SOILS INVESTIGATIONS OF THE DONGARA PROJECT AREA

STAGE 2

Prepared for

Tiwest Pty Ltd

by

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1.0 EXECUTIVE SUMMARY

Stage 2 soil investigations of the Dongara project area builds on the data generated in the initial survey (Blandford, 2007) and further investigates soil profile characteristics adjacent to ore bodies and the relationship of the palaeo lake system with adjacent land. Profile characteristics were also investigated in greater detail within the palaeo lake system to better understand profile stratigraphy.

The Dongara soil and soil landscapes survey project area covers approximately 113km^2 and is located 28km south-east of the coastal hamlet of Port Denison. The area lies west of the Gingin Scarp and east of a band of outcropping Tamala Limestone in a physiographic feature known as the Eneabba Plain.

Three soil landscapes are defined: an eastern ferricrete/clay system, a central sand plain system, and a western relict palaeo lake system. Each has a distinctive suite of soil profile characteristics. The eastern ferricrete system, which was formed by alluvial/colluvial outwash fans passing off the scarp onto the coastal plain has profiles in which the presence of ferricrete dominates, either as well sorted gravels or older, strongly weathered ferruginous rubble. Clays may be associated with these deposits and many of the profiles are duplex in nature.

The central sand plain, the largest and dominant soil landscape, comprises generally aeolian sand sheets, which in part, on-lap the eastern ferricrete sediments. The sands also partly obscure the western palaeo lake system. The soils in this landscape are deep sands, at times well sorted, and demonstrating generally strong fabric development. Deeper horizons display strong induration. Locally, dunes have been formed but this surface form is not common.

The western relict palaeo lake system appears to be the remnants of an ancient, and much larger lacustrine system that was probably continuous along the length of the project area. Profile morphology is complex, tends to be characterised by well-defined horizonation that is stratigraphic rather than pedologic, and dominated by pedogenic and biogenic silica. The nature of silica precipitation indicates long periods of geomorphic stability.

It is likely that the development of the sand sheet and the demise of the lake system were contemporaneous and it is likely that both were associated with the onset of aridity and accelerated wind activity. There is field evidence indicating that some drainage systems, originating from the outwash fans entered the lake system. In the southern areas, highly weathered ferricrete rubble is present at depth, suggesting the remnants of ancient pisolitic ferricrete deposited as outwash gravels. North of Mt Adams Road, the palaeo lake system is more complex and evidence exists for a number of streams entering the ancient system from the north-east.

The extended depth of profile investigations carried out as part of this Stage 2 survey indicated groundwater north of the Mt Adams Road at between 3 and 4m below ground level. Gleying at some of the sites indicates prolonged periods of saturation and reducing conditions. It is possible that the profiles, (A-11 to A-14) showing shallow groundwater are directly influenced by contributions from the palaeo drainage systems.

Re-assessment of the potential boundaries of the soil landscape of the western relict palaeo lake system has resulted in an extension of this landscape type.

At the time of the survey, vegetation was exhibiting drought stress.

2.0 INTRODUCTION

The Stage 2 soil survey of the Dongara project area is designed to further investigate soils adjacent to ore bodies and to assess limitations associated with the profiles and soil materials examined. In addition, further investigations were carried out within the relict palaeo lake system along the western margin of the study area. Where possible, excavations into the palaeo lake sediments were taken as far as possible with the equipment available, to help define profile stratigraphy and potential links with contemporary groundwater regimes. The additional data collected from the Stage 2 survey will be added to that already collected and accordingly, will form a comprehensive data set for strategic planing, operational management, and rehabilitation design.

2.1 LOCATION

The centre of the Dongara project area is located approximately 28km south-east from the coastal hamlet of Port Denison on the shore of Azurine Bay, and some 370km north of Perth. The project area, which lies east of the Brand Highway covers an area of approximately 113km^2. Mt Adams Road passes east to west through the area, joining the Brand Highway approximately 9km west of the project area boundary.

2.2 SCALES OF TIME AND SPACE

The Swan Coastal Plain forms the major regional physiographic unit of the project area and within this unit, three principal sub-units can be recognised. These are:

- a coastal dune system of Holocene age (<10,000 ybp), the Quindalup Dune System (McArthur and Bettenay, 1960; Semeniuk *et al.,* 1989), which, west of the project area has a width of 4.5km, and immediately to the east is;
- an inland dune system of Middle to Late Pleistocene age (800,000 ybp to 100,000 ybp), the Spearwood Dune System (McArthur and Bettenay, 1960), now referred to as the Tamala Limestone, outcrops of which are present in the central project area; and
- the Eneabba Plain (Playford *et al.* 1976), an area of undulating but gently rising plain between the Tamala Limestone and the Gingin Scarp.

The Dongara project area lies wholly within the Eneabba Plain and is shown in Figure 1.

2.3 PHYSICAL FRAMEWORK

The north-south axis of the area of investigation parallels the regional grain of the country, formed by two sub-parallel soil landscape systems. These are swamp and lacustrine deposits forming an irregular band running the full length of the area along the western side, and a larger area of non-calcareous sand over the remainder (Mory, 1995). The area is bounded on the east by the Gingin Scarp, which reaches its maximum elevation of 256m at Mt Adams. The Gingin Scarp which is characterised by a westerly facing slope of a generally uniform gradient and comprising sand over ferruginous laterite is the source area of a number of drainage systems that discharge onto the project area along its eastern boundary. The drainage systems present today are relicts of a larger palaeo drainage system that operated during much wetter periods, probably during the Pleistocene. These systems were modified by the onset of aridity, which resulted in an increase in sediment loads, and reduced periodicity of discharge events. Two major systems can be recognised, a smaller channel system entering the project area near the eastern end of Mt Adams road and a second, larger system that enters the project area south of the Tompkins Road – Mt Adams Road intersection. These

systems are characterised by a series of outwash alluvial deposits. Neither of these contemporary drainage systems have continuous nor well incised channels.

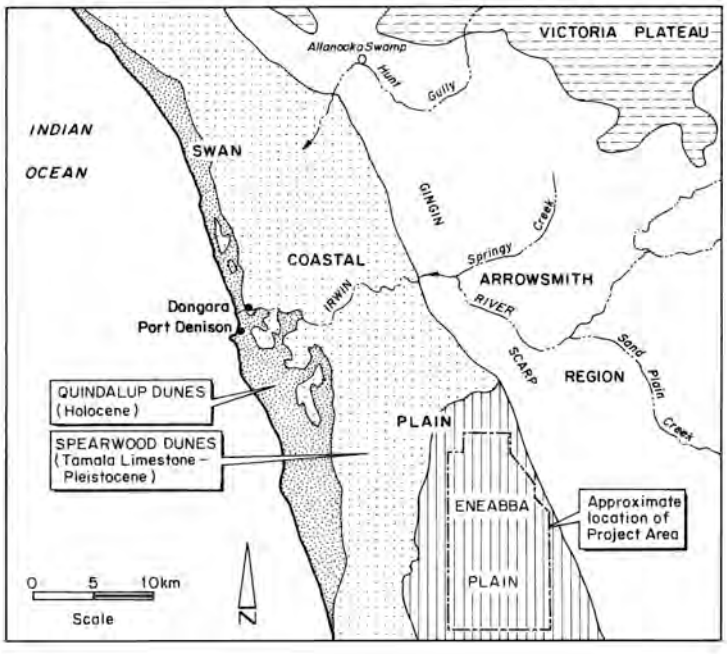


Figure 1 Regional time-stratigraphic framework showing the location of the project area within the boundaries of the Eneabba Plain (Blandford, 2007 as modified from Mory, 1995)

2.4 SOIL LANDSCAPES OF THE DONGARA PROJECT AREA

It is not intended to discuss at length the soils of the project area. The reader is referred to the first report (Blandford, 2007) wherein full descriptions are given. However, it is appropriate to give a general description of the soil landscapes present so that the results from the Stage 2 survey can be put into context. The investigation sites from the Stage 2 survey are given in Figure 2.

2.4.1 The Eastern Ferricrete/Clay Unit

The eastern ferricrete/clay unit has been identified on the basis of the presence of either duplex profiles or on the presence of ferricrete within the profile. There are no depth-dependent criteria associated with these characteristics. This unit is confined to the area of a complex series of outwash alluvial structures, comprising a number of lobes, the dominant being the Demeter Lobe and the Dionysus Lobe. Profiles within this soil landscape are complex with sand upper horizons (A horizons) overlying lower (B) horizons that contain ferricrete rubble in various stages of weathering, nodular to pisolitic ferricrete gravels, or residual weathering ferricrete debris, all of which are generally associated with non-smectite clays. In some areas, the A horizon has been almost completely removed by erosion, leaving the clayey B horizon just below the surface. In other locations, the depth to the clay layer ranges from 1m to 2m below the surface.

The presence of weathering ferricrete rubble, and/or a clay horizon, is a precursor to inclusion in this unit and in a number of sites, these characteristics were only found at depth in the profile. No attempt has been made to differentiate profile characteristics on either the depth of ferricrete rubble, nor the extent of the resultant increase in fines content.

The principal profile characteristics include duplex profiles, the presence of highly weathered to unweathered ferricrete rubble, nodules, or pisolites, and profiles in which there is strong fabric development and elevated moisture retention.

2.4.2 The Central Sand Plain

The central sand plain comprises deep uniform sand profiles in which the solum is dominated by the sand fraction, which may vary from fine- to coarse-grained sand. This is an extensive soil landscape and accordingly contains a wide range of soil and profile characteristics. It is probable that if pit excavation penetrated to greater depths, the sheet sand would be found to overlie palaeo sediments of alluvial/colluvial origin belonging to the outwash debris of the eastern drainage lines or remnants of the palaeo lake system.

The sheet sands of the central sand plain are complex in surface form and demonstrate directional structure. It is probable that they form an on-lapping relationship with the ferricrete landscape to the east. The sheet sands, which blanket, in part, the palaeo lake system, have, themselves, also been reworked by wind. This wind action, including erosion, has also ensured that some of the palaeo lake sediments have remained exposed. In other areas, it is most likely that the old lakes remained unaffected by aeolian sands.

Many of the soil profiles developed within the sheet sands are characterised by a high degree of fabric development and induration. This level of material competence, which was demonstrated by non-collapse of profiles to depths exceeding 3m, is attributed, in part, to the greater age of the sediments at Dongara, relative to, say, the much younger sediments at Falcon and Cooljarloo.

2.4.3 The Western Relict Palaeo Lake System

Additional data collected during the Stage 2 survey, together with updated aerial photographs has allowed an extension of the boundaries of this soil landscape north of the Mt Adams Road. No attempt has been made to reinterpret data south of this road due to the blanket effect of the sheet sands.

We have used the term relict to indicate that what is exposed and accessible at the surface is all that remains of a past, well-developed, fluvio-lacustrine system that appears to be partially intact to the north of the study area.

This soil landscape is located along the western side of the project area and forms a spatially discontinuous series of highly stratified sediments. Profiles tend to be complex, no two profiles are alike, and the majority of profiles, examined in the field, are characterised by the presence of silica. Pedogenic silica appears to be common, with distinctive forms such as globules, irregular masses, nodules, pendants and stalagmites being characteristic forms. A number of sites displayed secondary precipitation of silica as a thick skin over already partially cemented but quite porous clean sands. Elsewhere, biogenic silica is present as thin, highly stratified sediment, often inter-bedded with, or infused with, calcium carbonate. The profiles examined in this landscape all demonstrate a complex pre-history in terms of depositional environment and field evidence suggests strong periodicity in process during a period of geomorphic stability.

Field evidence also suggests that this soil landscape, and particularly the individual profiles examined, is not subject to prolonged inundation nor to extended periods of waterlogging. The relict palaeo lakes do not fit naturally into a classification of wetlands for the Swan Coastal Plain.

3.0 METHOD

3.1 SOIL PROFILE DESCRIPTION

Soil profiles were examined using inspection pits excavated with a backhoe to refusal, or to a depth commensurate with the location. A total of 35 sites were investigated or described to varying degrees of detail. At some sites, an observation hole was excavated to confirm assumptions regarding stratigraphy.

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, or non-ferricrete gravels;
- the nature of horizon boundaries;
- texture;
- structure;
- colour; and
- fabric.

When present, the following features were also assessed and recorded:

- the presence and nature of palaeosols;
- the presence of seepage or free water in the profile;
- indicators of geomorphic pre-history; and
- the presence of relict palaeo drainage systems.

It was not intended to collect soil materials for laboratory analysis unless the material was considered a departure from that already examined during the Stage 1 survey. However, each profile was photographed where possible, but the overall greater depth of the surface sands and the greater depth to the clay layer - surface sand interface, precluded detailed profile photography.

3.2 SITE VEGETATION DESCRIPTION

Mrs Anne Harris, consulting botanist, provided the information associated with vegetation at the soil inspection pit sites. Vegetation structure descriptions are based on the Vegetation Classification Table developed by Muir (1977) with a slight modification. The separation of shrub and tree layers within height categories were not used e.g. Low Heath D for shrubs from 0m-0.5m and Low Heath C for shrubs from 0.5m-1m were combined into one category of Low Heath (0m-1m), and the height of the tallest shrub given in the description. Vegetation within parts of the project area at the time of the Stage 2 survey in February were exhibiting moderate to severe drought stress responses, including, chlorosis of foliage, leaf drop and partial to whole of plant death. Throughout the project area, *Banksia attenuata, B. hookeriana* and *B. candolleana* grew as shrub forms. *Banksia menziesii* grew as either a tree or shrub. The majority of *Eucalyptus todtiana* grew as mallee-form (Harris field notes, 2008).

Within the vegetation descriptions presented in the Results, the dominant species within each structure layer, in terms of density and foliar cover, have been written by listing from the most to the least dominant. Soils have been commented on (A.Harris) wherever there appears to be an indication that the vegetation community can be associated with a particular soil profile, or there is a reason for the specific state of health of the vegetation. The data presented are site specific within the broader vegetation mapping carried out by Woodman (2007).

4.0 RESULTS

4.1 SITE LOCATION

The location of soil inspection sites for the Stage 2 survey is set out in Figure 2 below.

