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UPPER SOUTH EAST DRYLAND SALINITY AND FLOOD MANAGEMENT PLAN: EXCAVATION CHARACTERISTICS AND SLOPE DESIGN FOR THE DRAINAGE CHANNELS

VOLUME I

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Upper South East Dryland Salinity and Flood Management Plan: Excavation Characteristics and Slope Design for the Drainage Channels

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The Upper South East Dryland Salinity and Flood Management Plan proposals aim to address the worsening salinisation problems now clearly visible in the area.

This report provides feasibility and preliminary project design data to the E&WS engineers who are preparing cost estimates for the project. It refers specifically to the excavation properties and side wall designs of both the proposed groundwater interception drains on the interdunal flats where these may be of up to 5 metres depth, and to the exit drain crossing points through the ridges where excavation depths may be up to 30 metres.

Field work comprised excavation of 13 pits to up to 5 metres depth and seven boreholes to between 9 and 30 metres depth. Units intersected in the pits, which were confined to the interdunal flats, include the fine grained aeolian quartz sands of the Molineaux Sand and the extremely variable ephemeral lacustrine sediments of the Padthaway Formation. The drilling, sited on the ridges, intersected variably cemented bioclastic sands and sandstones of the Bridgewater Formation.

The pits showed the Padthaway Formation sands, sandy clays and clays have been altered by calcrete formation within the top 2 to 3 metres. The resulting substance strengths which would be encountered during construction of the groundwater would vary from soil to strong rock. In the northern section of the interdunal flats the predominant lithology is sand, while in the central and southern sections the sediments are more cohesive. While steep side walls are considered feasible in the south and central areas, the sands in the north are likely to collapse to form stable long term slopes of low angles.

The deeper channelways will pass through the high dunes of the Bridgewater Formation. The slopes will need to be benched, but overall slope stability would appear to permit steeper than expected overall slope angles, a factor which may aid in reducing the exposure of the slopes to wind and water erosion, a problem recognised in newly excavated road cuttings.

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CONCLUSIONS

General

1. There is a need for a much higher density of data and large scale excavation trials in typical areas prior to project design refinement.

2. Substantial dewatering of excavations is necessary and methods of achieving this should be resolved early in the design stage.

Groundwater Interception Drains - Interdunal Flats

3. There is no recognisable correlation between individual pits, but the northern area has many clean sands and silts while the southern and central areas are dominated by cohesive materials.

4. Rock - mainly calcrete - is found in all areas. The Komatsu PC 220 excavator met refusal on this material in four pits and larger equipment would be more appropriate for the construction of the drains. The high strength calcrete is thought likely to be largely confined to a zone of approximately one metre thickness, within 1 to 3 metres of the surface.

5. The groundwater interception drains should be costed on the basis of side slope information in Figure 8.

6. The predominance of sands in the northern area and the need for wider channel cuts may render drainage in that area relatively expensive.

7. Groundwater inflows were dominated by fissure flow in the calcrete and rock layers.

Cross Dune Drainage Channels - Dune Ridges

8. The materials of the dune ridges are very variable, both laterally and vertically, in strength, permeability and most other geotechnical parameters. The materials comprise:

    - weakly cemented to apparently non-cemented sands and
    - calcareous sandstone of up to high strength.

9. Three alternative preliminary slope design geometries are indicated on Figure 9.

    - Configuration B is considered appropriate unless a trial excavation is undertaken.
    - The more economic Configuration C may be acceptable from construction, safety and maintenance viewpoints, but must firstly be subject to evaluation in a trial excavation.

10. Excavation through dune ridges is not expected to be difficult. Scrapers will need assistance in areas of stronger rock and there will be a need for some ripping.

11. Longitudinal drainage along berms will be required to protect batters from erosion.

RECOMMENDATIONS

1. The groundwater interception drains on the interdunal flats should be costed using the side slope configurations given on Figure 8.

2. The deep cuttings through the high ridges should be costed using the configurations given on Figure 9.

   - Configuration B is recommended unless a trial excavation is undertaken.

   - Configuration C is recommended subject to evaluation of a trial excavation.

3. This report provides data at feasibility level for the purposes of preliminary costing of the proposed excavations. Further excavations, drilling and seismic work, similar to that undertaken for this study, plus large scale excavation trials, with monitoring, are recommended as part of the design process.

INTRODUCTION

Shallow, rising groundwater tables are giving rise to severe land degradation throughout the upper South East which covers an area of some 4000 km^2 of South Australia. It has been proposed to construct an extensive system of drainage channels to draw down saline groundwater levels, and to collect excess surface water. The suggested means of achieving this is to excavate a network of groundwater interception drains to intersect near surface groundwater. Flows would be channelled to a suitable area for disposal.

In order to assess the environmental impact of and to establish preliminary costing for the project it was necessary to have an understanding of the geological materials to be excavated and their slope forming properties. This report presents the results of the feasibility level geotechnical investigations undertaken by DME in association with geotechnical consultants R M Herriot and Associates Pty. Ltd. It comprises two main components of geotechnical assessment:

- excavation properties and aspects of drain design on the interdunal flats where drains may be up to 5 metres deep, and

- excavation properties, slope stability and slope design in the ridge crossings where cuttings may be up to 30 metres deep.

The area investigated is shown on Figure 1.

SCOPE OF THE GEOTECHNICAL WORK

The geotechnical work consisted of four main components:

- excavation of pits to investigate the interdunal flats

- seismic soundings to extend the interpretation of results from test pits

- drilling and testing to investigate the dune ridges

- examination of existing drainage works and road cuttings through the interdunal flats and the dune ridges.

Excavator Pits

These were located in the interdunal flats as shown on Figure 1, and detailed pit logs are included in Appendix A. Photographs are included in Appendix D. Material types are summarised in Table 1.

In the interdunal flats, 13 excavator pits to depths of up to 5.5 m (the limit of the Komatsu PC 220 in soft ground) were excavated and geotechnically logged. Samples of the various materials were taken and groundwater inflows monitored.

Seismic Refraction Survey

Single spread seismic traverses (approximately 100 m long) were carried out at eight selected sites adjacent to excavator pits (Taylor 1992). The aim of the seismic survey was to relate the calcrete strength and relative ease of excavation of materials logged in the pits with seismic velocity, and to assess the continuity of and the unifrommity of depth to the stronger layers. This work is discussed in Appendix A.

Borehole Drilling

A total of five boreholes were drilled at two ridge top sites (Sites 1 and 2) to provide information along the alignment of the proposed deep drain cuttings through high ridges of the Bridgewater Formation, approximately 8 km inland of Salt Creek (refer Figure 1).

A third site was selected near a road cutting about 24 km south east of Salt Creek (see Figure 1) and two boreholes were drilled in an attempt to calibrate the existing road cutting slopes with the drilling and Standard Penetration Test (SPT) results. Undisturbed block samples were recovered from the road cutting for laboratory strength and density tests. The drilling is discussed in Appendix B, and the laboratory testing in Appendix C.

Inspection of Existing Works

Existing drainage scheme works were inspected, and a number of road cuttings were visited. The drains were to the south of the currently proposed scheme, but traverse similar geological regimes.

The road cuttings expose the top few metres of the dune ridge sediments, and demonstrate the erodability and some of the slope design issues to be addressed in the proposed Upper South East scheme.

REGIONAL GEOLOGY

The South East region of South Australia comprises a series of long, sandy, north west trending ridges, with low lying, broad, flat areas between them. These features, which mark the positions of prograding coastlines, were formed during the Pleistocene as a consequence of successive interglacial high sea level stands while the coastal plain was slowly rising. The ridges and the interdunal flats are progressively older, and the ridges at least are increasingly indurated, with increasing distance from the coast. The zone exhibiting these features is approximately 100 by 200 km in extent, and the study area shown on Figure 1 comprises its northern half. It includes ridges termed B to H on the plan.

The ridges comprise calcareous sand of the Bridgewater Formation, deposited in shallow subtidal, beach and coastal dune environments.

The sediments underlying the interdunal flats were deposited contemporaneously, landward of the barrier islands and peninsulas of the dunes, in lagoonal and lacustrine conditions. These sediments are carbonate, clay and fine grained sand of the Padthaway Formation which have been modified by the extensive formation of calcrete in the top few metres.

The Bridgewater and Padthaway Formations are partially covered by a layer of fine grained quartz sand derived from reworking of the Bridgewater and from other, siliceous, deposits further north and northeast. In the northern area of the Upper S[illegible] East study area these sands are named the Molineaux Sand, but it is beyond the scope of this report to attempt to further delineate these units.

The Younghusband Peninsula and the modern Coorong comprise a continuation of the progradation of the coastline, although they belong to a different unit, the Holocene St. Kilda Formation. The peninsula comprises the Semaphore Sand Member. These units are less consolidated and, although they were not examined as part of this study, the Coorong deposits are thought to be different to those encountered further east.

Interdunal Flats

The pit logs are contained in Appendix A, and the material types encountered in the pits are summarised in Table 1. Pit locations are shown on Figure 1.

It is probable that most of the material encountered in the pits excavated on the interdunal flats in the southern and central area during this investigation was Padthaway Formation, within which has formed a fairly ubiquitous calcrete. Most of the carbonate material encountered in the pits was calcrete, not sedimentary limestone or dolomite. Most soils did, however, contain interstitial carbonate. Overlying the Padthaway Formation is an average thickness of about 0.3 metres of fine grained quartz sand. In the northern area a similar sand, the Molineaux Sand, blankets the Padthaway Formation on the interdunal flats and the Bridgewater Formation ridges.

Geological Materials

A wide range of material types was encountered in the pits. They included clays, silts, sands and mixtures of these, and calcrete, sandstone and calcarenite. Sands and sandstones, although calcareous, were predominantly fine to medium grained quartz. No detailed correlation has been possible between pits. For this reason, the data are treated as statistics in this report.

However, on a broad scale, it is clear that the pits in the northern section encountered more clean, sandy sediments (eg. pits 1, 2, 3 and 5, with pits 4 and 6 not penetrating the whole profile). Although not universally true, clays were more often found below 2 metres depth.

Clays were generally light green to off-white, variably silty and sandy, calcareous, medium to high plasticity and were estimated to be stiff to very stiff.

Sand was fine to medium grained with density estimates ranging from loose to dense. Some was cemented although the induration was in thin layers or was discontinuous on the scale of the pit exposures. The sandy materials were light green, grey and light yellow, ranging from clean sand through silty sand to clayey and very clayey sand. In pit 9, below 2.5 m depth, a more substantial sandstone was intersected, but while the sandstone had considerable substance strength it was discontinuous and was easily excavated at that location.

Silt soils made up only a minor proportion of the materials seen in the pits. They were off white to light brown, strongly calcareous, sandy, low plasticity and estimated to be medium dense. These soils comprise a stage in the formation of calcrete and probably occur as patches within the calcrete.

Calcrete was intersected in 11 of the 13 pits. It was generally off-white to light brown, occurred variously as silty or clayey gravel, nodular masses and continuous or semi-continuous sheets. It ranged in substance strength from extremely weak to strong. Point Load test results are included in Appendix A. It was generally excavated as cobble to boulder sized fragments. The excavator refused where the rock strength materials were continuous, moderately strong to strong, sheet like and relatively homogeneous (ie. few discontinuities). This occurred in four of the pits (4, 6, 11 and 13). The majority of the calcrete is likely to be encountered within the top three (3) metres of the surface of the interdunal flats. The stronger rock appears to begin at 1 to 2 metres and could persist to 3 metres. The position of the calcrete in the soils of the Padthaway Formation may be able to be used to set limits on the evaporative zone above the water table as it existed prior to the extensive vegetation clearance which followed development of the region.

Calcarenite, identified as indurated Bridgewater Formation, was encountered in pit 11 from 2.1 m depth. It was light yellow to light brown, coarse grained and moderately strong. It was relatively homogeneous on the scale of the excavation, containing few defects, and refusal was encountered at 2.5 m depth on this rock. This represents the only intersection of the Bridgewater Formation *in situ* in the interdunal pits.

The results of the seismic survey are in good agreement with the materials encountered in the excavator pits. A marked velocity contrast was generally detected adjacent to each of the eight pits close to a depth corresponding to the first major strength/competency change picked up in the pits. The velocity contrasts detected correspond in most places to the top of the shallowest layer of calcrete rock.

In 7 of the 8 seismic spreads, the calcrete horizon was found to be laterally consistent over the 100 m or so of the spread. The exception was adjacent to pit 9 where the horizon appeared to rapidly deepen by over 2 m at about 40 m distance from the pit. The results from near the other pits showed minor fluctuations in apparent horizon depth of up to 1 m. Seismic velocities varied laterally in all areas tested by up to about 40%. This indicates that variations in strength and induration, and hence excavatability, of the rock layers are likely over distances of 50 m or so. Comparison of the seismic results with the data from the pits indicates that the method is likely to be a useful indicator of excavatability. The comparison is summarised in Table 2.

Groundwater

Groundwater was intersected in all pits, with water levels reported to be between 0.7 and 2.0 metres below the ground surface. Inflows were often small or absent in the clays and clayey sands, with major inflows being confined to the calcrete layers.

Summary of Interdunal Flats

Southern and Central areas

In broad terms, all 9 pits in the southern and central zone encountered a similar profile consisting of:

- a sandy topsoil layer between 0.1 and 0.5 metres thick.
- a calcrete layer in most but not all test pits which varied significantly in ease of excavation and which extended to depths between 2 and 3 metres.
- below the calcrete layer, the soils were generally clayey with some clayey sands.

Northern area

The northern sandy flat, VII N, was investigated by 4 test pits which encountered generally sandy conditions with little calcrete.

- the sand is fine grained and typically uncemented
- there are some minor thin calcrete and clay layers.

Dune Ridges

The ridges east of the Coorong comprise Bridgewater Formation which may be veneered with Molineaux Sand, particularly in the north. In this report it has been assumed that all materials which will be encountered in the proposed deep excavations across the dune ridges will be Bridgewater Formation.

The drilling and sampling is discussed in Appendix B, and photographs of the drill core are included in Appendix D. The location of the drilling, near Salt Creek, is shown on Figure 1. Strength results from the SPTs are summarised on Figure 2, with some zones being too strong for testing with the SPT. The higher strength zones were cored.

Geological Materials

Materials of this geological unit, which comprises the ridges B to H (Figure 1), are almost entirely of poorly graded, fine or medium or coarse grained sand. The sand is notoriously heterogeneous in type and degree of induration both laterally and vertically, with a wide range of strengths.

The sample recovery from the SPTs at Sites 1 and 2 led to doubt about the void ratios in the weakly cemented sand, and to queries about the safety of excavating the deep cross dune drains. The SPT results at Sites 1,2 and 3 are summarised on Figure 3, and are interpreted to show the uncemented or weakly cemented sand to be medium dense to dense. These results, were compared with other Bridgewater Formation data from Port Lincoln, an area within the recent experience of one of the authors (Figure 4). The Port Lincoln data show a similar lower bound to the "N" values to the limit of testing at 6 m depth, with the high values being effective refusal on calcrete, which was not encountered in the dunes near Salt Creek.

The application of the Standard Penetration Test to materials within the Bridgewater Formation is discussed more fully in Appendix B, and laboratory studies supporting the investigation of this issue are presented in Appendix C.

The laboratory test results on blocks of Bridgewater Formation provided accurate void ratio data to compare with the estimates from the SPTs, and with the Port Lincoln data and published figures. The void ratios of 0.7 to 0.9 from Cantara Road are high but are not considered abnormally so (Table 3). Figure 5 compares the sample recovery in the SPTs at Sites 2 and 3, but the data fails to show a correlation between apparent strength and recovery.

The block samples were taken from the side of the road cutting adjacent to Site 3, as shown on Figure 6. The three confined compressive strengths ranged from 100 to 440 kPa. These are thought to be higher than the strengths from SPT results in the boreholes at Site 3, drilled only 10 m away. It is tentatively concluded that the blocks represent materials which have gained strength since their exposure at the time of the road widening. There is anecdotal evidence at many sites in the Bridgewater Formation that "case hardening" is a widespread phenomonen in this geological unit.

Summary of Dune Ridges

Drilling and observations in the road cuttings show the Bridgewater Formation to be a poorly graded calcareous sand or sandstone, of fine or medium or course grain size, with little or no fines. The continuity and degree of induration is extremely variable, with strengths ranging from those of unconsolidated, medium dense or dense sand to strong rock. It is considered, however, that there is some effective cohesion in almost all Bridgewater Formation materials. There is a suggestion that the stronger materials may be more usually coarse grained. Materials exposed to weathering become more cemented ("case hardened"), where erosion is not active, than those not exposed.

DISCUSSION

The geotechnical investigation comprised establishing the excavation properties and the side wall designs of:

- the groundwater interception drains of up to 5 m depth where they traverse the interdunal flats
- the main drainage channels of up to 30 m depth where they pass through the dune ridges

This work has been done at the feasibility level for the purpose of establishing cost estimates for these aspects of the proposed Upper South East Dryland Salinity and Flood Management Plan.

Groundwater Interception Drains - Interdunal Flats

The proposed routes for the drains are shown approximately on Figure 1. The southern and central area (Interdunal Flats II to VII S) is geologically different to the northern area (designated VII N).

Excavation Properties - Southern and Central Area

Table 1 shows the degree of difficulty encountered in digging the soil and rock materials, including a semiquantitative assessment of productivity for the Komatsu PC220 machine. This reflects the amount of work (and hence time) to produce a single bucketful of spoil within each material type.

The relatively small Komatsu PC220 machine used for the excavations met refusal in 3 of the pits at depths ranging from 1.2 m to 2.6 m. However, the only materials which provided any significant degree of difficulty to excavate were the rock materials, calcrete and calcarenite. In instances where the rock layers were thin, highly heterogeneous, contained many natural defects (or cementing was discontinuous) or were weak, the excavator was able to penetrate and continue digging in the unconsolidated materials below. Where the rock layer was thicker, much stronger and/or more massive and homogeneous, excavation was more difficult and refusal was generally encountered. The approximate seismic velocity value above which refusal was met was 2200 m/s. Some velocities were as high as 4000 m/s (Table 2).

Table 4 summarises the excavation properties within horizontal slices; 0-1 metre, 1-2 metres, etc., giving approximate percentages of materials, on a statistical basis, within each excavation category in each metre-thick slice. Note that almost all of the "difficult", "very difficult" and "refusal" occurred between 1 and 3 metres depth, making it inevitable that these materials will be encountered in the drains.

A number of the pits collapsed during or soon after excavation while others stood with little or no sign of distress for the hour or so during which the water inflow was observed. Collapse was not confined to sandy materials, but included zones with rock and sand/clay mixtures; for example, the gravelly, nodular calcrete. This is discussed further below.

It is concluded that the combination of calcrete and clays, which together comprise the bulk of the material observed in the southern and central area pits, is favourable for the excavation of steep side walls in the drains. However, the calcrete will prove difficult to excavate, requiring considerable force in some localities. Where it is gravelly (or where other non cohesive material is present), it will tend to behave as a granular soil. The clayey soils which are present beneath the rock zones in most pits, have sufficient cohesion to stand steeply, and they will resist erosion from the flowing water. Dewatering of the soils ahead of the excavated face by allowing drainage to the advancing trench will be essential to productivity and the formation of stable side slopes (see below).

This conclusion forms the basis for the design of the side slopes, but it is unlikely that the drains, when constructed, will have a uniform shape throughout their length in the southern and central area.

Excavation Properties - Northern Area

Five pits were excavated in Flat VII N, but Pit 5 has soils which group with the southern and central area. Of the remaining 4, one refused on calcrete at 2.1 m, with the others being largely in sand and silty clay (Table 1). The sandy materials were noted to collapse when the pits were left open.

Dewatering of the soils ahead of the excavated face will be necessary (See below).

Seismic refraction was used in the northern area only at pit 4, with the calculated velocity being 2700 m/s.

On the basis of this information, it is concluded that the northern area is predominantly sandy with less calcrete which is generally also less well developed than it is further to the south. Excavation would require less energy, but stable side wall slopes predominantly in cohesionless sands, would be flat. The velocity of water flowing in the drain would need to be low enough to avoid erosion.

Again, variation must be expected in ground conditions and consequently, in the drain shape in the northern area .

Inflows of Groundwater - All Interdunal Areas.

Groundwater will be encountered in all excavations of greater than about a metre on the interdunal flats. Inflows of water will degrade excavator productivity in the groundwater interception drains, and will affect side slope stability.

Estimated standing water levels in the pits (excavated in May, prior to the winter rains) ranged from 0.7 m depth to 2.0 m depth (average about 1.1 m), and the water table will be closer to the surface during and following the wet season. While there was often minor seepage noted at or close to estimated SWL, the water inflows were often not appreciable until the pits were extended to greater depth. This was particularly noticeable where groundwater entered freely from fissures in rock layers, as it did wherever rock was encountered below the water table. Inflows in almost all the pits were described as moderate or high and it was generally impossible, once the pits were more than about 3 metres deep, to bail the water out with the excavator bucket faster than it was flowing in. Detailed measurements of water inflows were made for 6 of the pits and plots of these values are shown in Figure 7. It may be possible to calculate approximate hydraulic properties from these data, although it is to be stressed that the predominant influence on the inflow rates was the presence of free-draining fissures in the rock materials, and few of these exist below 2 to 3 metres depth.

These data could be of assistance in the groundwater modelling.

The high initial groundwater gradients towards the newly excavated pits contributed to the collapse of several of the pits. Dewatering by excavating upslope from a down gradient point to achieve dewatering ahead of the advancing excavation is considered essential, as it appears to offer the only feasible dewatering method for the project, given that the discharge will be saline. It is considered that achieving:

- minimum excavation
- minimum "second pass" and/or maintenance targets

hinge on this point. If drainage is not immediately available to the ultimate discharge point then a temporary discharge point will have to be found.

Cross Dune Drainage Channels

The investigation was confined to ridge C, where the deepest excavation is proposed, and to ridge B, near Salt Creek (Figure 1).

Excavation Properties

The dune ridge materials (Bridgewater Formation) intersected in the boreholes and observed at exposures in the existing works and in road cuttings, are expected to be predominantly easy to excavate. It is thought that a scraper operation would be a suitable method of construction. The rock materials, however, will require scrapers to be dozer assisted and, in some places, the higher strength materials will require prior ripping with a bulldozer. Further work will be required for subsequent design and detailed costing phases of the project.

Channels cut through the older dune ridges further inland are likely to encounter significantly more rock materials, unless the Bridgewater Formation is absent, with the inland dunes being (or being capped by) the uncemented Molineaux Sand.

Erodability

In the case of the deep excavations through high dune ridges, great care will have to be taken to ensure proper drainage of the slope due to the initially erodable nature of the weakly cemented sands. For each batter above the lowest, all runoff from each batter must be contained on the bench below it and must drain laterally along the slope to a collection point where it can run into the drain without scouring the lower batter slopes. Runoff from the natural surface behind the excavated slope will have to be similarly channelled for appropriate disposal. If the lower slope proves to be very weakly cemented then some formal protection, perhaps in the form of Shotcrete, may be warranted.

SIDE SLOPE DESIGNS

Groundwater Interception Drain Side Slopes - Interdunal Flats

The side slopes of the broad, shallow, surface water drains and those of the (ideally) narrow, deeper groundwater drains are two separate issues.

For the broad, shallow, surface water drains (taken to be less than 1.5 metres deep), it is suggested that the slopes be cut at a nominal ½:1 (63°), and the soils be allowed to fail to a stable configuration. Some field adjustment could be warranted.

The ultimate side slopes of the deeper, groundwater interception channels will be controlled not only by the types of materials present but also by their distribution within the wall profile, and to a major degree by the groundwater conditions during excavation and the inundation characteristics of the drains where cohesionless materials are present.

Hydraulic characteristics for the channels were not available at the time of writing. It has therefore been assumed that the drains in the southern flats will be typically between three and four metres deep with long term clear channel base widths of at least one to three metres, ie the width after allowing for some initial degradation and fretting of the freshly cut slopes. The philosophy behind this approach has been based on the assumption that some degradation will occur, but that maintenance requirements should be held to a low level due to the difficulty of getting equipment back over the trench.

It is clearly the case that there is insufficient data to do other than treat the costing exercise for the drains in the interdunal flats on the basis of the statistics and apparent trends noted in the 13 pits.

Southern and Central Area

On the above basis, the following presumptive preliminary cross sections are recommended for adoption in Flats II to VII S. These cross sections are intended for preliminary costing exercises and should not be taken as the final design recommendation (See Figure 8).

- slopes should be excavated one half (horizontal) to one (vertical) full height. In reality the sandy topsoils will probably be set back and the calcrete excavated at a steeper slope. However, the uniform slope should be assumed for volume calculations.

- the slope each side should be excavated one half metre wider than dictated by minimum hydraulic requirements.

- the channel should be excavated one half metre deeper than required by minimum hydraulic requirements.

Northern Area

In the sandy northern Flat VII N, a different drain cross section will apply. It is understood that in this area the drains may combine both surface and groundwater drainage. The following presumptive cross section is recommended (Figure 8).

- no over excavation below minimum hydraulic requirements.
- excavation volumes based on an initial one (horizontal) to one (vertical) cut but assuming a minimum long term hydraulic base width based on the assumption that the initially excavated slope will collapse to two (horizontal) to one (vertical).

It must be noted that the long term stability of the slopes in the sandy, uncemented soils of the northern flat, VII N, is not fully established. In particular, if the eventual minimum hydraulic base width is less than about three metres then it is believed that there is a significant risk of blocking of the channels or of significant long term maintenance requirements.

Cross Dune Drainage Channels Side Slopes - Dune Ridges.

Drilling and sampling at three sites plus observations and other exposures of the Bridgewater Formation, both locally and elsewhere in South Australia, have indicated that variable material properties will always be encountered in this formation. The site investigations show that both soil or weak rock, and strong rock, will be encountered within the proposed cuttings.

Although conditions are variable, it is also our opinion that on the moderate to large scale there is always some cementing or effective cohesion present. That is, the Bridgewater Formation will exhibit more cohesion than the uncemented coastal dune sands of the Semaphore Sand on the Younghusband Peninsula, to the west of the Coorong.

It is also clear from the present investigations that a very high overall slope angle cutting with no intermediate benches, such as was constructed some years ago to the south of Kingston at Woakwine, is not achievable in the materials present in the dune ridge near Salt Creek.

Stability calculations suggest, however, that only relatively small values of cohesion are required to maintain stability for both the individual benches and for quite steep overall slopes. The results of the drilling and testing, tempered with experience, indicate that assuming an internal angle of friction (Phi') at 37° and a cohesion (C') of 10 kPa for these materials would be appropriate. These strengths are considered to be realistic and probably conservative. The average effective cohesion for deep circular failures is in fact probably significantly higher than 10 kPa due to the presence of rock layers.

These strengths have been used in the check slope stability analyses of the options set out below. Both the overall slopes and individual benches were analysed, with the results set out in Table 5, and they apply to the profiles shown on Figure 9. All analyses and resulting factors of safety have assumed the groundwater level is below the base of the cut and the slope is dry. For a partly saturated slope the stability would be reduced. Further analysis of this type is not warranted without additional study.

The Bridgewater Formation strata are also relatively porous. However, in our opinion they are not of sufficiently low density to be subject to sudden, large scale, brittle failures and collapse. Experience elsewhere and natural coastal exposures also support this contention.

It is evident that some fretting and surface degradation of freshly cut slopes must be anticipated. However, a surface "skin", or "case hardened" zone, may be expected to form soon after exposure in a newly cut face in the Bridgewater. This results in a decrease and eventual practical cessation of fretting and degradation with time. It is not completely certain whether the strengths measured in the block samples from the road cutting are representative of conditions within the mass of the Bridgewater Formation encountered in drilling at Site 3 or whether the strength has increased due to exposure close to the cut face. However, it is thought that when considering erosion or fretting, there is sufficient strength, or that sufficient strength develops, such that slopes may be safely cut at angles steeper than the angle of repose for uncemented sands.

As the minimisation of surface fretting is partly a function of the exposed sloping surface area it would appear desirable to make bench slopes as steep as practicable whilst maintaining berm widths sufficiently wide to allow for both drainage and access for maintenance. On this basis the following alternatives would appear suitable (See Figure 9):

A) 10 metre high benches at 50 degrees with 6 metre wide berms,

B) 7.5 metre high benches at 60 degrees with 6 metre wide beams,

C) 7.5 metre high benches at 70 degrees with 7 metre wide berms.

Assuming the required excavation volume above the slope only is 1.0 for the pre-investigation presumptive design suggested by Collingham (see References), the above designs have a relative excavation volume of 0.93, 0.88 and 0.80 respectively. Alternative (C) has a marginal calculated bench slope factor of safety.

Based on the available information, Alternative C is recommended if project scheduling allows time for a trial excavation and monitoring period. If not, it would be prudent to adopt the slightly more conservative Alternative B.

The existence, relative thickness, position and strength of the sandstone encountered in the deeper boreholes can only be relied upon to provide significant contribution to slope stability if subsequent more extensive investigations show this to be generally the case.

In addition, it is expected that older dune ridges further from the coast will be progressively more indurated and will permit the use of steeper side slopes. The extent to which these slopes can be steepened can be best ascertained through further site investigation work.

FURTHER INVESTIGATION

Considering the magnitude of the proposed project (with respect to both the extent of the groundwater drains and the total volume of the deep cuttings in the dunes), the amount of investigation and testing completed to date has been relatively small.

