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Lower Balonne Airborne Geophysical Project

FLUVIAL ARCHITECTURE OF THE SUBSURFACE OF THE LOWER BALONNE AREA, SOUTHERN QUEENSLAND, AUSTRALIA

Jonathan D. A. Clarke and Anne L. Reisz

CRC LEME OPEN FILE REPORT 162

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This report is one of six CRCLEME Open File Reports contributing to the Lower Balonne Airborne Geophysical Project funded by the National Action Plan for Salinity and Water Quality. The project is providing new knowledge and developing methodologies for improved natural resource management in the Murray Darling Basin area of southern Queensland. This integrated project has a multidisciplinary team with skills in regolith geology, geomorphology, bedrock geology, hydrogeology, geophysics and soil science, working to understand the processes and controls on salinity in a variable regolith terrain.

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EXECUTIVE SUMMARY

Integrating Airborne Electromagnetic (AEM) and borehole data from the St George study region has revealed several new aspects of the architecture of the fluvial sediments that cover much of the area and the underlying weathered bedrock. This report contends that:

- The Cretaceous bedrock of the region was deeply weathered prior to incision of a palaeodrainage network, comprising the Dirranbandi and Moonie Palaeovalleys and their tributaries. The saprolite is variably and discontinuously ferruginised, with major ferruginous zones apparently coinciding with conductive zones on AEM sections and Layered earth Inversion (LEI) depth slices. Overprinting silicification locally obliterates the conductive signature.
- The deepest palaeovalleys were incised to fresh rock below the base of weathering, up to 200 m below the present land surface. This is based on the interpretation of AEM sections which show the truncation of weathered bedrock against the sides of the palaeovalleys, confirming the interpreted drill hole information. There is a suggestion of structural control, possibly sag along deep-seated faults, to the rectilinear nature of the palaeodrainage network.
- The fluvial succession first filled the incised palaeovalleys and then onlapped the shoulders of the palaeovalleys, forming a laterally unconfined aggrading plain. Bedrock hills in the study area are isolated remnants, rising above the level of the encroaching sedimentary plain. Like the contemporary rivers of the region, deposition occurred from mud dominated anastomosing rivers with sinuous to meandering channels. Braided streams are a subordinate facies during the aggradational plain phase.
- Deposition of the cover sediments mostly likely commenced in the Pliocene, based on palynological evidence and has continued to the present without major breaks in the stratigraphy. The sedimentary architecture has, however, changed several times though time, the most significant such event coinciding with the change from confined sedimentation in the palaeovalleys to unconfined sedimentation on the aggrading plain, and due to the internal sedimentary dynamics of that plain. There is no evidence of ongoing tectonic influence or changes in external base level to the sedimentary succession.
- There are three discrete layers evident in the AEM LEI depth slices. They consist of: the 40-160 m aggregate layer (incised valley fill). The 15-40 m aggregate layer (the aggrading plain fill). The 0-15 m aggregate layer (with the distinctive signature of the modern surface).

The documented fluvial architecture of the Lower Balonne Airborne Geophysics Project (LBAGP) has numerous implications for the hydrology of the region. In particular the documented architecture affects the aquifer structure, connectivity, and recharge potential. The implications are:

- A predominance of anastomosing over braided or meandering architectures means that sand bodies are more likely to aggrade vertically than accrete horizontally. As a result the lateral extent of sand bodies is low. Because axial extent remains high this introduces a strong anisotropy to the aquifer geometry.
- The sands of the palaeovalley fill (40-160 m aggregate layer) host the confined subartesian lower aquifer of previous workers. These sands are likely to be recharged by horizontal flow upstream of the LBAGP.
- Sands of the aggrading plain succession (15-40 m aggregate layer) host the unconfined upper aquifer. Especially important to the aquifer’s storage potential are localised braided stream facies between Dirranbandi and St George. The upper aquifer is likely to be recharged by thick anastomosing sands associated with contemporary and recently abandoned channels, and where the braided stream facies reach the surface north of the Noondoo Rises.