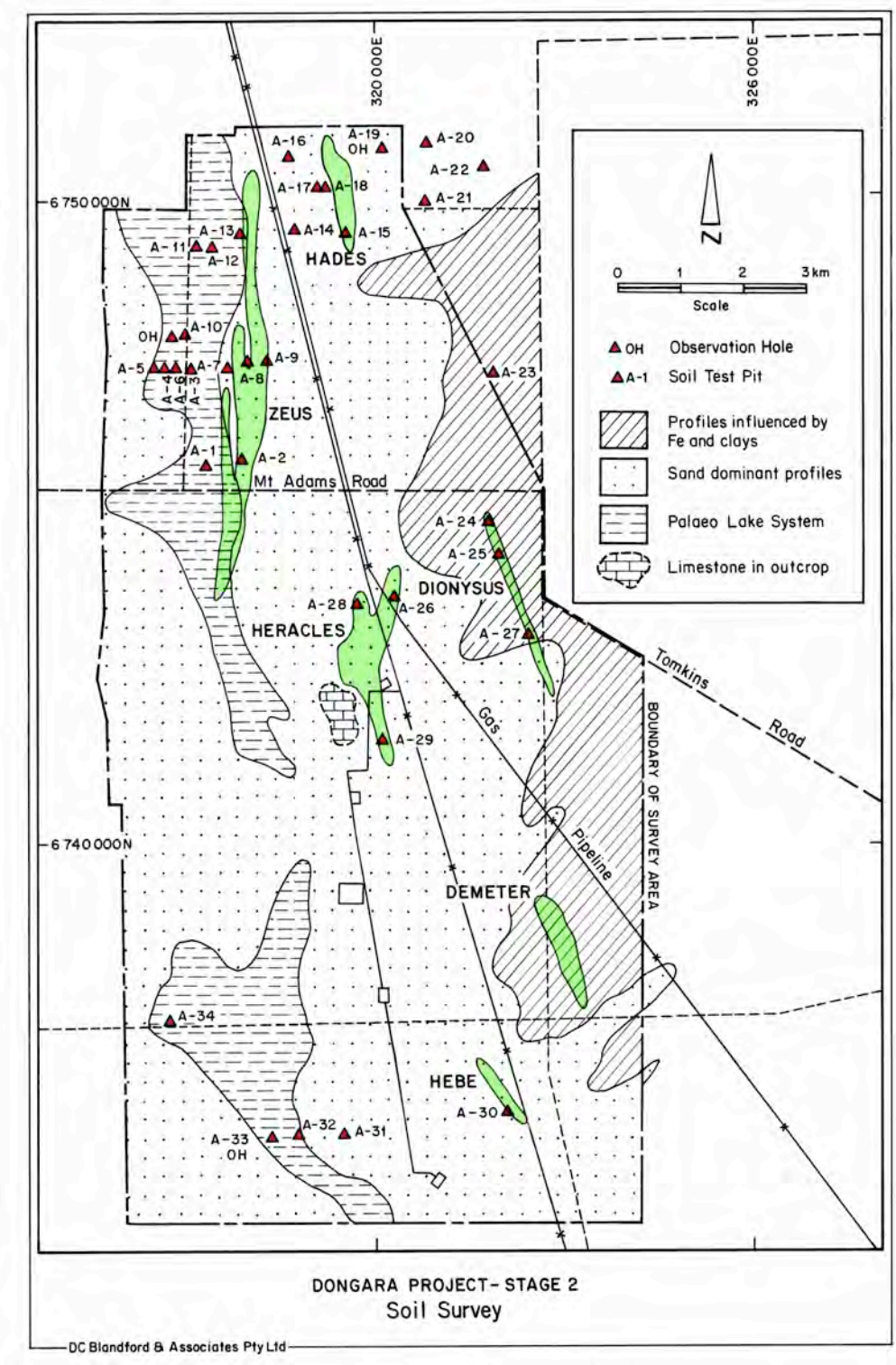
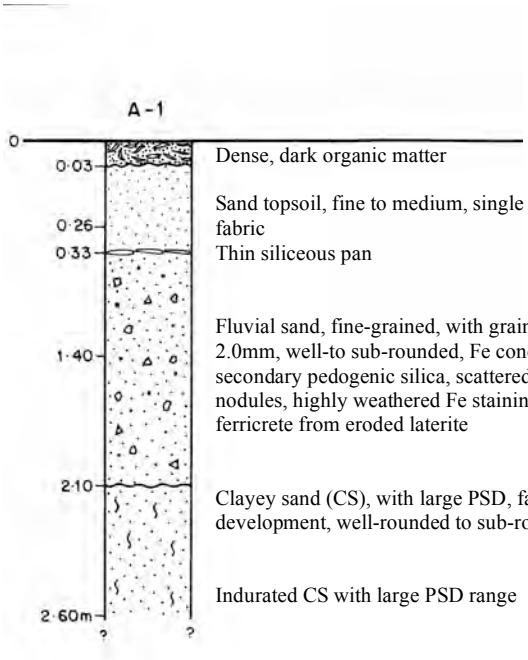


Figure 2: The original soil landscapes of the Dongara project area showing Stage 2 soil inspection pit sites

4.2 SOIL PROFILE DESCRIPTIONS

SITE A-1



Dense, dark organic matter

Sand topsoil, fine to medium, single grained fabric
Thin siliceous pan

Fluvial sand, fine-grained, with grains to 2.0mm, well-to sub-rounded, Fe concretions, secondary pedogenic silica, scattered Fe nodules, highly weathered Fe staining, residual ferricrete from eroded laterite

Clayey sand (CS), with large PSD, fabric development, well-rounded to sub-rounded

Indurated CS with large PSD range

The sub-soil material at 2.6m demonstrated post compaction deflocculation with field indications of Class 3(2)

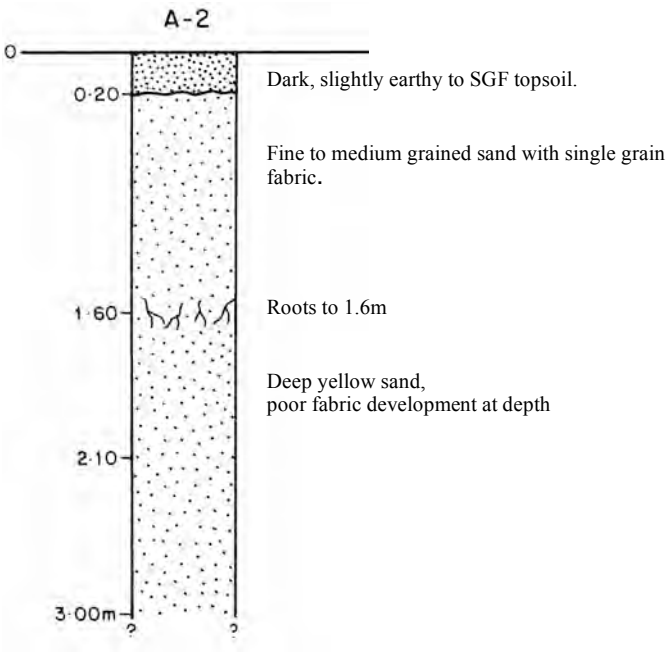
Location:
0317347E
6745950N

Vegetation: (A. Harris)

Open Scrub to 3m of *Acacia scirpifolia* and *Hakea psillorrhyncha* over Heath to 1.5m dominated by *Banksia leptophylla* var. *melletica* over Open Dwarf Scrub to 0.8m of *Xanthorrhoea drummondii* and *Melaleuca leuropoma*, on a 2% slope within gently undulating terrain. Scattered *Banksia menziesii* and *Eucalyptus todtiana* trees to 4m occur in the area.

The Priority 3 species, *Verticordia luteola* var. *luteola* occurs within 50m west of this site. No evidence of drought stress was recorded. The site is on the boundary of the vegetation communities mapped by Woodman Environmental Consulting (WEC) as T2 and W6. However, the local vegetation structure fits the broader WEC description for community H2.

SITE A-2



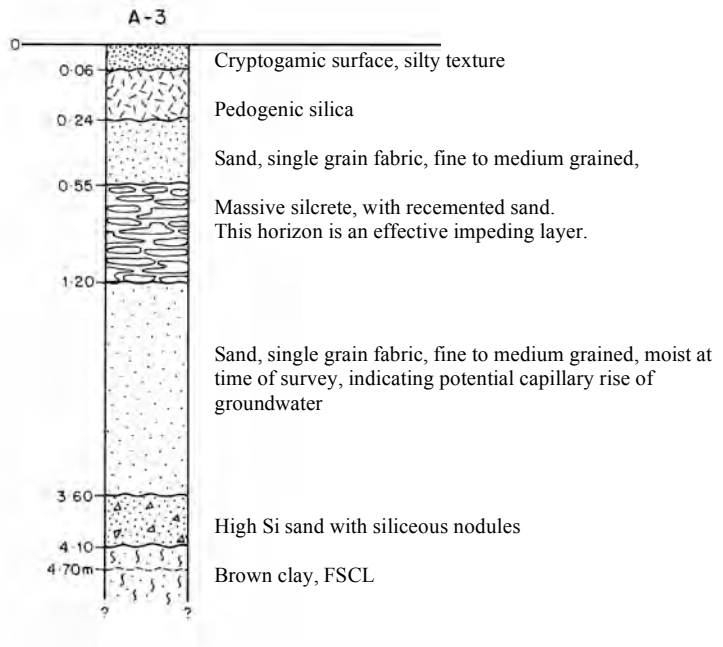
Location:
0317884E
6745960N

Vegetation: (A. Harris)

Low Scrub to 1.6m of *Banksia hookeriana* over Dwarf Scrub to 0.8m dominated by *Beaufortia elegans, Hakea polyanthema* P3 and *Melaleuca leuropoma* over Very Open Herbs and Tall Sedges dominated by *Conostylis aurea* and *Ecdeiocolea monostachya* on a 4% slope at high elevation within rolling terrain. Scattered *Eucalyptus todtiana* patches occur in the area.

No evidence of drought stress was recorded. The site is within the vegetation community mapped by WEC as H3 however, the local vegetation structure fits the broader WEC description for community T3.

SITE A-3



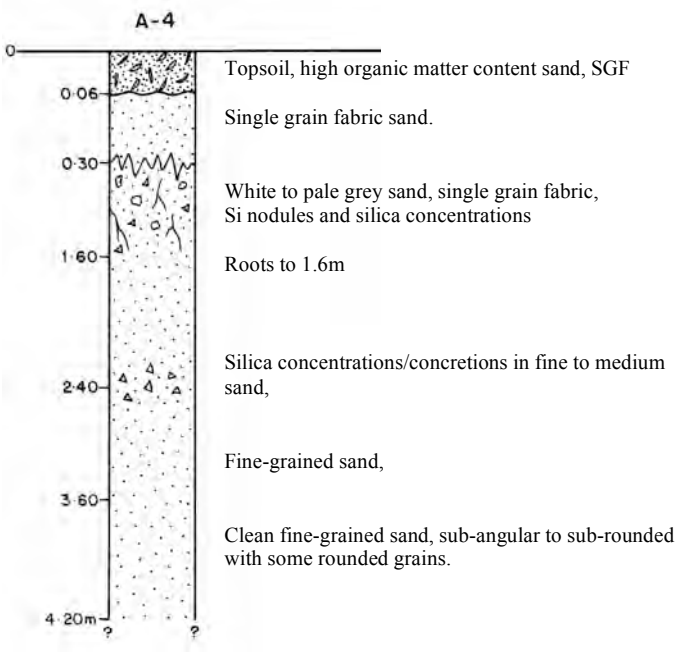
Location:
0317066E
6747426N

Vegetation: (A. Harris)

Thicket to 2.5m dominated by *Allocasuarina campestris* over Low Scrub to 1.7m dominated by *Melaleuca systena* on a 1% slope within a low-lying area. A 2-10% surface coverage of cryptogams was recorded and surface water ponding was evident. The vegetation was exhibiting signs of drought stress with 30-70% of foliar cover recorded as dead or chlorotic. The most affected species were *Allocasuarina campestris* and *Banksia leptophylla* var. *melletica.* The site is within the vegetation community mapped by WEC as T2 and also matches the description.

Drought stress within T2 vegetation at site A-3.
(Photo and caption: A Harris)

SITE A-4



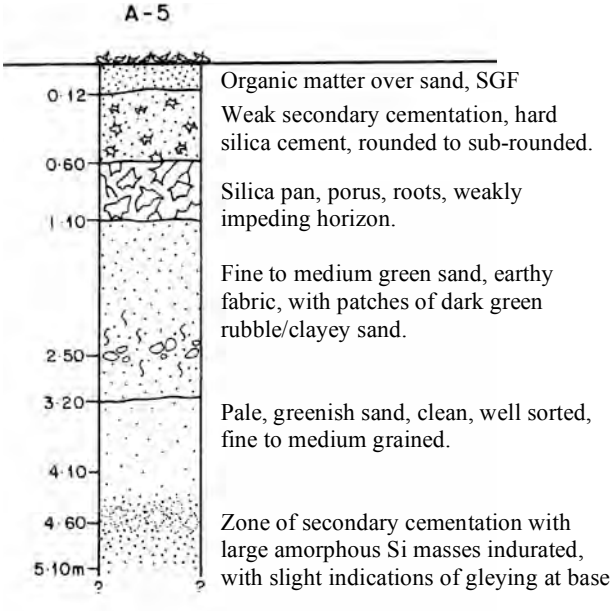
Location:
0316634E
6747393N

Vegetation: (A. Harris)

Low Forest to 4.5m of *Banksia prionotes* over Heath to 2m dominated by *Allocasuarina campestris* and *Banksia leptophylla* var. *melletica* on a 1% slope within a low-lying area.

The high density of foliage cover recorded for *Banksia prionotes* at this site is quite localised, and there was no evidence of drought stress recorded. It is within the vegetation community mapped by WEC as T1 however, the local vegetation structure fits the broader WEC description for community W4. No limestone was seen in the soil profile, which was recorded by WEC as occurring within the profile for W4 community.