Clearly additional drilling and testing must be undertaken along the length of each major cutting during the design stage. In our view it will also be highly desirable to undertake major trial excavation(s). Trial excavations have a number of useful features. Firstly they give a direct indication of excavation conditions using equipment similar to that which will be used by the contractor during construction. It also provides opportunity for tenderers to either experience in person or by video tapes, conditions encountered during the trial at the tender stage. In addition it will most significantly allow monitoring of slopes in order to assess the degree of degradation and weathering for differing bench slopes.

It is therefore recommended that a trial be undertaken. It should comprise an excavation of a minimum of 12 metres depth, with several different cut slopes. Observations should be taken on cuts facing both north and south, as existing road cuttings suggest weathering is related to the direction of exposure. A trial at several different locations along the axis of the deep cutting(s) is recommended. The trials should be sited within the limits of the excavations.

It is further recommended that trial excavations be undertaken at several locations along the groundwater drains where these traverse the interdunal flats, for although they are relatively shallow structures, their total length is such that improvements in the knowledge about their excavation characteristics and their behaviour under semi-dewatered conditions would be significant.

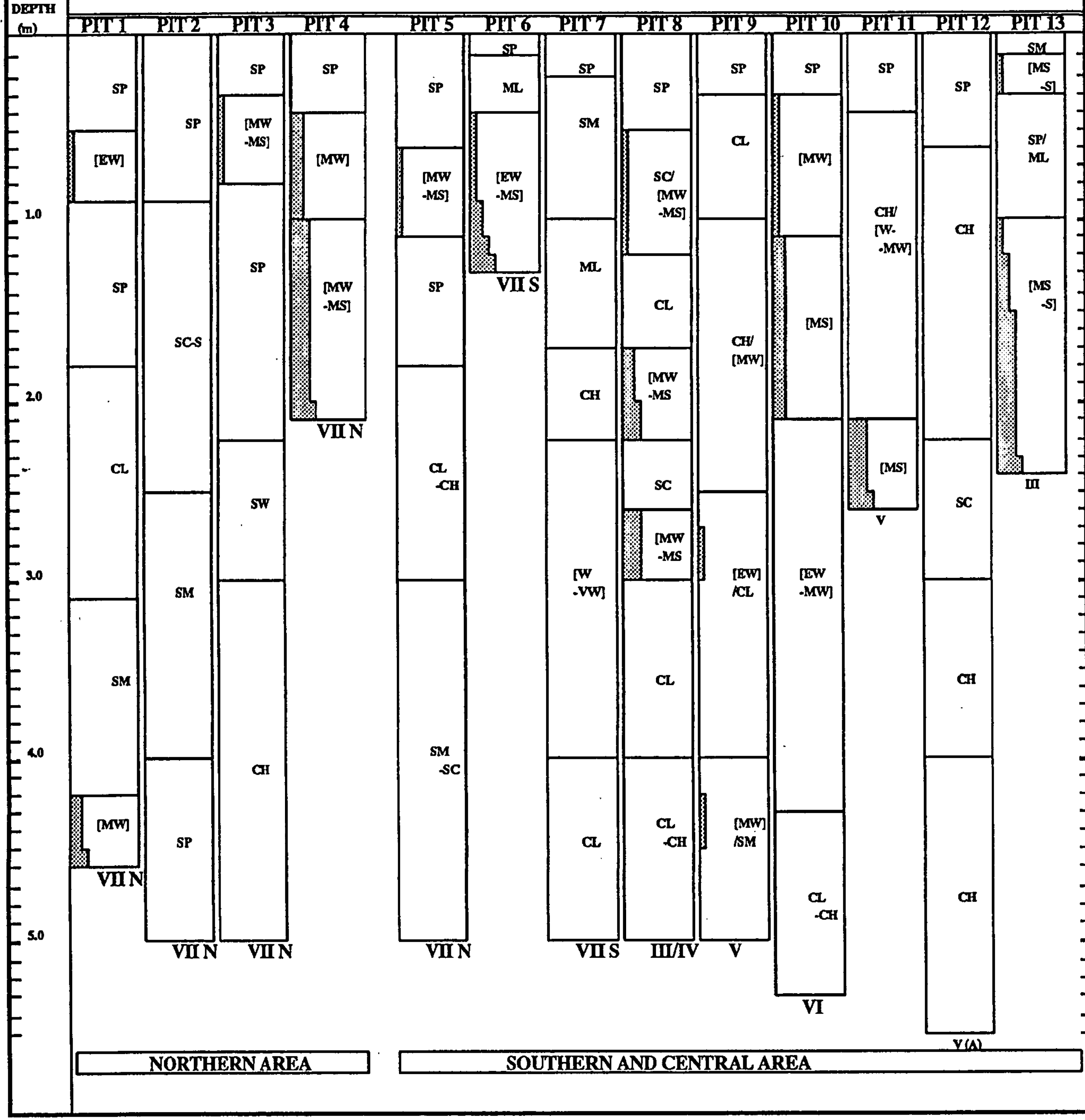
REFERENCES

Belperio, A.P., and Cann, J.H., 1990. Quaternary Evolution of the Robe-Naracoorte Coastal Plain: An Excursion Guide. S. Aust. Dept. of Mines and Energy, Rept. Bk. No. 90/027. (unpublished)

Collingham, Ed. 1992. [Interim Design Slopes] For Deep Cut Slopes Through Dune Ridges, Memorandum: EC to Project Manager, Project 6915; 11th. June, 1992. (unpublished)

Taylor, B.J. 1992. Refraction Seismic Spreads over Excavation Test Sites in the Upper South East (unpublished).

TABLE 1: SOIL AND ROCK MATERIAL CLASSIFICATIONS



EASE OF DIGGING WITH KOMATSU PC220 EXCAVATOR

- EASY - SINGLE STROKE PER BUCKETFUL
- MODERATELY DIFFICULT - 2 to 3 STROKES PER BUCKETFUL
- DIFFICULT - 4 to 10 STROKES PER BUCKETFUL
- VERY DIFFICULT - CONSIDERABLE JARRING TO BREAK
- REFUSAL

FIELD SOIL CLASSIFICATION TO UNIFIED SYSTEM (see attachment)

ROCK STRENGTH CLASSIFICATION SHOWN IN [ ] (see attachment)

PIT LOCATION AND NOMENCLATURE APPLYING TO INTERDUNAL FLATS SHOWN ON FIGURE 1

TABLE 2: ASSESSMENT OF SEISMIC RESULTS

PIT NO	SEISMIC INTERPRETATION			ACTUAL MATERIAL BOUNDARY		
	VELOCITY IN UPPER LAYER (m/sec)	VELOCITY IN LOWER LAYER (m/sec)	DEPTH TO BOUNDARY (m)	UPPER LAYER MATERIAL	LOWER LAYER MATERIAL	DEPTH IN PIT (m)
4	640	2700	0.5	SAND	CALCRETE	0.4
6	400	4000	1.2	CALCRETE	REFUSAL (CALCRETE)	1.2
7	470	2000	1.6	SILT	CLAY	1.7
8	400	1900	1.3	CLAYEY SAND	CLAY	1.3
9	1250	2000	2.2	CLAY/ CALCRETE	CEMENTED SANDSTONE	2.5
10	450	2500	1.2	NODULAR CALCRETE	MASSIVE CALCRETE	1.1
11	450	2600	0.8	SAND	CALCRETE	0.4
13	425	2200	0.8	SAND/SILT	CALCRETE	1.0

TABLE 3

IN SITU VOID RATIOS

SOURCE	VOID RATIO	REMARKS
Site 3 Bulk Samples	0.78 / - 0.77 / 0.73 0.87 / 0.90	Measured from block sample / calculated from absorption test
From Standard Penetration Tests Site 2 Site 3	 2.0 ? 1.2 ?	Considered unrealistic. 100% material recovery unlikely.
Port Lincoln Reconstituted Samples	0.73 0.59 0.71	
Published Data U.S. Navy - SM/SP Medium Dense Sand Sowers & Sowers -Uniform sub-angular Sand -well graded, sub-angular Sand	 0.45 - 0.8 0.5 - 0.85 0.35 - 0.70	

TABLE 4. MATERIALS DISTRIBUTION BY DEPTH

DEPTH from NS (m)	PERCENT OF MATERIALS INTERSECTED (%)				
	RELATIVE DEGREE OF EXCAVATABILITY (see note 1)				
	Easy	Moderately Difficult	Difficult	Very Difficult	Refusal
	No ripping required		Ripping with bulldozer advis-able to improve productivity	Heavy ripping with bulldozer mandatory (see note 2)	Heavy ripping with bulldozer or possibly blasting (see note 2)
0 to 1	70	24	6	0	0 pits (of 13)
1 to 2	69	5	13	13	2 pits (of 13)
2 to 3	84	2	1	13	2 pits (of 11)
3 to 4	99	1	0	0	0 pits (of 9)
4 to 5.5	94	3	0	3	1 pits (of 9)

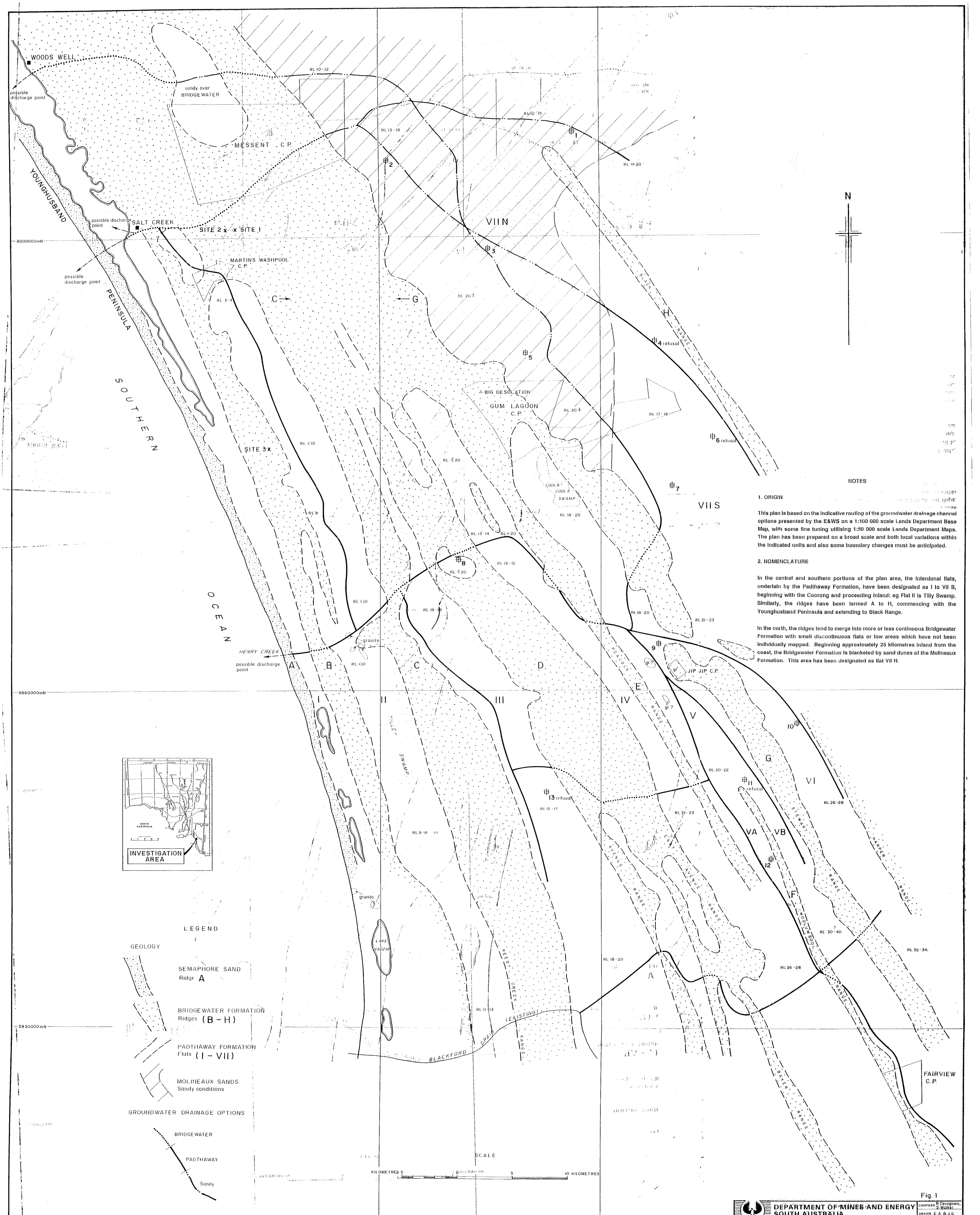
NOTES
1. Komatsu PC 220 Excavator used to dig pits
2. Caterpillar D9N Bulldozer assumed

TABLE 5: RESULTS OF SLOPE STABILITY ANALYSES

Slope Characteristics	Factor of Safety for 30m Benched Slope	Factor of Safety for Individual Bench
OPTION A Bench Height 10m Batter Angle 50ł Berm Width 6m	1.40	1.27
OPTION B Bench Height 7.5m Batter Angle 60ł Berm Width 6m	1.34	1.20
OPTION C Bench Height 7.5m Batter Angle 70ł Berm Width 7m	1.25	1.06

PARAMETERS ADOPTED :

Apparent Cohesion c'=10 kPa
Angle of Friction Ø=37ł
Insitu Bulk Density = 17 tonnes per cubic metre
Groundwater : Assumed DRY Slope



NOTES

1. ORIGIN

This plan is based on the indicative routing of the groundwater drainage channel options presented by the E&WS on a 1:100 000 scale Lands Department Base Map, with some fine tuning utilising 1:50 000 scale Lands Department Maps. The plan has been prepared on a broad scale and both local variations within the indicated units and also some boundary changes must be anticipated.

2. NOMENCLATURE

In the central and southern portions of the plan area, the interdunal flats, underlain by the Padthaway Formation, have been designated as I to VII S, beginning with the Coorong and proceeding inland: eg Flat II is Tilly Swamp. Similarly, the ridges have been termed A to H, commencing with the Younghusband Peninsula and extending to Black Range.

In the north, the ridges tend to merge into more or less continuous Bridgewater Formation with small discontinuous flats or low areas which have not been individually mapped. Beginning approximately 25 kilometres inland from the coast, the Bridgewater Formation is blanketed by sand dunes of the Molineaux Formation. This area has been designated as flat VII N.

Fig. 1

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

UPPER SOUTH EAST DRYLAND SALINITY & FLOOD MANAGEMENT PLAN

DRAINAGE DESIGN

COMPILED R. Cavagnaro, S. Walker
DRAWN E.A & J.G.
DATE August, 1992
CHECKED
C.D.O. DATE
SCALE As shown
PLAN NUMBER 92-921

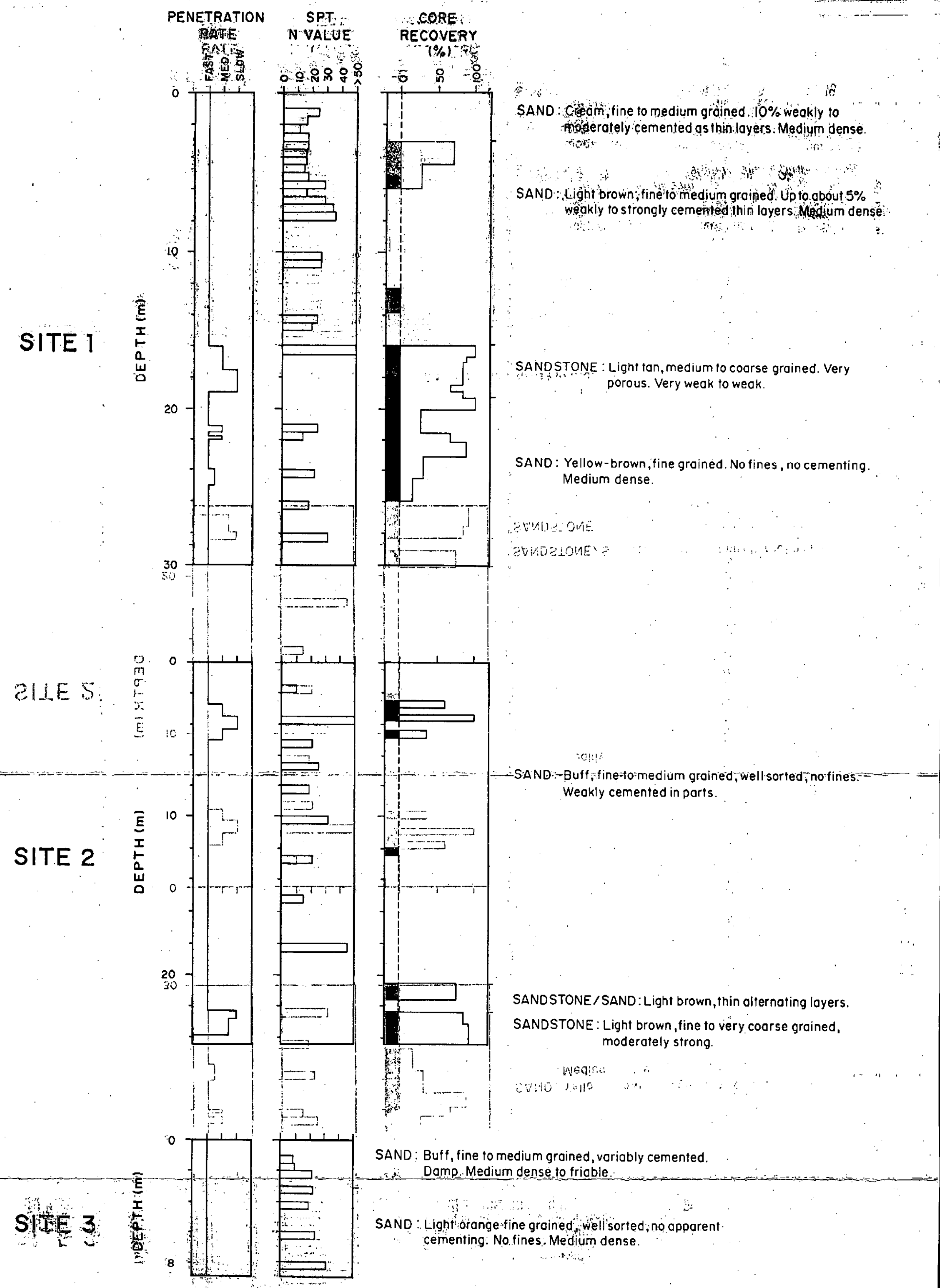


Fig. 2

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S. Walker
	DRAWN J. Gray
UPPER SOUTH EAST DRYLAND SALINITY AND FLOOD MANAGEMENT PLAN	DATE Sept. 1992
	CHECKED 20/10/92 C.D.O. DATE
SUMMARY OF STRENGTH DATA	SCALE As shown
	PLAN NUMBER 92-1138

5683

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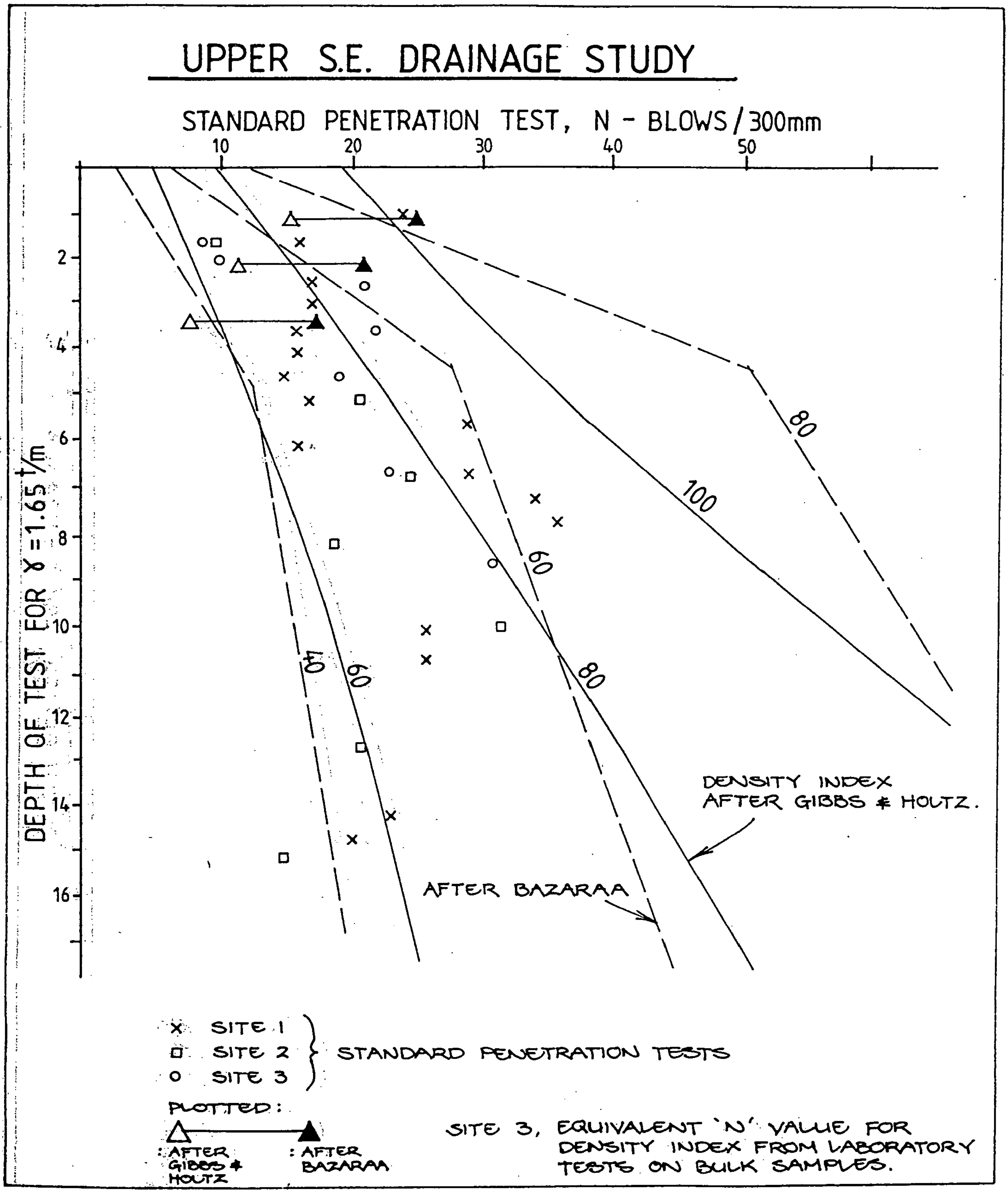
ACEA



SPT INTERPRETATION - UPPER SOUTH EAST **FIGURE 3**

Job: UPPER S.E. DRYLAND SALINITY AND FLOOD MANAGEMENT STUDY.	Reference DEP'T OF MINES & ENERGY.	Drn.	R.L.C.
		Date	7 SEPT. 92
		Job	G9205-058
		Page	

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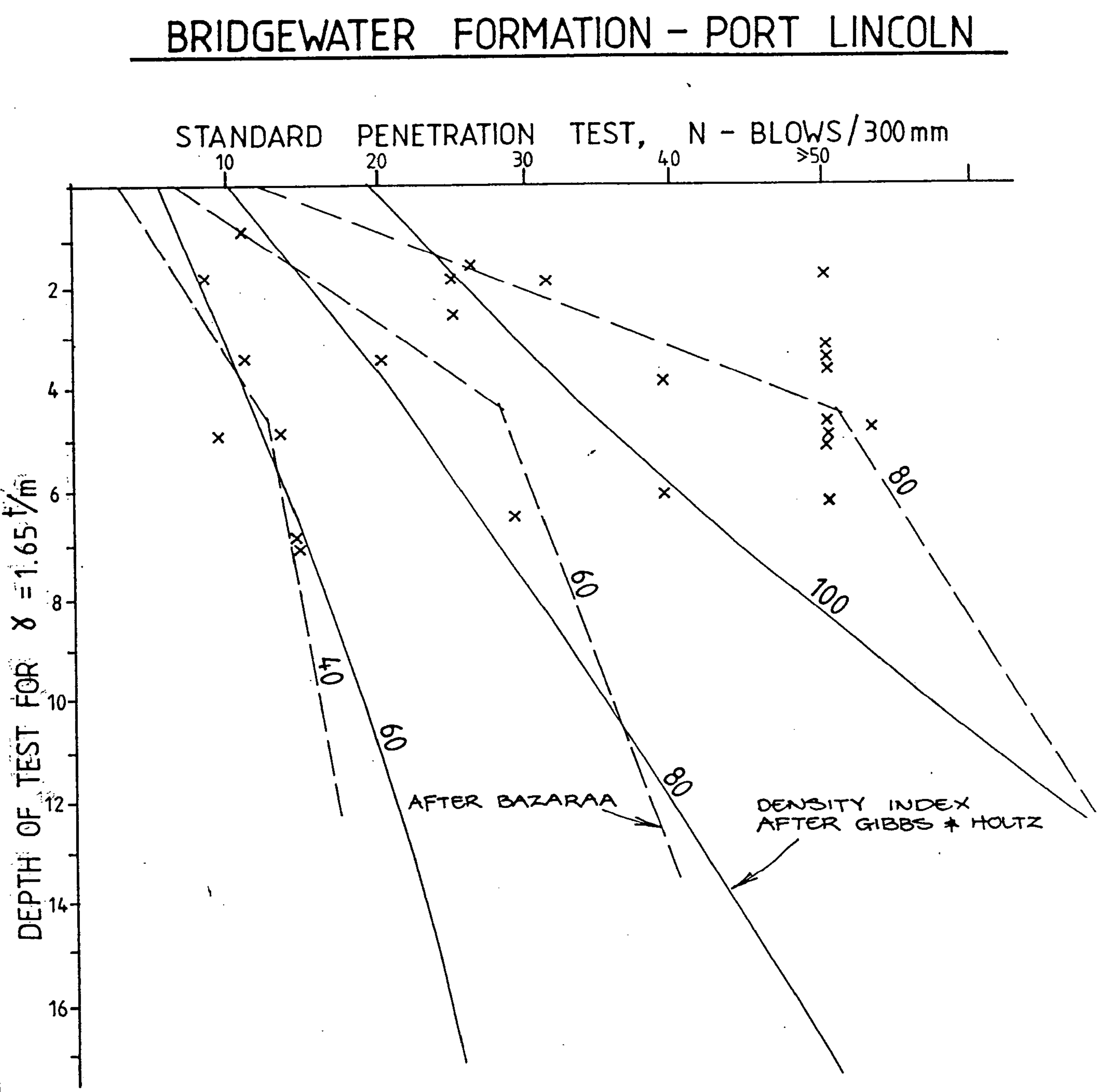

SPT INTERPRETATION - PORT LINCOLN

FIGURE 4

Job	Reference		
UPPER S.E. DRYLAND SALINITY AND FLOOD MANAGEMENT STUDY.	DEPT OF MINES & ENERGY.	Drn.	R.L.C.
		Date	7 SEPT. 92
		Job	G9205-058
		Page	

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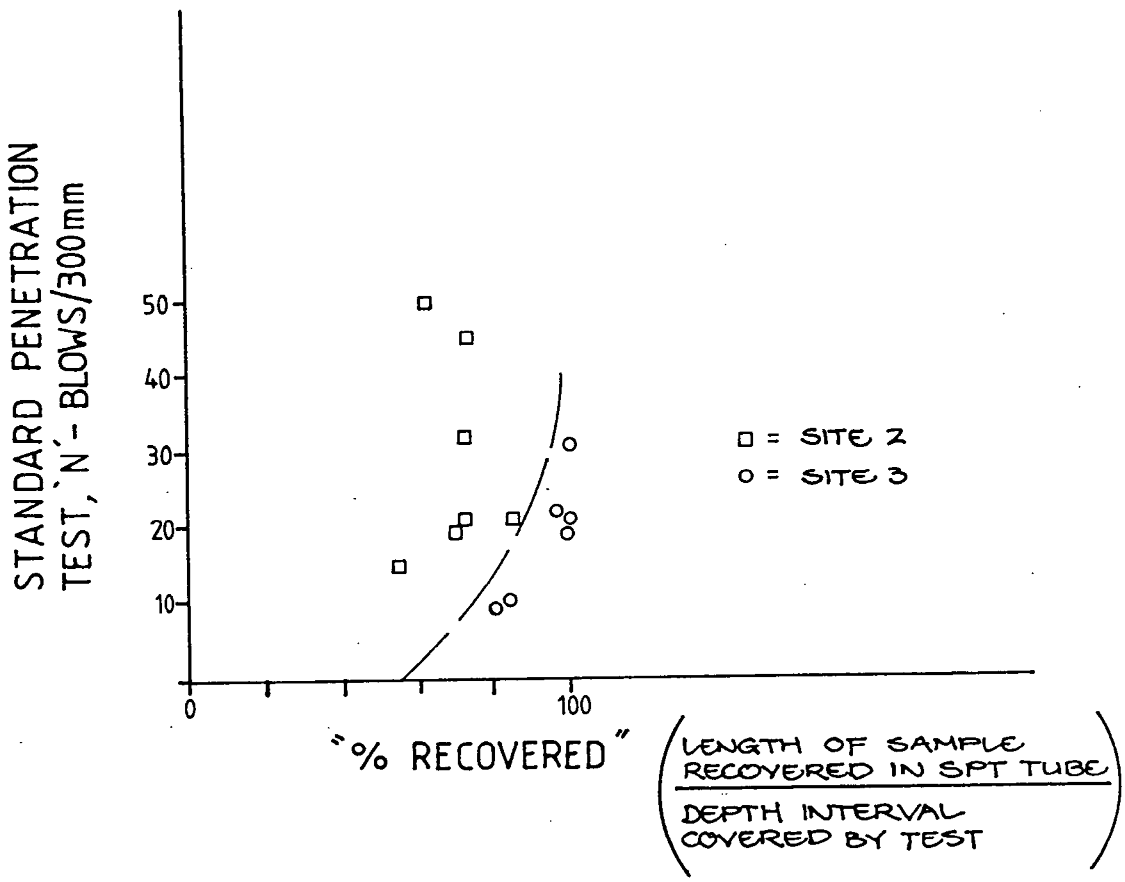