Abbreviations in this Report

AEM	Airborne Electromagnetics
BRS	Bureau of Resource Sciences
CRC LEME	Cooperative Research Centre for Landscape Environments and Mineral Exploration
GA	Geoscience Australia
GRS	Gamma Ray Spectrometry
LBAGP	Lower Balonne Airborne Geophysics Project
LEI	Layered Earth Inversion
NRM&E	Queensland Department of Natural Resources and Mines
RLU	Regolith Landform Unit

1. INTRODUCTION

This report is part of the ongoing investigation Lower Balonne Airborne Geophysics Project (LBAGP), undertaken in collaboration with CRC LEME, NRM&E and BRS. The study area is located in the upper reaches of the Murray Darling Basin and water management in the area is important. An understanding of the previous and current fluvial systems in the area is needed to enhance understanding of water movement in the surface and subsurface of the area. When combined with the results of other investigations in the LBAGP, more effective management of the water resources in the study area is possible.

The objective of this part of the LBAGP is to provide a conceptual model of the fluvial architecture of the lower Balonne area. The information needed to create this model is derived from an integration of AEM surveys, geomorphic mapping and drilling to provide a conceptual model of the fluvial architecture of the region.

This report outlines the concept of fluvial architecture and its significance to the hydrogeology of the lower Balonne area.

Outputs of this part of the LBAGP are this report and two plans of the interpreted gross architecture of the study area. Aspects of this study have been briefly reported previously elsewhere (Clarke *et al.* a, b).

2. STUDY AREA

2.1 Location

The lower Balonne study area is situated in south western Queensland (Figure 1). The only major town in the area is St George and the other smaller township is Dirranbandi. The study area is located in the upper reaches of the Murray Darling Basin, in the Balonne-Maranoa catchment.

2.2 Climate

The climate of the Lower Balonne area is sub-humid to semi-arid warm temperate (Bureau of Meteorology, 2003). Mean monthly temperatures range from less than 10^{o}C in winter to over 30^{o}C during summer. Frost occurs during some winters. Mean annual rainfall at St George is 516 mm, distributed unevenly throughout the year. January is the wettest month, whilst August and September are the driest months. The highest recorded monthly rainfall is in January (415 mm) and the lowest recorded rainfall is 0 mm and has occurred in all months during drought years.

2.3 Vegetation

Grassland, low open-woodland, open-woodland, woodland and open-forest are the predominant vegetation communities in the area (Galloway *et al.* 1974). Most of the natural vegetation in the study area has been cleared, and in many areas introduced vegetation including pasture and crops dominate the landscape.

2.4 Geology

Bedrock geology of the area consists of the Cretaceous Griman Creek Formation which is characterised by labile sandstone, siltstone and minor mudstone which is calcareous in part. The unit is more than 300 m thick and the interval 0-50 m below surface is variably weathered (kaolinised, silicified, ferruginised). The Griman Creek Formation was deposited in a deltaic to marine environment at its base and in a fluviatile environment in the upper part.

Earlier workers (Senior, 1972, Exon 1976) describe a sequence of Tertiary quartzose, sandstone and conglomerate which are variably silicified and ferruginised. Siltstone and minor mudstone are also present in this unit. The unit locally exceeds 20 m in thickness and is interpreted as deposited in a fluviatile environment. It occurs as local hill capping because of topographic inversion.