SITE A-5



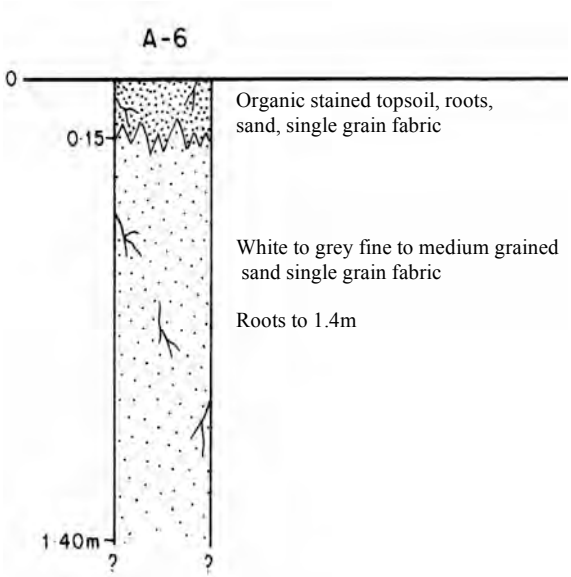
Location:
0316503E
6747396N

Vegetation: (A. Harris)

Dense Heath to 1.6m dominated by *Banksia leptophylla* var. *melletica* and *Actinostrobus pyramidalis* and associated *Melaleuca viminea* subsp. *viminea* and *M. huegelii* var. *huegelii* on flat terrain within a mid-level broad depression.

This site is within the vegetation community mapped by WEC as T2 however, the local vegetation structure fits the broader WEC description for community T1. The vegetation is regrowth after a hot fire ≥3yrs ago and may be the reason for the vegetation to be a Heath and not a Thicket. No evidence of drought stress was recorded at this site.

SITE A-6



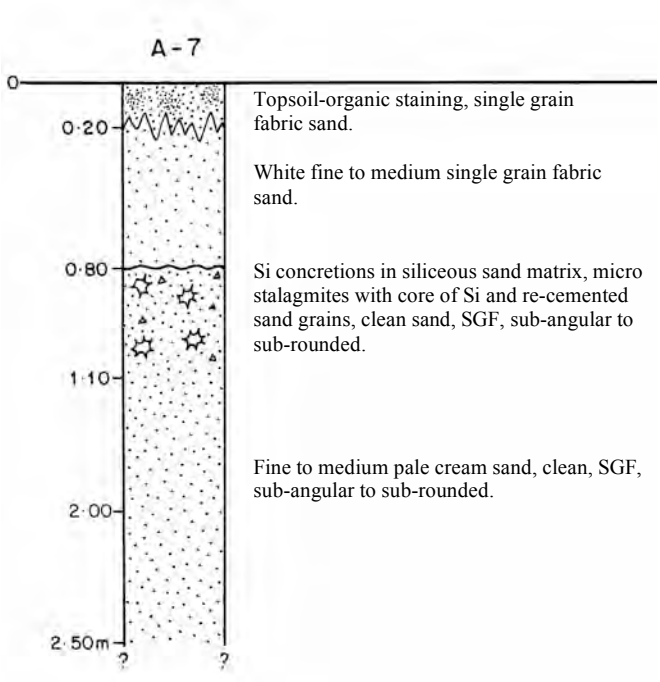
Location:
0316844E
6747388N

Vegetation: (A. Harris)

Thicket to 2.5m dominated by *Allocasuarina campestris* and *Acacia scirpifolia* over Dwarf Scrub to 1m dominated by *Melaleuca leuropoma* over Very Open Low Sedges to 0.15m of *Desmocladus asper* on a 1% slope at low elevation within gently undulating terrain.

No evidence of drought stress was recorded at this site, which is within the vegetation community mapped by WEC as T2 and also matches the description.

SITE A-7



Location:
0317633E
6747400N

The topsoil at this site demonstrates post compaction deflocculation, with a field indication of Class 3(2).

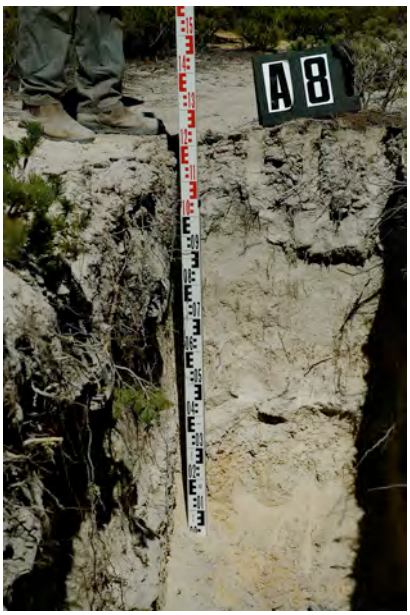
Vegetation: (A. Harris)

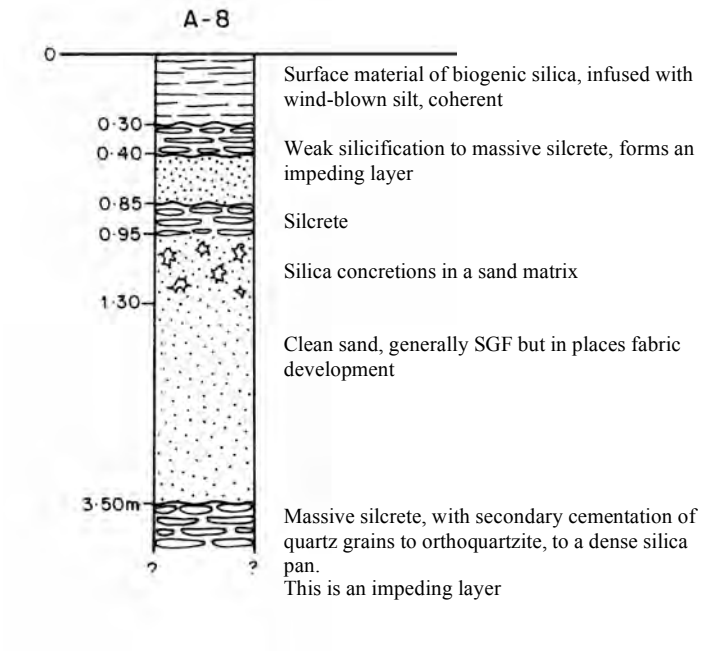
Open Low Woodland of *Banksia menziesii* to 3m over Low Scrub to 1.6m dominated by *Banksia attenuata and Actinostrobus pyramidalis* over Dwarf Scrub to 1m dominated by *Verticordia densiflora* var. *densiflora* over *Pterochaeta paniculata* Very Open Herbs on a 1.5% slope of a localised rise within a regional depression.

The vegetation was exhibiting signs of stress with 10-30% plant deaths recorded. The majority of dominant species at the site were affected and included *Actinostrobus pyramidalis, Verticordia densiflora* var. *densiflora, Eremaea beaufortioides* var. *microphylla, Stirlingia latifolia, Allocasuarina campestris, Melaleuca leuropoma* and *Petrophile brevifolia.* The stress is localised at the site and may be a spot infection of a pathogen from the adjacent track.

This site is within the vegetation community mapped by WEC as W6, and is a transition site between W6 and T1 with components of H2.

SITE A-8





Location:
0317991E
6747394N

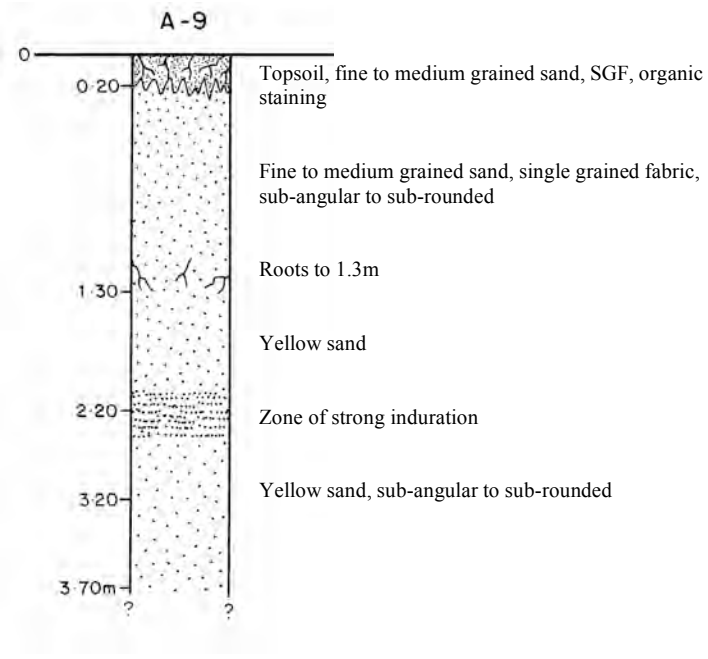
The surface material at this site demonstrated post compaction deflocculation with an indicated field class of 3(2)

Vegetation: (A. Harris)

Heath dominated by *Banksia leptophylla var. melletica* to 1.4m over Dwarf Scrub to 0.8m dominated by *Calothamnus hirsutus* at the base of a 4% slope within a regional depression.

No evidence of drought stress was recorded. The site is within the vegetation community mapped by WEC as H3 however, the local vegetation structure fits the broader WEC description for community H2.

SITE A-9



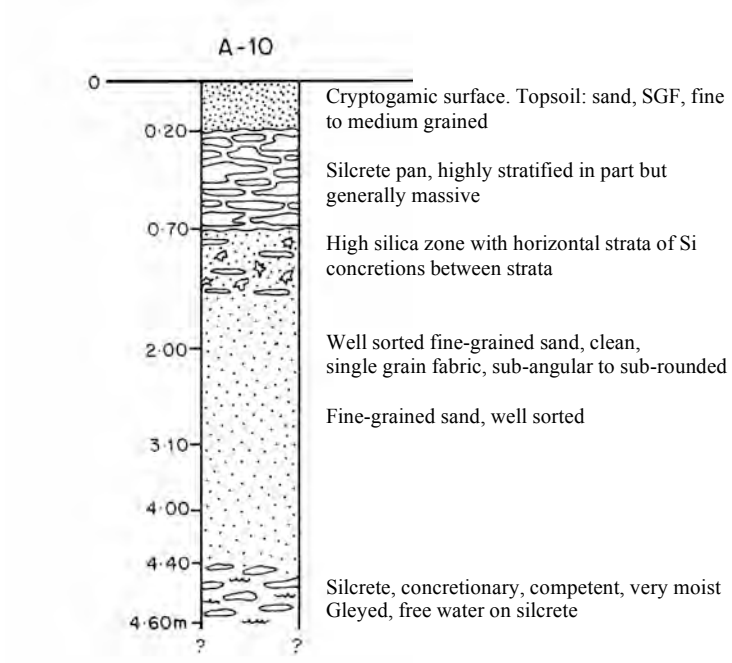
Location:
0318298E
6747449N

Vegetation: (A. Harris)

Open Low Woodland to 3.5m of *Xylomelum angustifolium* and *Eucalyptus todtiana* over Low Scrub to 1.7m dominated by *Banksia hookeriana* and *Calothamnus blepharospermus* over Dwarf Scrub to 0.8m dominated by *Hakea polyanthema* P3, over Very Open Low Sedges to 0.4m of mixed species at the rise of a 4% slope.

No evidence of drought stress was recorded. The site is within the vegetation community mapped by WEC as H3 however, the local vegetation structure fits the broader WEC description for community W5 with components of H3.

SITE A-10



Location:
0316957E
6747875N

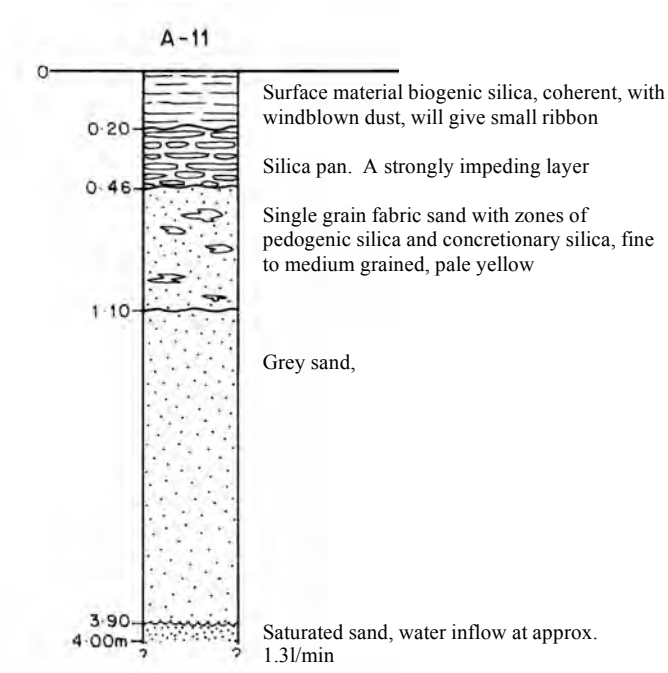
Vegetation: (A. Harris)

Scrub to 3m dominated by *Melaleuca cardiophylla* and *M. huegelii* var. *huegelii* over Dwarf Scrub to 0.8m dominated by *Guichenotia macrantha* on flat terrain within a drainage area that is a seasonal wetland.

The vegetation was exhibiting signs of stress with >50% plant deaths noted with 2-10% of those being recent plant deaths due to drought. The most affected species were *Melaleuca cardiophylla* and *Guichenotia macrantha.* The vegetation community would have been a Thicket before drought stress reduced the foliar cover.

The site is within the vegetation community mapped by WEC as T2, and also matches the community description of T2 with components of T4.

