to be representative of Project Area soils.

# 3.0 LANDFORMS OF THE WALLABY PROJECT AREA

## 3.1 INTRODUCTION

The Wallaby Project Area lies in the Eastern Goldfields Province of the Yilgarn Block within the Western Shield, a major but general morphotectonic-geological division of Western Australia. Within this division, the Yilgarn Plateau forms a major geomorphologically complex unit. Project location is shown in Figure 1.

The landforms of the Project Area are dominated by four major groups:

- erosional remnants of the Archaean Yilgarn Plateau;
- colluvial outwash plains;
- dune fields; and
- playa/salt pan drainage systems associated, in part, with the Lake Carey palaeoriver.

Each of these groups comprises a number of discrete landforms which are described below.

## 3.2 TERRESTRIAL LANDFORMS

### 3.2.1 Erosional Remnants of The Yilgarn Plateau

The erosional remnants of the Yilgarn Plateau are typically low rounded hills or sharp ridgelines formed by erosion-resistant meta-sediments including banded-iron-formation. These later ridgelines are flanked by steep slopes grading from 40º in upper slope positions to 10º in lower slope positions before grading into the surrounding outwash plain. Within the immediate Project Area, relief rarely exceeds 15 m and such landforms are shown in Plate 1.

### 3.2.2 Colluvial Outwash Plains

As the name suggests, this is a group of landforms dominated by very low relief and is defined as a gently undulating to flat-lying plain with a low regional slope of 1.0 to 1.5% towards the Lake Carey playa. The surface comprises quite large areas of lag gravels which are often bi-modal and with a continuous fabric. These may grade into mono-modal lags with discontinuous fabrics. In other areas, lag gravels may be absent.

Where contemporary drainage systems cross the plain, these may be incised up to 0.6 m below the surface of the plain. These drainage systems tend to flood at bankfull stage rather than eroding further to form a deeper channel. The drainage patterns across the outwash plain are typically dendritic in the upper areas but become less distinct in the lower slope positions adjacent to Lake Carey (Plate 2).
In some locations, the surface is interrupted by very low relief (<5 m) mounds which are taken to be erosion remnants. The physical characteristics of the outwash plain in the immediate Project Area are shown in Plate 3.

### 3.2.3 Dune Fields

The sand dunes associated with the Wallaby Project Area occupy a strip of land fringing the Lake Carey playa and extending from west of the Wallaby orebody to a point west of Jubilee Well and approximately 20 km south-east of the proposed mine site. The dune system is generally less than one kilometre wide. Locally, relief is less than 5 m. The dunes are often not readily defined, however, as a general rule, the flanks of the dunes have slopes of 7% and crests are generally broad and flat or rounded. The characteristic landforms of the dune fields are shown in Plate 4.

### 3.2.4 Saline Flats

The saline flats of the Wallaby Project Area are typified by the *Halosarcia* dominated flats in the salinaland north-west of the Wallaby ore body and adjacent to the shoreline of the playa. Saline flats are, as the name indicates, level areas of land that may be bounded on all sides by other fringing landforms, such as dunes, or they may grade into adjacent surface features. It is possible that many of the saline flats adjacent to the Lake Carey playa have their origins in a retreat of a past higher water level on the playa surface and the upward movement of salts under the influence of evaporation. In areas adjacent to the Lake Carey playa, many saline flats display a secondary surface morphology that may include minor aeolian features including low-relief dunes of well-sorted sand, blowouts, and depending on location, a well-developed set of regression strand-lines.

The soils of saline flats, which are varied in both texture and structure, support a distinctive suite of halophytic vegetation (Plate 5).

### 3.2.5 Salt Pans

Salt pans are restricted in size and surface area (see 2.3.1 below), they do not generally support a distinctive suite of halophytes, and the surface is such that the habitat is hostile to fauna (Plate 6).

## 3.3 LANDFORMS OF THE LAKE CAREY PLAYA

### 3.3.1 Definitions

Before describing the geomorphic features of this group of landforms, it is appropriate to define the terminology used in this report in relation to the distinctive inland features of Western Australia generally referred to as 'Salt Lakes'.

The term 'pan' (salt pan) is applied to all small basins (nominally <100 m across), that are generally devoid of vegetation, with or without a salt crust on the surface, that occur within the Project Area and that have clearly defined boundaries to the level surface of the pan. The pans present in the Project Area are not defined by hydrologic process, rather by the geomorphic effects of wind and arid zone processes. Pans are often the recipients of surface runoff, and accordingly may have a complex surface hydrology-vegetation association. Pans are relegated to the terrestrial environment of the Wallaby Project Area.