SPT vs PERCENT RECOVERED

FIGURE 5

Job	Reference		
UPPER S.E. DRYLAND SALINITY AND FLOOD MANAGEMENT STUDY.	DEPT OF MINES & ENERGY.	Drn.	RLC.
		Date	7 SEPT. 92
		Job	G9205-058
		Page	

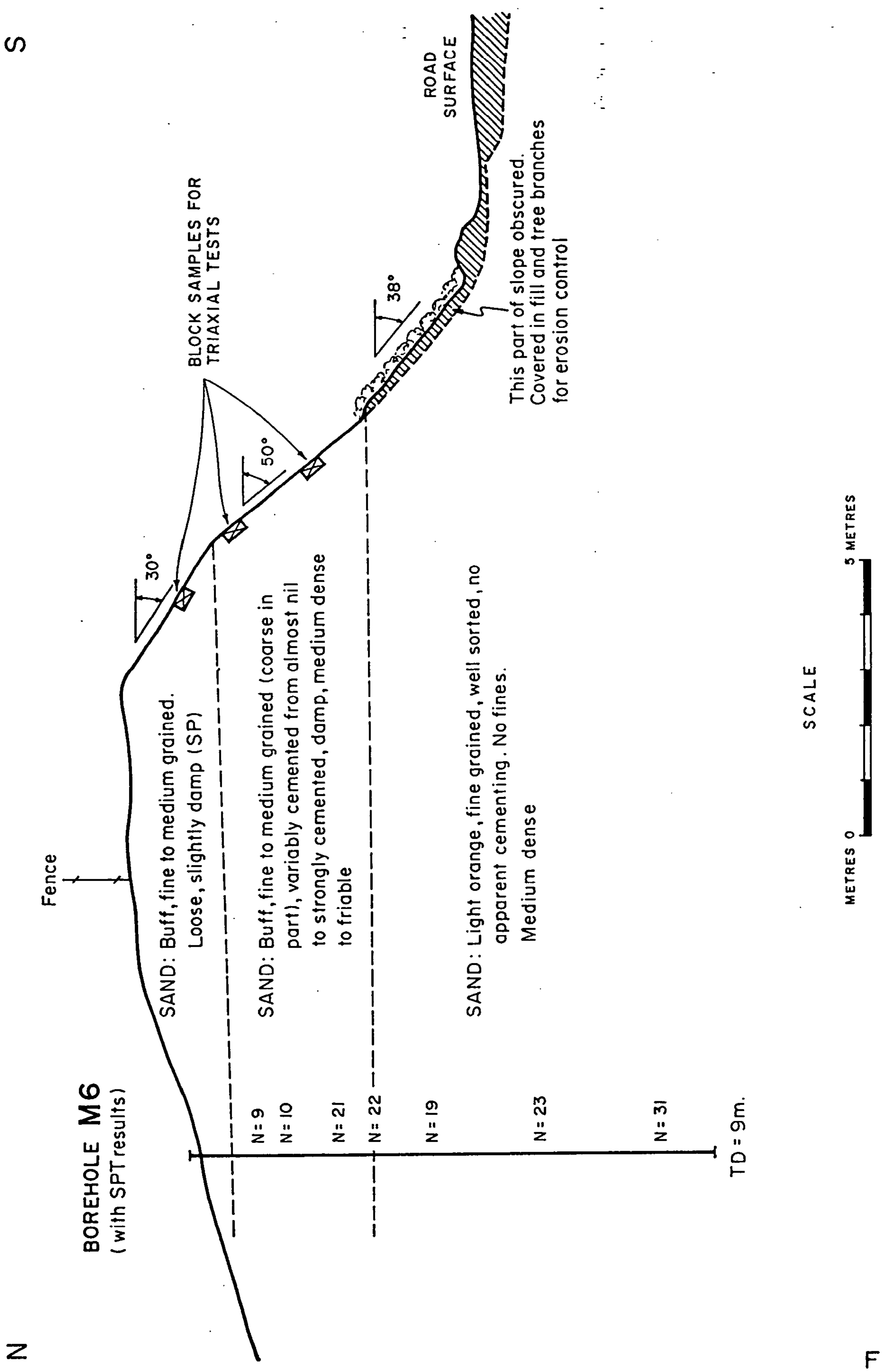

Fig. 6

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S. Walker	C.D.O. 20/11/92 DATE
UPPER SOUTH EAST DRYLAND SALINITY & FLOOD MANAGEMENT PLAN	DRAWN J. Gray	SCALE As shown
SITE 3 : CANTARA ROAD CUTTING GEOLOGICAL SECTION	DATE Sept. 1992 CHECKED	PLAN NUMBER 92-1139

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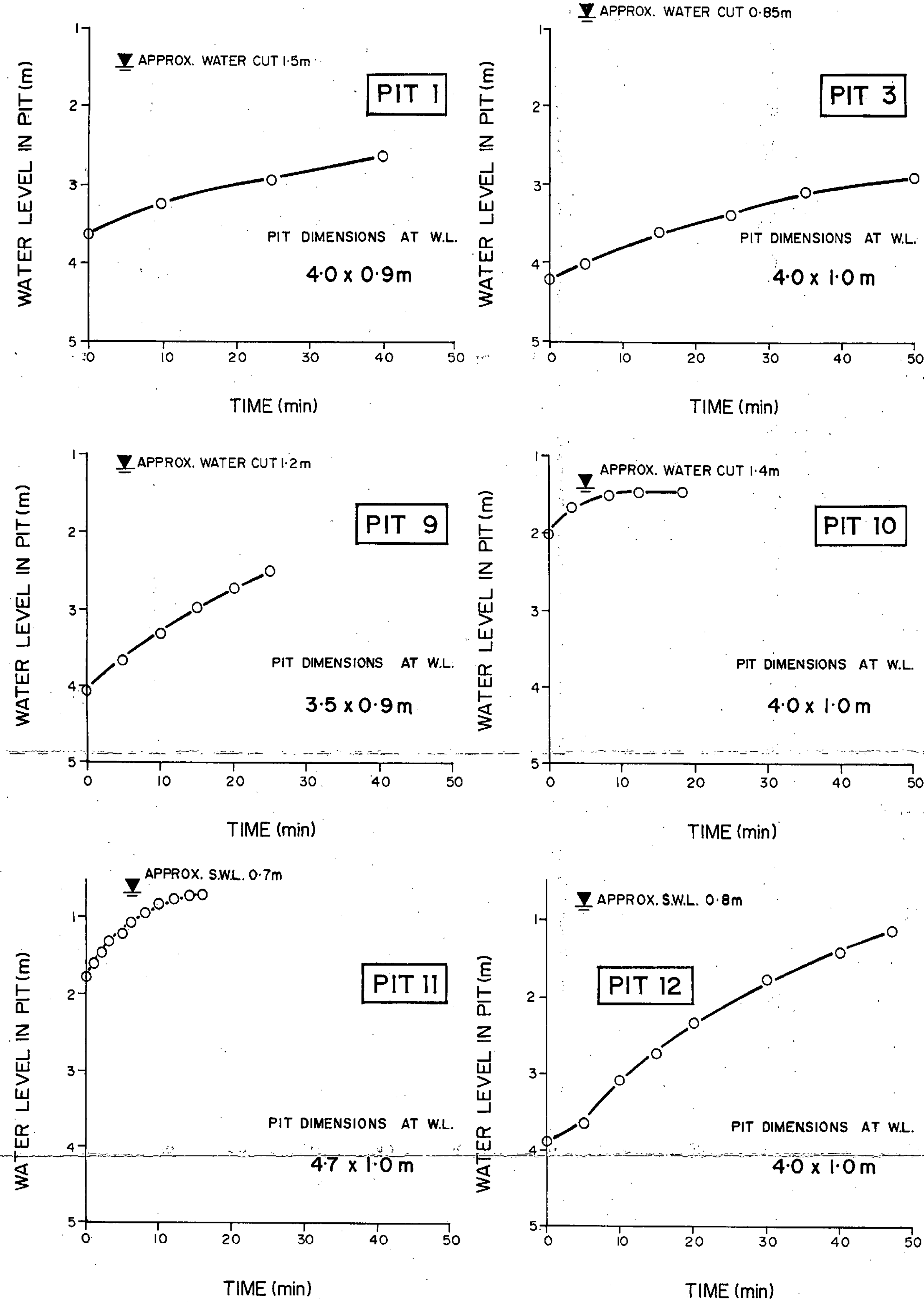

Fig. 7

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

UPPER SOUTH EAST DRYLAND SALINITY AND FLOOD MANAGEMENT PLAN

DRAINAGE STUDY

GROUNDWATER LEVEL RECOVERY IN PITS

COMPILED	S. Walker
DRAWN	N. Adams
DATE	4 Sept. 1992
CHECKED	20/1/92 C.D.O. DATE
SCALE	As Shown
PLAN NUMBER	92-1137

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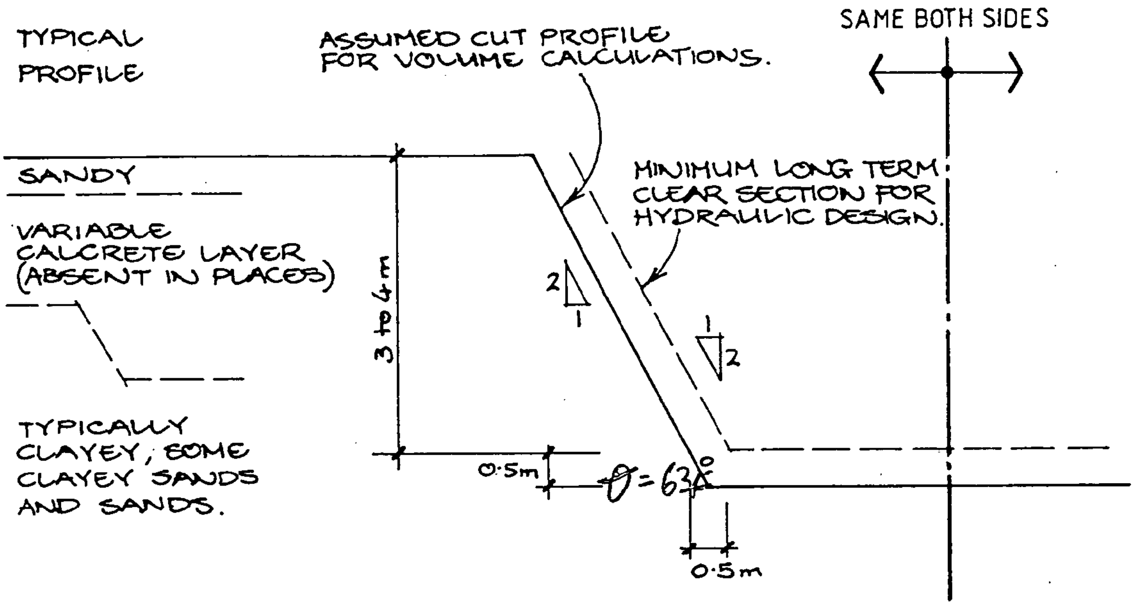
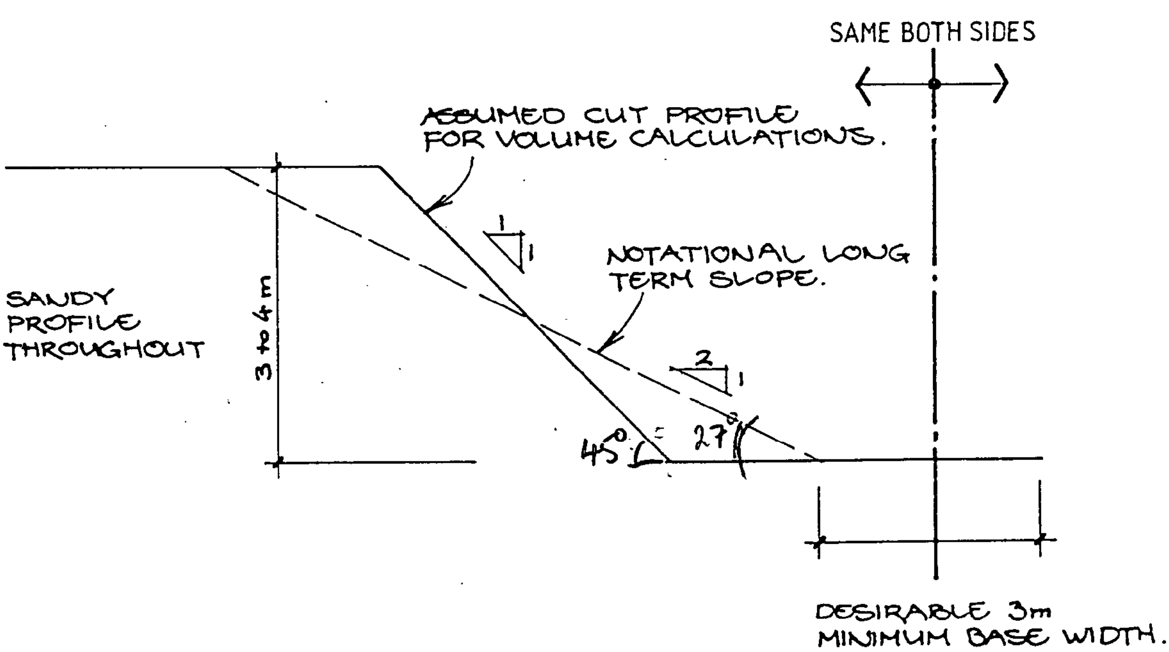


EXCAVATION PROFILE FLATS II TO VII S



EXCAVATION PROFILE FLAT VII N

EXCAVATION PROFILES - INTERDUNAL DRAINS **FIGURE 8**

Job UPPER SOUTH-EAST DRYLAND SALINITY AND FLOOD MANAGEMENT STUDY.	Reference DEPARTMENT OF MINES & ENERGY.	Drn.	R.L.C.
		Date	10·7·92
		Job	G9205-058
		Page	1 OF 1

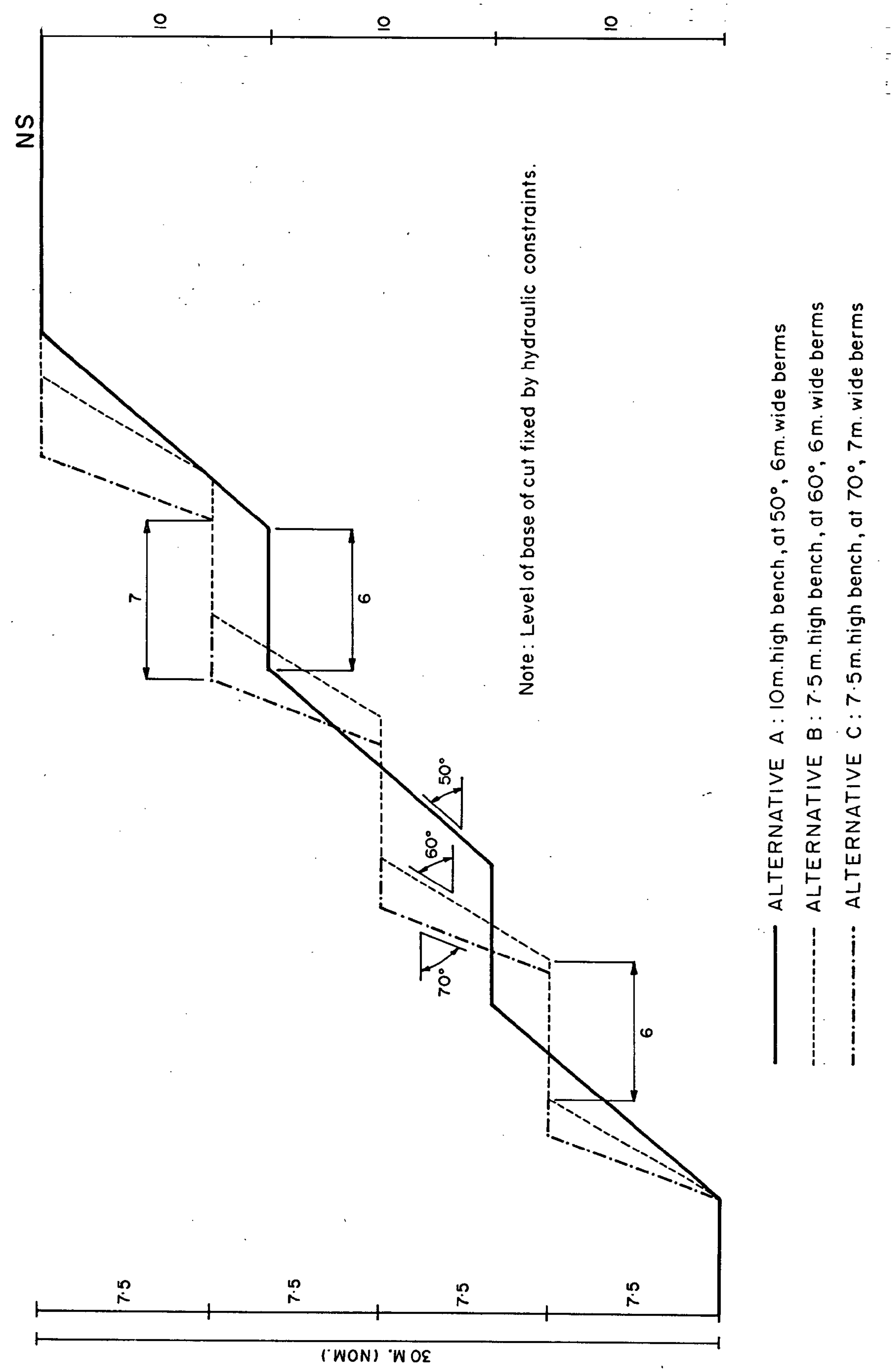


Fig. 9

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S. Walker	20/11/92 C.D.O. DATE
UPPER SOUTH EAST DRYLAND SALINITY & FLOOD MANAGEMENT PLAN	DRAWN J. Gray	SCALE As shown
PRELIMINARY ALTERNATIVE SLOPE PROFILES FOR CUTS THROUGH HIGH DUNES	DATE Sept. 1992	PLAN NUMBER
	CHECKED	92-1149

5683

APPENDIX A

TEST PITS AND SEISMIC PROGRAM

TEST PITS AND SEISMIC PROGRAM

The sub-surface materials of the interdunal flats were investigated by means of thirteen (13) excavator pits to depths of up to 5.5m (the limit of the Komatsu PC220 in soft ground). The pit locations are shown on Figure 1. Geotechnical pit logs, using the Unified Soil Classification System, are included in this Appendix, and the materials have been summarised in Table 1. Excavation properties are summarised in Tables 1 and 4. Details of groundwater inflows into the pits are recorded on the pit log forms and are summarised on Figure 7. The strengths of some of the rock materials were gauged on site using a point load test machine. Results are detailed on the test sheets in this Appendix. Photographs are shown in Appendix D.

In the central and southern portions of the project area, the interdunal flats have been designated as I to VII S beginning with the Coorong and proceeding inland: eg Flat II is Tilly Swamp. These are delineated on Figure 1.

In the north, the ridges tend to merge into more or less continuous Bridgewater Formation with small discontinuous flats or low areas which have not been individually mapped. Beginning approximately 25 kilometres inland from the coast, the Bridgewater Formation gives way to an area which has been substantially covered with sand dunes of the Molineaux Formation. There are no easily discernible drainage patterns on the 1:50 000 maps and this area has been designated as a flat, VII N. An additional low lying sandy area also has been identified in the north western corner of Messent Conservation Park.

Comprising the southern and central area, Flats II - VII S (as delineated on Figure 1) were investigated by a total of nine (9) excavator test pits. One pit was sited in each of Flats III & VI and three pits each in Flats V and VII S, and a further pit was excavated in a small interdunal area between Flats III and IV. No pits were excavated in Flat II, the Tilly Swamp, or in Flat IV (Table A-1).

Flat VII N, the northern area, was investigated by four (4) test pits.

Flat I, the Coorong, has not been investigated to date. Where exposed, the surface is sandy but, presumably, will also be underlain by soft clays, particularly at the more northern crossings which are permanently below water, and by sedimentary carbonate. Calcrete is considered unlikely to be present in the Coorong sediments. Further investigation is required in these areas once discharge or crossing points have been defined.

Formations encountered in the pit excavations consisted mainly of the Padthaway Formation of Pleistocene age, and the Holocene Molineaux Sand of aeolian origin which generally overlies the Pleistocene sediments as a thin blanket, mainly in the north. Except for a single instance in Pit 11, the Bridgewater Formation, also of Pleistocene age, was encountered *in situ* only in the drilling.

Calcrete formation has, however, modified the Padthaway sediments in most places. It ranges from uncemented calcareous silts to variably cemented gravels and cobbles (nodular calcrete) to discontinuous or continuous sheets of high substance strength. Seismic velocities are compared with observations in the pits and with the performance of the excavator in Table 2. While the calcrete formation appears to be much more advanced in the southern and central areas, it was also present in the north. The seismic work at 8 sites showed the calcrete to be laterally consistent over at least 100 metres although variable in strength. The strongest layers of the calcrete fluctuate by up to 1 metre in depth below the ground surface.

Of the 13 backhoe pits, calcrete layers of variable thickness and strength were encountered in 11 pits. Four (4) of the pits refused on calcrete. The majority of the calcrete is likely to be encountered within the top three metres of the surface. The stronger rock appears to begin at about 2 metres and could persist to 3 metres. The calcrete, while present in the northern area (Flat VII N), is thin and much less well developed than it is in the southern and central area (Table 1).

TABLE A-1

DISTRIBUTION OF TEST PITS (INTERDUNAL FLATS)

AREA	FLAT	NO. OF PITS	COMMENT
SOUTHERN & CENTRAL			
	II	NIL	TILLEY SWAMP
	III	1	
	IV	NIL	
	V	3	
	VI	1	
	VII S	3	
	III/IV	1	
NORTHERN			
	VII N	4	
	I	NIL	COORONG - NOT SUBJECT OF INVESTIGATION.

Apart from calcrete formation within the Padthaway Formation, the sediments, as encountered in the pits, are largely uncemented. However, there are some materials which demonstrate localised induration and possess rock substance strengths. These stronger materials appear discontinuous in the pit excavations, and were not noted to significantly retard excavation rates, nor did their presence add to pit side slope stability, as the rock strength fragments were dispersed as gravel to cobble sized fragments in a soil strength matrix.

There is a strong indication in the pit logs that the Padthaway Formation has more clean sands in the north and more clay in the south and central areas. This is most readily seen in Table 1, which summarises the materials encountered.

No more detailed correlation of individual Padthaway Formation soil layers has been possible between test pits; nor was it expected to be, in view of the substantial distances between pits. There were no specific trends between flats that could be discerned, with the following possible exceptions:

- slightly harder excavation conditions may be encountered in the calcrete with increasing distance from the coast

- the calcrete may be nearer to the surface on the eastern side of the flats.

Both of these trends would need to be confirmed by further work, although the former would appear to be a logical consequence of the greater age and hence the possibly of greater time for the formation of the calcrete.

Summary

Southern and Central areas

In broad terms, all pits in the southern and central zone encountered a similar profile consisting of:

- a sandy topsoil layer between 0.1 and 0.5 metres thick.
- a calcrete layer in most but not all test pits which varied significantly in ease of excavation and extended to depths between 2 and 3 metres.
- below the calcrete layer, the soils were generally clayey with some clayey sands.

Northern area

The northern sandy flat, VII N, was investigated by four (4) test pits. They encountered generally sandy conditions with some minor thin calcrete and clay layers. The sands were fine grained and typically uncemented.

NOTE Ⓐ SOIL TYPE

42. Classification of soils

42.1 Use of the system. Use of the British Soil Classification System for Engineering Purposes (BSCS) described in 42.3 is discretionary; for many purposes, a full description of soils in accordance with clause 41 will suffice. The BSCS is recommended primarily for soils to be used as construction materials, when it is particularly useful. When the symbols for the BSCS are used, a full written description, including both the soil group name and supplementary descriptive terms as discussed in clause 41, is also required.

Not included in these notes

42.2 Nature and purpose of soil classification

42.2.1 *Distinction between soil description and soil classification.* A full description gives detailed information on the grading, plasticity, colour, and particle characteristics of a soil, as well as on the fabric, the state of bedding, nature of discontinuities and strength condition in which it occurs in a sample, borehole or exposure. Few, if any, soils will have identical descriptions. On the other hand, a soil classification places a soil in a limited number of groups on the basis of grading and plasticity of a disturbed sample. These characteristics are independent of the particular condition in which a soil occurs, and disregard the influence of the structure, including fabric, of the soil mass; but they can give a good guide to how the disturbed soil will behave when used as a construction material, under various conditions of moisture content.

41.3 Material characteristics of soils

41.3.1 *Range of application.* Material characteristics refer to those characteristics that can be described from visual and manual examination of either disturbed or undisturbed samples, and include soil name, colour, particle shape and particle composition.

In a soil description, the main characteristics should preferably be given in approximately the following order.

(a) *Mass characteristics* (see 41.2)

(1) Field strength or compactness (see table 6), and indication of moisture condition.

(2) Bedding.

(3) Discontinuities.

(4) State of weathering.

(b) *Material characteristics* (see 41.3)

(1) Colour.

(2) Particle shape and composition.

(3) Soil name (in capitals, e.g. SAND), grading and plasticity.

(c) *Geological formation, age and type of deposit* (see 41.4).

(d) *Classification* (optional) (see clause 42).

Soil group symbol.

Examples:

Firm closely-fissured yellowish-brown CLAY of high plasticity. London Clay.

41.3.2.5 *Colour.* Details are given in the extreme right hand column of table 6. For more detailed descriptions, colour charts based on the system of Munsell may be used [156, 157] †.

41.3.2.6 *Particle shape and composition.* Where appropriate, particle shape may be described by reference to the general form of the particles, their angularity which indicates the degree of rounding at edges and corners, and their surface characteristics. Some recommended terms are as follows.

Angularity	angular
	subangular
	subrounded
	rounded
Form	equidimensional
	flat
	elongated
	flat and elongated
	irregular
Surface texture	rough
	smooth

41.3.3 *Made ground.* It is rarely possible to carry out significant soil tests on made ground, and descriptions of the material are all that remains after the samples have been discarded or pits filled in. Good descriptions are, therefore, of even greater importance with this type of material and should include information on the following as well as on the soil constituents.

(a) Mode of origin of the material.

(b) Presence of large objects such as concrete, masonry or old motor cars.

(c) Presence of voids or collapsible hollow objects.

(d) Chemical waste, and dangerous or poisonous substances.

(e) Organic matter, with a note on the degree of decomposition.

(f) Odourous smell.

(g) Striking colour tints.

(h) Any dates readable on buried newspapers.

(i) Signs of heat or internal combustion under ground, i.e. steam emerging from borehole.

41.3.2 *Soil name*

41.3.2.1 *Introduction.* The soil name is based on particle size distribution and plastic properties. These characteristics are used because they can be measured readily with reasonable precision, and estimated with sufficient accuracy for descriptive purposes.

Table 7. Names and descriptive letters for grading and plasticity characteristics

		Descriptive name	Letter
Coarse components	Main terms	GRAVEL	G
		SAND	S
	Qualifying terms	Well graded	W
		Poorly graded	P
		Uniform	Pu
		Gap graded	Pg
Fine components	Main terms	FINE SOIL, FINES	F
		may be differentiated into M or C	
		SILT (M-SOIL)*	M
		plots below A-line of plasticity chart of figure 31 (of restricted plastic range)	
		CLAY	C
		plots above A-line (fully plastic)	
	Qualifying terms	Of low plasticity	L
		Of intermediate plasticity	I
		Of high plasticity	H
		Of very high plasticity	V
		Of extremely high plasticity	E
		Of upper plasticity range†	U
		incorporating groups I, H, V and E	
Organic components	Main term	PEAT	Pt
	Qualifying term	Organic	O
		may be suffixed to any group	

*See note 5 following table 8.

†This term is a useful guide when it is not possible or not required to designate the range of liquid limit more closely, e.g. during the rapid assessment of soils.