SITE A-11



Location:
0317118E
6749316N

The surface material demonstrated post compaction deflocculation with a demonstrated field class of 3(1). Surface infiltration rate was 120 -180mm/h

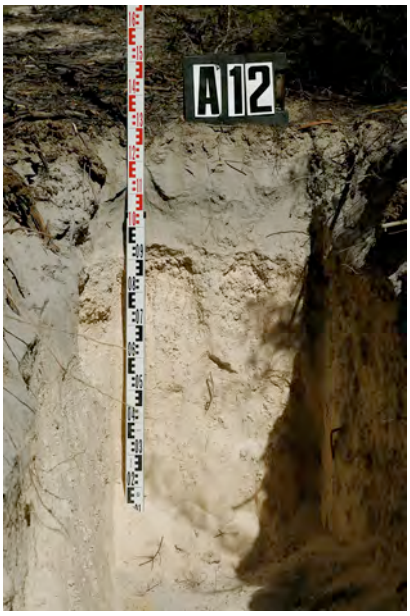
Vegetation: (A. Harris)

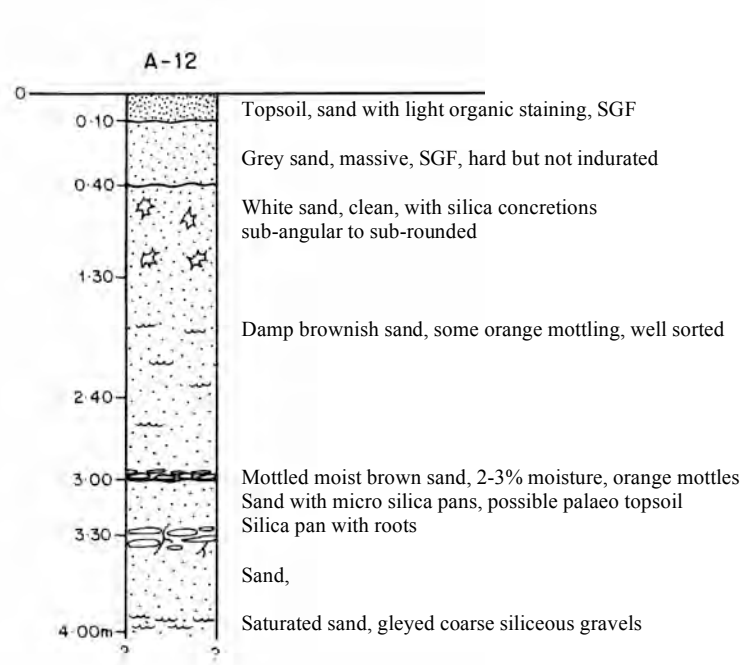
Open Scrub to 1.9m dominated by *Actinostrobus pyramidalis* over Heath to 1.7m dominated by *Banksia leptophylla* var. *melletica* and *Hakea trifurcata* over Open Dwarf Scrub to 0.3m dominated by *Calothamnus hirsutus* on low-lying flat terrain.

No evidence of drought stress was recorded. The site is within the vegetation community mapped by WEC as T1, and also matches the community description of T1 with components of H2.

The surface horizon at this site (biogenic silica combined with wind-blown dust) has similar characteristics to a low clay content soil material, with regard to water penetration. The pH level of 5.5 indicates moderately acid soils. The surface infiltration rate was measured at 120 to 180mm/hr. The dominant impact on surface conditions is the presence of an impeding layer at 0.2m below the surface.

SITE A-12

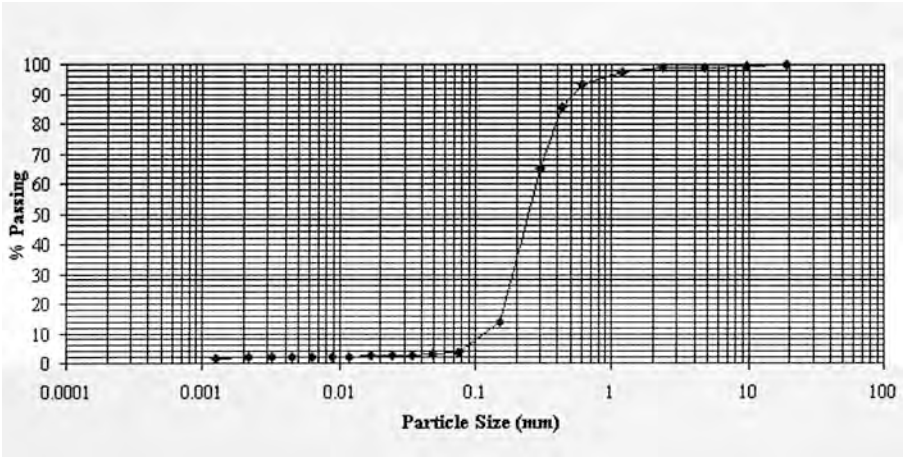




Location:
0317382E
6749319N

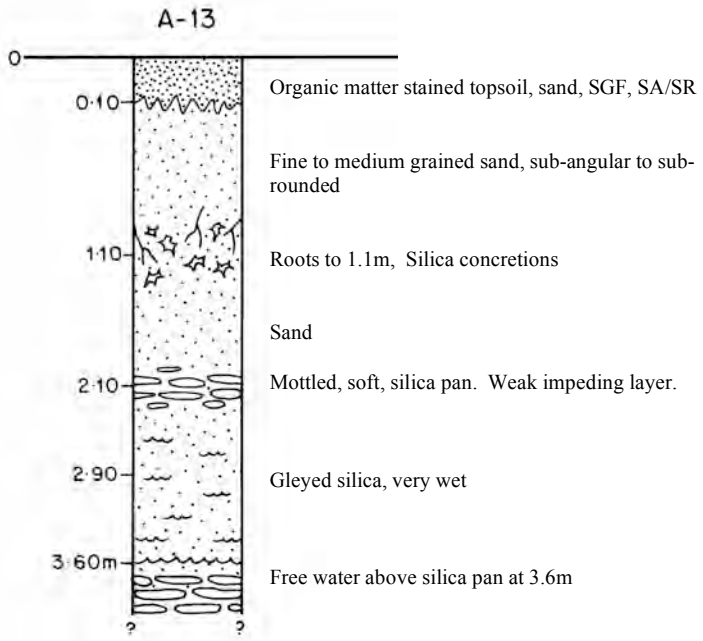
Vegetation: (A. Harris)

Open Low Woodland to 3.5m of *Banksia prionotes* over Scrub to 2.5m of *Actinostrobus pyramidalis* and *Eremaea beaufortioides* var. *microphylla* over Heath to 1.6m dominated by *Banksia leptophylla* var. *melletica, Verticordia densiflora* var. *densiflora* and *Calothamnus quadrifidus* at high elevation locally, within regionally undulating terrain that contains many low-lying flat areas of Heath vegetation. This site is within the vegetation community mapped by WEC as T1 however, the local vegetation structure fits the broader WEC description for community H2 with components of W4. No limestone was found to occur within the soil profile, as was recorded with the W4 community by WEC. There is no evidence of current drought stress at this site. Micro-silica pans forming at 3.3m will benefit water retention of the soil above for longer periods. Free water was found to occur at 4.1m, which is accessible to the *Banksia prionotes* roots. Therefore, saturation of the soil occurring at 4.1m, along with higher water retention of the soils above the silica pans affords protection from insufficient meteoric input through drier periods.



Particle Size Distribution Curve: Saturated siliceous sands at 4.0m

SITE A-13

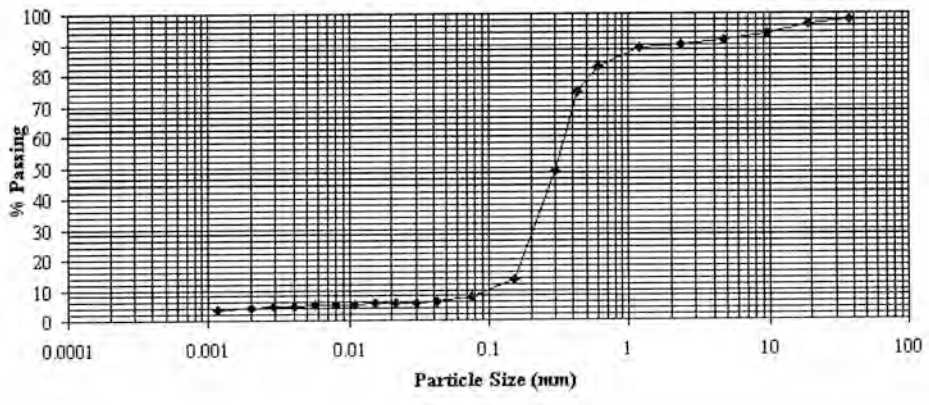


Location:
0317853E
6749546N

Vegetation: (A. Harris)

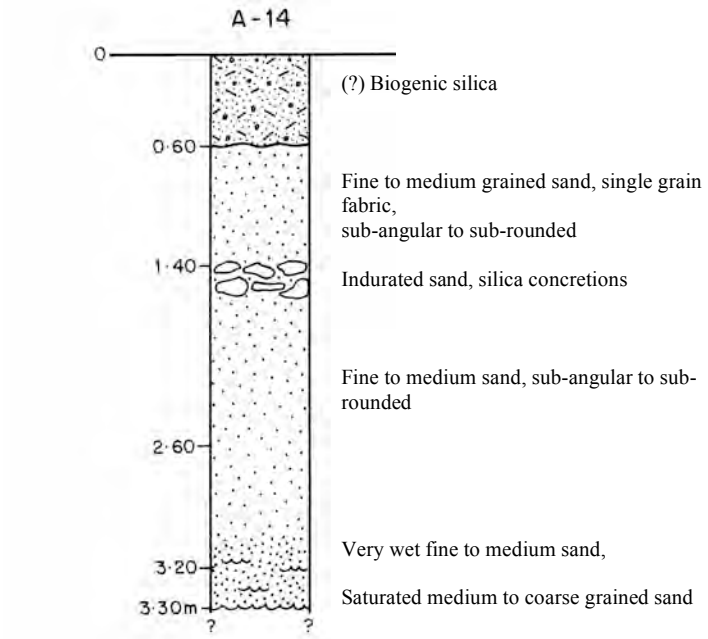
Low Woodland to 5m dominated by *Banksia prionotes,* and *B. elegans* P4, over Scrub to 3m dominated by *Acacia scirpifolia* over Low Scrub to 1.8m dominated by *Banksia leptophylla* var. *melletica* and *B. attenuata* over Dwarf Scrub to 0.9m dominated by *Hibbertia hypericoides* on the rise of a sand dune. An extremely old large *Melaleuca preissiana* was recorded growing ~45m south-west of the site with *Eucalyptus gittinsii* subsp. *illucida.*

No evidence of drought stress was recorded at this site, which is within the vegetation community mapped by WEC as T1, and does not align with any of the other community descriptions. The vegetation was recorded as the healthiest of any seen during the project with high species diversity, and appears to be a transitional Woodland between mapped Thickets.
The most notable difference in the vegetation at this site when compared to other sites is that the structure consists of four layers of shrubs with sedges present at a low density, rather than one or two more dense layers.



Particle size distribution in gleyed sand at 3.6m

SITE A-14

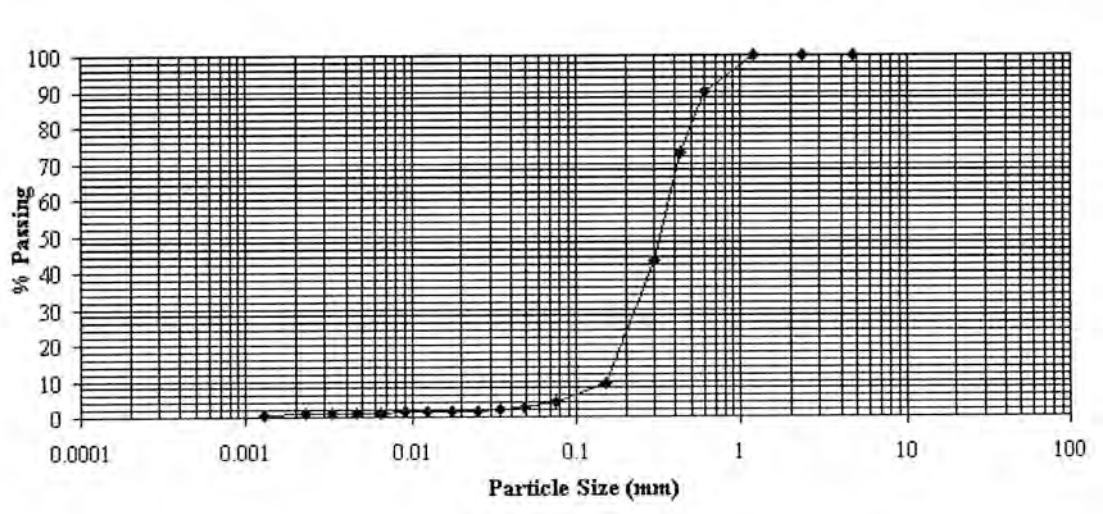


Location:
0318675E
6749561N

Vegetation: (A. Harris)

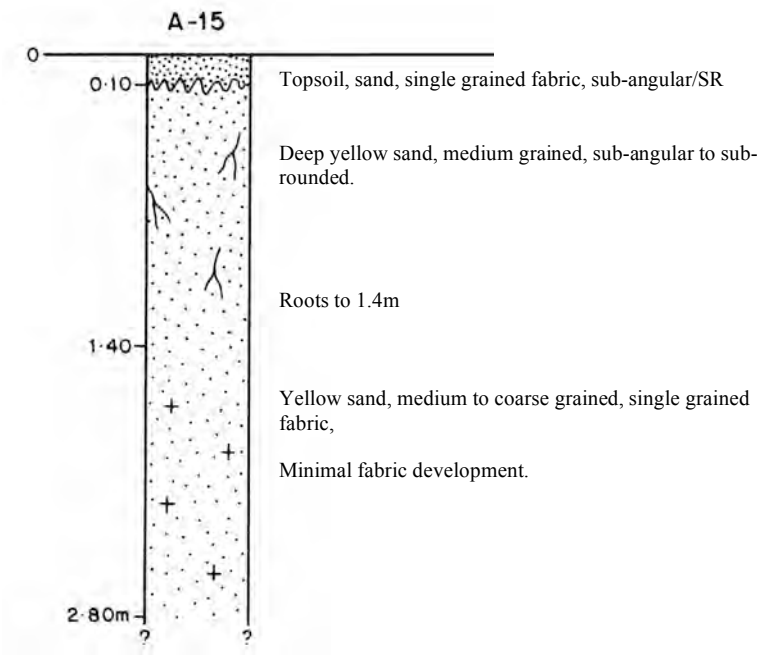
Scrub to 3.5m of *Acacia scirpifolia* over Heath to 1.8m with co-dominants of *Calothamnus quadrifidus, Banksia leptophylla* var. *melletica*, *Melaleuca systena*, *Verticordia densiflora* var. *densiflora* and *Allocasuarina campestris* on a 3% slope at high elevation locally.