The term playa is confined to the Lake Carey system and is defined here as a fluvio-lacustrine endoreic basin, comprising shallow groundwater, surface features that are shaped by both aeolian and fluvial processes, and a significant depth of sediments including evaporites and material of fluvio-alluvial origin, through which protrude erosion remnants of Archaean age forming islands within the playa sediment. Calcrete-capped evaporite remnants may also form limited and discrete surface features within the playa. The islands, which vary in size from less than one hectare to approximately 7 $km^2$ (Kevin Island East), contain assemblages of arid zone fauna and flora.

It can be argued that the Lake Carey playa is a large pan. However, the surface form of pans tends to be dictated by arid zone geomorphic processes which may, over time, bury the pan surface through aeolian deposition. The playa system is the contemporary remnant and surface expression of an ancient drainage system comprising alluvial and lacustrine features which have as their basis, prolonged periods of deposition under extremes of climatic variability. Contemporary aeolian processes, and runoff onto the playa surface now contribute to surface form through the addition and removal of sediment.

### 3.3.2 Prehistory of the Lake Carey Playa

The Lake Carey playa forms a contemporary remnant of the Carey Palaeoriver, an extensive palaeodrainage system that had its origins during the early Tertiary Period approximately 65 million years ago (BMR, 1990, van de Graaf *et al*. 1977). During this period, much of inland Western Australia comprised a vast network of active drainage systems that flowed in a south-easterly direction, discharging into a major delta system straddling the W.A.-S.A. border in what is now known as the Nullarbor Plain. During the Late Eocene to Early Oligocene Epoch (approximately 52-37 million years ago), a major marine transgression resulted in shallow seas developing in the south-east corner of Western Australia and the south-west corner of South Australia. This transgression resulted in drowning of the lower valleys of the major Palaeorivers (Hocking and Cockbain, 1990) with the shallow seas in the valleys reaching up towards Kalgoorlie. Churchill (1973) suggests that the maximum extent of this transgression approximates the present-day 300 m contour. The retreat of the inland sea during the Middle Miocene (approximately 9-10 million years ago), was perhaps a result of gentle epeirogenic movement that also significantly reduced the system gradients and discharge. This marine regression exposed what is now the Nullarbor Plain and the extensive limestone deposits (exposed as cliffs on the Great Australian Bight) laid down in the shallow sea.

The Carey Palaeoriver has no surface expression beyond Lake Minigwal where the system vanishes beneath the sand dunes of the Great Victoria Desert. However, the Raeside and Rebecca Palaeorivers do have a contemporary surface expression in the form of Ponton Creek which drains the southern end of Lake Raeside and, after linking with the outflow from Lake Rebecca, continues to flow in a south-easterly direction where it eventually loses identity in the north-western edge of the Nullarbor Plain.

As with the Carey Palaeoriver, the Lefroy and Yindarlgooda Palaeorivers also have no continuous surface expression linking the playas to the Nullarbor Plain.

It is most likely that at least some of the original palaeochannels are still actively discharging via the palaeosystem delta developed when the system was active during the Early Tertiary Period. It is also likely that during major discharge events, such as those generated by rainfall associated with decaying cyclones, many of the small salt lakes and pans would be filled by surface runoff, resulting in a major surface discharge. The relationship of the major palaeoriver systems in the region is shown in Figure 2.

### 3.3.3 Contemporary Geomorphic Status

It can be argued that the Lake Carey playa is degrading and it can also be argued that the Lake Carey playa, as a defined wetland, is dying. As the system is endoreic, there is no discharge from the playa by surface streams. All surface discharge is onto the playa, and accordingly there is a net gain in sediment. This is resulting in a gradual accumulation of sediment across the surface of the playa, raising the elevation of the surface and forcing flood events to transgress onto sand banks and other saline flats surrounding islands. Such flood transgressions add sediment to the system, further raising the height of both the saline flats and the playa surface. These geomorphic processes will continue until there is not enough capacity within the playa to accommodate an extreme runoff event, at which time, water will flow out of the Carey system via Lake Minigwal where it will establish a preferred drainage line until it too loses its identity in the sand dunes of the Great Victoria Desert.

Once this process is completed, the presence of a preferred drainage line will result in a discrete drainage system across the surface of the playa. This system will reduce the wetland status to a more riverine status and what is now the playa surface with its faunal assemblages will degenerate to a saline flat, the surface features of which will be dominated by aeolian processes and occasional flooding.

### 3.3.4 Landforms of the Lake Carey Playa

The Lake Carey playa is a dominant landform in the Wallaby Project Area and represents the final downslope component in the geomorphological continuum of erosion remnants - outwash plain - playa. The dune field is superimposed onto the playa near-shore environment. This geomorphic continuum is shown in Figure 3.

The Lake Carey playa has a local catchment area of 5,020 $km^2$ and a surface area of 884 $km^2$, based on the 1:250,000 topographic map series (NATMAP, 1987, 1998). The surface area is the total surface area of the playa and includes all islands, sand bars, and sand banks.