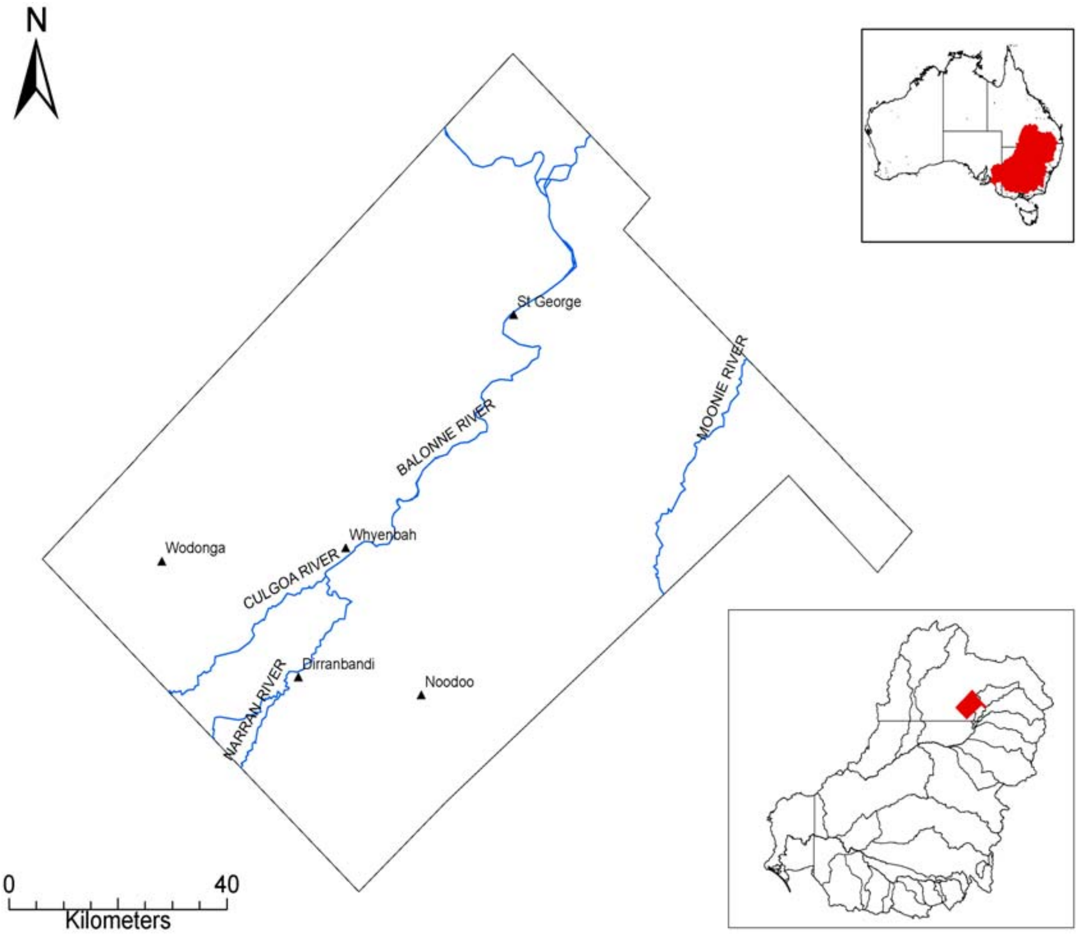

Figure 1. Location and main geographic features of study area. Top right inset shows in red the extent of the Murray Darling basin, of which the Lower Balonne River is a part. The bottom left inset shows in red the extent of the study area with the Murray Darling Basin.

It is our opinion that the entire cover succession, both the units described as Tertiary and as Quaternary (c.f. McAlister 2000), apart from the residual ridge-capping units, are all of Pliocene to Holocene age. The architecture and depositional environment of these sediments which are locally of the order of 200 m in thickness, is the subject of this report.

The previously interpreted Quaternary to Late Tertiary succession consists of red-brown quartz sand, sandy soil, silt, gravel, sand, and clay up to 200 m thick, with a superficial covering of unconsolidated sand, gravel, silt, and clay. The current river systems are recycling sediments from the upper flood plains down onto the fans (Brennan 2001). Unlike the older post-Cretaceous sediments, these have not undergone topographic inversion

2.5 Land Use

Irrigated cotton farms, improved and non-improved pasture for extensive grazing, together with some relict native vegetation are the main land uses of the study area.

3. FLUVIAL ARCHITECTURE

3.1 What is fluvial architecture?

The term "fluvial architecture" is widely used to describe the geometric relationships between the different components of a fluvial sedimentary succession. Architectural elements include features such as the distribution of sands and gravels, representing channel and crevasse-splay deposits, silts and clays which represent flood plain and levee deposits, and other features such as coals and fossil soils. A standard work on the study of fluvial architecture is Miall (1996).