The Priority 4 species, *Banksia elegans* occurs at the site. No evidence of drought stress was recorded. The site is within the vegetation community mapped by WEC as T1 however, the local vegetation structure fits the broader WEC description for community T2.



Particle Size Distribution Curve: Saturated sand at 3.3m

SITE A-15



Location:
0319545E
6749554N

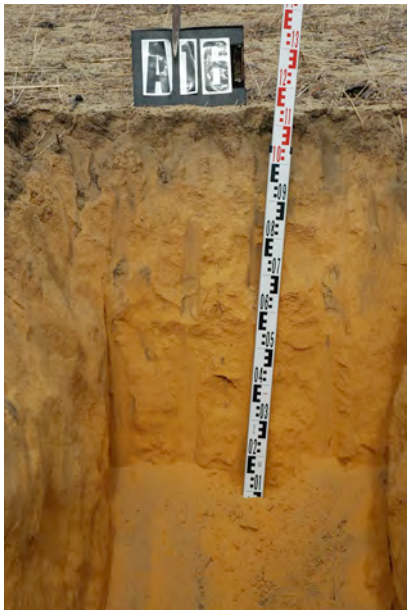
Vegetation: (A. Harris)

Heath to 1.3m dominated by *Eremaea beaufortioides* var. *microphylla* and *Hakea polyanthema* P3 over Open Tall Sedges to 0.8m dominated by *Ecdeiocolea monostachya* on a 2% upper slope of a rolling sand dune.

The Priority 1 species, *Mesomelaena stygia* subsp. *deflexa* occurs at the site. The vegetation was exhibiting signs of drought stress with 10-30% plant deaths recorded. The most affected species were *Hakea polyanthema, Banksia hookeriana, Eremaea beaufortia* var. *microphylla,* and *Daviesia divaricata* subsp. *divaricata*.

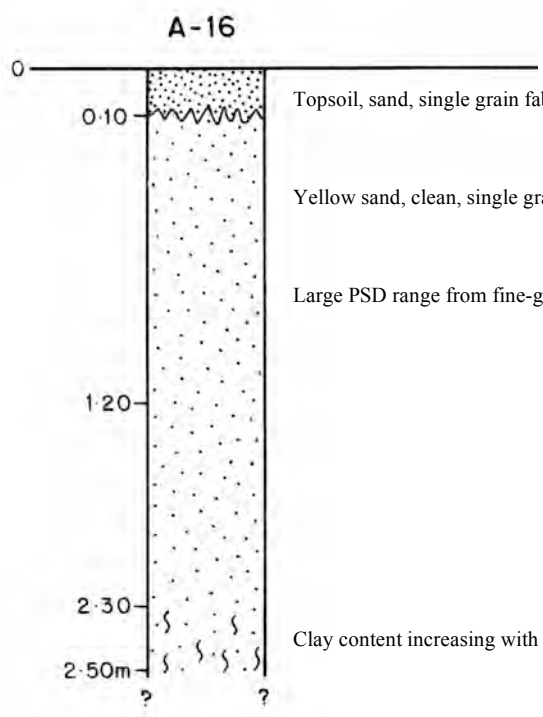
The site is within the vegetation community mapped by WEC as T3 however, the local vegetation structure fits the broader WEC description for community H3.

SITE A-16



Location:
0318582E
6750645N

This site is an old cultivation site.



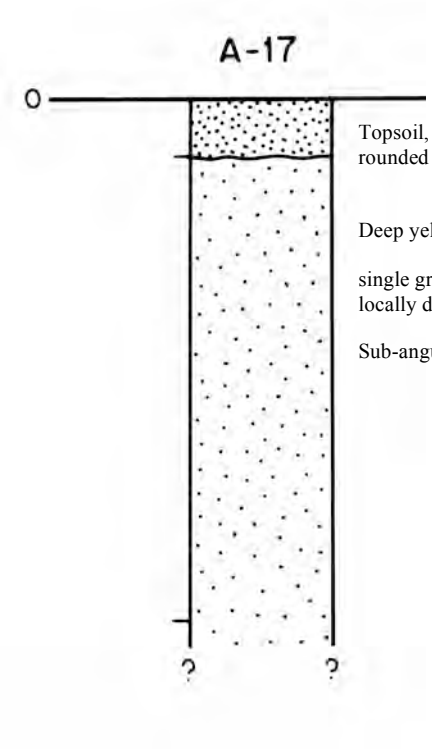
Topsoil, sand, single grain fabric, some organic staining

Yellow sand, clean, single grain fabric, sub-angular to subrounded

Large PSD range from fine-grained sand to coarse-grained sand.

Clay content increasing with depth, estimated clay content at 2.5m is 2-3%

SITE A-17



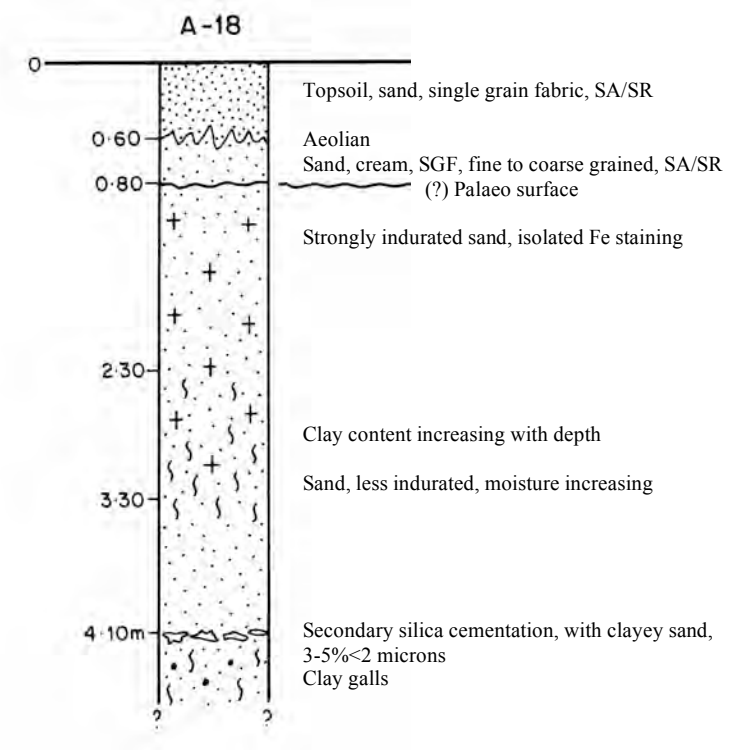
Topsoil, sand, single grain fabric, sub-angular to sub-rounded

Deep yellow sand,

single grain fabric but with minimal fabric development locally down the profile

Sub-angular to sub-rounded

A-18



Topsoil, sand, single grain fabric, SA/SR

Aeolian
Sand, cream, SGF, fine to coarse grained, SA/SR
(?) Palaeo surface

Strongly indurated sand, isolated Fe staining

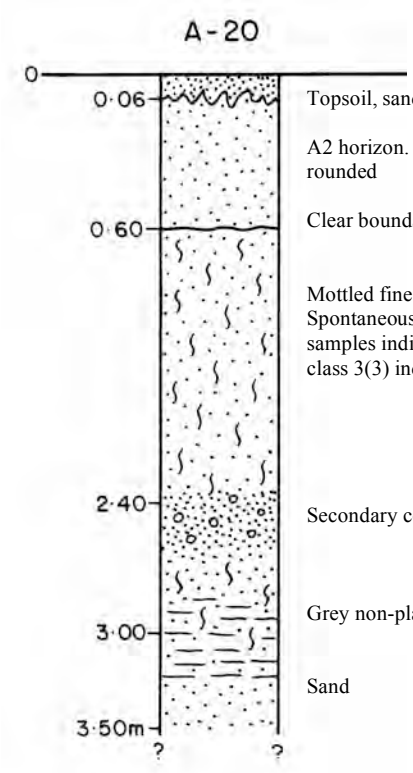
Clay content increasing with depth

Sand, less indurated, moisture increasing

Secondary silica cementation, with clayey sand,
3-5%<2 microns
Clay galls

SITE A-20

This site is in the centre of a drainage depression in pasture land



Topsoil, sand, SGF, sub-angular to sub-rounded

A2 horizon. Sand, single grain fabric, sub-angular to sub-rounded

Clear boundary to

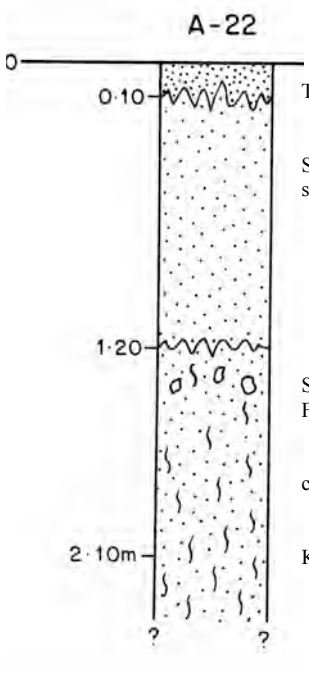
Mottled fine sandy clay loam (FSCL)
Spontaneous dispersion, field class 2(1) and also additional samples indicated post compaction deflocculation with field class 3(3) indicated.

Secondary cementation of sand with sub-rounded qtz grains

Grey non-plastic silty clay, kaolinitic

Sand

SITE A-22



Topsoil, organic staining, sand, SGF

Sand, single grained fabric,
sub-angular to sub-rounded

Sand to clayey sand with orange mottles,
Fe staining,

clay content increasing with depth

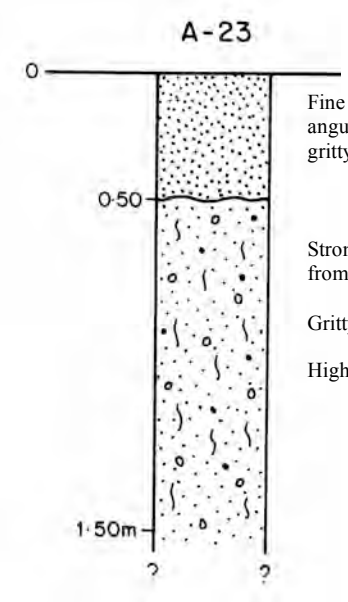
Kaolinitic mineralogy

SITE A-23

Vegetation: (A. Harris)

Low Heath to 0.5m dominated by *Melaleuca aspalathoides* and *Dryandra carlinoides* over Open Low Sedges dominated by *Mesomelaena pseudostygia* and *Ecdeiocolea monostachya* on a 4% regional slope.

No evidence of drought stress was recorded. The site is on the boundary of the vegetation communities mapped by WEC as H3 and H5. The local vegetation structure fits the broader WEC description for community H5. Evidence of surface water flow was noted, which is a consequence of the shallow impeding layer of cemented iron gravel found within the soil profile. Such a layer allows water to only penetrate slowly.



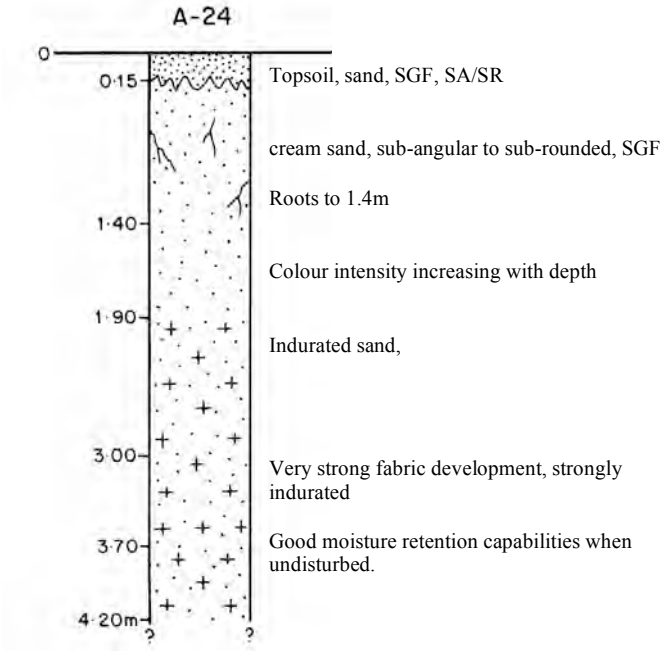
Fine to coarse-grained white sand, single grained fabric, sub-angular to sub-rounded
gritty, with grains to 3mm

Strongly mottled deltaic-outwash fan sediment, Fe staining from weathering Fe nodules, quartz grains to 3mm,

Gritty sand matrix with higher induration levels, competent, hard

Highly variable clay content

SITE A-24

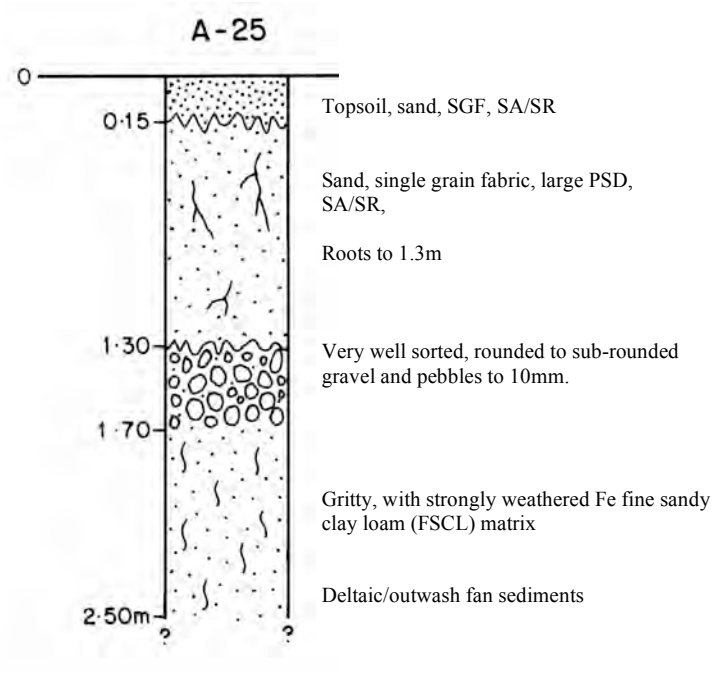


Vegetation: (A. Harris)

Heath to 1.3m dominated by *Hakea polyanthema* P3 and *Calothamnus blepharospermus* over Open Low Sedges to 0.5m of *Ecdeiocolea monostachya* on a 2% local upper slope within undulating terrain. Scattered patches of *Eucalyptus todtiana* and *Acacia scirpifolia* occur within the area.