41.3.2.3 *Plasticity.* Clay and silt, both alone and in mixtures with coarser material, may be classified as follows:

Term	Range of liquid limit
of low plasticity	under 35 %
of intermediate plasticity	35 % to 50 %
of high plasticity	50 % to 70 %
of very high plasticity	70 % to 90 %
of extremely high plasticity	over 90 %

Term	Composition of the coarse fraction
Slightly sandy GRAVEL	up to 5 % sand
Sandy GRAVEL	5 % to 20 % sand
Very sandy GRAVEL	over 20 % sand
GRAVEL/SAND	about equal proportions of gravel and sand
Very gravelly SAND	over 20 % gravel
Gravelly SAND	20 to 5 % gravel
Slightly gravelly SAND	up to 5 % gravel

41.3.2.4 *Deposits containing boulder-sized and cobble-sized particles.* Usually, very coarse deposits can be described only in excavations or exposures. They are described as follows:

	Main name	Estimated boulder or cobble content of very coarse fraction
Over 50 % of material is very coarse (over 60 mm)	BOULDERS or BOULDER GRAVEL	Over 50 % is of boulder size (over 200 mm)
	COBBLES or COBBLE GRAVEL	Over 50 % is of cobble size (200 mm to 60 mm)

BOULDERS			> 200mm
COBBLES			> 60 < 200mm
GRAVEL	Coarse		20 - 60mm
	Medium		6 - 20mm
	Fine		2 - 6mm
SAND	Coarse	0.6 - 2mm	
	Medium		0.2 - 0.6mm
	Fine		0.06 - 0.2
SILT	Coarse		0.02 - 2mm
	Medium		0.006 - 0.02
	Fine		0.002 - 0.003
CLAY			< 0.002

NOTE (B) GRAPHIC LOG

Made ground

GRAVEL (GW.GP)

SAND (SW.SP)

SILT (ML.MH)

CLAY (CL.CH)

ORGANIC SOILS (OL.OH.Pt)

THIN LAYER

COMPOSITE/INTERBEDDED - EXAMPLES

SILTY SAND (SM)

SANDY CLAY (CL)

SP CLAY (CL) WITH THIN SAND (SP) INTERBEDS

CLAY (CH) WITH SAND (SC) DYKE, AND FISSURE (BOTH VERTICAL)

NOTE: In all the above cases bedding would have been either observed as, or assumed to be horizontal, unless otherwise stated.

To be used for Peat exclusively

Rocks		
Sedimentary	Metamorphic	Igneous
Chalk		
Limestone	Coarse-grained	Coarse-grained
Rudaceous: Conglomerate	Medium-grained	Medium-grained
Rudaceous: Breccia		
Arenaceous: Sandstone	Fine-grained	Fine-grained
Argillaceous: Siltstone		
Argillaceous: Mudstone		
Argillaceous: Shale		
Coal		
Pyroclastic (volcanic ash)		
Gypsum, Rocksalt etc		

Note that symbols for organic and composite/interbedded examples are modified BS5930 1981 by D. Stapledon. All other symbols are BS5930 1981.

Table 12. Special symbols for borehole record

Fault

Slip surface

Organic layer+

Marine band

Shell band

(+ Not within BS 5930 1981)

Examples:

Medium-grained igneous faulted against coarse-grained metamorphic rock

Fault in sandstone

Slip surface in sandstone

Slip surface in shale

NOTE (C) MOISTURE CONTENT

2. DEGREE OF SATURATION OF SANDS — DESCRIPTIVE TERMS

Condition of sand	Criteria	Degree of saturation (%)
Dry	Oven dried. Not usually met in field.	0
Humid	Feels dry, grains "run" freely in hands.	1–25
Damp	Feels cool, slight darkening of colour, grains have slight tendency to adhere to one another.	25–50
Moist	Feels cool, darker colour, grains tend to adhere to one another.	50–75
Wet	Feels cold, makes hands wet; should be close to water table.	75–99
Saturated	Below water table, or static water level in excavation or drill holes.	100

7.8.4. MOISTURE CONTENT OF CLAY SOILS[1]

Abbreviations	Meaning
MC ≃ LL	Moisture content near liquid limit
MC < LL	Moisture content less than liquid limit
MC > PL	Moisture content greater than plastic limit
MC ≃ PL	Moisture content near plastic limit
MC ≤ PL	Moisture content less or equal to plastic limit
MC < PL	Moisture content less than plastic limit
MC ≪ PL	Moisture content much less than plastic limit

(Taken from AIMM Field Geologists Manual. 2nd edition)

NOTE (D) DENSITY

The relative density of sands and gravels may be determined by the standard penetration test. A scale in terms of *N*-values (see BS 1377) is as follows.

Term		SPT *N*-values: blows/300 mm penetration	Relative density %
Very loose	(VL)	0 to 4	< 15
Loose	(L)	4 to 10	15 to 35
Medium dense	(MD)	10 to 30	35 to 65
Dense	(D)	30 to 50	65 to 85
Very dense	(VD)	over 50	> 85

Correct for effect of overburden pressure

NOTE (E) CONSISTENCY

Consistency*: For materials which have cohesive properties the following terms are used to describe consistency.

		Term		qu unconfined compressive strength (KPa)	Undrained shear strength (KN/m²)
SILT		Soft or loose	Easily moulded or crushed in the fingers.		
SILT		Firm or dense	Can be moulded or crushed by strong pressure in the fingers.		
CLAY	(VS)	Very soft	Exudes between fingers when squeezed in hand.	< 25	less than 20
CLAY	(S)	Soft	Moulded by light finger pressure.	25 to 50	20 to 40
CLAY	(F)	Firm	Can be moulded by strong finger pressure.	50 to 100	40 to 75
CLAY	(St)	Stiff	Cannot be moulded by fingers. Can be indented by thumb.	100 to 200	75 to 150
CLAY	(VSt)	Very stiff	Can be indented by thumb nail.	200 to 400	greater than 150
		Hard+		> 400	

+ From Australian Standard 1726-1981 (ref: D.3.2.1)

* Legend colum may be used to indicate pocket penetrometer values (p.p.).

NOTE (F) IN-SITU TESTS

2.5 In situ tests

S — Standard penetration test (SPT). A 50 mm diameter split spoon sampler is driven 450 mm into the soil using a 65 kg hammer with a 760 mm drop, and the penetration resistance is expressed as the number of blows required to obtain 300 mm penetration below an initial penetration of 150 mm through any disturbed ground at the bottom of the borehole.

In the borehole record, the depth of the test is that at the start of the normal 450 mm penetration. The number of blows to achieve the standard penetration of 300 mm (the '*N*' value) is shown after the test index letter, but the seating blows through the initial 150 mm penetration are not reported unless the full penetration of 450 mm is not achieved. In the latter case, the symbols below are added to the test index letter:

S* — Seating blows only.

S‡ — Blow count includes seating blows.

S" — No penetration.

S+ — Split spoon sampler sank under its own weight.

The test is usually completed when the number of blows reaches 50. For tests achieving the full penetration of 450 mm, the depth at which the test procedure is commenced is given in the depth column on the borehole record, whilst for those tests not achieving full penetration, the depths of both the top and the bottom of the test drive are shown. If a sample is not recovered in the split spoon sampler, a disturbed sample is taken on completion of the test drive. Both are given the same depth as the top of the SP test drive.

C — Dynamic Cone Penetration Test (CPT). A test conducted usually in coarse granular soils using the same procedure as for the SPT but with a 50 mm diameter, 60° apex solid cone fitted to the split spoon sampler. Variations in test results are indicated by the same symbols as for the SPT. The bulk disturbed sample taken, is given the same depth as the top of the CP test drive.

V — Vane test.

J — Borehole jack test. See text of report for full description.

K — Permeability test. See text of report for full description.

Legend column may be used to indicate drill water loss % if applicable.

NOTE Ⓖ ROCK TYPE

44.1.2 *General description.* Rocks seen in natural outcrops, cores and excavations should generally be described in the following sequence:

- colour;
- grain size;
- texture and structure; (Fabric)
- state of weathering;
- rock name (in capitals, e.g. GRANITE);
- strength;
- other characteristics and properties.

Term	Description
Fresh	No visible sign of weathering of the rock material.
Discoloured	The colour of the original fresh rock material is changed and is evidence of weathering. The degree of change from the original colour should be indicated. If the colour change is confined to particular mineral constituents this should be mentioned.
Decomposed	The rock is weathered to the condition of a soil in which the original material fabric is still intact, but some or all of the mineral grains are decomposed.
Disintegrated	The rock is weathered to the condition of a soil in which the original material fabric is still intact. The rock is friable, but the mineral grains are not decomposed.

44.2.5 *Rock name.* An aid to the identification of rocks for engineering purposes is given in table 9. The table follows general geological practice, but is intended as a guide only; geological training is required for the satisfactory identification of rocks. Engineering properties cannot be inferred from the rock names in the table.

44.3 Description of rock masses

44.3.1 *Introduction.* The description of rock masses requires information additional to the description of the rock material. A rock mass should be described first as a rock material, followed by additional information about discontinuities and other features of engineering significance. Such information includes:

(a) the description of rock types in the mass, with reference to major geological structures;

(b) the dip magnitude and direction, nature, spacing and persistence, width of opening of discontinuities;

(c) details of the weathering profile.

44.3.2 *Structure.* The structure of the rock mass is concerned with the larger-scale inter-relationship of textural features. Common terms should be used where possible. Terms frequently used to describe sedimentary rocks include bedded, laminated; metamorphic rocks may be foliated, banded, cleaved; igneous rocks may be massive, flow banded.

Descriptive terms used for the spacing of these planar structures are as follows.

Term	Spacing
Very thick	greater than 2 m
Thick	600 mm to 2 m
Medium	200 mm to 600 mm
Thin	60 mm to 200 mm
Very thin	20 mm to 60 mm
Thickly laminated (Sedimentary) Narrow (Metamorphic and igneous)	6 mm to 20 mm
Thinly laminated (Sedimentary) Very narrow (Metamorphic and igneous)	less than 6 mm

Spacings can be shown graphically adjacent to "core" column if desired.

44.2.2 *Grain size.* A descriptive classification scheme is given in table 9. Grain size refers to the average dimension of the mineral or rock fragments comprising the rock. It is usually sufficient to estimate the size by eye, which may be aided by a hand lens in the assessment of fine-grained or amorphous rocks. The limit of unaided vision is approximately 0.06 mm.

44.2.3 *Texture and fabric.* The texture of a rock refers to individual grains. The arrangement of grains, referred to as the rock fabric, may show a preferred orientation. Terms frequently used include: porphyritic, crystalline, cryptocrystalline, granular, amorphous and glassy.

Table 10. Scale of weathering grades of rock mass

Term	Description	Grade	Legend*
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.	I	(Fr)
Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering.	II	(SW)
Moderately weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones.	III	(MW)
Highly weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as corestones.	IV	(HW)
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	V	(CW)
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI	(RS)

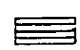
(*Choice of symbol at discretion of user and is not within BS 5930 1981)

44.2.8 *Examples.* The following descriptions are given for guidance in the use of appropriate descriptive terms.

For example, a metamorphic rock material might be described as a 'dark grey, medium grained, thinly foliated, fresh GNEISS, very strong'; a typical description of a sedimentary rock might be a 'yellowish brown, coarse grained, wholly discoloured, micaceous SANDSTONE, moderately weak'; an igneous rock might be described as 'dark greyish green, medium grained, partly discoloured, quartz DOLERITE, extremely strong'.

For strength term see note Ⓗ

In CONDENSED REPORT LOG use the following symbols. Where rock mass is converted to residual soil use appropriate soil symbol.

Fresh to slightly weathered 

Moderately weathered 

Highly weathered 

Completly weathered 

NOTE (H) ROCK STRENGTH

44.2.6 *Strength of rock material.* A scale of strength, based on uniaxial compressive testing, is as follows.

Term	Symbol	Compressive strength, MN/m^2	Approx. Is 50 (MPa) *	Geol. Society (Ref.3) +	Approx kg/cm^2
Very weak	(VW)	less than 1.25	< 0·05	Very weak: Broken by hand with difficulty.	<15
Weak	(W)	1.25 to 5	0·05 – 0·2	Weak: Material crumbles under blows with the sharp end of a geological pick.	15 – 50
Moderately weak	(MW)	5 to 12.5	0·2 – 0·5	Moderately weak: Too hard to cut by hand into a triaxial specimen.	50 – 130
Moderately strong	(MS)	12.5 to 50	0·5 – 2·0	Moderately strong: 5 mm indentations with sharp end of pick.	130 – 500
Strong	(S)	50 to 100	2·0 – 4·0	Strong: Hand held specimen can be broken with single blow of geological hammer.	500 – 1000
Very strong	(VS)	100 to 200	4·0 – 8·0	Very strong: More than one blow of geological hammer required to break specimen.	1000 – 2050
Extremely strong	(ES)	greater than 200	> 8·0		

(note: 1 MPa ~ 145 psi ~ 10 kg/cm^2)

The strength of a rock material determined in the uniaxial compression test is dependent on the moisture content of the specimen, anisotropy and the test procedure adopted.

* Legend column may be used to indicate point load strength index, Is 50 (MN/m^2). (Correcting for any fabric anisotropy).

\+ Geological Society. Engineering Group Working Party (1977) The Description of Rock Masses for Engineering Purposes. Q. Jnl. Eng Geol. V-10. pp 355-388.

Australian Standard AS 1726-1981

D5.2 Strength. The following terms are used to describe rock strength:

Rock strength class	*Abbreviation*	*Point load strength index, I_s (50)* (MPa)
Extremely low	EL	< 0.03
Very low	VL	0.03 to 0.1
Low	L	0.1 to 0.3
Medium	M	0.3 to 1
High	H	1 to 3
Very high	VH	3 to 10
Extremely high	EH	> 10

NOTE (I) CORE QUALITY

44.2.7 *Fracture state.*

Elsewhere [161], a determination of Rock Quality Description (RQD) has been proposed as a quantitative measure of the fracture state of rock. RQD is the percentage of rock recovered as sound lengths which are 100 mm or more in length. Only core lengths determined by geological fractures should be measured. Descriptive terms are as follows.

RQD	Term	Suggested symbol +
0 % to 25 %	Very poor	(VP)
25 % to 50 %	Poor	(P)
50 % to 75 %	Fair	(F)
75 % to 90 %	Good	(G)
90 % to 100 %	Excellent	(E)

(+Not within BS 5930 1981)

2.3 **Rock core descriptions** (Values may be shown graphically in "core" column)

TCR Total core recovery. The length of the total amount of core sample recovered expressed as a percentage of the length of core run.

SCR Solid core recovery. The length of core recovered as solid cylinders, expressed as a percentage of the length of core run.

RQD Rock quality designation. The sum length of all core pieces that are 10 cm or longer, measured along the centre line of the core, expressed as a percentage of the core drilled.

NOTE (J) HYDROGEOLOGY

Water cut, standpipe and piezometer installation indicate if sample taken, date and by whom. Show base of standpipe and centre of piezometer in legend column. Show time and dates of water level observations.

NOTE (K) DISCONTINUITY DESCRIPTION

44.3.3.2 *Discontinuity spacing in one dimension.*
The following descriptive scheme should be used.

Term	Spacing	Suggested Symbol +
Very widely spaced	greater than 2 m	(VWS)
Widely spaced	600 mm to 2 m	(WS)
Medium spaced	200 mm to 600 mm	(MS)
Closely spaced	60 mm to 200 mm	(CS)
Very closely spaced	20 mm to 60 mm	(VCS)
Extremely closely spaced	less than 20 mm	(ECS)

(+ Not within BS 5930 1981)

44.3.3.3 *Discontinuity spacing in three dimensions.*
The spacing of discontinuities may be described with reference to the size and shape of rock blocks bounded by the discontinuities. Rock blocks may be approximately equidimensional, tabular or columnar in shape. Descriptive terms may be used in accordance with the following.

First term	Maximum dimension
Very large	greater than 2 m
Large	600 mm to 2 m
Medium	200 mm to 600 mm
Small	60 mm to 200 mm
Very small	less than 60 mm

Second term	Nature of block
Blocky	Equidimensional
Tabular	Thickness much less than length or width
Columnar	Height much greater than cross section

The use of these terms requires an understanding of the distribution of discontinuities in three-dimensions; in consequence they cannot be used in the description of drill core.

NOTE (L)

41.4 **Geological formation, age and type of deposit.** The geological formation should be named where this can be done with confidence, but it may not be easy to tell to which formation a sample belongs, or to locate formation boundaries in a borehole or exposure; conjecture should be avoided.

The characteristic lithology is sometimes indicated in the formation name, e.g. London Clay, but it should be remembered that at a particular location or horizon the lithology may be completely different from that indicated in the formation name.

A term indicating the geological origin or type of the deposit may be given on the map legend, e.g. Made ground, Peat, Head, Alluvium, River terrace, Brickearth, Blown (aeolian) sand, Till. The term can indicate to the engineer some of the characteristics that the deposit may be expected to show.

NOTE (M)

41.5 **Additional information.** Any additional information on the composition, structure, behaviour or other characteristics of the soil that would be of value in assessing its nature and properties should be recorded. Special note should be made if the properties of the material are considered to be unusual in relation to the rest of its description. Note should also be made if there is doubt whether the sample described is representative of the material at the level from which it was sampled, due, for instance, to fracture of particles or loss of fines during sampling, or to the sample size or borehole diameter being too small in relation to the grading or structure of the material being sampled. Where relevant, it should be made clear whether the sample on which the description is based was disturbed or undisturbed. Where the strength of the soil is likely to vary because of seasonal variations in moisture content, this should be noted.

Suggested Method for Determining Point Load Strength ______ [in part]

PROCEDURE

Specimen selection and preparation

6.(a) A test sample is defined as a set of rock specimens of similar strength for which a single Point Load Strength value is to be determined.

(b) The test sample of rock core or fragments is to contain sufficient specimens conforming with the size and shape requirements for diametral, axial, block or irregular lump testing as specified below.[7]

(c) For routine testing and classification, specimens should be tested either fully water-saturated or at their natural water content.[8]

Calibration

7. The test equipment should be periodically calibrated using an independently certified load cell and set of displacement blocks, checking the P and D readings over the full range of loads and displacements pertinent to testing.

The diametral test[2]

8.(a) Core specimens with length/diameter ratio greater than 1.0 are suitable for diametral testing.

(b) There should preferably be at least 10 tests per sample, more if the sample is heterogeneous or anisotropic.[7]

(c) The specimen is inserted in the test machine and the platens closed to make contact along a core diameter, ensuring that the distance L between the contact points and the nearest free end is at least 0.5 times the core diameter (Fig. 3a).

(d) The distance D is recorded $\pm 2\%$.[4]

(e) The load is steadily increased such that failure occurs within 10–60 sec, and the failure load P is recorded. The test should be rejected as invalid if the fracture surface passes through only one loading point (Fig. 4d).

(f) The procedure (c) through (e) above is repeated for the remaining specimens in the sample.

The axial test[2]

9.(a) Core specimens with length/diameter ratio of 0.3–1.0 are suitable for axial testing (Fig. 3b). Long pieces of core can be tested diametrally to produce suitable lengths for subsequent axial testing (provided that they are not weakend by this initial testing); alternatively, suitable specimens can be obtained by saw-cutting or chisel-splitting.

(b) There should preferably be at least 10 tests per sample, more if the sample is heterogeneous or anisotropic.[7]

(c) The specimen is inserted in the test machine and the platens closed to make contact along a line perpendicular to the core end faces (in the case of isotropic rock, the core axis, but see paragraph 11 and Fig. 5).

(d) The distance D between platen contact points is recorded $\pm 2\%$.[4] The specimen width W perpendicular to the loading direction is recorded $\pm 5\%$.[9]

(e) The load is steadily increased such that failure occurs within 10–60 sec, and the failure load P is recorded. The test should be rejected as invalid if the fracture surface passes through only one loading point (Fig. 4c).

(f) The procedures (c) through (e) above are repeated for the remaining tests in the sample.

The block and irregular lump tests

10.(a) Rock blocks or lumps of size 50 ± 35 mm and of the shape shown in Fig. 3(c) and (d) are suitable for the block and the irregular lump tests. The ratio D/W should be between 0.3 and 1.0, preferably close to 1.0. The distance L (Fig. 3c and d) should be at least $0.5W$. Specimens of this size and shape may be selected if available or may be prepared by trimming larger pieces by saw-or chisel-cutting.

(b) There should preferably be at least 10 tests per sample, more if the rock is heterogeneous or anisotropic.[7]

(c) The specimen is inserted in the testing machine and the platens closed to make contact with the smallest dimension of the lump or block, away from edges and corners (Fig. 3c and d).

(d) The distance D between platen contact points is recorded $\pm 2\%$. The smallest specimen width W perpendicular to the loading direction is recorded $\pm 5\%$. If the sides are not parallel, then W is calculated as $(W_1 + W_2)/2$ as shown in Fig. 3d.[4] This smallest width W is used irrespective of the actual mode of failure (Figs 3 and 4)

(e) The load is steadily increased such that failure occurs within 10–60 sec, and the failure load P is recorded. The test should be rejected as invalid if the fracture surface passes through only one loading point (see examples for other shapes in Fig. 4d or e).

(f) The procedure (c) through (e) above is repeated for the remaining tests in the sample.

Anisotropic rock

11. (a) When a rock sample is shaly, bedded, schistose or otherwise observably anisotropic it should be tested in directions which give the greatest and least strength values, which are in general parallel and normal to the planes of anisotropy.

(b) If the sample consists of core drilled through the weakness planes, a set of diametral tests may be completed first, spaced at intervals which will yield pieces which can then be tested axially.

(c) Best results are obtained when the core axis is perpendicular to the planes of weakness, so that when possible the core should be drilled in this direction. The angle between the core axis and the normal to the weakness planes should preferably not exceed 30°.

(d) For measurement of the I_s value in the directions of least strength, care should be taken to ensure that load is applied along a single weakness plane. Similarly when testing for the I_s value in the direction of greatest strength, care should be taken to ensure that the load is applied perpendicularly to the weakness planes (Fig. 5).

(e) If the sample consists of blocks or irregular lumps, it should be tested as two sub-samples, with load applied firstly perpendicular to, then along the observable planes of weakness.[10] Again, the required minimum strength value is obtained when the platens make contact along a single plane of weakness.

CALCULATIONS

Uncorrected point load strength

12. The Uncorrected Point Load Strength I_s is calculated as P/D_e^2 where D_e, the "equivalent core diameter", is given by:

$D_e^2 = D^2$ for diametral tests;

$= 4A/\pi$ for axial, block and lump tests;

and

$A = WD$ = minimum cross sectional area of a plane through the platen contact points.[6]

Size correction

13.(a) I_s varies as a function of D in the diametral test, and as a function of D_e in axial, block and irregular lump tests, so that a size correction must be applied to obtain a unique Point Load Strength value for the rock sample, and one that can be used for purposes of rock strength classification.

(b) The size-corrected Point Load Strength Index $I_{s(50)}$ of a rock specimen or sample is defined as the value of I_s that would have been measured by a diametral test with D = 50 mm.

(c) The most reliable method of obtaining $I_{s(50)}$, preferred when a precise rock classification is essential, is to conduct diametral tests at or close to D = 50 mm. Size correction is then either unnecessary (D = 50 mm) or introduces a minimum of error. The latter is the case, for example, for diametral tests on NX core, D = 54 mm. This procedure is not mandatory. Most point load strength testing is in fact done using other sizes or shapes of specimen. In such cases, the size correction (d) or (e) below must be applied.

(d) The most reliable method of size correction is to test the sample over a range of D or D_e values and to plot graphically the relation between P and D_e^2. If a log–log plot is used the relation is generally a straight line (Fig. 6). Points that deviate substantially from the straight line may be disregarded (although they should not be deleted). The value of P_{50} corresponding to $D_e^2 = 2500$ mm² (D_e = 50 mm) can then be obtained by interpolation, if necessary by extrapolation, and the size-corrected Point Load Strength Index calculated as $P_{50}/50^2$.

(e) When neither (c) nor (d) is practical, for example when testing single sized core at a diameter other than 50 mm or if only a few small pieces are available, size correction may be accomplished by using the formula:

$$I_{s(50)} = F \times I_s$$

The "Size Correction Factor F" can be obtained from the chart in Fig. 7," or from the expression:

$$F = (D_e/50)^{0.45}$$

For tests near the standard 50 mm size, very little error is introduced by using the approximate expression:

$$F = \sqrt{(D_e/50)}$$

(f) The size correction procedures specified in this paragraph have been found to be applicable irrespective of the degree of anisotropy I_a and the direction of loading with respect to planes of weakness, a result that greatly enhances the usefulness of this test.

Mean value calculation

14.(a) Mean values of $I_{s(50)}$ as defined in (b) below are to be used when classifying samples with regard to their Point Load Strength and Point Load Strength Anisotropy Indices.

(b) The mean value of $I_{s(50)}$ is to be calculated by deleting the two highest and lowest values from the 10 or more valid tests, and calculating the mean of the remaining values. If significantly fewer specimens are tested, only the highest and lowest values are to be deleted and the mean calculated from those remaining.[12]

Point load strength anisotropy index

15. The Strength Anistropy Index $I_{a(50)}$ is defined as the ratio of mean $I_{s(50)}$ values measured perpendicular and parallel to planes of weakness, i.e. the ratio of greatest to least Point Load Strength Indices. $I_{a(50)}$ assumes values close to 1.0 for quasi-isotropic rocks and higher values when the rock is anisotropic. On average, uniaxial compressive strength is 20–25 times point load strength, as shown in Fig. 9. However, in tests on many different rock types the ratio can vary between 15 and 50 especially for anisotropic rocks, so that errors of up to 100% are possible in using an arbitrary ratio value to predict compressive strength from point load strength.

$I_{s(50)}$ is approximately 0.80 times the uniaxial tensile or Brazilian tensile strength.

7. Because this test is intended primarily as a simple and practical one for field classification of rock materials, the requirements relating to sample size, shape, numbers of tests etc, can when necessary be relaxed to overcome practical limitations. Such modifications to procedure should however be clearly stated in the report.

11. The size correction factor chart (Fig. 7) is derived from data on cores tested diametrally and axially and from tests on blocks and irregular lumps, for rocks of various strengths, and gives an averaged factor. Some rocks do not conform to this behaviour, and size correction should therefore be considered an approximate method, although sufficient for most practical rock classification applications. When a large number of tests are to be run on the same type of rock it may be advantageous to first perform a series of tests at different sizes to obtain a graph of load vs D_e^2 as in Fig. 6. If the slope of such a log–log graph is determined as "n", the size correction factor is then $(D_e/50)^m$ where $m = 2(1 - n)$. This can either be calculated directly or a chart constructed.

*Paragraph and figure numbers are those of the original reference: ISRM Commission on Testing Methods 1985. Suggested method for determining Point Load Strength (revised version) Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 22, 51-60.

Important references for further reading:-

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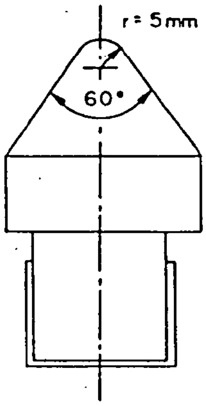


Fig. 2. Platen shape and tip radius.

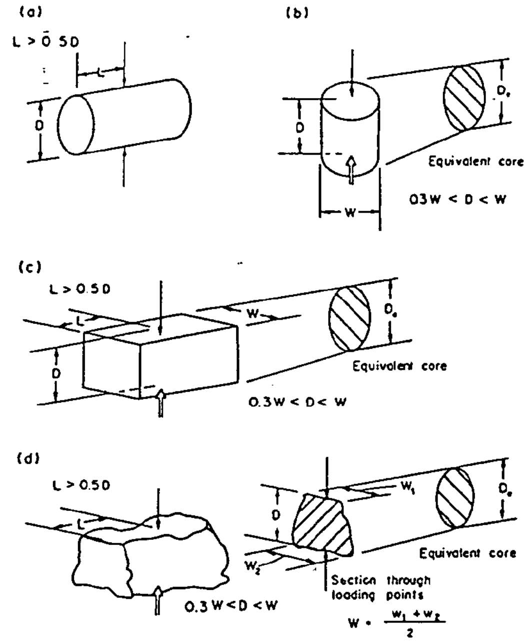


Fig. 3. Specimen shape requirements for (a) the diametral test, (b) the axial test, (c) the block test, and (d) the irregular lump test.

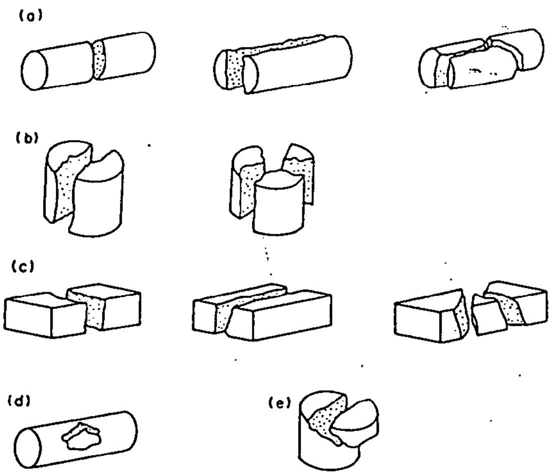


Fig. 4. Typical modes of failure for valid and invalid tests. (a) Valid diametral tests; (b) valid axial tests; (c) valid block tests; (d) invalid core test; (e) invalid axial test.

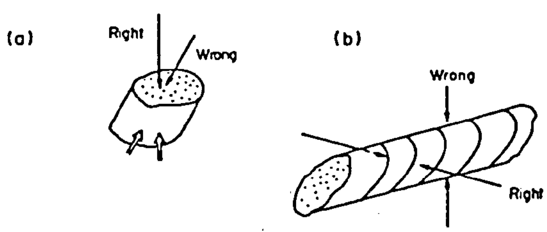


Fig. 5. Loading directions for tests on anisotropic rock.