3.2 Why is fluvial architecture important?

There are many types of fluvial systems including braided and meandering channels, alluvial fans and deltas. Each has its own characteristic architecture reflecting the interaction between factors such as gradient, flow, seasonality, vegetation and sediment loading. If these characteristic archiectures can be identified in an ancient fluvial succession these various factors can be reconstructed. It is then possible to deduce much useful information about the ancient sedimentary environment, its dynamics and history, thereby leading to improved management of the natural resources

A fluvial succession consists of many different units often spatially discontinuous. These include channel deposits of sand and gravel, levee bank silts, overbank silts and clays, organic rich deposits and palaeosols (Miall 1992, Reineck and Singh 1980) Fluvial architecture thus provides a description of many features important to hydrogeology including aquifer volumes, the distribution of aquitards, permeability and porosity, aquifer connectivity and recharge potential. Good management requires a knowledge of this features.

4. FLUVIAL ARCHITECTURAL SYSTEMS

4.1 Surface system geometry

Valley fills and plains are predominantly linear to tabular bodies of fluvial sediment. In contrast, fans consist of radial distributaries, typically where a fluvial system debouches from a hilly hinterland onto a plain. Fan morphology is strongly dependent on gradient. Classic alluvial fans are characterised by steep gradients and gravity flow processes (Stanistreet and McCarthy 1993), although fans can also form on slopes of very low relief (e.g. Pain *et al.* 1997). Deltas are also characterised by radial distributary patterns where rivers enter a standing body of water, be it a lake or the ocean. A third morphology is centripetal drainage, such as occurs on the margins of the Eucla Basin (Alley *et al.*1999). However, this type of drainage does not occur in the study area and will not be considered further.

Rivers can consist of either single (straight, meandering) or multi-channel (meandering, anastomosing, braided, anabranching) systems (Friend 1983) (Figure 2). These morphologies can occur in fans, valley and plain deposits, and in deltas. Straight channels are rare, generally exist over short distances (Reineck and Singh 1980), and occur in rivers that transport sediment as bed load, mixed load, or suspended load.

Meandering channels are found on low gradient slopes and are dominated by finer–grained sediments (typically sands and silts). Sediment is transported either as a mixed load (bed and suspended), or as predominantly suspended load. Vegetation stabilising the banks can prevent the development of multiple channels (Miall 1992, Reineck and Singh 1980). Most meandering channels migrate laterally, forming meander belts of sand rich sediments surrounded by flood plain deposits of silts and clays. Meander belts in the sub surface consist of single cycle upward fining sand bodies with thickness to width to ratios of 1:100 (Payenberg and Reilly 2003). Lateral correlation between sand bodies formed as a result of channel migration is not as high as with braided systems.

Anastomosing channels develop on very low gradient slopes, are typically low in overall sand content and rich in fine-grained sediments. Unlike meandering and braided channel systems where there is often active channel migration, anastomosing channel systems are often stable and fixed in position (Miall 1992, Gibling *et al.* 1998). Very low gradient fans are characterised by anastomosing streams, for example the Okavango Fan of Africa (Stanistreet and McCarthy 1993), and include the largest subaerial fans known. Many Australian examples are known, including those along the shores of the Gulf of Carpentaria (Pain *et al.* 1997), but are poorly documented. In the sub surface anastomosing channels are characterised by multi-cycle upward fining and often mud-rich channel fills (Makaske 2001). Because the channels are fixed, lateral correlation is difficult to make in the subsurface between sand bodies. Makaske (2001) notes that thickness to width ratios of channel sands are typically of the order of 1:10 in anastomosing rivers, although crevasse splay deposits are thinner and more extensive. Sediment transport in anastomosing channels occurs predominantly through suspended load.