No evidence of drought stress was recorded. The site is within the vegetation community mapped by WEC as H3 and also matches the description.

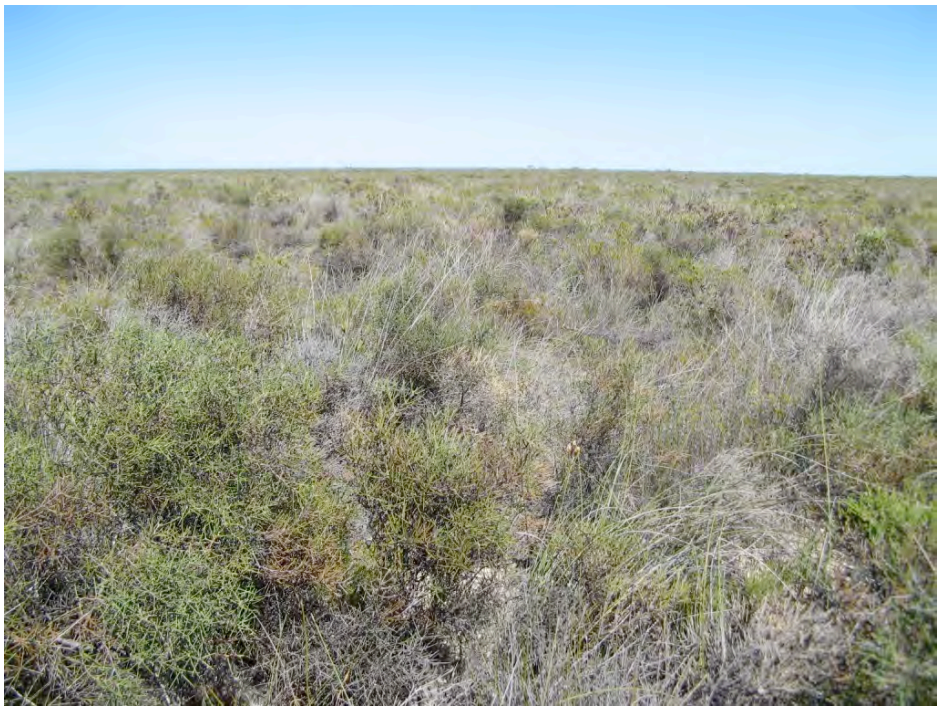
SITE A-25



Vegetation: (A. Harris)

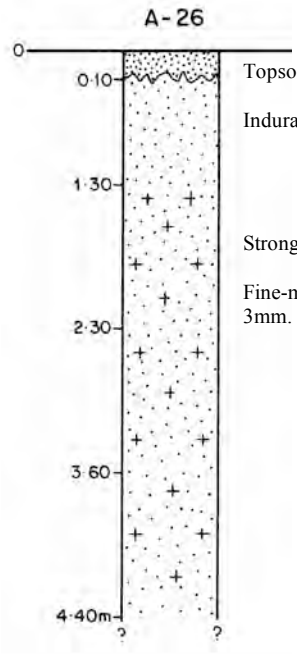
Low Heath dominated by *Hakea polyanthema* P3 over Open Tall Sedges of *Ecdeiocolea monostachya* and *Mesomelaena pseudostygia* on a 2% slope within gently undulating terrain.

The Priority 3 species, *Isopogon tridens,* and the Priority 2 species, *Persoonia filiformis* occur at the site. No evidence of drought stress was recorded. The site is within the vegetation community mapped by WEC as H3 and also matches the description.



Vegetation typical of an H3 community (A. Harris: photo and caption)

SITE A-26



Topsoil, sand, SGF, SA/SR

Indurated sand with strong fabric development

Strongly indurated sand,

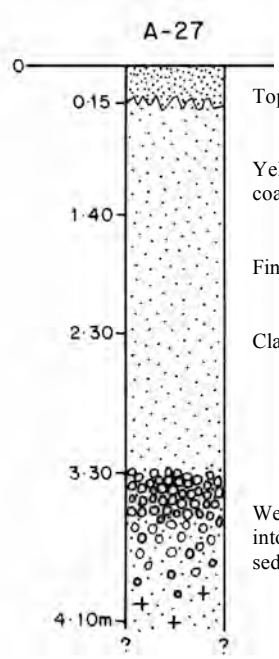
Fine-medium-coarse sands with quartz grains to 3mm.

Vegetation: (A. Harris)

Low Scrub to 1.3m dominated by *Banksia candolleana* and *B. attenuata* over Dwarf Scrub to 0.9m dominated by *Hakea polyanthema* P3 over Open Tall Sedges dominated by *Ecdeiocolea monostachya* on a 1% slope within gently undulating terrain. Scattered patches of *Eucalyptus todtiana* and *Xylomelum angustifolium* occur within the area.

The Priority 3 species, *Isopogon tridens* occurs at the site. No evidence of drought stress was recorded. The site is within the vegetation community mapped by WEC as H3 and also matches the description of H3 community with components of W5.

SITE A-27



Topsoil, sand, SGF, SA/SR

Yellow sand, some fabric development, coarse to medium grained, SA/SR

Fines increasing with depth,

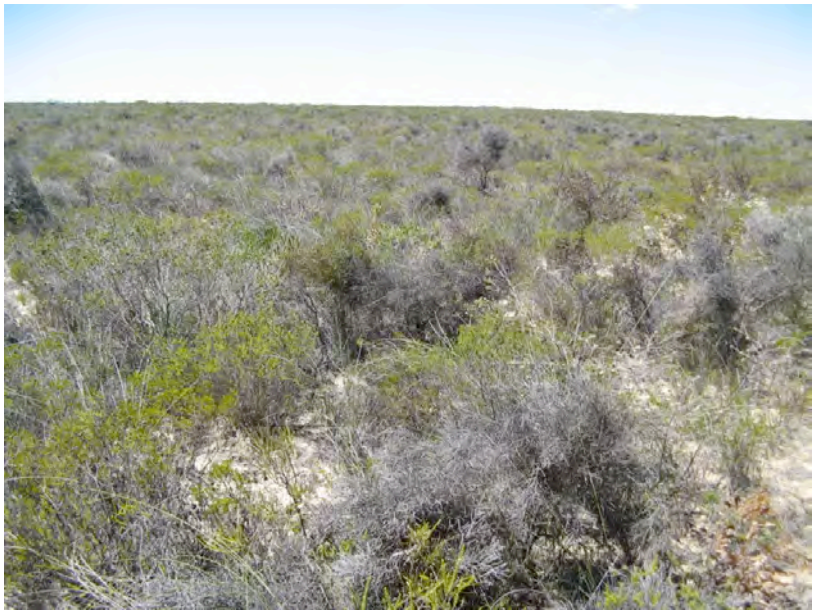
Clay content 3%

Well sorted, well rounded gravel layer, grading into indurated Fe weathering, hard, drainage line sediments

Vegetation: (A. Harris)

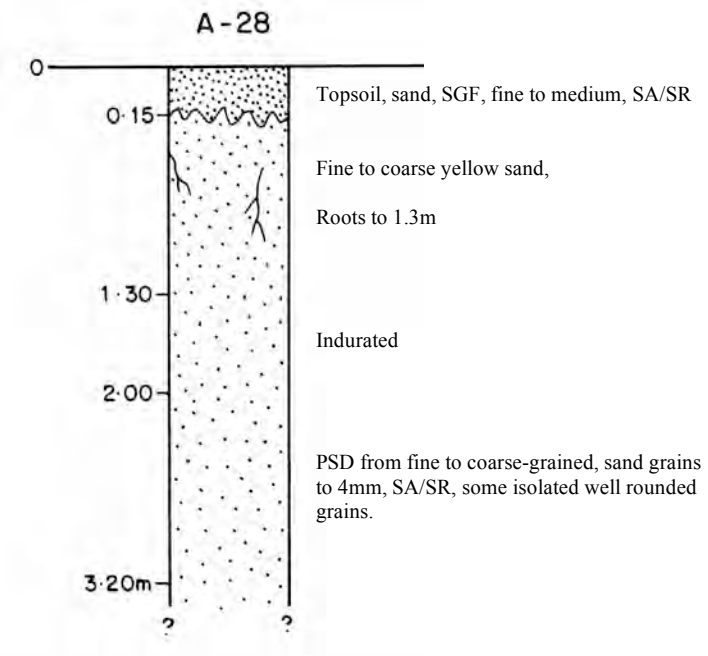
Low Scrub to 1.1m of *Hakea polyanthema* P3 and *Eremaea beaufortioides* var. *microphylla* over Dwarf Scrub to 0.5m dominated by *Melaleuca leuropoma* over Very Open Tall Sedges to 0.6m dominated by *Ecdeiocolea monostachya* on a 2% slope within gently undulating terrain. Scattered *Banksia candolleana* occurs in the area. The Priority 3 species, *Isopogon tridens* occurs at the site. The vegetation was exhibiting signs of drought stress with 10-30% plant deaths recorded. The most affected species were *Hakea polyanthema,* and *Petrophile macrostachya*. Vegetation in the area is still regenerating from a fire <3yrs ago and the recent drought stress is now affecting it. The structure of the community will become a Heath over time with adequate rainfall.

The site is within the vegetation community mapped by WEC as H3 and also matches the description.



Vegetation of H3 showing drought stress (Photo and caption A. Harris).

SITE A-28



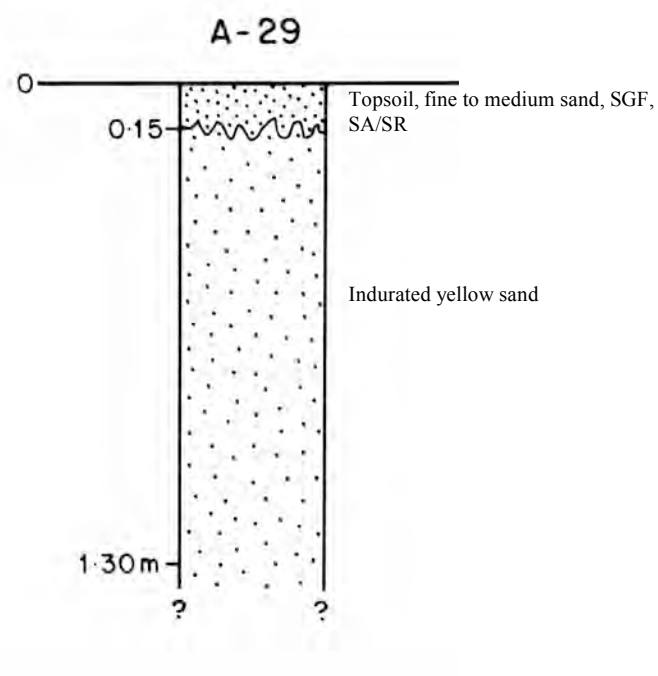
Vegetation: (A. Harris)

Low Scrub to 1.2m dominated by *Hakea polyanthema* P3 and *Banksia candolleana* over Dwarf Scrub to 0.8m dominated by *Calothamnus blepharospermus* and *Beaufortia elegans* over Open Tall Sedges to 0.8m dominated by *Ecdeiocolea monostachya* on a 2% slope within gently undulating terrain.

The vegetation was exhibiting signs of drought stress with 10-30% of foliar cover recorded as dead. The most affected species were *Hakea polyanthema, Eremaea beaufortioides* var. *microphylla, Daviesia divaricata* subsp. *divaricata* and *Dryandra lindleyana var. lindleyana*.

The site is within the vegetation community mapped by WEC as H3 and also matches the description.

SITE A-29



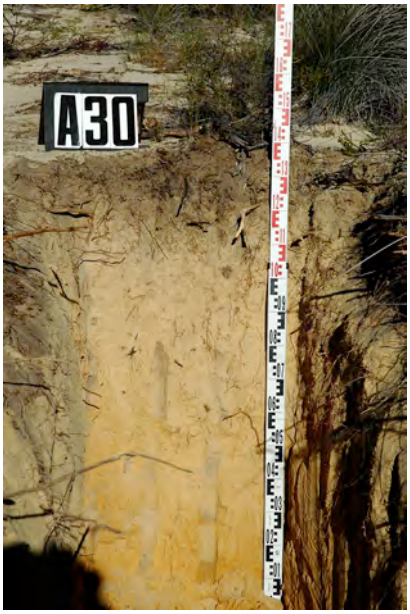
Vegetation: (A. Harris)

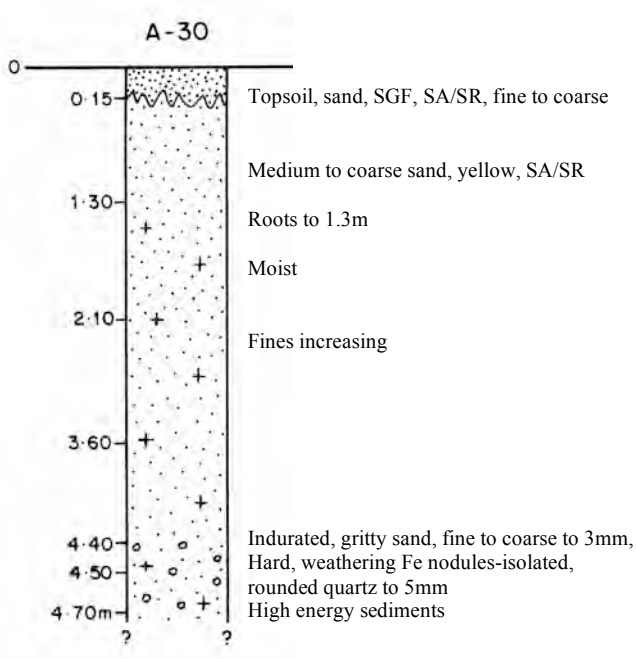
Low Scrub to 1.3m of *Calothamnus blepharospermus* and *Eremaea beaufortioides* var. *microphylla* over Dwarf Scrub to 0.8m dominated by *Daviesia divaricata* subsp. *divaricata* over Open Tall Sedges to 0.6m dominated by *Ecdeiocolea monostachya* on a 3% slope low in the landscape towards a drainage line. Scattered *Xylomelum angustifolium* to 3m occur in the area.