The local catchment area is the internally draining catchment area in which surface drainage lines can be defined flowing into the Lake Carey playa. Immediately north of the playa, between Mt McKenzie and Goose Hill, there is an area of undefined drainage that may, during periods of prolonged and accelerated runoff, contribute to discharge into Lake Carey through runoff contributions from the Mappa Lake area, the surface expression of the Carey Palaeoriver to the north. If this northern region were to contribute runoff to the playa, then the catchment area could be extended by a further 3–4,000 $km^2$.

The topography of the local catchment is defined as an open-ended basin with the northern end dominated by Mt Barnicoat at an elevation of 525 m, and the southern end located at the southern extremity of the playa at an elevation of 400 m. The playa, which lies wholly within the 400 m contour, has a maximum width of 31 km and a maximum length along the centreline of 87 km.

The Lake Carey playa is an endoreic depositional drainage basin underpinned by the Carey Palaeoriver system. No attempt is made in this report to interpret stratigraphy within the lake sediments or to develop a time-stratigraphic sequence for the system. Rather, the playa system is defined as comprising a number of features and structures which together describe the geomorphology of the playa.

The playa surface is flat lying within a regional slope trend to the south-east and contains local depressions in the surface which vary in area up to several square kilometres. These depressions are broad undulations in the surface sediments and are probably formed by a combination of processes including ablation and preferential deposition of fine-grained sediment by contemporary influent drainage systems. A broad depression, which occurs immediately off-shore from the Wallaby orebody, trends north-west to south-east, sub-parallel to the modern shoreline.

The islands, sand banks, and saline flats that dominate the surface of the playa contain a number of geomorphic features that allow a crude interpretation of recent geomorphic history of the playa system (Plate 7).

In the northern areas of the playa, erosion remnants (Archaean) are present on Kevin Island East and West where they form low rounded hills. Elsewhere, there is a complex network of ridges (erosion remnants) that now tend to form the 'backbone' of many of the islands (Plate 8). Slope geometry of these ridges indicates two levels of competence in the material making up the structure. The surface capping appears to comprise an indurated 'crust', with a less competent material forming the lower slope (Plate 9). Brearly *et al.* (1997) suggest that these structures are 'kopi' dunes formed from wind-blown calcium sulphate (gypsum). There is a problem with this hypothesis in that a 'kopi' dune is a material-specific ($CaSO_4$) lunette which is (in plan), a fixed cresentic dune. The structures present in the northern half of the Lake Carey playa are generally longitudinal in plan, not cresentic, and accordingly do not satisfy the shape requirements of lunettes. As a general rule, the 'ridges' appear to have an average width of approximately 130 m but narrower ridges with a width of 32 m also occur. The ridges tend to share the same level of planation on their upper surface but this has not been confirmed by detailed survey. The origin of these structures, including the origin of the 'indurated' cap is also unconfirmed but it is useful to place these structures into some form of geomorphic context.

The surface 'crust' of the ridges has a remnant columnar structure and a distinctly alabastrine appearance. It is possible that the present surface crust is a pedogenic illuvial gypsiferous horizon which now forms a prominent surface feature through erosion of unconsolidated overlying surface material. Watson and Nash (1997) note that the surface forms of gypsum crusts are typically columnar, powdery, and cobble with characteristic alabastrine textures. Watson (1988) notes that most surface crusts are exhumed mesocrystalline crusts. The origin of the underlying and less competent material is not confirmed, but as Watson and Nash (*op cit.*) indicate, there are three chemically distinct forms of gypsum crusts, lacustrine, phreatic, and pedogenic, each with significant differences in $CaSO_4$ content with sodium levels being highest in the lacustrine evaporites.

If the ridges are aeolian evaporite (gypsum) dunes of Pleistocene origin, as postulated by Brearley *et al*. (*op cit*), then the climatic extremes that occurred during the Quaternary would have eroded and removed such unconsolidated dune material. Even though gypsum (calcium sulphate) has low solubility (2.0 g/L), the solubility increases to 8.0 g/L in the presence of hypersaline water with a sodium chloride content of 10% (Zen, 1965). It is suggested that the indurated capping has resisted the erosion forces present during the Quaternary to allow development of the present surface features.

It is also interesting to note that there is pisolitic, nodular, and quasi-massive calcrete in some soil profiles in the general area of the Wallaby orebody. Field evidence suggests that this calcrete is not *in situ* but rather a component of the transported palaeosol underlying the modern shallow siliceous sand on the surface but overlying the silcrete pan at approximately 0.9 m. The indications are that the calcrete has its origins in the weathering and subsequent reworking of a pre-existing regional calcrete pan (calcretes are present north of the Mt Margaret Mission). The calcrete occurring throughout the region is possibly a groundwater calcrete originally formed by precipitation below the water table, under conditions of high evaporation, low and irregular rainfall, little surface drainage or runoff, and a shallow water table with sluggish groundwater movement. Mann and Horwitz (1979) considered that the groundwater calcretes of Western Australia developed in an arid period some time before 36,500 years ago. As Bowler (1976) points out, arid conditions commenced in the Pliocene, the last Epoch of the Tertiary Period, which started about 5.3 million years ago and ended at the start of the Pleistocene, the first Epoch of the Quaternary Period, about 1.8 million years ago. This suggests that calcretes may have been formed greater than 1.8 million years ago, or they may be the result of a younger period of aridity, that occurred between 1.8 million years and 36,500 years before present.