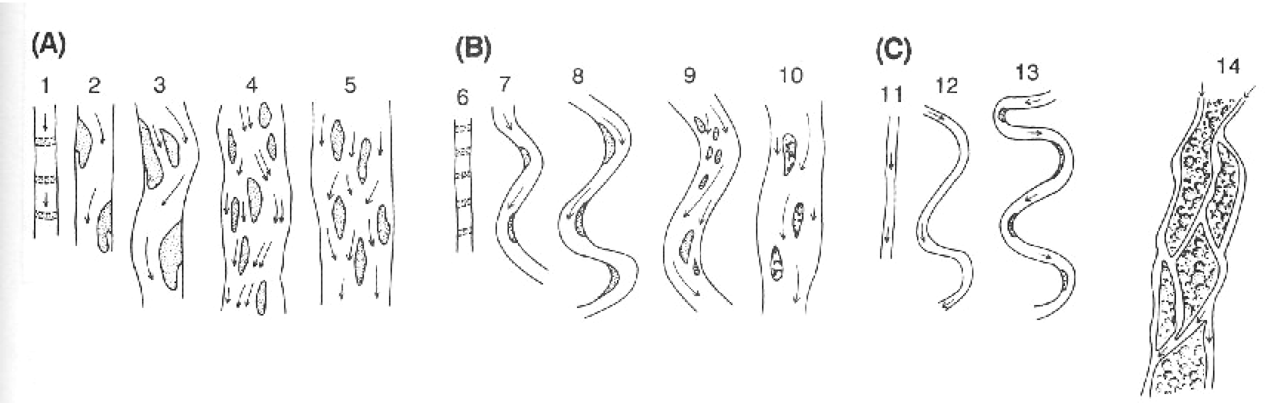

Figure 2. Fluvial channel styles (after Miall 1992). Examples include straight (1, 2, 3, 6, 11), meandering (7, 8, 12, 13), braided (3, 4, 5, 9, 10), and anastomosing (14). Those under (A) are bedload rivers, under (B) mixed load rivers, and (C) suspended load.

Braided channels have numerous channels and bars, the latter representing temporary sediment storage during transport downstream. Braided channels are formed by high sediment loads, especially high base loads, and highly variable discharge. Braided channels are thus common in areas of strongly seasonal and /or episodic precipitation and with poorly stabilised banks. Sediments are typically coarse, being either sand or gravel dominated, with silt and clay deposits a small component. A typical sequence consists of sand and gravel bodies in fining upward cycles with thickness to width ratios of 1:500 (Payenberg and Reilly 2003). Examples are found in arid zones, glacial outwash plains and rivers draining mountainous terrain (Miall 1992). Braided channels form one variant of alluvial fans, especially those of moderate gradients, such as the Sun Kosi Fan in India (Stanistreet and McCarthy 1993). Although individual sand bodies may be difficult to correlate laterally in the subsurface, aggregate sand bodies should show good correlation. Braided channels carry sediment either as bed or mixed load.

4.2 Aggradational styles

Rate and degree of aggradation plays an important role in determining the architecture of a river channel. Not only does the degree of aggradation determine the volume of sediments, it also determines the basic architecture and sand-silt-clay ratios. When aggregation is low, laterally migrating rivers can erode their own overbank deposits, resulting in preservation of relatively sand rich deposits. In contrast, fixed-channel rivers aggrade vertically, resulting in relatively low volumes of sandy sediment which occur in vertical columns of channel sediment surrounded on both sides by flood plain clays and silts.

Fixed channels are generally associated with rivers that have been artificially constrained by levee construction and canalisation. However, Australian research has documented extensive fixed channel aggradation in Holocene meandering rivers along the New South Wales south coast (Nanson and Young 1981), Quaternary anastomosing rivers in the Queensland channel country (Gibling *et al.* 1998), and Eocene palaeovalley fills in Western Australia (Igoe 1998). In these cases, correlation in the sub surface between sand bodies is difficult to achieve, even with closely spaced drilling. This is quite different from classic fluvial architecture models in which meandering and braided systems are assumed to undergo extensive lateral migration, allowing correlation between sand bodies even in widely spaced drilling.