The vegetation was exhibiting signs of drought stress with 10-30% of foliar cover recorded as dead. The most affected species were *Banksia hookeriana,* and *Isopogon tridens* P3.

The site is within the vegetation community mapped by WEC as W6 however, the local vegetation structure fits the broader WEC description for community H3.

SITE A-30





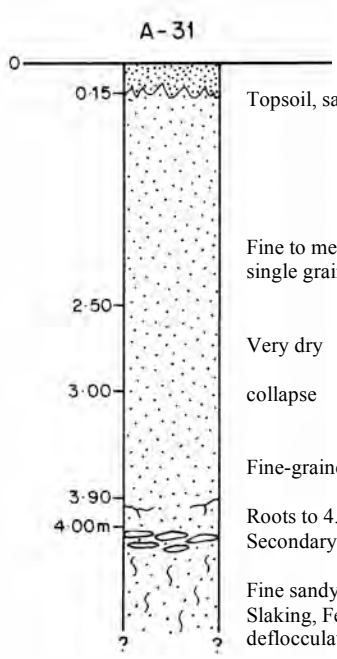
Vegetation: (A. Harris)

Low Scrub to 1.7m dominated by *Calothamnus blepharospermus, Hakea polyanthema* P3 and *Banksia attenuata* over Dwarf Scrub to 0.8m dominated by *Dryandra shuttleworthiana* and *Melaleuca leuropoma* over Open Tall Sedges dominated by *Ecdeiocolea monostachya* on a 3% slope at high elevation within undulating terrain. Isolated *Xylomelum angustifolium* trees occur in the area.

The Priority 3 species, *Isopogon tridens* occurs at the site. The vegetation was exhibiting signs of drought stress with 2-10% of foliar cover recorded as dead. The most affected species was *Hakea polyanthema* P3.

The site is within the vegetation community mapped by WEC as T3 however, the local vegetation structure fits the broader WEC description for community H3, of which the mapped boundary is 160-180m to the north.

SITE A-31



Topsoil, sand, SGF, fine to medium

Fine to medium white sand,
single grain fabric, sub-angular to sub-rounded

Very dry

collapse

Fine-grained white sand,

Roots to 4.0m in moist, indurated coarse sand.
Secondary cementation of fine sand grains, massive

Fine sandy clay loam to sandy clay
Slaking, Fe staining, post compaction
deflocculation, class 3(2)

Location:
0319470E
6735431N

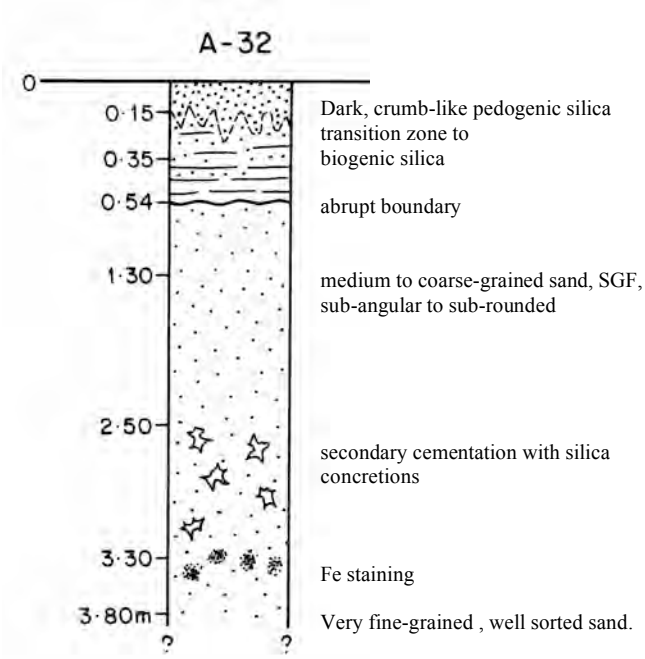
Vegetation: (A. Harris)

Open Low Woodland to 5m of *Eucalyptus todtiana, Banksia menziesii* (tree form) and *Nuytsia floribunda* over Heath to 1.6m dominated by *Banksia leptophylla* var. *melletica, B. attenuata* over Open Dwarf Scrub to 0.6m dominated by *Melaleuca leuropoma* and *Stirlingia latifolia* over Very Open Low Sedges to 0.3m dominated by *Ecdeiocolea monostachya* on a 6% slope low in the landscape towards a drainage area of a long rolling dune. Scattered *Melaleuca preissiana* trees occur in the area.

The Priority 4 species, *Banksia elegans* occurs in the area. No evidence of drought stress was recorded. The site is within the vegetation community mapped by WEC as W7 and also matches the description. This community is reported as being not well represented within the area.

Vegetation within the W7 community (Photo and caption A.Harris)

SITE A-32



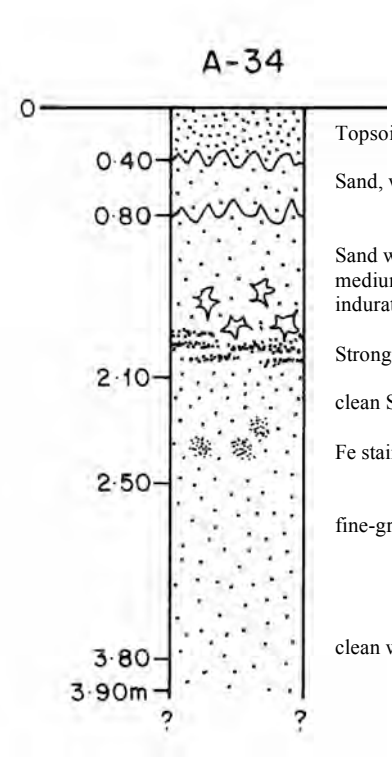
Location:
0318775E
6735415N
Vegetation: (A. Harris)

Open Scrub to 2.3m of *Allocasuarina campestris* over Low Scrub to 1.8m dominated by *Acacia rostellifera* and *Banksia leptophyllya* var. *melletica* on a flat surface within a broad circular depression. The depression has steep edge slopes of 11%. The vegetation was exhibiting signs of severe drought stress with 30-70% of foliar cover recorded as dead. Between 80-100% of foliage on all dominant species was affected. Of note, is that all of the plants of the less dominant species, *Calothamnus quadrifidus* remained healthy. The site is within the vegetation community mapped by WEC as T2. Due to the severity of stress symptoms, the vegetation structure at this site has been altered from a Thicket to an Open Scrub over Low Scrub. The species description still matches that of the WEC community T2.

The T2 community does not occupy the entire basin as mapped. Only 20m to the north of the site, the community changes to H2, where *Banksia leptophylla* var. *melletica* and *Calothamnus hirsutus* are dominant. Again the *Calothamnus* species do not show the same severity of drought stress as the other plants.

Vegetation within the T2 community showing severe drought stress.
(Photo and caption: A Harris)

SITE A-34



Topsoil, dark brown sand, SGF, SA/SR

Sand, weak induration

Sand with discrete silica concretions,
medium to coarse-grained,
indurated

Strongly indurated silica/sand, this is an impeding layer

clean Sandra

Fe stained sand, with galls of Fe sand, indurated

fine-grained, clean white sand

clean white sand.

Vegetation: (A. Harris)

Scrub to 2.5m dominated by *Acacia scirpifolia* over Low Scrub to 0.8m dominated by *Calothamnus quadrifidus* and *C. homalophyllus* over Open Herbs of *Waitzia acuminata* and Open Low Sedges of *Desmocladus asper* on a 2.5% slope on the edge of a drainage depression.

The vegetation was exhibiting signs of severe drought stress with 30-70% of foliar cover recorded as dead. The most affected species were *Acacia scirpifolia, Melaleuca systena* and *Desmocladus asper*. Both *Calothamnus* species did not show stress symptoms. The site is within the vegetation community mapped by WEC as H1 (on the border of W6). The local vegetation structure in part matches the description of H1; however the dominant species are those of H4. The loss of foliar cover has altered the vegetation structure to that of a Scrub over Low Scrub rather than a Heath.

Vegetation showing severe symptoms of drought stress within an H1 community. (Photo and caption: A Harris)

5.0 DISCUSSION

5.1 DISPERSION

Dispersion was examined in the field with samples from a range of profile depths and from all soil landscapes. Typically, fine sandy clay loams exposed at depth indicated both spontaneous dispersion [A-20, 2(1) at 0.8m] and at one site, A-31, post compaction deflocculation (PCD) was observed [3(2)] at a depth of 4.0m.

Of greater interest was the presence of PCD in surface materials in the palaeo lacustrine sediments where aggregate stability classes of 3(1, 2) were observed. 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 kinetic energy of raindrop impact, the passage of implements of tillage, or the removal transport, and replacement of soil material by mining machinery. Following an episode of energy input, an aggregate stability class of 3 will be observed. The level of dispersion will define the sub-class and hence the intensity of dispersion. 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.

Biogenic silica was present as a surface material at two of these sites, A-8, and A-11. It is suggested that minute amounts of clay were present as it was possible to get a 'ribbon' up to 5mm long when the material was sheared at field moisture capacity. Further, organic matter present in the sediment may have contained enough electrical charge to attract Na^+ ions, resulting in dispersion. Site A-7 where the surface material was sand, also demonstrated PCD with an aggregate stability class of 3(1). This surface material appeared to be very low in clay but high in organic matter. The dispersion present at this site is shown in Plate 1.

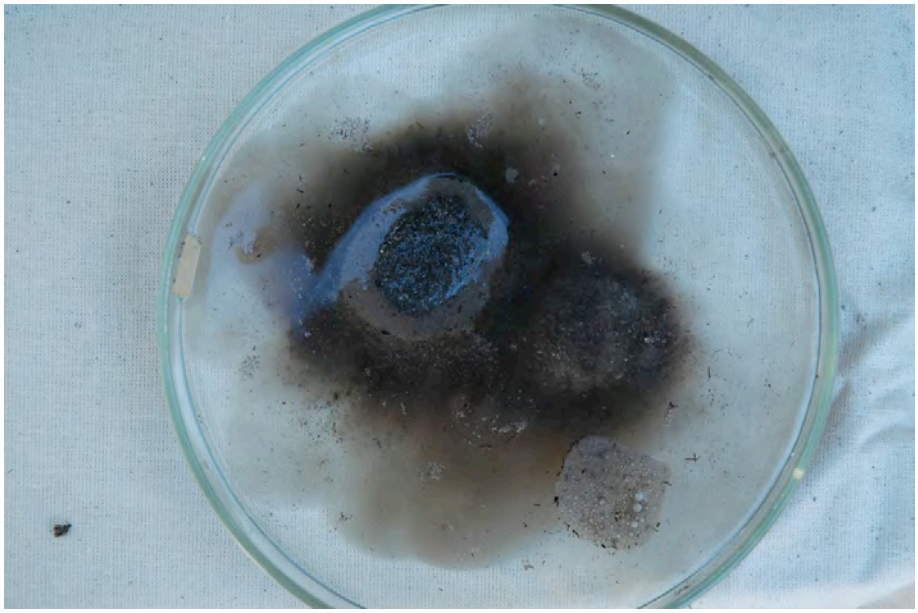


Plate 1 Topsoil from site A-7 showing post compaction deflocculation with a field aggregate stability class of 3(1) demonstrated.

None of the dispersive soils examined in the field pose problems for environmental management beyond normal strategies and techniques for reducing the dispersion percentage to below 30% and reducing ESP's to as close to 6 as possible. The key issue derived from the data to date is the presence of PCD in surface soil and topsoil. Again, aggregate stability classes of 3(1) and 3(2) do not pose special problems for management and such soils are readily treated with gypsum at rates of approximately 2-5t/ha/m_v. These suggested rates are subject to confirmation once replacement landforms and soil profile reconstruction criteria have been determined.

5.2 INDURATION AND MOISTURE RETENTION

As with the results from the Stage 1 survey, the profiles examined during the Stage 2 survey also demonstrated high levels of induration. While this may, in part, be due to the greater age of the sediments, it is also partly due to the presence of iron oxides in the soil resulting from the transport of high iron content materials from the Gingin Scarp onto the plain, and to eluviation. The presence of the remnants of weathered ferricrete debris is ubiquitous throughout the Eastern Ferricrete Landscape and soil profiles in this landscape demonstrated high degrees of competence in terms of strength.

This trend of competent sand profiles continues into the Central Sand Plain and most profiles examined showed strong fabric development at depth. The high levels of fabric development and the degree of induration present suggest that these materials will have elevated moisture retention capabilities in the undisturbed state.

The areas demonstrating the least competent materials again occurred in the Western Relict Palaeo Lake landscape where the subsurface sediments examined tended to be very clean and well sorted sand, often very fine grained.

5.3 THE RELICT PALAEO LAKE SYSTEM

This soil landscape was further investigated in some detail to examine the potential links with the central sand plain immediately adjacent to the east and to assess internal lake structure and stratigraphy, all as part of ongoing assessment of potential environmental impacts with proposed mining of Zeus. Also of interest were issues associated with profile reconstruction following mining and landform re-instatement in terms of profile function.

The palaeo system, as it stands today, is complex. The complexity lies in lateral discontinuity of individual profile stratigraphy. It is likely that if enough inspection pits were excavated, a trend would emerge. However, such detail is not necessary to determine the relationship with the adjacent sand plain, nor for an understanding of internal structure.