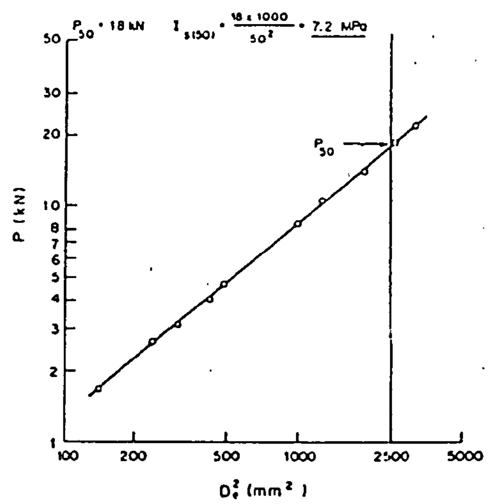


Fig. 6. Procedure for graphical determination of $I_{s(50)}$ from a set of results at D_e values other than 50 mm.

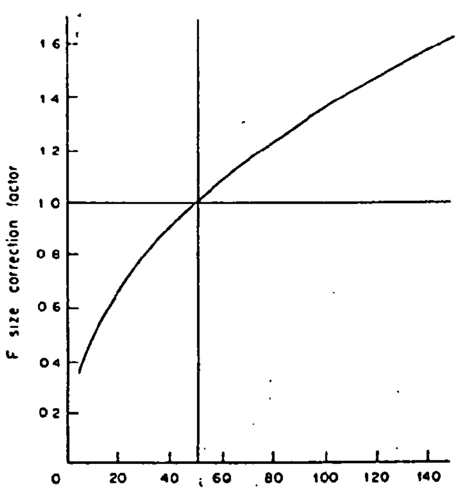


Fig. 7. Size correction factor chart.

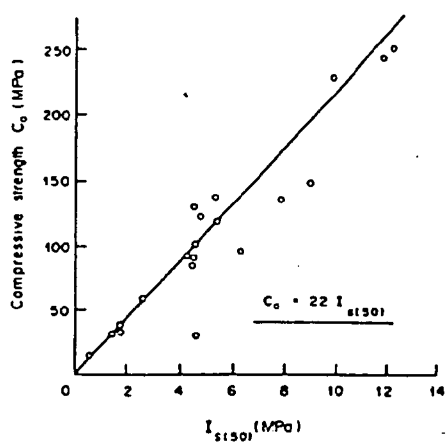
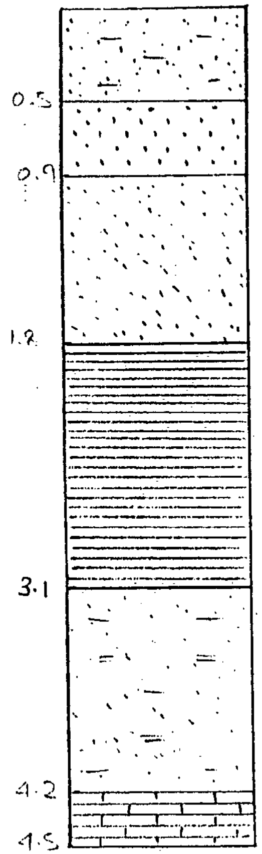


Fig. 9. Example of correlation between point load and uniaxial compressive strength results.



SAND (SP); brown, fine grained, slightly silty, humic, damp; Loose.

SANDSTONE; light brown, fine grained, poorly cemented (calcareous) Extremely Weak.

SAND (SP); light yellow, fine grained, Loose to Medium Dense small amount of weakly cemented gravel.

CLAY (CL); off-white, silty, calcareous, trace of fine sand, low to medium plasticity, Firm to Stiff

SAND (SM); light olive green, fine grained, silty and clayey Medium Dense.

LIMESTONE; light green to off-white, Moderately Weak.

EXCAVATION DISCONTINUED AT 4.5m DEPTH – REFUSAL

Department of Mines & Energy – South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: UPPER SOUTH EAST DRAINAGE Client:
Locality[1]: MOUNT CHARLES
Site Identification: PIT 1

JOB Nos: ENG. GEOL. 92-14-1 : DME
Date: 21/5/92 Data By: SW

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: UPPER SOUTH EAST DRAINAGE **Client:** E&WS

Locality[1]: MT CHARLES (25 km W Keith) **JOB Nos:** ENG. GEOL. 92-14-1 : DME

Site Identification[2] PIT 1 **Date:** 21/5/92 **Data By:** SW

GROUNDWATER

- WATER CUT AT ABOUT 1.5m DEPTH
- FLOW OF WATER INTO COMPLETED PIT:

DIMENSIONS OF PIT APPROX 4m x 0.9m

13:50	3.65m
14:00	3.25m
14:15	2.95m
14:30	2.65m.

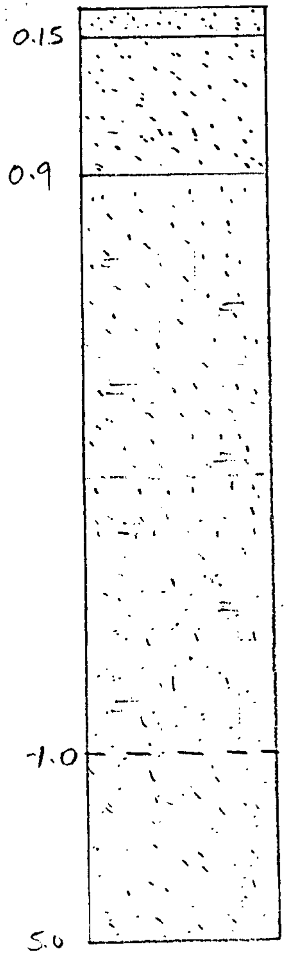
- LARGEST INFLOWS FROM SAND BETWEEN 2.1m and 4.2m DEPTH

SOIL SAMPLE DEPTHS:

0.9
1.3
2.5
4.2

NOTES:
1 Map sheet, Sect/Hd, Town etc
2 Pit No., localizing reference to plan etc

G01862 MF 192



SAND (SP); light brown, fine grained, humic, damp, Loose

SAND (SP); light brown, fine grained, damp, Loose.

SAND (SC-SM); mottled light green to grey, fine grained clayey, low plasticity, Medium Dense

SAND (SM); green to grey, silty, fine grained, non-plastic, Medium Dense to Dense. (Pockets of SAND (SC-SM) as above). Very weakly cemented 2.5m to 3.0m

SAND (SP); grey-brown, fine to medium grained, MD-D.

NOTE: Excavation discontinued at approx 5m. Pit walls were falling in excessively and it was close to the limit of reach of the excavator. By time depth had reached 3m collapse was excessive and samples mixed.

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE **Client:** EAWS
Locality[1]**:** TAUNTA DOWNS **JOB Nos: ENG. GEOL.** 92-14-1 **: DME**
Site Identification: PIT 2 **Date:** 21/5/92 **Data By:** SW

G01862 MF 192

South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: UPPER SOUTH EAST DRAINAGE **Client:** E&WS

Locality[1]: TAUNTA DOWNS (41 km W Keith) JOB Nos: ENG. GEOL. 92-14-1 : DME

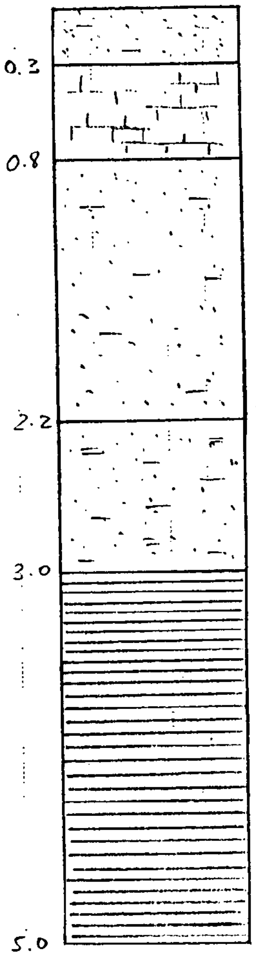
Site Identification[2] PIT 2 **Date:** 21/5/92 **Data By:** SW

GROUNDWATER

- Water cut at about 0.9m depth.
- Pit was left open overnight to allow water level to stabilise. By next morning the water level had recovered to 0.90m. Pit walls had also severely collapsed and pit was about 4m across at the surface. Tension cracks up to 2m from these edges indicated further collapse was likely with time.

SOIL SAMPLE DEPTHS : 1.0m, 1.3m, 2.5m, 5.0m

NOTES:
[1] Map sheet, Sect/Hd, Town etc
[2] Pit No., localizing reference to plan etc



SAND (SP); brown, fine grained, sl. silty, sl. humic, damp, Loose

CALCRETE; light yellow, partly nodular. Variable strength MW - MS. Excavation was not difficult

SAND (SP); light grey and yellow mottled, slightly silty, fine grained, moist, Loose to Medium Dense.

SAND (SW); light green, silty, slightly clayey, fine grained, odorous MD (Firm where more clayey)

CLAY (CH); light grey, silty, slightly calcareous, high plasticity Stiff to very stiff, M>Wp.

PIT BECAME VERY WET AND SLOPPY FROM ABOUT 4m DUE TO HIGH INFLOWS OF GROUNDWATER

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: USE DRAINAGE
Locality[1]: LESRON
Site Identification: PIT 3

Client: E&WS
JOB Nos: ENG. GEOL. 92-14-1 : DME
Date: 22/5/92 Data By: SW

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E. DRAINAGE **Client:** E & WS

Locality[1]: LESRON (32 km W Keith) **JOB Nos:** ENG. GEOL. 92-14-1 : DME

Site Identification[2] PIT 3 **Date:** 22/5/92 **Data By:** SW

Water cut at about 0.85 m

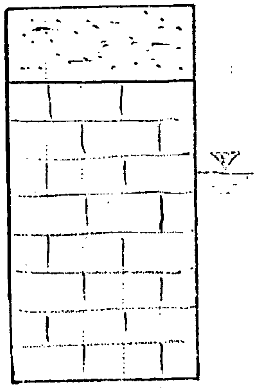
Flow of water into completed pit:
(Dimensions approx 4m x 1m at WL)

11:35 am	4.2 m depth
11:40	4.0 m
11:50	3.6 m
12:00	3.4 m
12:10	3.1 m
12:25	2.9 m

SOIL SAMPLE DEPTHS 2.0 m, 4.0 m

NOTES:
1 Map sheet, Sect/Hd, Town etc
2 Pit No., localizing reference to plan etc

0.4



2.0

SAND(SP), brown to light grey, slightly silty, damp, Loose.

CALCRETE, light brown, massive, MW-S
Excavated with much difficulty as pieces up to about 200mm × 400mm × 200mm.

Very permeable as pit fills with water faster than excavator bucket can bail

Pit abandoned at 2.0 m depth. Excavator making no further progress

Water cut at 0.9m

Department of Mines & Energy — South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE
Locality[1]: BIRKS
Site Identification: PIT 4

Client: E&WS
JOB Nos: ENG. GEOL. 92-14-1 : DME
Date: 22/5/92 Data By: SW

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

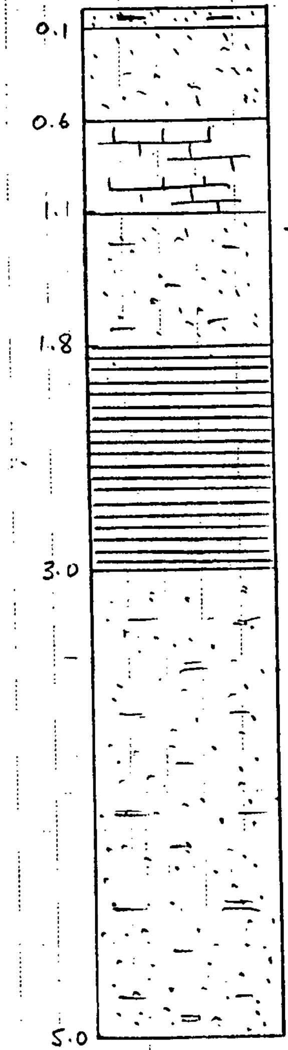
Project: U.S.E. DRAINAGE **Client:** E&WS

Locality[1]: BIRKS (22 km SW Keith) JOB Nos: ENG. GEOL. 92-14-1 : DME

Site Identification[2] PIT 4 Date: 22/5/92 Data By: SW

SAMPLE 1.5m

NOTES:
1 Map sheet, Sect/Hd, Town etc
2 Pit No., localizing reference to plan etc



SAND(SP); brown, silty, humic, damp, Loose

SAND(SP); light grey, fine grained, damp, MD

CALCRETE; off white, MW–MS. Rock defects about 100 mm to 200mm apart (some appear as JOINTS, rough, curved). Although difficult to break through initially, once penetrated it can be easily excavated.

SAND(SP); light grey and yellow mottled, slightly silty, fine grained, wet, MD.
-very permeable.

CLAY(CL-CH); yellow/brown/grey mottled, sandy (fine grained), medium to high plasticity, Very Stiff (Some resistance to excavator).

SAND(SM-SC) yellow and green mottled, clayey and silty, fine grained, low plasticity fines, Medium Dense.
-significantly more permeable than overlying layers

Pit discontinued at limit of reach of excavator.

Pit walls collapsed severely during and immediately after excavation
-attempts to monitor rate of inflow of water were abandoned.

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE
Locality[1]: KALTEE
Site Identification: PIT 5

Client: E&WS
JOB Nos: ENG. GEOL. 92-14-1 : DME
Date: 22/5/92 Data By: SW

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E DRAINAGE **Client:** E&WS

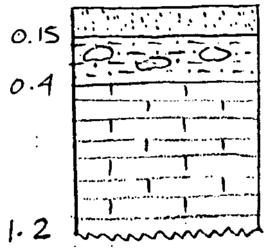
Locality[1]: KALTEE (32km WSW Keith) **JOB Nos:** ENG. GEOL. 92-14-1 : DME

Site Identification[2] Pit 5 **Date:** 22/5/92 **Data By:** SW

Water cut at about 1.2m
Water level was 1.1m depth immediately after completion

SOIL SAMPLE DEPTHS : 2.8m, 3.5m.

NOTES:
[1] Map sheet, Sect/Hd, Town etc
[2] Pit No., localizing reference to plan etc



SAND (SP); brown, silty, loose.

SILT (ML); brown, cobbly and sandy, medium plasticity. (Cobbles of calcrete)

CALCRETE; pale brown, very variable strength both laterally and vertically from EW to MS.
Excavated in pieces 0.3 x 0.2 x 0.2 m (AVG) but up to about 1.0 x 1.0 x 0.3m.
Excavatability moderately difficult to about 0.9m depth, difficult below 0.9m.

Pit was abandoned at 1.2m depth - Excavator unable to continue without likelihood of damage.

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE
Client: E&WS
Locality[1]: WITTALOOKA
JOB Nos: ENG. GEOL. 92-141 : DME
Site Identification: PIT 6
Date: 23/5/92 Data By: SW

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E. DRAINAGE Client: E&WS

Locality[1]: WITTALOOKA (25km SSW Keith) JOB Nos: ENG. GEOL. 92-14-1 : DME

Site Identification[2] PIT 6. Date: 23/5/92 Data By: SW

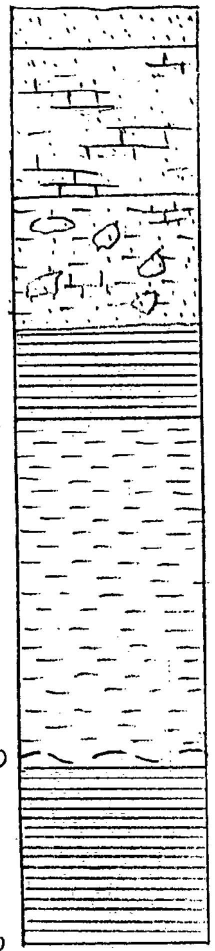
GROUNDWATER :

Water cut about 1.0m

Moderately large inflows of water from 1.0 to 1.2m.

SAMPLE : 1.0m

NOTES:
1 Map sheet, Sect/Hd, Town etc
2 Pit No., localizing reference to plan etc



0.2 1.0 1.7 2.2 4.0 5.0

SAND (SP); white, fine grained, Loose.

SAND (SM); light brown, very silty, very fine grained, MD
Contains much calcrete of Very Low strength excavated as pieces UP TO 0.4 x 0.3 x 0.15m

SILT (ML); off white, sandy, MD-D
Contains nodules and layers of Moderately Weak calcrete

CLAY (CH); grey green, silty, high plasticity, Stiff.

SILTSTONE; off white, thin to very thin bedding and must have many defects (easy excavation), Weak to Very Weak highly calcareous.

CLAY (CL); light olive green, very sandy (very fine grained), very low plasticity, Stiff.

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE
Client: E&WS
Locality[1]: COOLA COOLA
JOB Nos: ENG. GEOL. 92-14-1 : DME
Site Identification: PIT 7
Date: 23/5/92 Data By: JW

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E. DRAINAGE

Client: E&WS

Locality[1]: COOLA COOLA (32km SSW Keith)

JOB Nos: ENG. GEOL. 92-14-1 : DME

Site Identification[2] PIT 7

Date: 23/5/92 Data By: SW

GROUNDWATER :

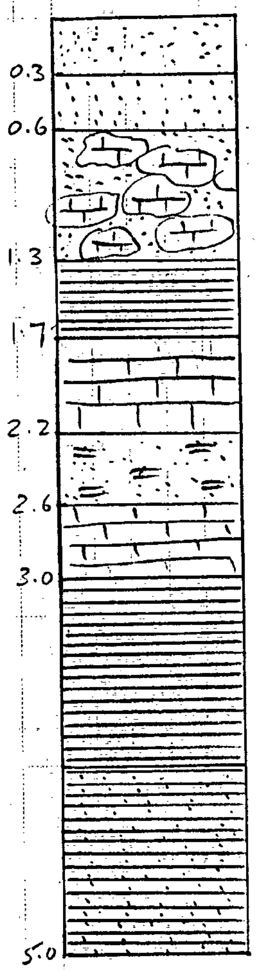
Water cut at about 1.7m.

Large inflows after about 2.2m. (Impossible thereafter to bail water level below 2.3m with excavator bucket)

WL had recovered to 1.52 m within about 5 mins after digging stopped and was still 1.52 m depth 10 mins later (ie appears WL fully recovered)

SOIL SAMPLE DEPTHS : 0.8, 1.9, 3.0, 4.5

NOTES:
1 Map sheet, Sect/Hd, Town etc
2 Pit No., localizing reference to plan etc



SAND (SP); light grey, fine grained, damp, Loose

SAND (SP), as above but cemented to extremely weak rock (easily excavated)

SAND (SC); light green, clayey, fine grained, Firm. AS MATRIX TO light brown, MW-MS. Cobbles and boulders up to 1.5m across. Moderately difficult to excavate

CLAY (CL); light green to grey, sandy to very sandy (fine grained), low plasticity, Stiff.

CALCRETE, light brown to off white, relatively unjointed, sheet-like, MW-MS. difficult to break through with excavator (rippable with DOZER)

SAND (SC); light green, clayey, Firm to Stiff (SC)

CALCRETE; as above.

CLAY (CL); off-white, very silty, low plasticity, Stiff.

CLAY (CL-CH); light green, very sandy (fine grained), calcareous, medium to high plasticity, Stiff.

* NOTE: Logging was very difficult below about 2.2m due to high water inflows, collapsing pit walls, and the heterogeneous nature of the strata.

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE
Client: E&WS
Locality[1]: KERCOONDA
JOB Nos: ENG. GEOL. 92-14-1 : DME
Site Identification: PIT 8
Date: 23/5/92 **Data By:** SW.

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E. DRAINAGE **Client:** E&WS

Locality[1]: KERCOONDA (48 km SW Keith) **JOB Nos:** ENG. GEOL. 92-14-1 : DME

Site Identification[2] Pit 8 **Date:** 23/5/92 **Data By:** SW

GROUNDWATER

Water cut at approx 2m; moderate inflow at first increasing with depth

SOIL SAMPLE DEPTHS: 1.5, 3.5, 4.0 and 5.0 m

NOTES:
1 Map sheet, Sect/Hd, Town etc
2 Pit No., localizing reference to plan etc

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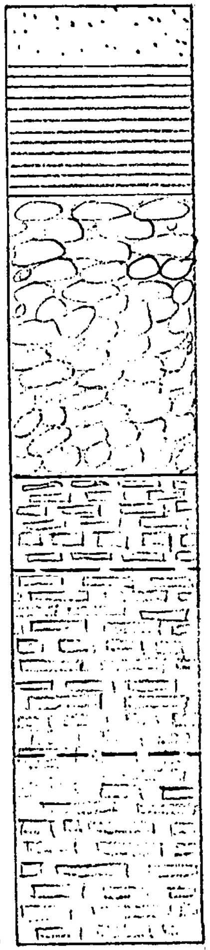

SAND (SP); dark grey to light grey, humic near surface, damp, Loose

CLAY (CL); green yellow mottled, very sandy, low plasticity, stiff

CLAY/CALCRETE (35/65)
CALCRETE NODULES, 50mm to 150mm in matrix of
CLAY (CH); green, silty, firm to stiff, high to medium plasticity
matrix becomes clayey sand at 1.5m, green, soft
% calcrete reduces to about 30% and size range 20 to 100mm

CLAYEY SAND/SANDSTONE (60/40): Clayey SAND is as above,
SANDSTONE is medium to fine grained, cemented, Moderately Strong
(as tabular pieces up to about 150 x 100 x 25mm)

SAND/SANDSTONE (60/40): SANDSTONE is as above,
SAND (SM); light grey-green, silty, fine grained, medium dense.

- SAND is only slightly silty below about 4m depth

* Pit walls were relatively stable, very little collapse

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE
Locality[1]: JIP JIP
Site Identification: PIT 9
Client: E & WS
JOB Nos: ENG. GEOL. 92-14-1 : DME
Date: 21/5/92 Data By: SW

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E. DRAINAGE **Client:** E&WS

Locality[1]**:** JIP JIP (33km WNW Padthaway) **JOB Nos:** ENG. GEOL. 92-14-1 : DME

Site Identification[2] PIT 9 **Date:** 24/5/92 **Data By:** SW.

GROUNDWATER:

Water cut at 1.2 m depth
Small inflows about 1.5m
Inflow markedly increased below about 3m depth

Recovery of water level in pit as follows: (Ground level datum)

9:50 am	4.05m
9:55	3.65m
10:00	3.30m
10:05	2.97m
10:10	2.70m
10:15	2.50m

* Approximate pit area at WL was 3.5m × 0.9m.

SOIL SAMPLE DEPTHS: 0.8m, 1.2m.

NOTES:
[1] Map sheet, Sect/Hd, Town etc
[2] Pit No., localizing reference to plan etc

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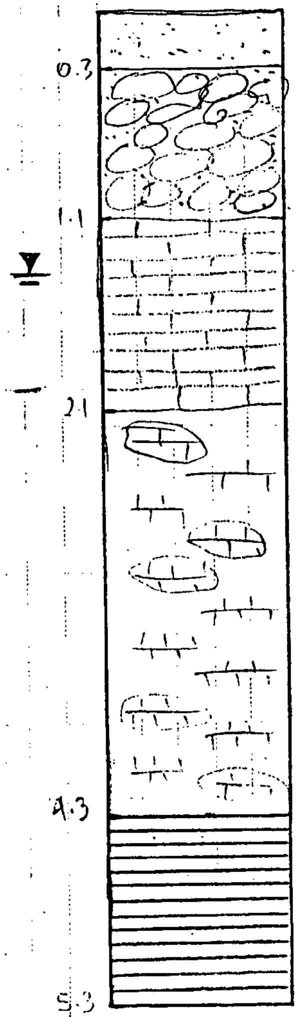

SAND (SP); grey, humic, Loose

CALCRETE; (MW) as nodules to 100mm across in matrix of calcareous SILT, GRAVEL & some green clayey SAND.

CALCRETE; massive (MS) as extensive layers and sheets, little jointing - difficult to excavate

CALCRETE; partly nodular and more friable. (EW - MW) consists of cobbles, gravel, sand & silt sized fragments - relatively easy to excavate.

CLAY (CL-CH); green grey, silty with a trace of fine sand, medium to high plasticity, Very Stiff to Hard. Broken pieces have a fissured appearance, minor white limey pockets, small amounts of white, fine calcrete gravel.

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE
Locality[1]: KYEEMA
Site Identification: PIT 10

Client: E&WS
JOB Nos: ENG. GEOL. 92-14-1 : DME
Date: 24/5/92 Data By: SW

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E. DRAINAGE **Client:** E&WS

Locality[1]: KYEEMA (18km WNW Padthaway) **JOB Nos:** ENG. GEOL. 92-14-1 : DME

Site Identification[2] PIT 10 **Date:** 24/5/92 **Data By:** SW

GROUNDWATER:

Water cut at approx. 1.4m depth.

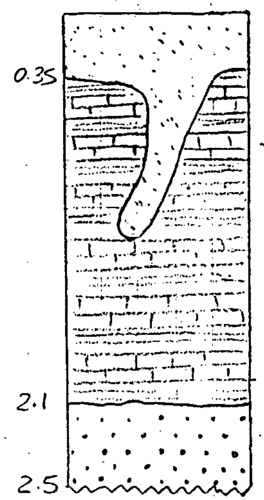
Flow markedly increased from about 2.3m

Recovery of water level in pit:

1:19pm	2.0m
1:22	1.65m
1:27	1.50m
1:31	1.48m
1:37	1.46m

SOIL SAMPLE DEPTH: 5m

NOTES:
[1] Map sheet, Sect/Hd, Town etc
[2] Pit No., localizing reference to plan etc



SAND (SP); light brown to light grey, fine - med - grained, quartz (moderately organic, slightly silty, fine roots to 0.05m)

CALCRETE / CLAY (65% : 35%)

CALCRETE as both nodules and as sheets with iron staining on ubiquitous irregular fracture surfaces. Breaks into pieces and nodules from 20mm to about 150 mm across

CLAY (CH); grey to yellow, sandy and soft

Note: The clay lines numerous fractures in the sheet-like calcrete. Some fractures contain fine rootlets to about 0.5m depth. Unit has low permeability.

CALCARENITE, light yellow to light grey, med-course grained, Moderately Strong. Very difficult to excavate

Excavation discontinued at 2.5m due to difficulty of excavation of strong rock.

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE
Locality[1]: WINDARA
Site Identification: PIT 11

Client: E&WS
JOB Nos: ENG. GEOL. 92-14-1 : DME
Date: 24/5/92 Data By: SW / LJM

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South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E. DRAINAGE **Client:** E & WS

Locality[1]: WINDARA (22km W Padthaway) **JOB Nos:** ENG. GEOL. 92-14-1 : DME

Site Identification[2] PIT 11 **Date:** 24/5/92 **Data By:** SW/LJM

GROUNDWATER:

Water cuts at approx 1.2m and 1.5m (weeps, slow transient trickle)
Very large water inflow at 2.5m depth (see figures below)
SWL approximately 0.7m.

3:40pm	1.78m
3:41	1.62m
3:42	1.47m
3:43	1.33m
3:45	1.22m
3:46	1.09m
3:47	1.03m
3:48	0.96m
3:49 pm	0.91m
3:50	0.85m
3:51	0.82m
3:52	0.79m
3:54	0.73m
3:56	0.72m

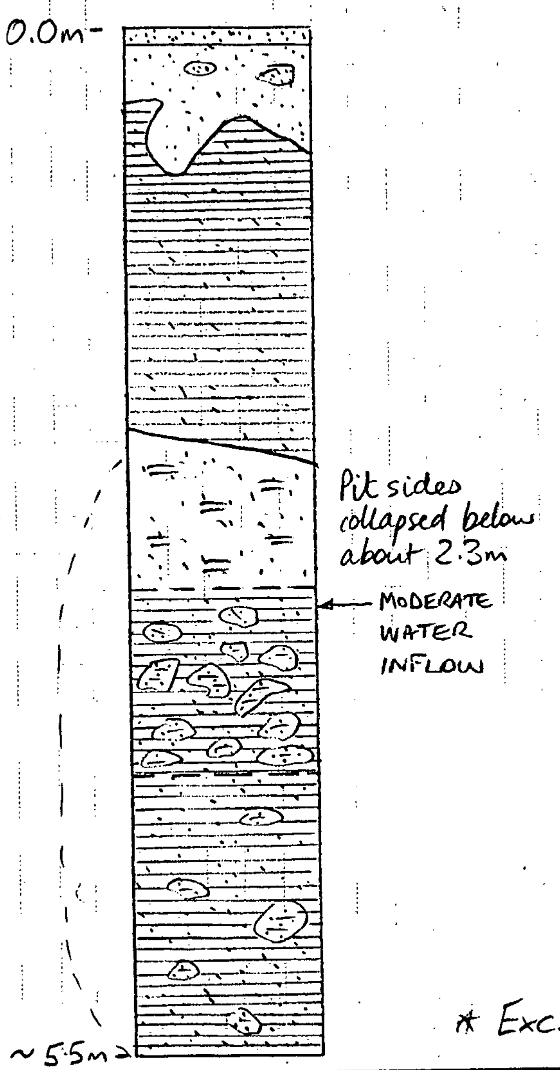
* Dimensions of pit at WL approx 4.7m x 1.0m.

(Q from 3:40 to 3:41 was about 12.5 l/sec)

SAMPLES: 0.5 to 1.2m, 2.1m

NOTES:
1 Map sheet, Sect/Hd, Town etc
2 Pit No., localizing reference to plan etc

G01862 MF 192



SAND (SP); black, fine-med grained, quartz, organic, fine roots, silty.

SAND (SP); white to pale yellow, fine-med grained, quartz, Medium dense (Est.) to weakly indurated with rare cobbles to 150mm ϕ of SANDSTONE, moderately strong. Base is variable 400 mm to 800 mm, roots to 3 mm ϕ.