4.3 Reconstructing subsurface architecture

A range of geophysical techniques can provide data about the fluvial architecture of shallow sedimentary systems. These include ground penetrating radar and shallow seismic investigations which image the architecture directly, and magnetics and Airborne Electro Magnetics (AEM) which provide imaging of the horizontal distribution of geophysical units. AEM can also provide sequential 2-D depth-slice information allowing reconstruction of 3-D architecture under favourable conditions.

Drilling, such as percussion, air-core and diamond coring provides unparalleled resolution of subsurface stratigraphy and lithology. However, inappropriate spacing of drilling can impose a serious limitation on the quality of the data and the confidence that can be placed on correlation of units between holes. Use of palynology and the comparison of pore fluid hydrochemistries can increase confidence in correlations.

5. INTERPRETATION OF DATA USED IN THE STUDY AREA

5.1 Interpretation of the Dirranbandi Palaeovalley

The existence of a deep palaeovalley beneath the Balonne floodplain with a succession of 200 m or more of Cainozoic sediments has been known for several decades. Earlier reports regarded this succession as being Cainozoic (Senior 1970), and deposited in a Mesozoic downwarp (Exon 1976). Radke *et al.*(2000) regarded the orientation of the Balonne River as following a previously existing structural feature in the Mesozoic or older basement, based on the coincidence of the main river orientation with magnetic linears to the northeast and southwest. This assumption is reasonable given the known antiquity of many aspects of the Australian landscape and its sedimentary cover. The sediments filling the trough were equated by Exon with the Tertiary Chinchilla In this report we use the informal term Dirranbandi palaeovalley for this trough because we believe that this better describes its origin and infill.

Palynological dating of sediments from the area (Macphail 2003, and written communications) showed that the succession, to at least a depth of ~100 m, and possibly to at least 150 m, is Early Pleistocene to Pliocene in age. The absence of any obvious breaks in the fluvial architecture suggests that the entire succession is no older that Pliocene and is essentially continuous through to the Holocene. This is consistent with the Pliocene age for the base of the Cainozoic sediments of the upper Darling Basin in New South Wales (Taylor 1978). Macphail (2003) also showed that the Plio-Pleistocene sediments were deposited under somewhat wetter conditions than present, based on the plant species present.

Because the area is currently undergoing deposition from active river systems, the current depositional geomorphology can shed some light on the possible subsurface architecture, assuming there is a continuity between the surface and subsurface. The Balonne River (Thoms and Sheldon 2002) downstream of St. George is dominated by anastomosing architecture (compared to upstream where it is anabranching). The continuity of this pattern into the subsurface is highly likely.

The AEM data successfully delineates the boundaries of the Dirranbandi Palaeovalley and its tributary valleys (see section 6). However, it does not show a great deal of detail of the internal architecture of the sediment package.

5.2 AEM data

AEM provides the bulk of the geophysical data for the LBAGP area. AEM data were processed as a series of depth slices using a Layered Earth Inversion (LEI) (Lane, *et al.*, 2003). This data can be divided into three vertical aggregate layers, each with a distinct fabric in the AEM depth slices (Table 1). Although there is inevitable averaging of the distribution of different conductivity units (interpreted as representing regolith architectural units) within each of these aggregate slices, there is good average consistency within them, at least at the 1:250,000 scale.

Table 1. Depth slices from AEM data

AEM layer (metres)	Aggregate layers (metres)	Interpretation
0-5 5-10 10-15	0-15	Fabric of this aggregate layer is dominated by surface architecture, including areas of shallow bedrock and the sediments of the Balonne Fan and Maranoa surface. Pattern closely resembles that of GRS and RLU mapping (Stage 4 of fill)
15-20 20-30 30-40	15-40	Fabric of this aggregate layer is dominated by broad valley fills in central and north eastern regions; broad valleys separated by bedrock highs; and first and second order dendritic valley fills in shallow bedrock areas (Stage 3 of fill)
40-60 60-80 80-160	40-160	Fabric of this aggregate layer is dominated by deeply incised trunk valleys and the Dirranbandi Palaeovalley (Stage 2 fill)