The current surface form of the ridges suggests that at least three major erosion/deposition episodes have occurred to develop the present surface morphology. The first episode resulted in erosion of the overlying sediment, exposing the indurated layer that is now the cap. The second episode incised the crustal sheet and underlying evaporites along preferred drainage pathways to form major channels (in reality, these drainage lines would be small perched palaeochannels). The third episode resulted in re-deposition of sediments, probably under both alluvial and lacustrine conditions, that infilled the drainage channels and provided the shallow water energy to develop 'wave cut platforms' and 'strand lines' that form significant contemporary features of the 'islands' on the playa surface. The data currently available on the near-surface stratigraphy tends to support a fluvio-lacustrine origin for the near-surface sediments.

The arrangement of strandlines on sand flats and saline flats, together with features on the playa surface suggest a lacustrine regression with the onset of aridity and diminished system gradient.

There is also evidence to suggest that within this regression, there were periods of intense fluvial activity that resulted in the formation of sand sheets that form an onlapping relationship with the underlying sediment (Plate 10). These 'onlapping sands' tend to have a preferred orientation through an arc of 95º ranging from 270º to 365º which trends generally with the long axis of the palaeoriver and therefore the major direction of system discharge, that is, the onlapping sand sheets are, as a general rule, on the upstream side of low-lying surface features. In addition, the sands themselves demonstrate features suggesting a regressing water level under conditions of increasing aridity. A fluvial origin for these sand sheets is preferred over an aeolian origin based on dunal form. If these were modern lunettes formed by a prevailing north-westerly wind, the horns of the dunes would be pointing into the wind, the opposite to barchanoid dunes, the horns of which point down wind. Such well-developed diagnostic features do not exist in these onlapping sands. Dunal form, together with the presence of strandlines overprinting the surface of the sands strongly suggests a sequence of lacustrine transgressions and regressions.

While it is probable that extreme climatic variability during the Holocene accounted for much of the recent geomorphic history of the Lake Carey playa, runoff events generated by the passage of Cyclone Bobby in February/March, 1995 have also contributed to contemporary surface form. A comparison of onlapping sand sheets, clearly defined in 1980 aerial photos, with the state of the same sand sheets in 1999, suggests that the sand has itself been onlapped, in part, by finer grained sediment (silts and clays) deposited by the 'Cyclone Bobby flood'. The depth of water across the Lake Carey playa was taken to average approximately 1 m (Rory Lamont, pers. comm.) and so many of the sand bars and saline flats flanking the islands would have been covered, at least in part, by the flood event.

Evidence such as this suggests that the Lake Carey playa is degrading in terms of wetland status. Commander (1999) also notes that Salt Lakes are displaced by alluvial fans, and accordingly are accumulating sediment. Under the present climatic regime, fluvial and aeolian deposition will continue as the major mechanism contributing to a net sediment gain and the salinity status of the surface sediment will continue to be dominated by evaporation. It is most likely that capillary rise of salt will continue, as the sediments will be dominated by the fine-grained fraction, thereby enhancing the processes. As with the present-day system, the relationship of groundwater and playa surface will continue to be complex. The depth of sediment may become too great for capillary rise of salts or the water table will rise in concert with the increase in surface elevation, thereby continuing the wetland status.

The movement of very fine-grained sediment, as a result of long wind fetch and constant velocity, relocating shallow water on the surface of the playa, may also be a process responsible for shaping the surface form of the playa through redistribution of sediment.

# 4.0 SOILS OF THE WALLABY PROJECT AREA

## 4.1 INTRODUCTION

The sites at which soils of the Wallaby Project Area have been examined in detail are given in Figure 4. These sites were chosen to represent the variability in Project Area soils, the range of soil types present, and the influence of topography and location on soil profile characteristics.

## 4.2 SOILS OF THE COLLUVIAL OUTWASH PLAINS

The soils of the outwash plains are characterised by great variability in depth, variability in texture and structure, and in some areas, a clearly defined horizonation that is a function of fluvial process rather than pedologic organisation.

The soils are described using the Principal Profile Form (PPF) of Northcote (1971) as the key discriminator as well as using specific material characteristics such as aggregate stability.

The soils of the Outwash Plains are generally classified as Gradational Soils, that are not calcareous throughout the profile, have a gradual increase in clay content with increasing depth, and a neutral to alkaline soil reaction trend. PPF's include Gn1.13 and Gn2.13. These PPF's are separated on the basis of sandy and earthy fabrics and a colour dominated by a value/chroma rating of 5.