CLAY (CH); yellow orange, sandy. Sand is fine-med grained, with pockets of SAND (SP) as above. PP 2.5-4.0 (3.0 ave.)

Grey with yellow mottles 1600-2300mm

SAND (SC); green and green-grey, clayey (glauconitic ?), fine to medium grained with plastic clay matrix, Medium Dense (Est.) Some orange mottling. Fine roots to 3mm ϕ

CLAY (CH); light grey, pale yellow and white mottled, sandy (medium to fine grained), gravelly in parts. Contains gravel to cobble and boulder sized fragments of SANDSTONE comprising cemented clayey sand and sand. Some banding (sedimentary layering) probably semicontinuous layers of weak to moderately weak rock

CLAY (CH); as above, gravelly, with cobble to boulder sized fragments as above to 10%.

* EXCAVATION WAS EASY IN ALL LAYERS.

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: USE DRAINAGE
Locality[1]: CLOVER RIDGE
Site Identification: PIT 12

Client: E&WS
JOB Nos: ENG. GEOL. 92-14-1 : DME
Date: 25/5/92 Data By: LJM

G01862 MF 192

South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E. DRAINAGE **Client:** E & WS

Locality[1]: CLOVER RIDGE (20km W Padthaway) **JOB Nos:** ENG. GEOL. 92-14-1 : DME

Site Identification[2] PIT 12 **Date:** 25/5/92 **Data By:** LJM

GROUNDWATER

Seeps from 800 to 1900 mm
Moderate inflow at 3100 mm

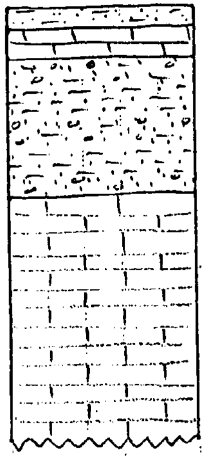
Water level recovered in pit as follows:

10:00 am	3900 mm
10:05	3650
10:10	3100
10:15	2750
10:20	2350
10:30	1770
10:40	1410
10:47	1150

SAMPLE DEPTHS:
0.1 to 0.6m
0.6 to 1.6m
1.6 to 2.0m
3.0 to 4.0m

NOTES:
1 Map sheet, Sect/Hd, Town etc
2 Pit No., localizing reference to plan etc

0.1
0.25
1.0
2.3



SAND (SM); black, silty, med-fine grained, quartz, organic, fine roots.
CALCRETE; light brown, banded layers of MS-S (est) strength as platey cobbles and boulders. Thinly jointed horizontally, medium spaced joints vertically.
SAND/SILT (SP/ML); white to light grey, calcareous,

CALCRETE; white to light brown as boulder sized fragments in calcareous silty gravel matrix. Strong (est)
with CLAY (CH) - light grey, limey, sandy (about 5%)

Department of Mines & Energy - South Australia
Engineering Geology Section **Site Inspection Plan/Log**

Project: U.S.E. DRAINAGE
Locality[1]: AVENUE RANGE
Site Identification: PIT 13

Client: E&WS
JOB Nos: ENG. GEOL. 92-14-1 : DME
Date: 25/5/92 **Data By:** L.J.M.

G01862 MF 192

South Australian Department of Mines and Energy
Engineering Geology Section

SITE INSPECTION PLANS/LOGS

Project: U.S.E. DRAINAGE **Client:** E&WS

Locality[1]**:** AVENUE RANGE (40 km W Padthaway) **JOB Nos:** ENG. GEOL. 92-H-1 : DME

Site Identification[2] PIT 13 **Date:** 25/5/92 **Data By:** LJM

GROUNDWATER:

Seepage at 0.8m

Moderate inflow at 1.0m.

SAMPLE: 1.5m

NOTES:
[1] Map sheet, Sect/Hd, Town etc
[2] Pit No., localizing reference to plan etc

DEPARTMENT OF MINES - SOUTH AUSTRALIA

ENGINEERING CLASSIFICATION OF SOILS

The Unified Soil Classification System

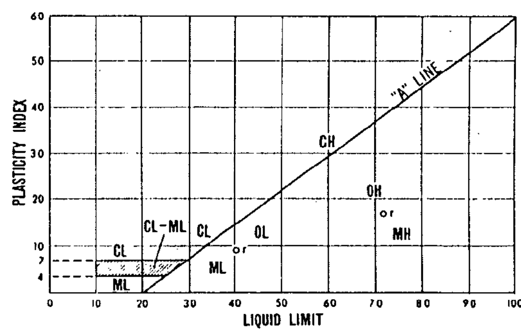
			FIELD INVESTIGATION PROCEDURES Excluding particles larger than 7·5cm and basing fractions on estimated weights	GROUP SYMBOL	GROUP NAME and typical materials	LABORATORY CLASSIFICATION CRITERIA	
COARSE-GRAINED SOILS More than 50% of material is larger than No. 200 B.S. sieve size	**GRAVELS** More than 50% of the coarse fraction is larger than 2mm. (retained on B.S.7 sieve)	**CLEAN GRAVELS** Little or no fines	Wide range in grain sizes, and substantial amounts of all intermediate particle sizes	GW	**GRAVEL, well graded;** gravel sand mixtures, little or no fines	$Cu = D60/D10$ Greater than 4 $Cc = (D30)^2/D10 \times D60$ Between 1 and 3	
			Predominantly one size or a range of sizes, with some intermediate sizes missing	GP	**GRAVEL, poorly graded;** gravel sand mixtures, little or no fines	Not meeting all gradation requirements for **GW**	
		DIRTY GRAVELS Appreciable amount of fines	Non-plastic fines—for indentification see **ML** below	GM	**GRAVEL, excess silty fines;** poorly graded gravel-sand-silt mixtures	Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines—for identification see **CL** below	GC	**GRAVEL, excess clayey fines;** poorly graded gravel-sand-clay mixtures	Atterberg limits above "A" line or PI greater than 7	
	SANDS More than 50% of the coarse fraction is smaller than 2mm. (passing B.S.7 sieve)	**CLEAN SANDS** Little or no fines	Wide range in grain sizes, and substantial amounts of all intermediate particle sizes	SW	**SAND, well graded;** well graded sands, gravelly sands, little or no fines	$Cu = D60/D10$ Greater than 6 $Cc = (D30)^2/D10 \times D60$ Between 1 and 3	
			Predominantly one size or a range of sizes, with some intermediate sizes missing	SP	**SAND, poorly graded;** poorly graded sands, gravelly sands, little or no fines	Not meeting all gradation requirements for SW	
		DIRTY SANDS Appreciable amount of fines	Non-plastic fines—for indentification see **ML** below	SM	**SAND, excess silty fines;** poorly graded sand-silt mixtures	Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines—for identification see **CL** below	SC	**SAND, excess clayey fines;** poorly graded sand-clay mixtures	Atterberg limits above "A" line or PI greater than 7	

GRAIN SIZE CURVES to be used to identify soil fractions

Coarse-grained soil classified on basis of percentage of fines, as follows

PERCENT OF FINES	GRAVELS	SANDS
Less than 5	GW GP	SW SP
More than 12	GM GC	SM SC
5 to 12 Borderline cases, use 2 symbols		

		FIELD INVESTIGATION PROCEDURES on fraction smaller than 0.4mm. (passing B.S. 36 sieve)						GROUP SYMBOL	GROUP NAME and typical materials
		SOIL CAST (soil wet)	SOIL THREAD	SHINE	DILATANCY	ODOUR	DRY STRENGTH		
FINE-GRAINED SOILS More than 50% of material is smaller than No. 200 B.S. sieve size	**SILTS AND CLAYS** Liquid limit less than 50	Forms fragile cast Cracks form when kneaded while moist	Thick crumbly thread; easily broken	None to very dull	Distinct	Not significant	None to slight	ML	**SILT SOIL, low plasticity;** inorganic silts and very fine silty or clayey sands, rock flour
		Cast maybe handled freely without breaking Can be kneaded moist without cracking Material adheres to the hand.	Thread can be pointed as fine as a lead pencil but is fragile	Moderate	None to slight	Not significant	Moderate	CL	**CLAY SOIL, low plasticity;** inorganic clays of low to medium plasticity, gravelly clay, sand, clays, silty clays, lean clays
		Cast fragile to cohesive material will adhere somewhat to the hand	Soft, weak thread	None to very dull	Slight to distinct	Decayed organic matter	Low	OL	**ORGANIC SOIL, low plasticity;** organic silts and silt clays of low plasticity
	SILTS AND CLAYS Liquid limit more than 50	Moderately plastic and cohesive Material adheres somewhat to the hand	Weak to medium thread May be crumbly	Dull	None to slight	Not significant	Moderate Powdered soil feels floury	MH	**SILT SOIL, high plasticity;** inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
		Very plastic and cohesive Material very sticky to the hand Greasy to touch	Very tough thread, can be rolled to a pin point	Very glossy	None	Strong earthy	High to very high Cannot be powdered by finger pressure	CH	**CLAY SOIL, high plasticity;** inorganic clays of high plasticity, fat clays
		Plastic and cohesive Feels slightly spongy Greasy to touch	Weak to medium thread Often soft and fibrous	Moderate to very glossy	None	Decayed organic matter	Moderate to high Powdered soil may be fibrous	OH	**ORGANIC SOIL, high plasticity;** organic clays of medium to high plasticity
		Readily identified by colour, odour, spongy feel and frequently by fibrous texture						Pt	**PEATY SOIL;** Peat and other highly organic soils



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE-GRAINED SOILS

NOTE: BOUNDARY CLASSIFICATIONS: Soil possessing characteristics of two groups are shown as a combination of two group symbols, eg. GW-GC, well graded gravel with clay binder.

Based on "The Unified Soil Classification System" United States Department of the Interior, Bureau of Reclamation "Earth Manual" First Edition, Denver COLORADO 1960.

S.A. Dept. of Mines

PIT	SAMPLE DEPTHS
1	0.9, 1.3, 2.5, 4.2
2	1.0, 1.3, 2.5, 5.0
3	2.0. 4.0
4	1.5
5	2.8, 3.5
6	1.0
7	0.8, 1.9, 3.0, 4.5
8	1.5, 3.5, 4.0, 5.0
9	0.8, 1.2
10	5.0
11	0.5-1.2 (Sand-boil), 2.1
12	0.1-0.6, 0.6-1.6, 1.6-2.0, 3.0-4.0
13	1.5 (approx)

ROCK STRENGTH

Strength of rock material. A scale of strength based on uniaxial compressive testing, is as follows:

Term	Compressive strength (~Is (50)x25)	Approx Is (50)	Strength in hand specimen	Symbol
Very weak	less than 1.25	<0.05	Broken by hand with difficulty.	(VW)
Weak	1.25 to 5	0.05-0.2	Material crumbles under blows with the sharp end of a geological pick.	(W)
Moderately weak	5 to 12.5	0.2-0.5	Too hard to cut by hand into a triaxal specimen.	(MW)
Moderately strong	12.5 to 50	0.5-2.0	5mm indentations with sharp end of pick.	(MS)
Strong	50 to 100	2.4-4.0	Hand held specimen can be broken with single blow of geological hammer.	(S)
Very strong	100 to 200	4.0-8.0	More than one blow of geological required to break specimen.	(VS)
Extremely strong	greater than 200	>8.0		(ES)

POINT LOAD STRENGTH TEST

JOB NO.: 92-14-1
SHEET 1 of 4

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

CLIENT: E&WS | TEST LOCALITY: Mt. CHARLES | DATE: 21/5/92
PROJECT: U.S.E | TEST MACHINE: ROB. RESEARCH. | TESTED BY: SW
LOCATION: PIT 1 (MT CHARLES) | DATE CALIBRATED: | CHECKED BY: TE

SAMPLE ID and LOCATION		PIT 1 4.3m	PIT 1 4.3m	PIT 1 4.3m	PIT 1 4.3m
SAMPLE DESCRIPTION (NOTE PLANES OF WEAKNESS)		CALCRETE (Limestone) off-white, Fresh	see left	see left	see left
MOISTURE / STORAGE HISTORY					
DIAMETER 1	W_1 (mm)	60	50	50	50
DIAMETER 2	W_2 (mm)	65	85	70	60
AVE. DIAMETER $W = \frac{W_1 + W_2}{2}$	W (mm)	62.5	67.5	60	55
PLATEN SEPARATION	D(mm)	43.5	37	55	40
LENGTH / DIAM. RATIO $0.3 < D/W < 1.0$	D/W	0.696	0.55	0.92	0.73
EQUIVALENT DIAM. $D_e = \sqrt{1.2732 (W \times D)}$	D_e (mm)	58.8	56.4	64.8	52.9
FAILURE LOAD (or GAUGE PRESSURE)	kN (kPa)	21.50 kN	20.0	17.5	9.0
CORRECTED LOAD	P(kN)	21.50	20.0	17.5	9.0
UN-CORRECTED P.L. STRENGTH INDEX $I_s = (P/D_e^2) \times 1000$	I_s (MPa)	6.21	6.29	4.17	3.21
SIZE CORR. FACTOR $F = (D_e/50)^{0.45}$	F	1.08	1.06	1.12	1.03
POINT LOAD STRENGTH (SIZE CORRECTED) $Is_{(50)} = Is \times F$	$Is_{(50)}$ (MPa)	6.68	6.64	4.68	3.30
APPROX. EQUIV. U.C.S. $Qu \simeq 24 \times Is_{(50)}$	Qu (MPa) (see Note 2)	160.4	159.3	112.3	79.1
TEST TYPE, SKETCH AND NOTES A = AXIAL SAMPLE TEST D = DIAMETRAL SAMPLE TEST B = BLOCK SAMPLE TEST I = IRREGULAR LUMP TEST		I	I	I	I

NOTES: 1. Testing in accordance with ISRM Point Load Test Method – see Explanatory Sheet 3.
2. Value for UCS is approximate only. Conversion from $Is_{(50)}$ to Qu is only accurate if extensively calibrated for specific site materials.

MF 195

POINT LOAD STRENGTH TEST

JOB NO. :
SHEET : 2 of 4

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

CLIENT : EWS TEST LOCALITY : DATE : 22/5/92
PROJECT : U.S.E TEST MACHINE : TESTED BY : SW
LOCATION : PIT4 DATE CALIBRATED : CHECKED BY : TE

SAMPLE ID and LOCATION		PIT4 1.5m	PIT4 2.0m	PIT4 2.0m	PIT4 2.0m
SAMPLE DESCRIPTION (NOTE PLANES OF WEAKNESS)		CALCRETE light brown, massive, Fresh	see left	see left	see left
MOISTURE / STORAGE HISTORY					
DIAMETER 1	W_1 (mm)	100	60	90	70
DIAMETER 2	W_2 (mm)	60	60	70	90
AVE. DIAMETER $W = \frac{W_1 + W_2}{2}$	W (mm)	80	60	80	80
PLATEN SEPARATION	D (mm)	32	41	35	35
LENGTH / DIAM. RATIO $0.3 \leq D/W < 1.0$	D/W	0.40	0.68	0.44	0.44
EQUIVALENT DIAM. $D_e = \sqrt{1.2732(W \times D)}$	D_e (mm)	57.1	56.0	59.7	59.7
FAILURE LOAD (or GAUGE PRESSURE)	kN (kPa)	5.05	12.2	16.0	14.0
CORRECTED LOAD	P (kN)	5.05	12.2	16.0	14.0
UN-CORRECTED P.L. STRENGTH INDEX $I_s = (P/D_e^2) \times 1000$	I_s (MPa)	1.55	3.90	4.49	3.93
SIZE CORR. FACTOR $F = (D_e/50)^{0.45}$	F	1.06	1.05	1.08	1.08
POINT LOAD STRENGTH (SIZE CORRECTED) $Is_{(50)} = Is \times F$	$Is_{(50)}$ (MPa)	1.64	4.10	4.86	4.25
APPROX. EQUIV. U.C.S. $Qu \triangleq 24 \times Is_{(50)}$	Qu (MPa) (see Note 2)	39.5	98.3	116.7	102.1
TEST TYPE, SKETCH AND NOTES A = AXIAL SAMPLE TEST D = DIAMETRAL SAMPLE TEST B = BLOCK SAMPLE TEST I = IRREGULAR LUMP TEST		I	I	I	I

NOTES: 1. Testing in accordance with ISRM Point Load Test Method – see Explanatory Sheet 3.
2. Value for UCS is approximate only. Conversion from $Is_{(50)}$ to Qu is only accurate if extensively calibrated for specific site materials.

MF 195

POINT LOAD STRENGTH TEST

JOB NO.	
SHEET	3 of 4

DEPARTMENT OF MINES AND ENERGY - SOUTH AUSTRALIA

CLIENT	E&WS	TEST LOCALITY		DATE	23/5/92
PROJECT	U.S.E.	TEST MACHINE		TESTED BY	T E
LOCATION	PIT 6	DATE CALIBRATED		CHECKED BY	T E

SAMPLE ID and LOCATION		PIT6 ·8m	PIT6 ·8m	PIT 6 ·8m	PIT6 ·8m
SAMPLE DESCRIPTION (NOTE PLANES OF WEAKNESS)		CALCRETE, pale brown, Fresh	see left	see left	see left
MOISTURE / STORAGE HISTORY					
DIAMETER 1	W_1 (mm)	80	60	70	160
DIAMETER 2	W_2 (mm)	70	50	90	100
AVE. DIAMETER $W = \frac{W_1 + W_2}{2}$	W (mm)	75	55	80	130
PLATEN SEPARATION	D(mm)	40	30	45	55
LENGTH / DIAM. RATIO $0.3 < D/W < 1.0$	D/W	0.53	0.55	0.56	0.42
EQUIVALENT DIAM. $D_e = \sqrt{1.2732(W \times D)}$	D_e (mm)	61.8	45.8	67.7	95.4
FAILURE LOAD (or GAUGE PRESSURE)	kN (kPa)	17	15	18	20
CORRECTED LOAD	P(kN)	17	15	18	20
UN-CORRECTED P.L. STRENGTH INDEX $I_s = (P/D_e^2) \times 1000$	I_s(MPa)	4.45	7.14	3.93	2.2
SIZE CORR. FACTOR $F = (D_e/50)^{0.45}$	F	1.10	0.96	1.15	1.34
POINT LOAD STRENGTH (SIZE CORRECTED) $Is_{(50)} = Is \times F$	$Is_{(50)}$ (MPa)	4.9	6.87	4.5	2.94
APPROX. EQUIV. U.C.S. $Qu \simeq 24 \times Is_{(50)}$	Qu (MPa) (see Note 2)	117.5	164.8	108	70.5
TEST TYPE, SKETCH AND NOTES A = AXIAL SAMPLE TEST D = DIAMETRAL SAMPLE TEST B = BLOCK SAMPLE TEST I = IRREGULAR LUMP TEST		I	I	I	I

NOTES: 1. Testing in accordance with ISRM Point Load Test Method - see Explanatory Sheet 3.

2. Value for UCS is approximate only. Conversion from $Is_{(50)}$ to Qu is only accurate if extensively calibrated for specific site materials.

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POINT LOAD STRENGTH TEST

JOB NO.:
SHEET: 4 of 4

DEPARTMENT OF MINES AND ENERGY - SOUTH AUSTRALIA

CLIENT: E&WS — TEST LOCALITY: SITE 11 — DATE: 24/5/92
PROJECT: U.S.E. — TEST MACHINE: — TESTED BY: JM
LOCATION: PIT 11 — DATE CALIBRATED: — CHECKED BY: JM

SAMPLE ID and LOCATION		PIT 11	PIT 11	PIT 11	
SAMPLE DESCRIPTION (NOTE PLANES OF WEAKNESS)		CALCARENITE, light yellow, Med-course grn massive.	see left	see left	
MOISTURE / STORAGE HISTORY					
DIAMETER 1	W_1 (mm)	80	70	80	
DIAMETER 2	W_2 (mm)	110	60	60	
AVE. DIAMETER $W = \frac{W_1 + W_2}{2}$	W (mm)	95	70	70	
PLATEN SEPARATION	D(mm)	54	40	52	
LENGTH / DIAM. RATIO $0{\cdot}3 < D/W < 1{\cdot}0$	D/W	0·57	0·57	0·74	
EQUIVALENT DIAM. $D_e = \sqrt{1{\cdot}2732(W \times D)}$	D_e (mm)	80·8	59·7	68·1	
FAILURE LOAD (or GAUGE PRESSURE)	kN (kPa)	9	9	6·5	
CORRECTED LOAD	P(kN)	9	9	6·5	
UN-CORRECTED P.L. STRENGTH INDEX $I_s = (P/D_e^2) \times 1000$	I_s (MPa)	1·38	2·52	1·40	
SIZE CORR. FACTOR $F = (D_e/50)^{0{\cdot}45}$	F	1·24	1·08	1·15	
POINT LOAD STRENGTH (SIZE CORRECTED) $Is_{(50)} = Is \times F$	$Is_{(50)}$ (MPa)	1·71	2·73	1·61	
APPROX. EQUIV. U.C.S. $Qu \simeq 24 \times Is_{(50)}$	Qu (MPa) (see Note 2)	41·0	65·6	38·4	
TEST TYPE, SKETCH AND NOTES A = AXIAL SAMPLE TEST D = DIAMETRAL SAMPLE TEST B = BLOCK SAMPLE TEST I = IRREGULAR LUMP TEST		I	I	I	

NOTES: 1. Testing in accordance with ISRM Point Load Test Method - see Explanatory Sheet 3.
2. Value for UCS is approximate only. Conversion from $Is_{(50)}$ to Qu is only accurate if extensively calibrated for specific site materials.

MF 195

APPENDIX B

DRILLING AND TESTING PROGRAM

DRILLING AND TESTING PROGRAM

Three high ridges of the Bridgewater Formation were investigated by means of a total of seven (7) boreholes. As the materials of this formation are known to be extremely heterogeneous, the drilling program was designed to include a range of drilling, sampling and testing methods at three sites to maximise the usefulness of the information obtained.

It was intended that at each of two sites, three holes would be drilled. The first was a relatively cheap, rapid open hole to identify the zones of high, low or medium resistance to penetration by the drill. Results from this first hole were used to plan the other drilling at each site. Relatively soft/weak zones were targeted to be investigated mainly by means of the Standard Penetration Test (SPT), while zones of higher strength were targeted for core drilling (PQ size, triple tube) in a third hole.

At the second site the first drill hole indicated only a small amount of rock strength materials and hence it was decided to combine SPT testing and coring in the same hole at that site.

A third site, Site 3, near to a cutting on Cantara Road, was drilled and tested with SPTs in order to compare the SPT values with the excavated face some 10 metres away.

The drilling is located as shown on Figure 1, which also shows the nomenclature used in discussing the ridges and flats. Sites 1 and 2 are in Ridge C which is the second Bridgewater Formation Ridge inland from the Coorong. Site 3 is in Ridge B, the first ridge inland from the Coorong, which is geologically slightly younger than Sites 1 and 2.

The condensed report logs in this Appendix present results of all of the drilling at each of the sites. Laboratory test results are included in Appendix C, and photographs of recovered core samples are included in Appendix D.

Drilling Results

Strata recovered from the cored boreholes at Sites 1 and 2 essentially comprise:

a) variable but generally weakly cemented to apparently non cemented, fine, medium and coarse grained sand with occasional thin limestone or sandstone bands

b) high strength, mainly coarse grained, calcareous sandstone which, in places, comprised cemented shell fragments with a high void ratio (See Appendix C).

The strength results of the drilling are summarised on Figure 2. Even with short runs and good techniques, core recovery was often low in the sandy sections. This is typical of drilling experience in other areas of the Bridgewater Formation. Much of the recovered core in the sandy sections appeared to contain little or no cementing. Standard Penetration Tests taken in adjacent boreholes failed to indicate that the recovered sand differed in characteristics to that in the non-cored sections.

The Standard Penetration Test (SPT) results from all three sites have been plotted on Figure 3. Results from another site at Port Lincoln are plotted on Figure 4 for comparison. The lower bound of the data for both sites is very similar. Also shown on the figures are lines of Density Index (DI) based on two published correlations between the "N" value and the DI. The correlation of SPTs with DI is influenced by many factors and wide variations can be obtained depending on which correlation is adopted. Since the correlations were developed for uncemented sands the published correlations may not be completely valid for the Bridgewater Formation, as that formation is cemented to some degree in most locations. The data can be used in a qualitative sense, however, and they give the best indication available of density and thus strength of the unit. The SPT results suggest that the sand is generally medium dense to dense. There also appears to be some consistent variation with depth in all three sites, which may be summarised briefly as:

0 - 5	metres	medium dense
5 - 10	metres	medium dense to dense
10 - 15	metres	medium dense (but probably less dense than from 0 - 5 metres)

Below 15 metres the tests are beyond the depth of the published correlations, however, they have similar "N" values to the medium dense layers at shallower depth.

Figure 5 presents a plot of SPT results or "N" value versus percent recovered for Sites 2 & 3 (That is the length of the sample recovered in the SPT tube compared to the distance the tube is driven into the ground during the test). There is no significant correlation. However the recovery at Site 3 was generally higher than at Site 2 for the same "N" value. The better recoveries at Site 3 may be due to a combined affect of variation in both Density Index and cementing, or alternatively the shallower depth of the tests.

Complete circulation was lost in places in the highly porous & shelly sections of the calcareous sandstone, a phenomenon which has also been observed elsewhere in the Bridgewater Formation. It suggests the Formation can have a very high permeability in places.

Summary of Site 1 Drilling

The uppermost 16 m comprises a light brown, poorly graded sand. It is fine to medium grained. Cementing of the sand is highly variable from nil to weak and in parts cemented sands make up to about 10% of the profile. From 16 m depth to about 19 m depth is light brown, medium to coarse grained, porous, weak sandstone. The sandstone is underlain by about 3 m of silty sand to a depth of about 22 m. This sand is yellowish brown, silty, fine grained with minor weak cementing. From about 22 m depth to the limit of drilling of 30 m depth the sediments consist of yellow green, fine grained, apparently uncemented sand.

Summary of Site 2 Drilling

From the surface to 21.5 m the drill holes intersected light orange to buff, fine to medium grained sand. It is poorly graded, with almost no fines and apparently only a small proportion of it is cemented.

The sand is underlain to a depth of at least 24.4 m (the limit of drilling at this site) by light brown shelly sandstone. It ranges from fine to very coarse grained, and is porous. It ranges in strength up to moderately strong.

Summary of Site 3 Drilling

The drill holes at site 3 penetrated 9 metres of fine to medium grained light orange sand. It is medium dense and poorly graded with few fines. No cementing was detectable with the drilling equipment used. However, cementing was obvious in the same material exposed 10 metres away in the adjacent road cutting.

Although much of the sand material of the Bridgewater Formation appeared, during drilling, to be uncemented it is thought that there is some small degree of cementing in most places but with a strength threshhold below that of the careful drilling and testing methods used.

SITE 1

PROJECT TITLE : UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type : MAYHEW
Operator : B. FAULKNER
Hole diameter : 120mm , PQ
Hole slope/bearing : 90°/–
Reference elevation :
Datum : NS
Co-ordinates :
Start : 4/8/92
Finish : 8/8/92
Project N° 92-14-1
Unit N°
Docket N° 273/91
Permit N°

Elevation	(F) In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	(A) Soil / rock type+ (G)	Symbol	(B) Graphic log	(C) Moisture content	(D) Density	(E) Strength term (H)x VW W MW MS S VS ES	(I) Core RQD VP P F G E	(K) Spacing of planar features, surface description, openness, orientation etc. ECS VCS CS MS WS VWS	(L) Origin type, mineral composition structure etc.	Formation
0							SAND, cream, fine to medium grain, about 10% weakly to moderately cement-ed (thin layers), trace silt. Slightly damp. Medium Dense									0
1	N=24		Non-cored					SP			MD					1
	N=16															
2	N=11															2
	N=17															
3	N=17						SAND, as above. Calcareous, very weakly cemented			DAMP						3
	N=16						SAND, light brown, slightly silty, fine to med. grained. Very weakly cemented from 3.39m to 3.49m	SP			MD				RUN 3.00 to 4.50m RECOVERY 70%	
4	N=16															4
	N=15		Cored				CORE LOSS - assume SAND as above									
5	N=17														RUN 4.50 to 6.00m RECOVERY 27%	5
	N=29						SAND, light brown, trace silt. Strongly cemented and calcareous from 5.60 to 5.67m									
6	N=16							SP			MD					6

(M) ADDITIONAL INFORMATION
Summary of Site 1 ; Holes M1 + M2 + M3

Recorded by : SW/TE
Date : 8/8/92
Sheet 1 of 5

* For all definitions see attached notes (A) to (M) | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

SITE 1

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW	Hole diameter: 120mm PQ	Reference elevation:	Start: 4/8/92	Project N° 92-14-1
Operator: B. FAULKNER	Hole slope/bearing: 90°/-	Datum: NS	Finish: 8/8/92	Unit N°
		Co-ordinates:		Docket N° 273/91
				Permit N°

Elevation	In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	Soil / rock type	Symbol	Graphic log	Moisture content	Density	Strength term	Core RQD	Spacing of planar features, surface description, openness, orientation etc.	Origin type, mineral composition structure etc.	Formation
	N=29		NON - CORED				SAND, cream, fine to med grained, trace silt. -up to about 5% thin, weakly cemented layers.	SP			MD					
7	N=34															7
	N=36															
8																8
											MD					
9																9
10	N=26															10
	N=26										MD					
11																11
12																12

Column groups: * DRILLING/EXCAVATION; (J) HYDROGEOLOGY; MATERIAL DESCRIPTION; (K) DISCONTINUITY DESCRIPTION; (L) GEOLOGICAL

Strength term: VW W MW MS S VS ES; Core RQD: VP P F G E; Spacing: ECS VCS CS MS WS VWS

(M) ADDITIONAL INFORMATION
Summary of Site 1

Recorded by: SW/TE
Date: 8/8/92
Sheet 2 of 5.