Data available to date suggest that the palaeo lake system was once a series of discrete shallow basins, probably alternating between being interconnected and to being isolated. The scale of basins was probably in the order of tens of metres up to hundred's of metres. The Dongara project area system, which comprises the three soil landscapes, appears to fit well with the model that suggests, that for southern Australia, a period of moist and cool climates were associated with the early stages of the last interglacial period some 120,000 years ago. During this time, there were periods of increased stream flow and sediment movement, together with associated deposition (formation of the eastern ferricrete/clay soil landscape). With development of the last glacial maxima, about 18,000 years ago (McKenzie *et al.* 2004, Kershaw, 1989), climates became cooler and dryer, what I have called in previous work, the onset of aridity. As a result of this glacial maxima, a temperature differential was established between equatorial and polar regions, resulting in increased winds, which in turn, resulted in major dune building activity across Australia. This concept of the onset of aridity is further supported by Krauss *et al.* (2006) who used OSL, (optically stimulated luminescence) to date the last period of mobility of sand dunes on the Eneabba Plain and adjacent scarp at between 15,000 and 35,000 years before present.

As I have noted previously (Blandford 2007), the characteristics of the sand sheet forming the central sand plain suggests an on-lapping relationship with the eastern ferricrete/clay landscape and the palaeo lake system. The data gathered during this survey further support this hypothesis. Profile morphology and stratigraphy across the palaeo lake system show a number of basins separated by sand ridges and allowing for a surface levelling effect by water, the stratigraphic relationships shown in Figure 4 indicate open-water basins with separation by sand ridges.

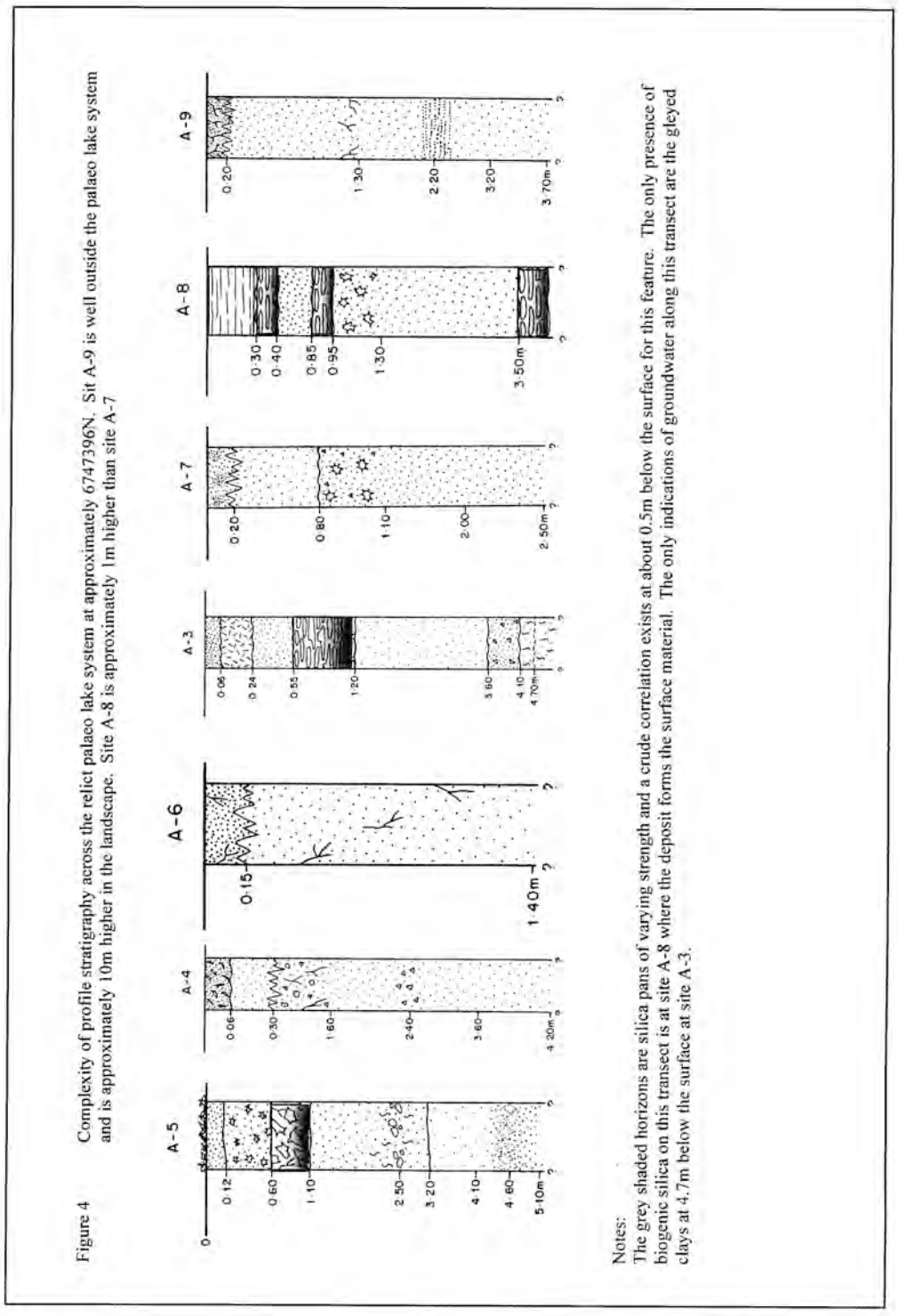
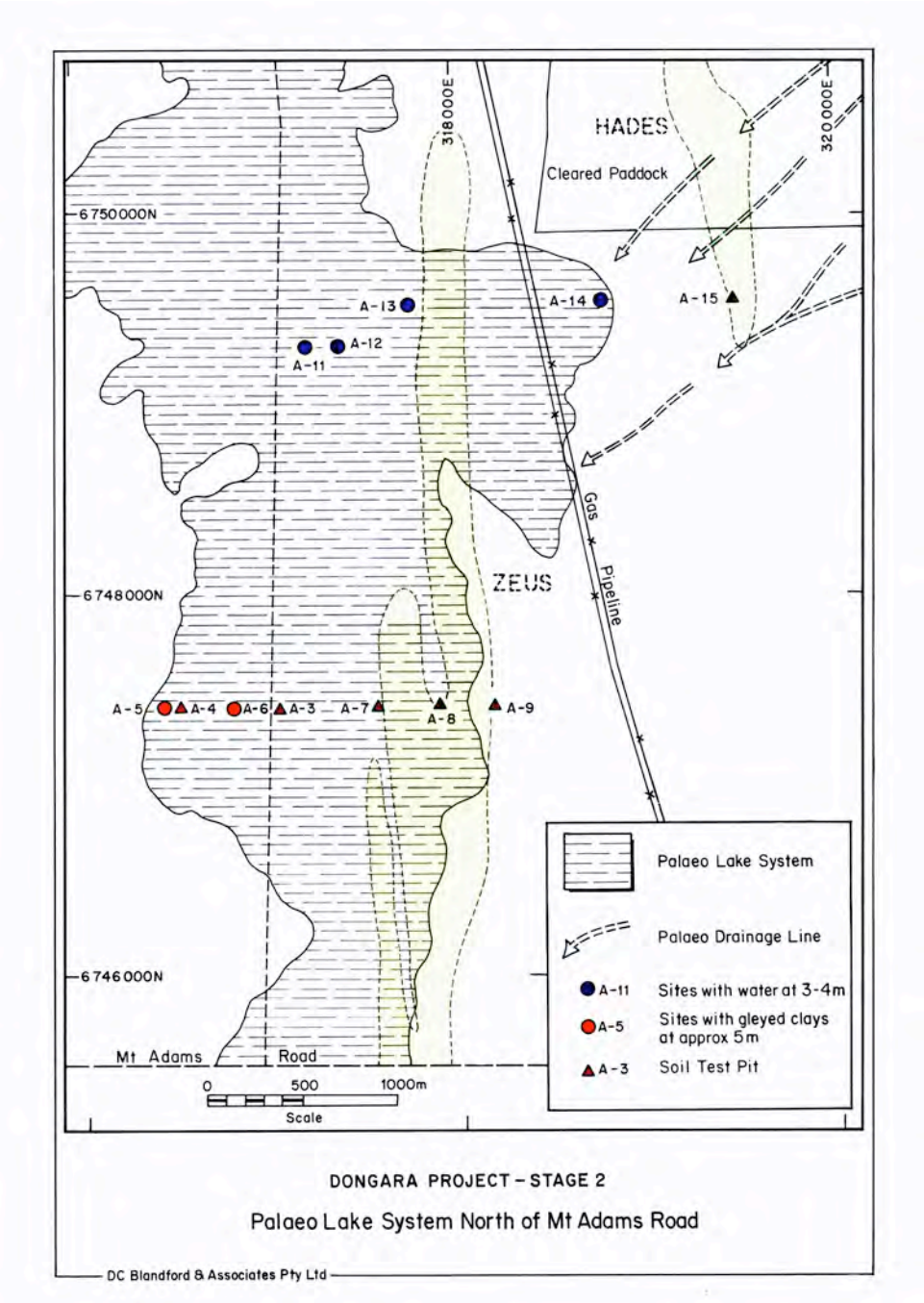


Figure 4 Complexity of profile stratigraphy across the relict palaeo lake system at approximately 6747396N. Sit A-9 is well outside the palaeo lake system and is approximately 10m higher in the landscape. Site A-8 is approximately 1m higher than site A-7

Notes:
The grey shaded horizons are silica pans of varying strength and a crude correlation exists at about 0.5m below the surface for this feature. The only presence of biogenic silica on this transect is at site A-8 where the deposit forms the surface material. The only indications of groundwater along this transect are the gleyed clays at 4.7m below the surface at site A-3.

As a result of the greater detail of survey in the palaeo lake system, a modified soil landscape map has been prepared for the area north of Mt Adams road and is presented as Figure 5. The data gives credence to the model suggested above and that at the time of deposition of the Eastern ferricrete/clay landscape, the western lacustrine system was quite active and being fed by inflow from the eastern uplands. Dune formation was instrumental, in part, for blanketing both landscapes and a decrease in rainfall contributed to the demise of the runoff and to water supply to the lake system.

Figure 5: The re-defined relict palaeo lake soil landscape north of Mt Adams Road following additional investigations as part of the Dongara Stage 2 survey.



The relict palaeo lake system is complex, with spatially discontinuous profile stratigraphy. This complexity mirrors past depositional environments and pedologic process. The profiles exposed at this point in time are essentially profiles of sand demonstrating deposition of silica as a function of changing conditions of soil pH, together with deposition of diatom skeletons to form the surface beds of biogenic silica. In the transect presented at Figure 4, the only indication of potential underlying material was the presence of a gleyed clay at 4.7m implying that sediment of eastern upland origin underlies the near-surface sediments of the palaeo lake system. Further, if this is indeed the case, then lake profile morphology is similar to many sites in that the soil profile is sand of varying thickness overlying a layer of material with varying amounts of clay. When examined in detail, the layers of silcrete, which may range from massive to concretionary, and from soft to very hard, form impeding layers to the vertical movement of water through the profile. However, only rarely was a silcrete considered to be a true impeding layer. As we have noted elsewhere, surface infiltration rates are quite high.

The vegetation across the western relict palaeo lake landscape forms a mosaic and does not reflect the complex stratigraphy indicated by Stage 2 survey data. This pattern of vegetation north of Mt Adams Road is shown in Figure 6 and described by Woodman (2007).

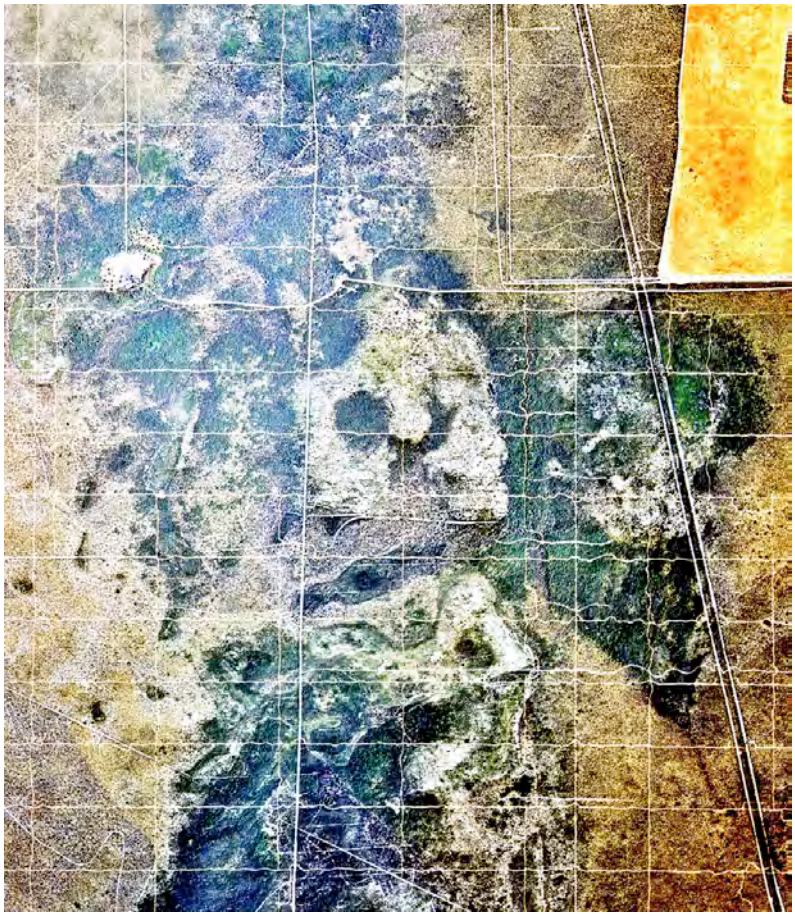


Figure 6 Vegetation patterns in the northern end of the western relict palaeo lake system. The pale areas through the centre tend to be dominated by biogenic silica at the surface, with associated high albedo. However, this is not always the case. The western boundary is confused due to the discontinuity of the on-lapping sheet sands.

Field evidence suggests that profile stratigraphy of the relict palaeo lake system has resulted in profile function that is not all that dissimilar to that occurring in a typical sand profile with an impeding layer at a given depth below the surface. As with profiles outside this soil landscape, the strength and effectiveness of the impeding layer is determined by the presence of pans, the permeability of clay horizons present, and the spatial extent of the layer. The various silica pans within the relict palaeo lake system provide this impeding layer at depth below the surface, and so the profiles tend to function as sand profiles elsewhere.

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