Uniform textured soils occur as major profile forms and Location 8, within the boundary of the orebody, contains a typical coarse-grained Uniform Soil (Uc1.23), of probable aeolian origin, overlying a discontinuous calcrete pan approximately 40 cm thick. In other areas within the orebody boundary, similar transported soils overlie a well-developed red-brown hardpan, an earthy pan with distinct laminar cleavage, typically redder than 2.5YR 3/6, that is very hard and dense (but has the appearance of being quite porous), and overlying a silcrete pan (Plate 11). No duplex soils were described in detail but field evidence suggests that this primary division occurs within the Project Area.

As a general rule, the surface soils are sandy in nature and range in textural grades from sand through loamy sand, fine sandy loams to loam, fine sandy. The vertical distribution of texture does not always follow normal profile form. Rather, the textural distribution is dictated, at least in part, by the erosion-deposition prehistory of the outwash plain and it is quite normal to find gritty and sandy horizons at depth underlying more clayey horizons.

The pH of surface soils in the Outwash Plain also varies across the Project Area and ranges from moderately acid (pH 5.5) to moderately alkaline (pH 8.5) and as such, falls within the expected range for arid and semi-arid regions although a pH of 5.5 is slightly more acidic than would be normally expected.

Extreme variability occurs in soil aggregate stability, both in depth below the surface and location. Values range from an $Em_c$ of 2 up to an $Em_c$ of 6 indicating that aggregate stability ranges from dispersible to highly flocculated. The implications of soil aggregate stability for soil management and rehabilitation are discussed in Section 4 of this report.

The soils of the Outwash Plains show varying degrees of instability and are prone to erosion in a disturbed state (Plate 12). As there is no continuity of either form or process in soil characteristics, specific soil management criteria must be developed for area-specific soils, as both the physical and chemical characteristics are dictated by development pre-history and cannot be predicted with any degree of certainty.

Representative soils of the Outwash Plains are characterised in Locations 1-4 and Locations 6-8.

Soil-specific terminology is defined in Table 1.

## 4.3 SOILS OF THE HILLS AND RANGES

The soils of the hills and ranges are dominated by shallow skeletal soils both of which display little pedologic organisation beyond minimal accumulation of organic matter on the surface.

The soils are classified as Uc1.23 and Um1.43 and both PPF's have Great Soil Group terminology of lithosols.

These shallow skeletal soils (<20 cm in depth), are typically slightly acid with pH's in the range 6-6.5, and have little value as a resource within the Project Area. The soils are physically infertile, generally contain an abundant stone and pebble content and tend to be erodible in the disturbed state.

**TABLE 1**

**Soil Profile Data Terminology**

| Term | Explanation |
|---|---|
| Colour 10R 3/4; 10R 3/6 | All colour definitions are from the Revised Standard Soil Colour Chart based on the Munsell system. Hue =10R, Value=3, Chroma=4 Colour is dark red |
| Colour 7.5R 4/6 | Colour is red |
| Colour 2.5YR 4/8; 5YR 4/8 | Colour is reddish brown |
| Depth | Depth in cm below the surface |
| Soils L | Soil texture is a loam |
| Soils FSCL | Soil texture is a fine sandy clay loam |
| $EC_{1:5}$ (Electrical Conductivity) | Total amount of soluble salts per unit weight of sample |
| PRI (Phosphorus Retention Index) | An index indicating the ratio of P adsorbed to P equilibrium |

## 4.4 SOILS OF THE DUNE FIELDS

The soils of the dune fields are typically siliceous sands and have a PPF of Uc1.23.

The soils are moderately acid with a pH of 5.4 and the particle size distribution indicates a high degree of sorting confirming an aeolian origin. The sand dunes examined in detail all contained sands in the fine-medium-coarse range but with only 7% of the material coarse sand (0.6-2.0mm).

Representative soils of the dune fields are characterised in Location 5.

## 4.5 SOILS OF THE LAKE CAREY PLAYA, SALT PANS, AND NEAR-SHORE ENVIRONMENT

### 4.5.1 Soils of the Lake Carey Playa

The soils (sediments) of the Lake Carey playa are included here as they form part of the geomorphic continuum within the Wallaby Project Area. As would be expected for near-surface sediments of the playa, the particle size distribution is dominated by sediment in the range clays to coarse silt/fine sand. At a depth of 30 cm below the surface, clays and silts make up approximately 80% of particle size. In the surface layer (0-3 cm), the clays and silts make up approximately 60-65% of the sediment but the percentage of fine sand increases to slightly over 30%. This increase in fine sand possibly reflects contemporary aeolian processes.

The particle size distribution of the playa sediments at 0-3cm is given in Table 2 and PSD curves for playa sediment at 30 cm are given in Figure 5.