* For all definitions see attached notes (A) to (M) | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

SITE 1

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW
Operator: B. FAULKNER
Hole diameter: 120mm, PQ
Hole slope / bearing: 90°/-
Reference elevation:
Datum:
Co-ordinates:
Start: 4/8/92
Finish: 8/8/92
Project Nº 92-14-1
Unit Nº
Docket Nº 273/91
Permit Nº

Elevation	(F) In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	(A) Soil / rock type+ (G)	Symbol	(B) Graphic log	(C) Moisture content	(D) Density	(E) Strength term (H)x	(I) Core RQD	(K) Spacing of planar features, surface description, openness, orientation etc.	(L) Origin type, mineral composition structure etc.	Formation
13							-cemented from 12.30 to 12.37m								CORE RUN 12.30m TO 13.80m RECOVERY 0%	13
14	N=23 N=20															14
15			CORED													15
16	N>50 (13, 18 blows for 120mm, refusal)						SANDSTONE, light tan, med to coarse grained, very porous due to dissolution of grains & shell fragments							Irregular zones of soil strength materials 30 to 40mm across	CORE RUN FROM 16.00 to 16.60 m. 100% RECD CORE RUN 16.60 TO 17.00m. 88% RECOVERY	16
17							- light yellow brown and coarse grained from 17.0m depth.							Core recovered as pieces 20 to 100mm long. Breaks between pieces very irregular & approx 90° to axis	CORE RUN 17.00 m TO 18.50m. 83% REC.	17
18																18

Column sub-headings: Strength term: VW W MW MS S VS ES; Core RQD: VP P F G E; Spacing: ECS VCS CS MS WS VWS.

(M) ADDITIONAL INFORMATION
Summary of Site 1

Recorded by: SW / TE
Date: 8/8/92
Sheet 3 of 5.

* For all definitions see attached notes (A) to (M) | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW	Hole diameter: 120mm, PQ	Reference elevation: Datum:	Start: 4/8/92	Project Nº 92-19-1 Unit Nº
Operator: B. FAULKNER	Hole slope/bearing: 90°/–	Co-ordinates:	Finish: 8/8/92	Docket Nº 273/91 Permit Nº

Elevation	Ⓕ In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	Ⓐ Soil / rock type+Ⓖ	Symbol	Ⓑ Graphic log	Ⓒ Moisture content	Ⓓ Density	Ⓔ Strength term Ⓗx (VW W MW MS S VS ES)	Ⓘ Core RQD (VP P F G E)	Ⓚ Spacing of planar features, surface description, openness, orientation etc. (ECS VCS CS MS WS VWS)	Ⓛ Origin type, mineral composition structure etc.	Formation
				←	MAJOR MUD LOSS AT 18.5m (NEED LCM)		SANDSTONE, as above							SOIL STRENGTH SAND FROM 18.69m TO 18.70m.	CORE RUN FROM 18.50m TO 18.88m. 66% REC	
19															CORE RUN FROM 18.88m TO 19.31m. 84% REC.	19
							SAND, yellowish brown to grey, silty to very silty, fine grained. Variable cementing (from none to weak)	SM			D MD-D				CORE RUN FROM 19.31m TO 20.06m. 100% RECOVERY	
20					MINOR WATER CUT AT ABOUT 20m										CORE RUN FROM 20.06m TO 21.56m. 27% REC.	20
21	N=24 N=14		CORED								MD					21
22															CORE RUN FROM 21.56m TO 22.16m. 67% REC	22
							SAND, yellow/grey green mottled, fine grained No fines No cementing	SP							CORE RUN FROM 22.16m TO 23.07m. 88% REC.	
23																23
															CORE RUN FROM 23.07m TO 24.57m. RECOVERY 31%	
24	N=22										MD					24

Ⓜ ADDITIONAL INFORMATION

Summary of Site 1

Recorded by: SW/TE

Date: 8/8/92

Sheet 4 of 5.

* For all definitions see attached notes Ⓐ to Ⓜ | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW	Hole diameter: 120mm, PQ	Reference elevation:	Start: 4/8/92	Project Nº 92-14-1
		Datum:		Unit Nº
Operator: B. FAULKNER	Hole slope/bearing: 90°/–	Co-ordinates:	Finish: 8/8/92	Docket Nº 273/91
				Permit Nº

* DRILLING/EXCAVATION — Ⓙ HYDROGEOLOGY — MATERIAL DESCRIPTION — Ⓚ DISCONTINUITY DESCRIPTION — Ⓛ GEOLOGICAL

Elevation	Ⓕ In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	Ⓐ Soil / rock type+Ⓖ	Symbol	Ⓑ Graphic log	Ⓒ Moisture content	Ⓓ Density	Ⓔ Strength term Ⓗx (VW W MW MS S VS ES)	Ⓘ Core RQD (VP P F G E)	Spacing of planar features, surface description, openness, orientation etc. (ECS VCS CS MS WS VWS)	Origin type, mineral composition structure etc.	Formation
			CORED				SAND, yellowish light brown, fine grained. No fines No cementing	SP								
25															CORE RUN FROM 24.57 TO 25.98m. 16% REC.	25
26	N=18										MD					26
27			NON-CORED													27
28	N=31										MD					28
29																29
30							30.00m E.O.H.									30

Ⓜ ADDITIONAL INFORMATION
Summary of Site 1

Recorded by: SW/TE
Date: 8/8/92
Sheet 5 of 5.

* For all definitions see attached notes Ⓐ to Ⓜ | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

SITE 2

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW	Hole diameter: 120mm / PQ	Reference elevation:	Start: 10/8/92	Project N° 92-19-1
Operator: B. FAULKNER	Hole slope / bearing: 90°/–	Datum: NS	Finish: 12/8/92	Unit N°
		Co-ordinates:		Docket N° 273/91
				Permit N°

Elevation	Ⓕ In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	Ⓐ Soil / rock type[+] Ⓖ	Symbol	Ⓑ Graphic log	Ⓒ Moisture content	Ⓓ Density	Ⓔ Strength term[x] Ⓗ VW W MW MS S VS ES	Ⓘ Core RQD VP P F G E	Ⓚ Spacing of planar features, surface description, openness, orientation etc. ECS VCS CS MS WS VWS	Ⓛ Origin type, mineral composition structure etc.	Formation
0–1			NON-CORED				SAND, light orange/brown, fine grained. Cementing from nil to very slight	SP			L-MD					
1–2	N=10						-weakly cemented in parts									1
2–2.5											MD					2
2.5–3			CORED				SILT, cream, sandy, very limey. Very weakly cemented, Friable								CORE RUN FROM 2.50m TO 2.92m. 60% REC. CORE RUN FROM 2.92m TO 3.34m. 0% REC.	
3–4	N>50						SAND, as above.	SP			MD				CORE RUN FROM 3.34m TO 3.76m. 100% REC.	3
4–4.4			NON CORED													4
4.4–4.82			CORED												CORE RUN FROM 4.40m TO 4.82m. 36% REC.	
5–6	N=21		NON-CORED								MD					5
6																6

Ⓜ ADDITIONAL INFORMATION

Summary of Site 2

Recorded by: SW/TE

Date: 12/8/92

Sheet 1 of 5

* For all definitions see attached notes Ⓐ to Ⓜ | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW
Operator: B. FAULKNER
Hole diameter: 120mm/PQ
Hole slope/bearing: 90°/–
Reference elevation:
Datum: NS
Co-ordinates:
Start: 10/8/92
Finish: 12/8/92
Project N°: 92-14-1
Unit N°:
Docket N°: 273/91
Permit N°:

Elevation	(F) In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	(J) Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	(A) Soil / rock type+ (G)	Symbol	(B) Graphic log	(C) Moisture content	(D) Density	(E) Strength term (H)x VW W MW MS S VS ES	(I) Core RQD VP P F G E	(K) Discontinuity description: Spacing of planar features, surface description, openness, orientation etc. ECS VCS CS MS WS VWS	(L) Geological: Origin type, mineral composition structure etc.	Formation
	N=25		NON-CORED				SAND, buff, fine to medium grained, very weakly cemented in parts.	SP			MD					
7																7
8	N=19															8
9																9
10	N=32															10
11																11
12																12

(M) ADDITIONAL INFORMATION

Recorded by: SW/TE
Date: 12/8/92
Sheet 2 of 5.

* For all definitions see attached notes (A) to (M) | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW	Hole diameter: 120mm/PQ	Reference elevation:	Start: 10/8/92	Project Nº 92-14-1	
Operator: B. FAULKNER	Hole slope/bearing: 90°/-	Datum: NS	Finish: 12/8/92	Unit Nº	Docket Nº 273-91
		Co-ordinates:		Permit Nº	

Elevation	Ⓕ In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	Ⓐ Soil / rock type+ Ⓖ	Symbol	Ⓑ Graphic log	Ⓒ Moisture content	Ⓓ Density	Ⓔ Strength term Ⓗ VW W MW MS S VS ES	Ⓘ Core RQD VP P F G E	Ⓚ Spacing of planar features, surface description, openness, orientation etc. ECS VCS CS MS WS VWS	Ⓛ Origin type, mineral composition structure etc.	Formation
		CORED						SP			MD				CORE RUN 12.00m TO 12.42m. 0% REC	
	N=21															
13							SAND, buff, fine to med. grained. Well sorted. No fines. Very weakly cemented in parts.									13
14																14
15	N=15	NON-CORED									MD					15
16																16
17																17
18	N=45										MD-D					18

Ⓜ ADDITIONAL INFORMATION

Recorded by: SW/TC

Date: 12/8/92

Sheet 3 of 5

* For all definitions see attached notes Ⓐ to Ⓜ | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW
Operator: B. FAULKNER
Hole diameter: 120mm/PQ
Hole slope/bearing: 90°/–
Reference elevation:
Datum: NS
Co-ordinates:
Start: 10/8/92
Finish: 12/8/92
Project Nº 92-14-1
Unit Nº
Docket Nº 273/91
Permit Nº

Elevation	Casing	Hydrogeology (Pressure test / Falling head / Pump test / Aquifer)	Soil / rock type	Symbol	Density	Discontinuity description	Geological (Origin type, mineral composition, structure etc.)	Formation
19–20.55	NON-CORED		SAND, buff, fine to med. grained. Well sorted - no fines.	SP				19, 20
20.55	CORED		SANDSTONE, cream, fine grained. Siliceous		?VD		CORE RUN 20.55m TO 21.58m. 77% REC.	
21	CORED		SAND, orange, very fine to med grained (fines upwards). Slightly silty and slightly cemented in parts, calcareous	SP	?VD			21
21.58–22.35	NON-CORED		SANDSTONE/SAND. Thin (to 20mm) layers of MS sandstone interspersed with thin (to 50mm) layers of fine to med grained sand, MD.			Thin layers (to 50mm) of SANDSTONE separated by v. thin layers of sand.	CORE RUN 22.35m TO 23.10m. 87% REC.	22
23–24	CORED	TOTAL LOSS OF RETURNS AT 23.2m	SANDSTONE light brown, fine to very coarse grained Shelly to very Shelly below about 23m. Minor thin conglomerate zones.			FRACTURED ZONES 23.15 to 23.18m 23.26 to 23.34m SOIL STRENGTH ZONES 23.51 to 23.55m 23.97 to 24.20m	CORE RUN 23.10m TO 24.40m. 94% REC. VERY PERMEABLE DUE TO DISSOLUTION OF SHELLS	23, 24

Ⓜ ADDITIONAL INFORMATION

Recorded by: SW/TE
Date: 12/8/92
Sheet 4 of 5

* For all definitions see attached notes Ⓐ to Ⓜ | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW	Hole diameter: 120mm/PQ	Reference elevation:	Start: 10/8/92	Project N°: 92-14-1
		Datum: N.S		Unit N°:
Operator: B. FAULKNER	Hole slope/bearing: 90°/–	Co-ordinates:	Finish: 12/8/92	Docket N°: 273/91
				Permit N°:

* DRILLING/EXCAVATION				Ⓙ HYDROGEOLOGY			MATERIAL DESCRIPTION							Ⓚ DISCONTINUITY DESCRIPTION	Ⓛ GEOLOGICAL	
Elevation	Ⓕ In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	Ⓐ Soil / rock type+Ⓖ	Symbol	Ⓑ Graphic log	Ⓒ Moisture content	Ⓓ Density	Ⓔ Strength term Ⓗx VW W MW MS S VS ES	Ⓘ Core RQD VP P F G E	Spacing of planar features, surface description, openness, orientation etc. ECS VCS CS MS WS VWS	Origin type, mineral composition structure etc.	Formation
			CORED				SANDSTONE, as above									
							24.90m EOH									
25																25
26																26

Ⓜ ADDITIONAL INFORMATION

Recorded by: SW/TE

Date: 12/8/92

Sheet 5 of 5

* For all definitions see attached notes Ⓐ to Ⓜ | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

PROJECT TITLE: UPPER SOUTH EAST DRAINAGE

CONDENSED REPORT LOG

Machine type: MAYHEW	Hole diameter: 120 mm	Reference elevation:	Start: 13/8/92	Project Nº 92-14-1
		Datum:		Unit Nº
Operator: FAULKNER	Hole slope/bearing: 90°/–	Co-ordinates:	Finish: 13/8/92	Docket Nº 273/91
				Permit Nº

Elevation	Ⓕ In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	Ⓐ Soil / rock type[+] Ⓖ	Symbol	Ⓑ Graphic log	Ⓒ Moisture content	Ⓓ Density	Ⓔ Strength term[x] Ⓗ VW W MW MS S VS ES	Ⓘ Core RQD VP P F G E	Ⓚ Spacing of planar features, surface description, openness, orientation etc. ECS VCS CS MS WS VWS	Ⓛ Origin type, mineral composition structure etc.	Formation
0							SAND + MINOR SILT, HUMIC CONTENT FG	SP								
1, 2	N = 9 N = 10 N = 21						SAND - CREAM/TAN FINE TO MED GRAIN SOME NODULAR CA RICH FRAGS 10% WITH TRACE SILT	SP			MD					
3, 4, 5	N = 22 N = 19						SAND CREAM/ORANGE FINE GRAIN, WELL SORTED, LOOSE, VISIBLE BROKEN SHELL FRAGMENTS, CA PRESENT.	SP			MD					

Ⓜ ADDITIONAL INFORMATION

Site 3

Recorded by: SW/TE
Date: 13/8/92
Sheet 1 of 2

* For all definitions see attached notes Ⓐ to Ⓜ | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

Department of Mines and Energy South Australia — Groundwater and Engineering Services

MF 173

SITE 3

PROJECT TITLE:

CONDENSED REPORT LOG

Machine type: MAYHEW Operator: FAULKNER	Hole diameter: 120mm Hole slope/bearing: 90°/–	Reference elevation: Datum: Co-ordinates:	Start: 13/8/92 Finish: 13/8/92	Project Nº 92-14-1 Unit Nº Docket Nº 273/91 Permit Nº

* DRILLING/EXCAVATION				(J) HYDROGEOLOGY			MATERIAL DESCRIPTION							(K) DISCONTINUITY DESCRIPTION	(L) GEOLOGICAL	
Elevation	(F) In situ test SPT, CPT, Drilling or excavation rate	Lift core loss	Casing	Water loss	Pressure test Falling head Pump test Aquifer	Piezometer	(A) Soil / rock type+ (G)	Symbol	(B) Graphic log	(C) Moisture content	(D) Density	(E) Strength term x (H) VW W MW MS S VS ES	(I) Core RQD VP P F G E	Spacing of planar features, surface description, openness, orientation etc. ECS VCS CS MS WS VWS	Origin type, mineral composition structure etc.	Formation
	N-23						SAND - AS ABOVE	SP								
7																
8	N-31										D					
9																

(M) ADDITIONAL INFORMATION

SUMMARY OF SITE 3 HOLES M6+M7

Recorded by: T ELBERG
Date: 13/8/92
Sheet 2 of 2.

* For all definitions see attached notes (A) to (M) | + Based on BSI code BS 5930 1981 | x For a soil state density or stiffness

APPENDIX C

LABORATORY TEST RESULTS

LABORATORY TESTING

There was a concern that the early SPT results from drilling at Sites 1 and 2 may have indicated, from the short sample length recovered relative to the distance the tube was driven, that the Bridgewater Formation may be weakly cemented in such a way that it resisted densification and consequently had a high void ratio. This could render the Bridgewater susceptible to rapid loss of strength, with consequent safety concerns in the proposed excavations of up to 30 metres depth near to Salt Creek.

There is widespread evidence that the formation is quite ubiquitously cemented to varying degrees, with much of the material being stronger than a similar, uncemented sand, but there was no other relevant data available. It was considered feasible and therefore advisable to test the hypothesis using laboratory tests.

Block samples recovered from the road cutting on Cantara Road adjacent to Site 3 (see Figure 1) were carefully preserved and transported to the Soils Laboratory of the E&WS Material Sciences Branch for testing.

Tests were carried out to approved Australian Standards and included:

- confined compressive strength
- moisture content
- specific gravity
- dry density - max, min and *in situ*
- voids ratio

The road cutting at Site 3 is some 6 metres in depth (see Figure 6). The cut has recently been widened and shows signs of surface erosion. The lower portion of the slope is covered with deliberately placed talus and brush in an attempt to reduce erosion. However it would appear that the cut (except for the top 1 - 2 metres which may be geologically younger than the Bridgewater Formation and which comprises completely uncemented sand) has been cut at approximately 50°. There are no signs of overall slope instability in this or other nearby excavations, an attribute which is common in man made cut slopes in the Bridgewater Formation, and which can also be seen where the unit is exposed in coastal cliffs. The most common mode of failure appears to be by erosion leaving more resistant layers of strata unsupported and which subsequently collapse.

Block samples were taken from 300 mm depth below the present surface in the road cutting. Field personnel indicated that in the process of digging the blocks out they noticed significant variations in strength over short distances. These variations were noted both between strata and as a mottled affect within individual strata. Such strength variations are typical for the Bridgewater Formation, and have been frequently observed elsewhere.

Three confined compression tests, the results of which are contained in this Appendix, were carried out on the material in the block samples. Strengths ranged from 100 to 440 kPa.

It is not certain whether these strengths are the result of near surface wetting and drying leading to localised additional cementing ("case hardening"), but the SPT results from the drilling done 10 metres behind the cut face at Site 3 would suggest that the block strengths are in part due to this effect.

Void Ratios calculated from the investigations on this and other sites, as well as published data, have been summarised in Table 3. *In situ* void ratios at Site 3 are at the high end of the anticipated range based on data from other areas and the published data, but not unusually so. The calculated void ratios from SPTs are believed to be unreliable in a quantitative sense.

The relatively high void ratios are also consistent with the observed highly permeable nature of the Formation.

EWS DEPARTMENT

Soils Laboratory
SOIL TEST SUMMARY

PROJECT: UPPER SOUTH EAS DRAINAGE SCHEME

DEPT. OF MINES + ENERGY

LOCATION

21. 8. 92.

BH	Depth m.	Compressive Strength (kPa)	Voids Ratio	M.C. %	S.G.	Dry Densities t/m³			Rel. Density %	Absorption Test							Linear Shrink %
						Insitu	Max.	Min.		Nat. m.c. wt.	S.S.D. air wt.	S.S.D. water wt.	Dry wt.	% m.c. after Abs.			
	1.0	95	0.779	13.6	2.65	1.49	1.55	1.22		Sample too fragile to stand up in water				-			
	1.8-2.0	403	0.766	8.4	2.68	1.52	1.64	1.32		503.41	573.28	274.85	463.48	23.7			
	3.1-3.4	438	0.870	7.0	2.67	1.43	1.59	1.29		522.25	631.12	287.02	484.35	30.3			

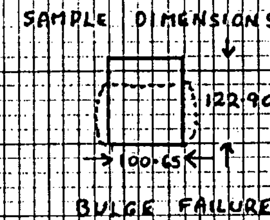
UPPER SOUTH-EAST DRAINAGE PROJECT 18-8-92

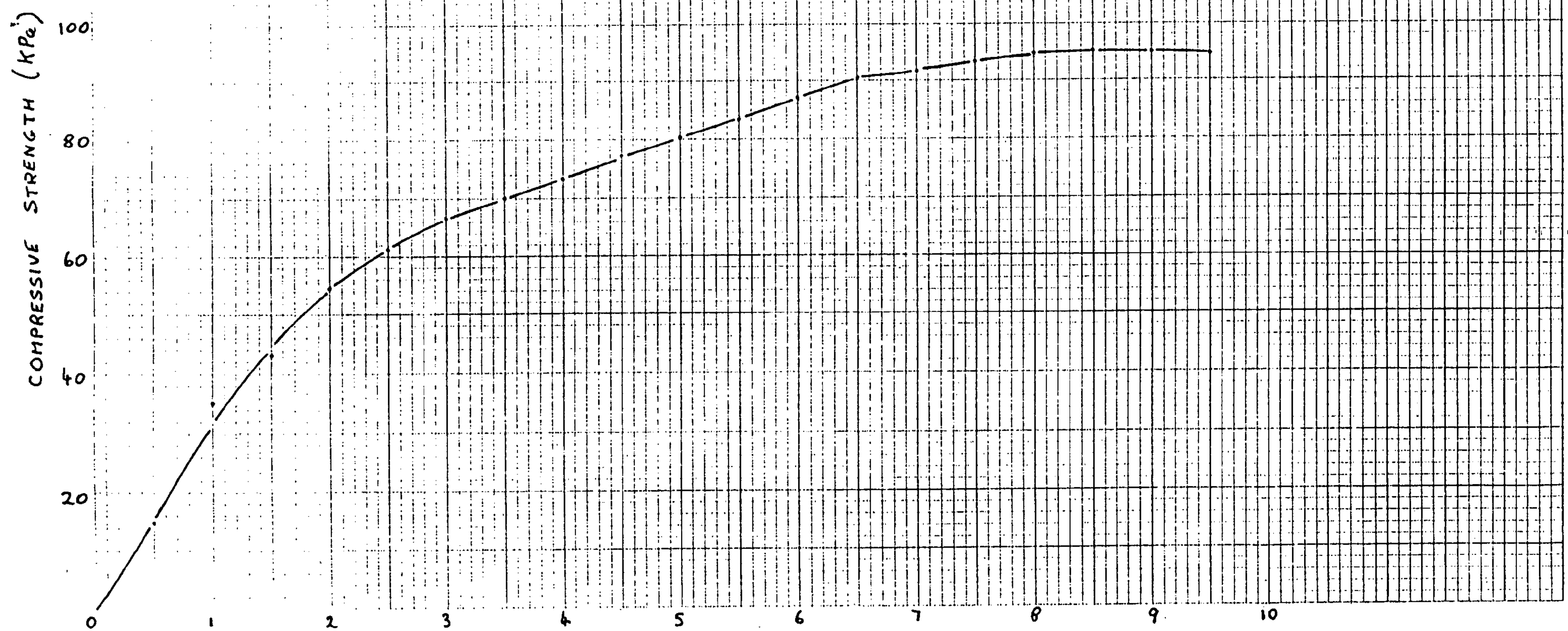
DEEP DRAIN

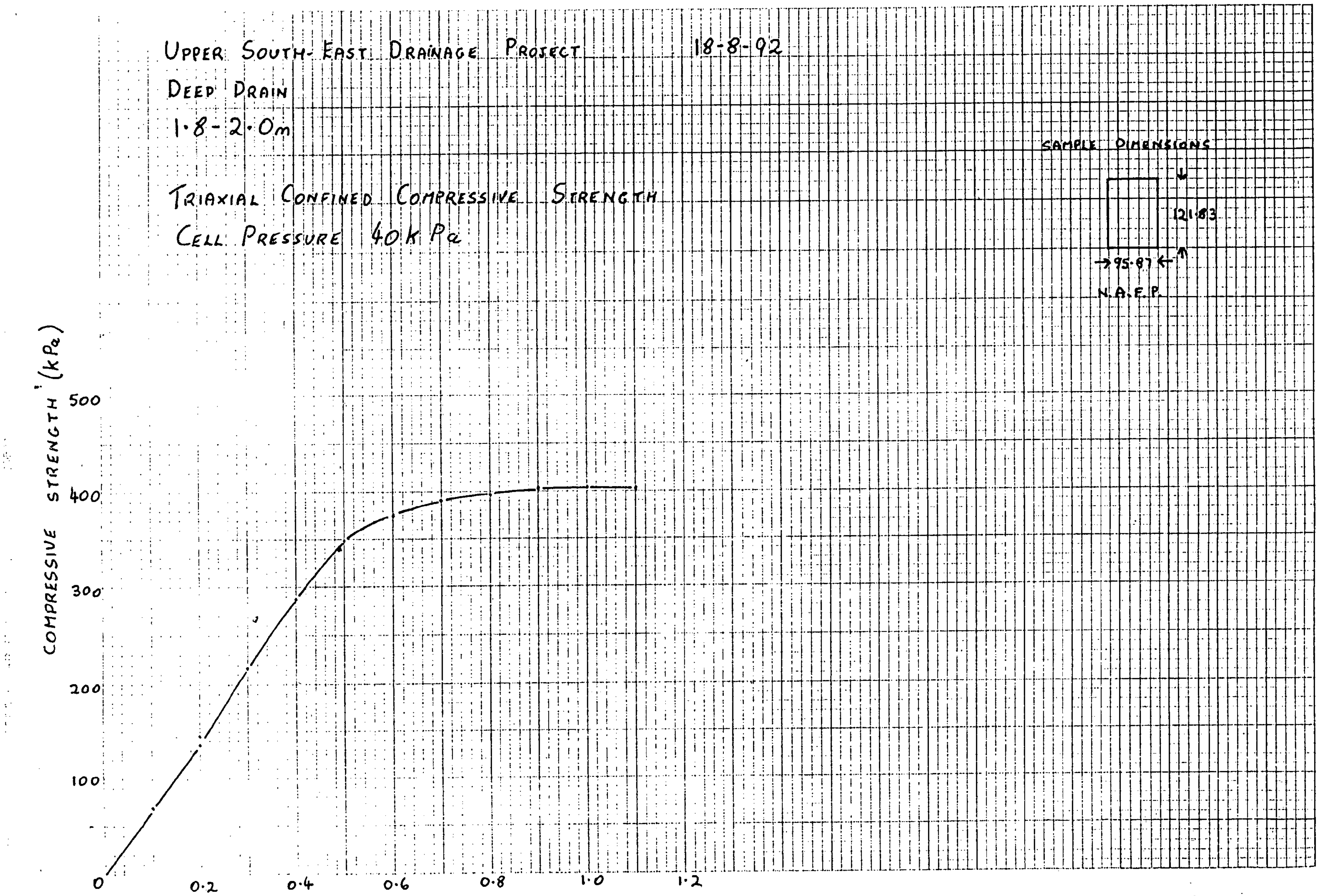
1·0m

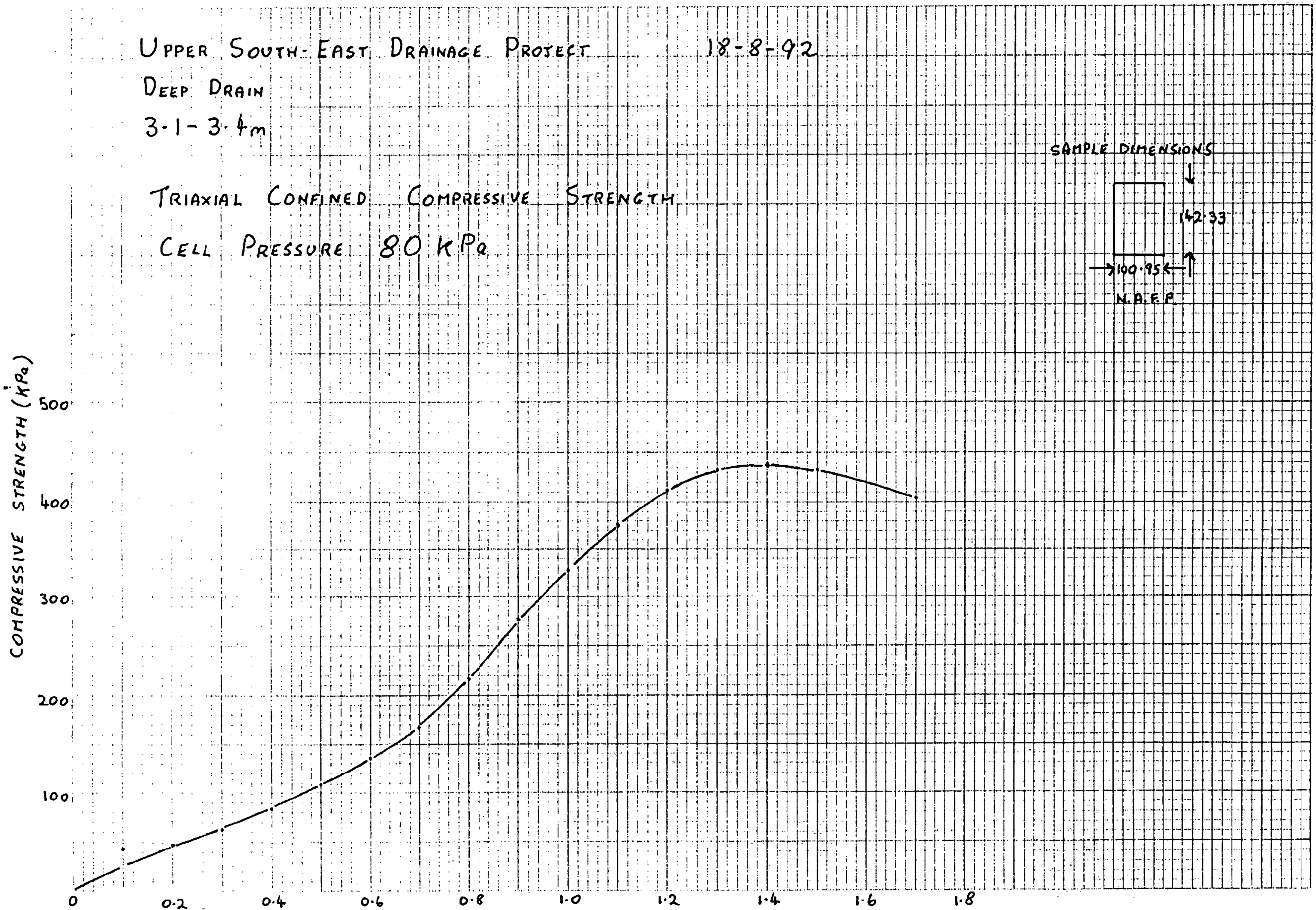
TRIAXIAL CONFINED COMPRESSIVE STRENGTH

CELL PRESSURE 20 KPa






UPPER SOUTH-EAST DRAINAGE PROJECT
18-8-92
DEEP DRAIN
1·8 - 2·0m
TRIAXIAL CONFINED COMPRESSIVE STRENGTH
CELL PRESSURE 40 kPa
SAMPLE DIMENSIONS
121·83
95·87
N.A.F.P.
COMPRESSIVE STRENGTH (kPa)
500
400
300
200
100
0
0·2
0·4
0·6
0·8
1·0
1·2



UPPER SOUTH-EAST DRAINAGE PROJECT
18-8-92
DEEP DRAIN
3·1-3·4m
TRIAXIAL CONFINED COMPRESSIVE STRENGTH
CELL PRESSURE 80 KPa
SAMPLE DIMENSIONS
142·33
100·95
N.A.F.P.
COMPRESSIVE STRENGTH (KPa)
500
400
300
200
100
0
0·2
0·4
0·6
0·8
1·0
1·2
1·4
1·6
1·8

APPENDIX D

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PLATE 3: Pit 9 - Note stable, smooth walls; recovering groundwater level. Photo No. 40285

PLATE 4: Pit 9 - Spoil- Note granular, blocky nature; wet, sloppy digging conditions. Photo No. 40286

PLATE 5: Pit 10 - Note stable walls, high SWL after rapid recovery. Photo No. 40287

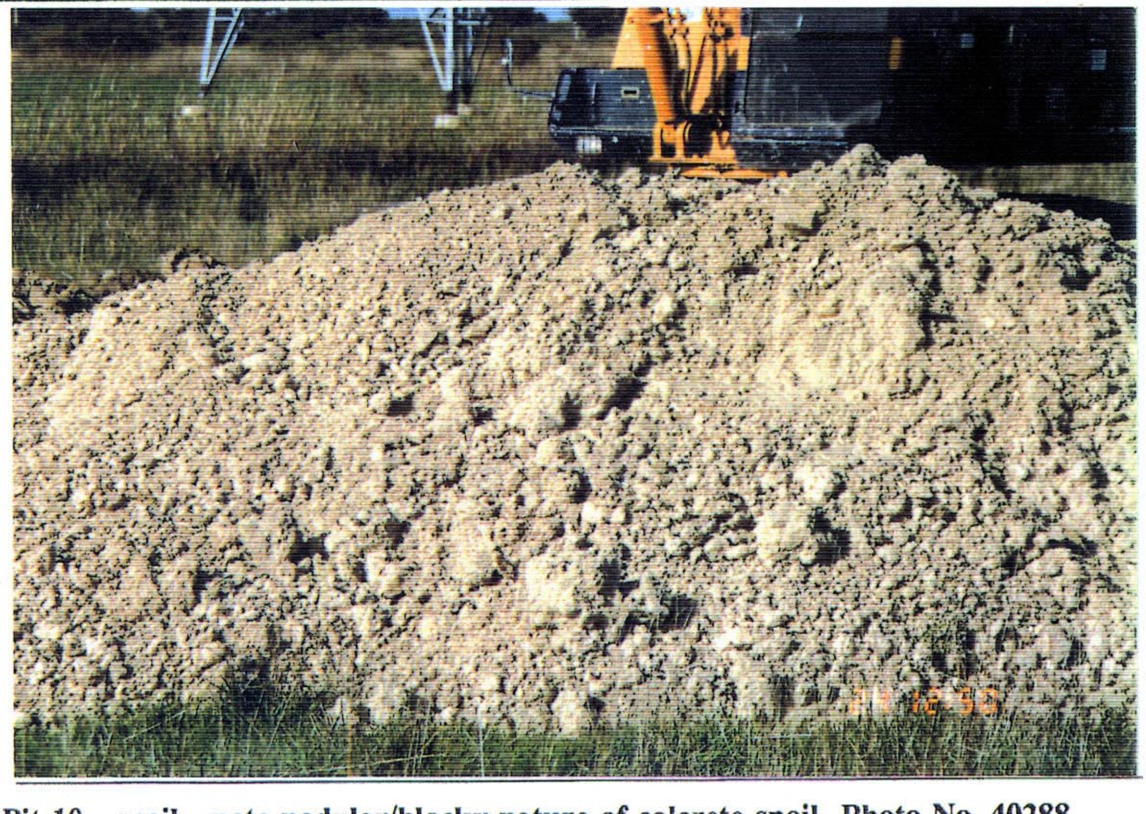

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PLATE 10: Pit 13
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PLATE 12: SITE 1, Borehole M3. Core sample from 16.00 m to 16.60 m depth
Photo No 40294

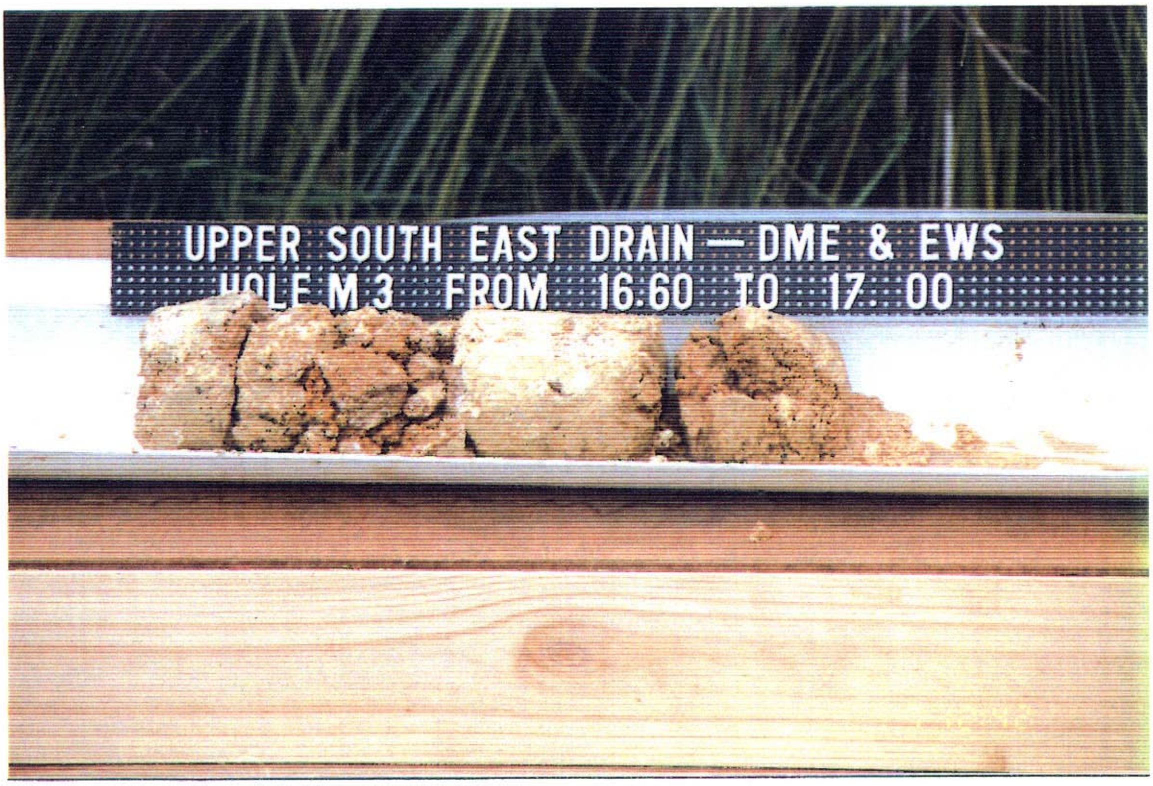

PLATE 13: SITE 1, Borehole M3. Core sample f 16.60 m to 17.00 m depth
Photo No 40295

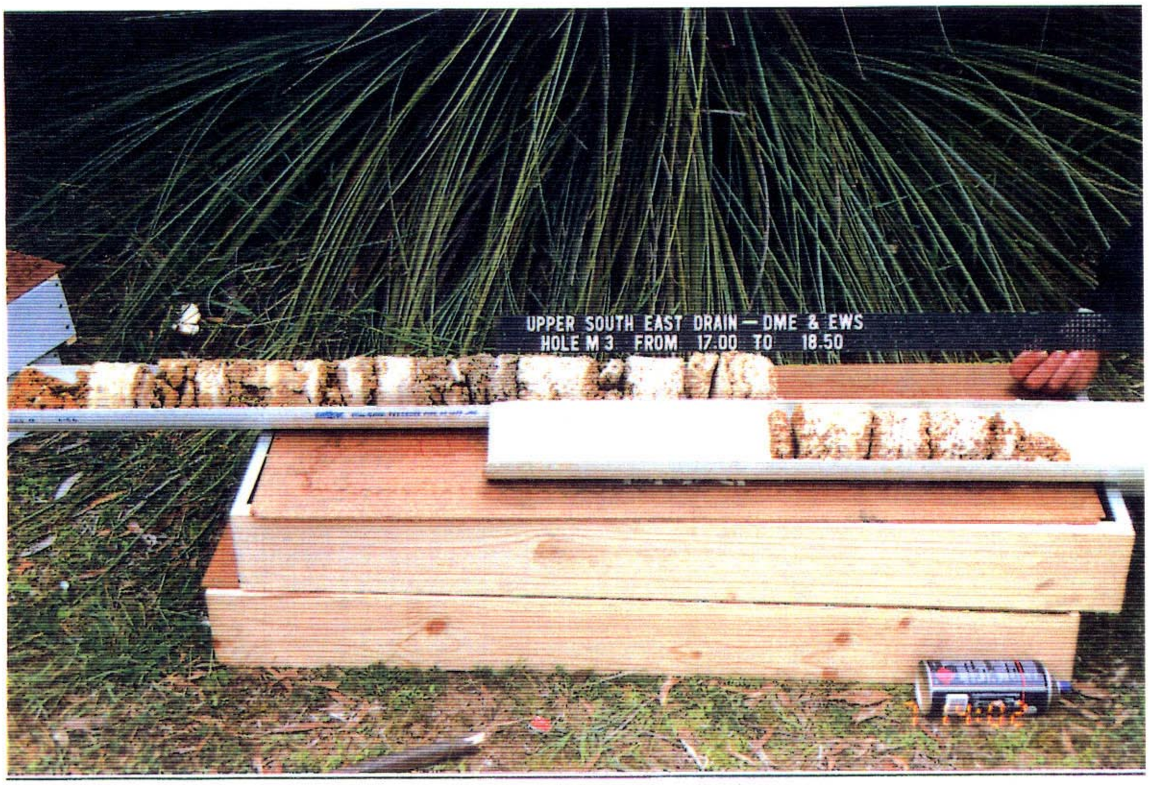

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Photo No 40296

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Photo No 40297

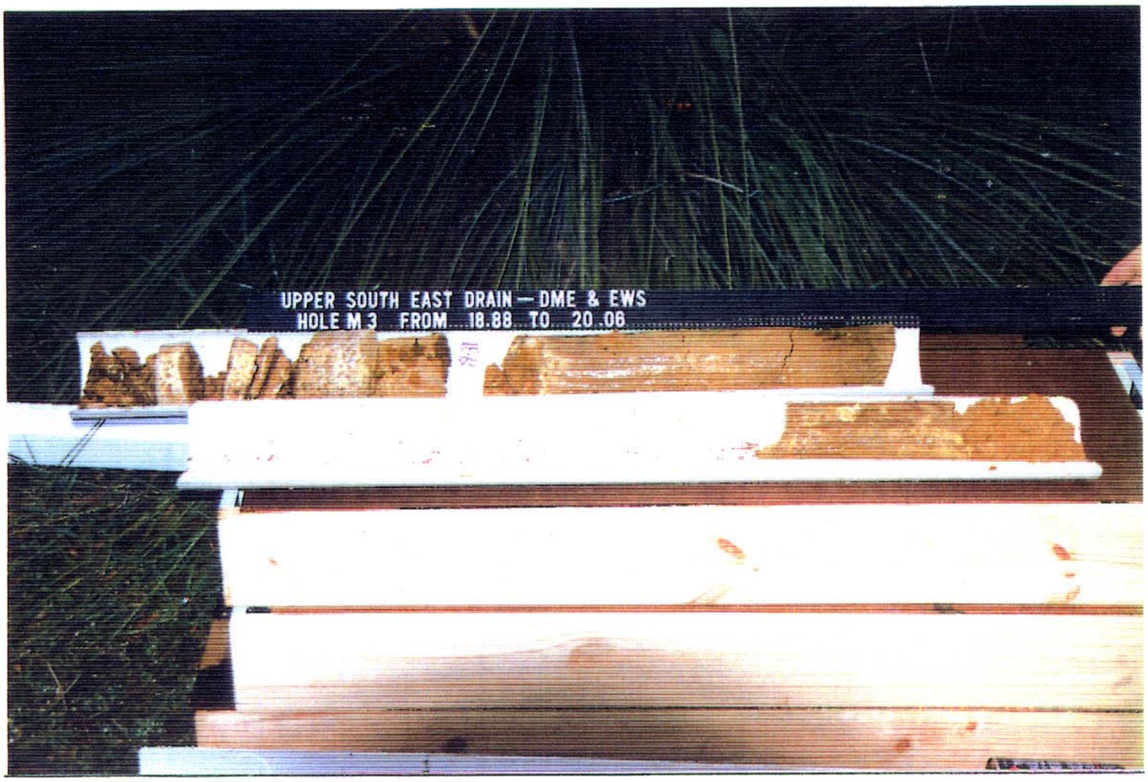

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Photo No 40298

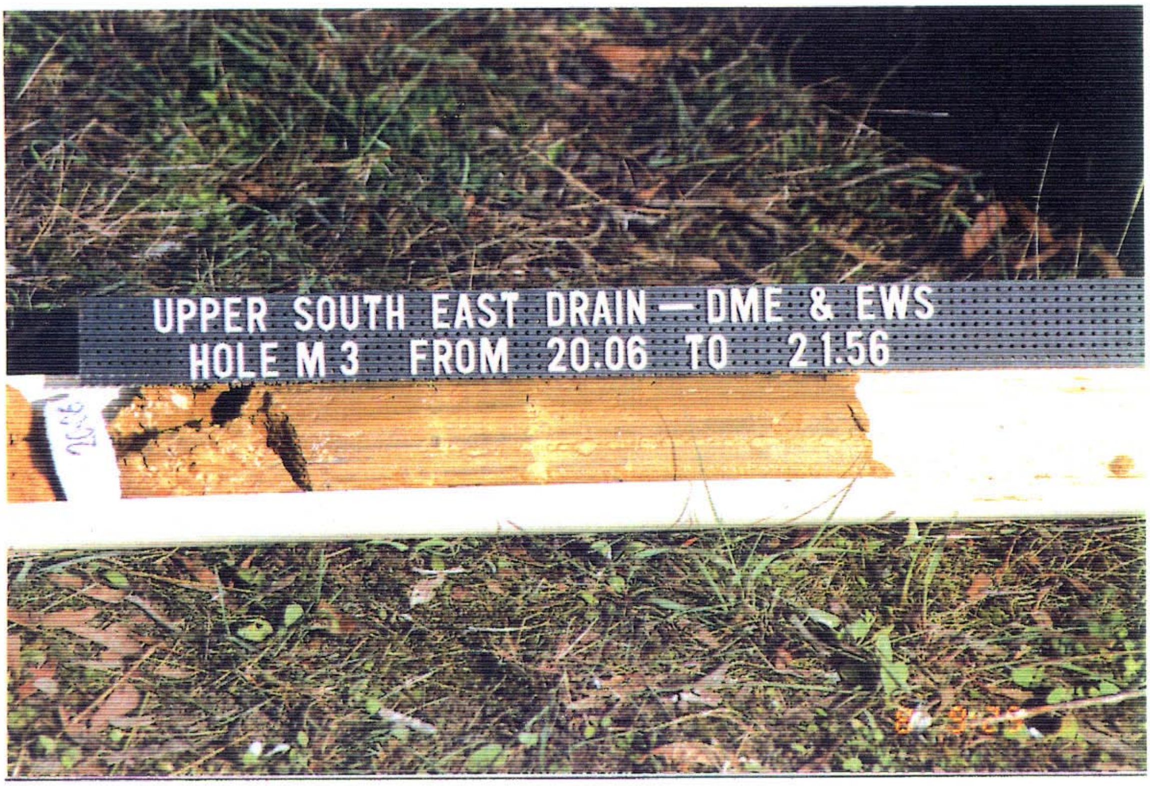

PLATE 17: SITE 1, Borehole M3. Core sample from 20.06 m to 21.56 m depth
Photo No 40299

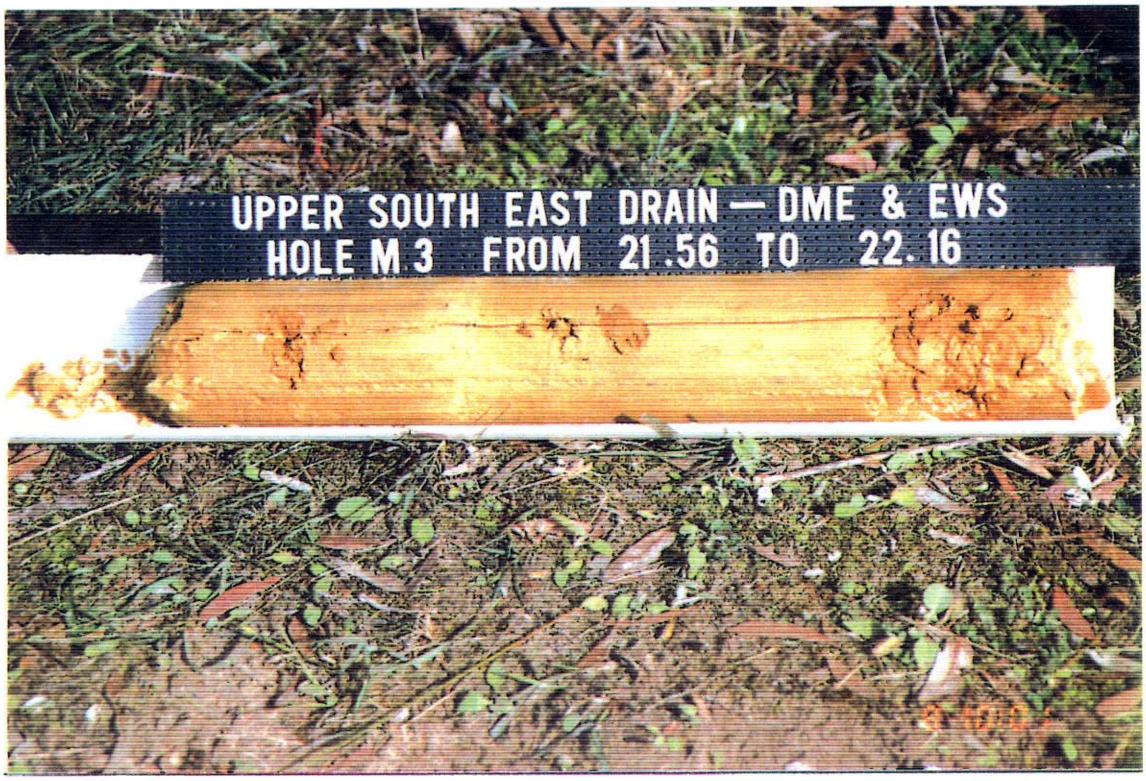

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Photo No 40300

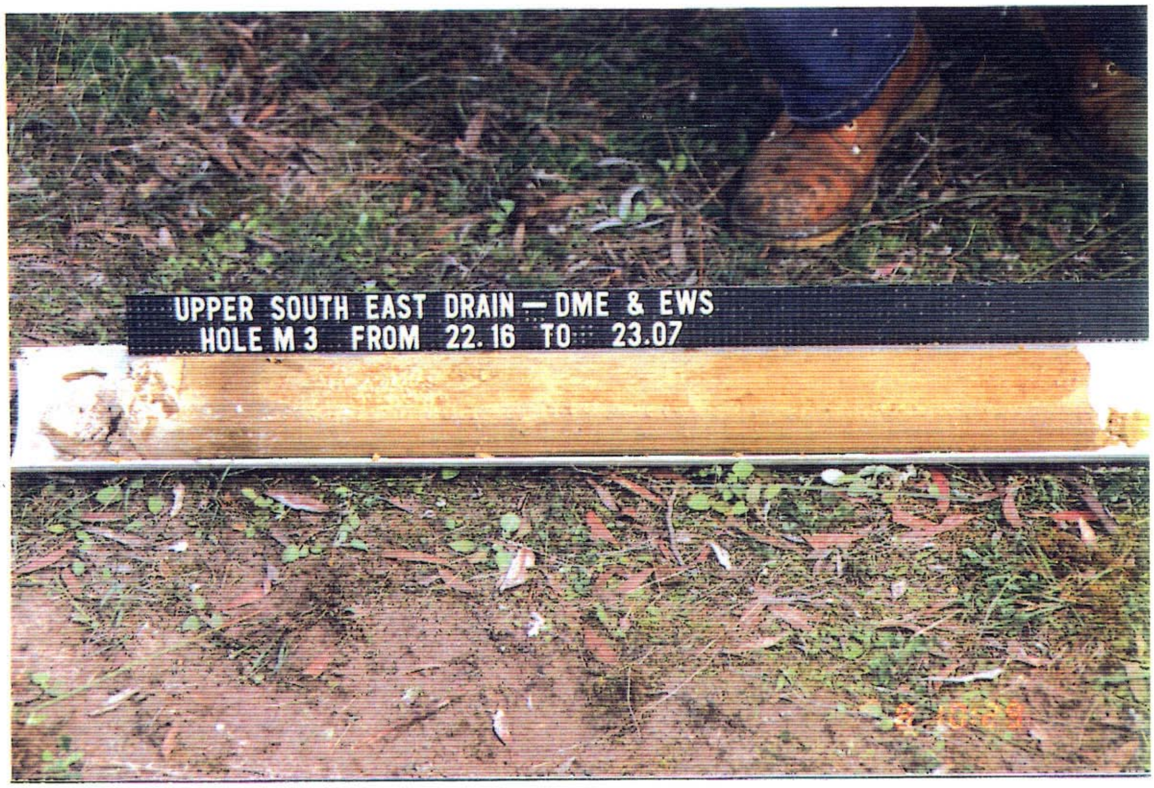

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Photo No 40301

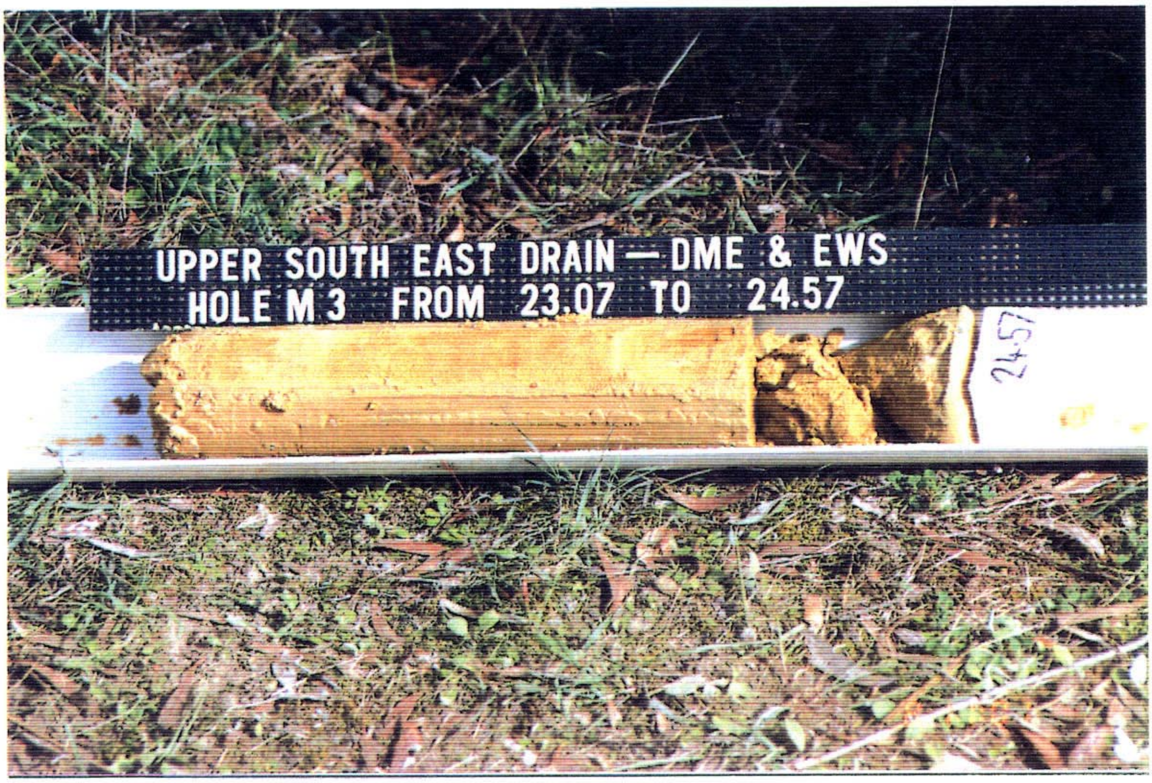

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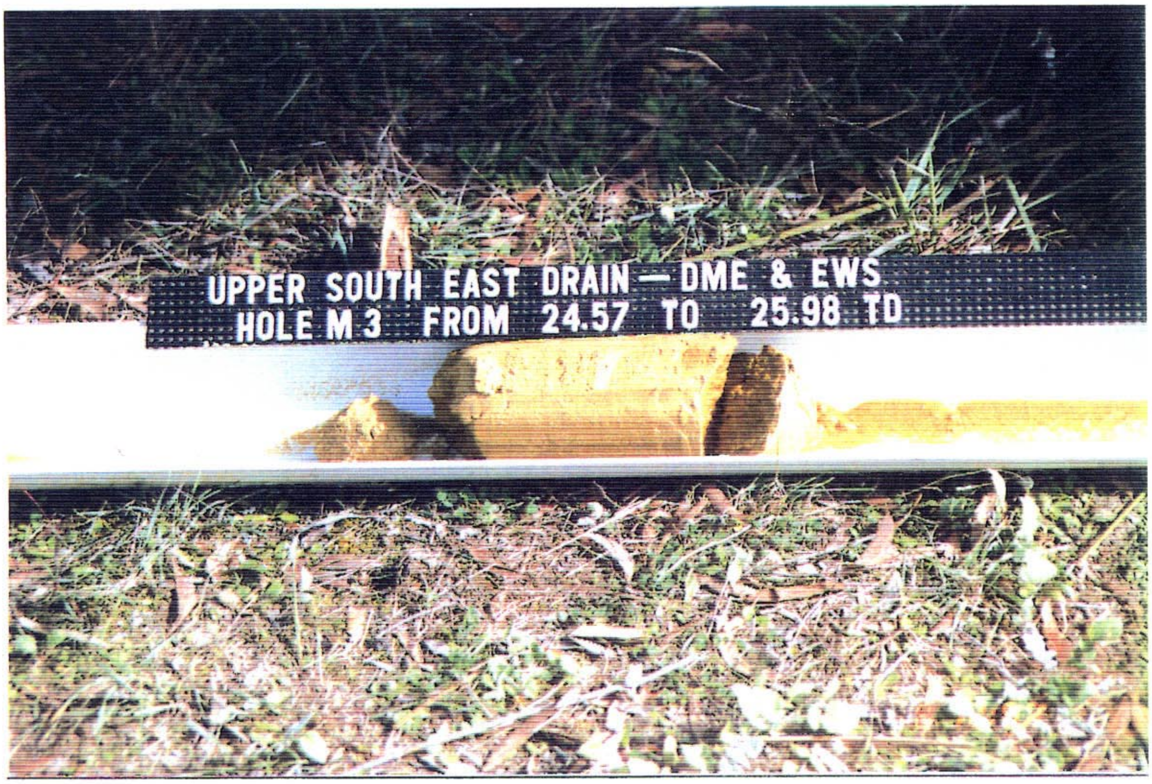
Photo No 40302



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