Sediment chemistry is characterised by elevated levels of soluble salts dominated by sodium chloride. The chemistry of sediment taken from a depth of 15 cm approximately 60 m off shore is given in Table 3.

The sediments of the Lake Carey Playa were also examined in terms of *in situ* permeability and surface infiltration rate. The infiltration rate was determined using a constant head infiltrometer at a site approximately 50 m off shore.

The results of permeability and infiltration rate testing are set out in Tables 4 and 5.

**TABLE 2**

**Particle Size Distribution of Lake Carey Playa Sediments**

| Parameter | WPLS-14 (%) | WPLS-12 (%) |
|---|---|---|
| Depth | 1 cm | 3 cm |
| Clay | 22 | 30 |
| Fine Silt | 10 | 10 |
| Medium Silt | 6 | 5 |
| Coarse Silt | 24 | 20 |
| Fine Sand | 32 | 30 |
| Medium Sand | 5 | 4 |
| Coarse Sand | 1 | 1 |

Note: WPLS-14 was the surface 1 cm. WPLS-12 was taken at 3 cm below the surface

### 4.5.2 Salt Pan Soils

This is a very diverse group of soils as both texture and structure are a function of pedologic prehistory as well as both contemporary pedo-geomorphic processes. The single soil examined was typically fine textured (loam, fine sandy), had a moderately alkaline pH of 8.5, was dark reddish brown in colour (2.5YR 3/6), and was non-calcareous. Many of the pans have aeolian silts and sands making up the surface layer for the first 1-2 cm.

**TABLE 3**

**Chemical Analysis of Sediment from the Lake Carey Playa**

| Parameter | PGS LS1 |
|---|---|
| Depth (cm) | 15 |
| pH (1:5) | 7.1 |
| $EC_{1:5}$ (µS/cm) | 18,000 |
| TSS (mg/kg) | 72,000 |
| Na (mg/kg) | 31,000 |
| K (mg/kg) | 420 |
| Ca (mg/kg) | 3,800 |
| Mg (mg/kg) | 1,400 |
| Cl (mg/kg) | 40,000 |
| $NO_3$ (mg/kg) | 3 |
| $SO_4$ (mg/kg) | 20,000 |
| Bicarbonate (mg/kg)<br>Carbonate (mg/kg) | 80<br><5 |

In a review of these chemical data, Coleman (1999), suggests that the total dissolved solids is probably closer to 96,000 mg/kg and notes that such a discrepancy may occur when the TDS values are derived by conversion from conductivity readings.

### 4.5.3 Soils of the Near-Shore Environment

The soils of the near-shore environment are also a complex, polygenetic group of soils, in that they too are strongly influenced by both past and present pedo-geomorphic processes. The low frontal dune forming a prominent beach-head marker was examined in some detail and the data are given in Location 9. The local prominence of the frontal dune is shown in Plate 13.

There is, typically, an increase in clay content with depth and this may be due to the onlap nature of the dune overlying fine-grained sediment or to partial illuviation of clays.

**TABLE 4**

**Permeability Data For Lake Carey Sediments**

| Sample No. | Dry Density ($t/m^3$) | Initial Moisture (%) | Final Moisture (%) | Permeability (m/sec) |
|---|---|---|---|---|
| WPPS - 1 | 1.60 | 27.1 | 28.8 | $1.3 \times 10^{-9}$ |
| WPPS - 2 | 1.56 | 26.2 | 31.3 | $4.6 \times 10^{-8}$ |
| WPSS - 3 | 1.53 | 26.6 | 27.4 | $1.6 \times 10^{-9}$ |
| WPSS - 4 | 1.26 | 38.4 | 40.0 | $4.2 \times 10^{-10}$ |
| WPSS - 5 | 1.39 | 30.3 | 36.6 | $6.8 \times 10^{-10}$ |

**TABLE 5**

**Lake Carey Surface Sediment**
**Constant Head Infiltration Rate**

| Location | Infiltration Rate (mm/h) |
|---|---|
| 430850 E<br>6808210 N | 196.0 |

Note: Infiltration Rate = Average of three tests.

# 5.0 SOIL USE AND SOIL MANAGEMENT ISSUES

## 5.1 INTRODUCTION

The soils of the Wallaby Project Area are complex in both texture and structural form, making it difficult to predict, with a high degree of accuracy, the behaviour of specific soil material from within the broad soil landscapes as described above. Topographic position will dictate, to some extent, the physical characteristics of the solum but the field evidence suggests that the relationship of topographic position and soil chemistry is, at best, unpredictable.

There is no doubt that the soils of the Wallaby Project Area are a potential resource for use in environmental management. What is important is that the constraints of particular soils are understood and that soil material is not used beyond its capability.

## 5.2 TOP SOIL AND SURFACE SOILS

The soils of the Project Area are all transported and this is characterised by very poorly structured surface soils. For example, the soil material on the surface of the Outwash Plain is typically poor in physical fertility in the upper 20-30 cm of the profile. However, with increasing depth from the surface, there is a gradual increase in clay content so that the lower horizons tend to have an improved physical fertility through an apparent textural improvement.

The key issue here is that because of area pre-history, and the variability in pedologic processes, there will be areas of very good soils mixed in with areas of very poor soils. Because of this, it is useful to consider the soils of the Project Area, not in terms of ‘topsoil’ *per se*, but in terms of a ‘surface soil resource’. The true topsoil can be defined as a thin layer, generally not exceeding 150-200 mm in depth, that contains elevated levels of organic material and is a potential seed source. By nature of the origin of this material, the physical fertility is very poor. On the other hand, the trend to increasing clay content with depth suggests that there is added value in utilising a greater depth of the soil profile. This is particularly so for areas that will be utilised for Project infrastructure such as tailing storage facilities, waste dumps, or heap leach pads.

The concept of saving ‘topsoil’ should also be treated with caution in the Wallaby Project Area as there are areas where the topsoil (A horizon) has been totally removed by erosion processes, exposing a truncated upper B horizon material. Just because this material is on the surface does not make it a topsoil in terms of potential use in environmental management programmes. Indeed, the dispersible nature of some of these soils relegates them to either a ‘non-use’ or ‘proceed with extreme caution’ category.

The term topsoil should be abandoned in favour of using the term 'surface soil' where field evidence suggests that up to 0.5 m of soil material is available for use in environmental management programmes such as rehabilitation of structural outslopes.

## 5.3 SOIL ERODIBILITY

The soils of the Wallaby Project Area are, as a general rule, highly erodible. The sandy and earthy fabrics of the soil mass, the poor coherence of the soil in the moist state, the particle size distribution generally dominated by material in the silt/sand range, and in some areas, the presence of well-sorted sands (Figure 6), means that detachment thresholds and maximum non-scour velocities are quite low and in the range of 0.15 to 0.3 m/s.

The presence of dispersible clays within the soil material will increase the erodibility of a given soil by several orders of magnitude. Reference to Plate 12 indicates the potential level of erosion of some Project Area soils in the disturbed state, although dispersibility in these soils has not been confirmed.

Many of the soils examined are described as being strongly flocculated. Soils with this characteristic tend to behave as a fine gravel or coarse sand due to the strength of the clay particle bonding, and so soils that are highly flocculated can also be highly erodible. As the strength of the clay bonding requires very high energy levels to destroy the bonding, there is often a differential rate of erosion of this soil material. Channelised flow can provide the energy to break down the clay bonds and so the energy of flowing water gradually destroys the aggregate, resulting in the accelerated transport of the finer material released by aggregate breakdown.

Dispersibility induced erosion can be activated under very low rainfall intensities and low overland flow velocities and so erosion generated or enhanced by this chemical state is an insidious process and one that requires specialised control techniques. The dispersibility of the clay is caused by a dominance of sodium on the clay nacelle and the presence of this characteristic should be confirmed for all soil material proposed for use in rehabilitation programmes at Wallaby.

Erosion of flocculated soils can be related directly to discharge velocity and accordingly becomes a more identifiable process, and one that has well-established control techniques.

Many of the deeper sands, such as occur in the Project Area dune fields should be regarded as stable in the non-disturbed state. The very high infiltration rates of these sands indicates that erosion by water will be uncommon. However, erosion by wind is a common process and removal of the protective cover of vegetation will accelerate the erodibility of these dunal soils.

## 5.4 SOIL SALINITY

As a general rule, the surface soils of the Wallaby Project Area are non-saline, and this is particularly so for the 'topsoils' throughout the area. The sediments of the Lake Carey playa are extremely saline.

As with the overall trend throughout Australia, there is a potential increase in salinity with depth. The profile examined at Location 6 (see Figure 4) typified this increase with the concentration of total soluble salts increasing from 150 mg/kg at a depth of 10 cm to 15,000 mg/kg at a depth of 65 cm.

Total salt contents of soils throughout the Wallaby Project Area ranged from a low of 27 mg/kg at Location 4 to a high of 15,000 mg/kg at Location 6. The sediment of the Lake Carey playa has a total soluble salt concentration of 72,000 mg/kg and is not considered in this discussion.
Soil salinity can have a major impact on the germination and survival rate of plants and is an important consideration in Project environmental management

programmes. The technique of analysis using a 1:5 soil:water suspension is fast and convenient but does not take soil texture into account, and therefore is not easily related to plant performance. Nevertheless, the technique does allow an evaluation of soil salinity through conductivity and the addition of the analysis of total soluble salts further increases value of the conductivity data. Conversion factors, *ie* from $EC_{1:5}$ to $EC_e$ seem to be based on NaCl being the only salt present and, accordingly, is not a useful technique in assessing plant performance through conductivity measurements.

The role of surface soil in rehabilitation programmes, as part of overall environmental management at Wallaby, is of paramount importance and although the data from this Soil and Landform Survey suggest that the salinity of surface soils will not be an issue, it will be appropriate to confirm this finding once the specific area soils, required for rehabilitation purposes, have been defined. At this time, and following species selection, the root-zone salinity of the growth media should be determined.

## 5.5 PARTICLE SIZE DISTRIBUTION

The particle size distribution (PSD) of Project Area soils has been examined in some detail as the relationship of size ranges present is the basis for textural classification. The arrangement of the various size ranges determines the structure of the soil. These two characteristics together strongly influence soil erodibility, permeability, moisture retention capability, and engineering constraints.

PSD data are presented in standard curve form where appropriate, to demonstrate the similarity of soils and to demonstrate the variability of soils in relation to profile horizonation and textural differentiation. A perusal of these data very quickly indicates which soils are the most suitable for rehabilitation programmes and which soils have a restricted PSD, thereby limiting their value as a growth medium for regeneration programmes.

An analysis of grading curves using specific geometric values, defined as grading characteristics, can be carried out. These are the effective size [$d_{10}$], the coefficient of uniformity [$C_u=d_{60}/d_{10}$], and the coefficient of curvature [$C_c=(d_{30})^2/(d_{60}*d_{10})$]

Defining the coefficient of curvature ($C_c$) is a useful technique for assessing the suitability of soils for rehabilitation. As a general rule, soils with a $C_c$ between 0.5 and 2.0 are regarded as well graded soils, but soils with a '$C_c$' value of 2 would be more desirable for rehabilitation programmes. Some caution must be exercised however in the interpretation of these data as it is possible to have a well-graded sand, *ie*. a sand that contains even proportions of fine, medium, and coarse-grained material in the sand fraction (0.06-2.0 mm) and such a material may not be suitable for rehabilitation purposes. A good example of this situation is the sand dune soils at Location 5. Typical '$C_c$' values for Project Area soils are set out in Table 6.

The generally sandy nature of surface soils throughout the Wallaby Project Area has resulted in high infiltration rates ($I_r$). The $I_r$ is determined by a number of factors including both texture and structure. The presence of lag gravels, algal mats, and both erosional/depositional areas, and the presence of dispersible/flocculated clays all impact to some extent on local infiltration rates. However, as a general rule, the surface soils have high rates of infiltration. The relationship of $I_r$ to rainfall intensity,

set out in Figure 7**,** clearly indicates that for the two soils tested, the infiltration rate exceeds normal design-intensity rainfall. While the $I_r$ data suggest good rates of infiltration, the actual rate will vary across the Project Area as a function of the parameters noted above. In addition, and because of the extreme polygenetic nature of the Wallaby soils, there will be areas exhibiting differential permeability where the horizontal permeability greatly exceeds the vertical permeability.

The high $I_r$ values tend to mirror the PSD data for surface soils and indicate that the higher the soil $I_r$ value, the less value the material is for rehabilitation. The dune sands at Location 5 gave $I_r$ values in excess of 600 mm/h, a value considered normal for this type of sand.

**TABLE 6**

**Typical $C_c$ Values for Project Area Soils**

| Sample No. | $C_c$ Value |
|---|---|
| WPSS-17 | 1.44 |
| WPSS-23 [Location 8] | 1.14 |
| WPSS-10 [Location 5] | 1.09 |

## 5.6 ATTERBERG LIMITS

The Atterberg Limits provide a classification of fine-grained soils where the engineering properties are dictated by the shape of the fine-grained particles rather than the size. Three representative soils were examined in terms of their plasticity and the data are set out in Table 7.

These data demonstrate, again, the extreme variability in Project Area soils which range from low plasticity (LL<35%) to high plasticity (LL 50-70%). Accordingly, there will be a corresponding range in soil properties such as shear strength and compressibility. It is important to note that the clay content comprises both clay and non-clay minerals with the true clay minerals making up possibly only 40-50% of the clay fraction. The degree of plasticity of the 'true' clay fraction, the *activity* of Project Area soils, is given in Table 8.

**TABLE 7**

**Atterberg Limits for Project Area Soils**

| Sample No. | Liquid Limit | Plastic Limit | Plasticity Index | Linear Shrinkage |
|---|---|---|---|---|
| WPSS-8 | 19 | 9 | 10 | 4 |
| WPSS-2 | 29 | 14 | 15 | 8.5 |
| WPSS-29 | 55 | 20 | 35 | 15.5 |

**TABLE 8**

**Activity of Project Area Soils**

| Sample No./Location | Activity | Inferred Clay Mineralogy |
|---|---|---|
| WPSS-8 Location 4 | 0.5 | 1:1 lattice-Kaolinite Group |
| WPSS-2 Location 1 | 0.65 | Kaolinites/Illites |
| WPSS-29 Location 7 | 1.75 | 2:1 lattice- Montmorillonite [Smectite Group] |

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