The 40-160 m and 15-40 m aggregate layers are the focus of detailed interpretation because of the presence of distinct architectural elements. The 0-15 m aggregate layer was not studied in detail because of its similarity to the surface features which are described in Kernich *et al.* (2003). Particularly noteworthy in this architecture is the fabric discordance between the different aggregate layers. The basins and deeply incised valley fills in the 15-40 m aggregate layer have not been obviously reflected in the fabric of the 15-40 m aggregate layer. Also, the broad valley filling fluvial systems of the 15-40 m aggregate layer are not reflected in the inset fan systems of the 0-15 m aggregate layer.

5.3 Well data

There is a vast body of data on the subsurface of the project area obtained from water and stratigraphic bores drilled since 1919. Lithological and gamma logs provide the bulk of information from this drilling. Very detailed logging of diamond cores obtained by BRS is a very important source of detailed data (Payenburg and Reilly 2003). Most holes in the study area are irregularly and widely spaced. Distances between holes are between two and four km. This distance provides a constraint on the correlatable stratigraphy between holes, so does the nature of sand body architectural elements (see section 5.5)

5.4 Architectural terminology

It is critical that a correct and consistent terminology be used in describing the architectural relationships of regolith and sedimentary units in the project area. Informal usage over the years has evolved a terminology that recognises a regolith architecture that consists of an upper and lower mottled zone, separated by bleached zone, overlying “marginal marine” Cretaceous (e.g. Kellett and Mullen 2003 and Pearce *et al.* 2004).

Difficulties with this terminology arise from the unclear division between architecture, lithostratigraphy, weathering profiles, and depositional environment, confusing terminology and hampering understanding. For example, terms such as “mottled zone” and “bleached” zone refer to weathering overprints which can occur on any lithology or stratigraphic units. They are not stratigraphic units, although they are treated as such. In the same way “marginal marine” is an interpretation of the depositional environment. It is not a lithostratigraphic unit, nor is the marginal marine depositional character of the Griman Creek (or any other formation) obliterated by later weathering.

In the same way, caution should be exercised when extrapolating features from exposures 750 km distant (for example, those documented by Senior and Mabbutt 1979, and Irdum and Senior 1978) to the St. George area. Weathering zones are not stratigraphic units (Pain and Ollier 1996) and nor should they be correlated over 100's of km. In addition weathering profiles do not always fit easily into pre-existing subdivisions, for example the profiles of senior and Mabbutt (1979) do not fit the stratigraphic terms of Kellett and Mullin (2003) or Pearce *et al* (2004). In the St. George area it is clear from drilling that adjacent drill holes do always not have this weathering stratigraphy (see Appendix 1) and the actual weathering profiles in individual holes do not match the traditional scheme (Appendix 2). Furthermore, many of the zones cross cut each other. For example, unpublished data of Ben Maly (2003, written communication) revealed that silicification in the St. George area can variably overprint all weathering types, not just the "upper mottled zone" and at all depths (see Appendix 2), eliminating a criterion for differentiating the upper and lower mottled zones.

Therefore this report uses the approach shown in Table 2 to avoid these difficulties. We believe this approach is more descriptive and less genetic than current usage.

Table 2. Architectural Terminology of the project area

Lithology	Weathering	Regolith architecture	Lithostratigraphy	Biostratigraphy	Depositional environment
Semi-consolidated sands, clays, gravels, lignites, etc.	Variably weathered	Cover	Younger sediments	Late Neogene	Non marine
Indurated siltstone, minor sandstone, glauconitic when fresh	Variably leached, ferruginised, & silicified beneath modern land surface & cover. Unweathered at depth & beneath Dirranbandi Palaeovalley	Weathered bedrock	Griman Creek Formation	Cretaceous	Marginal marine to marine
		Fresh bedrock			

5.5 Fluvial architecture

As noted in an earlier section (4.1), the nature of the fluvial architecture, whether the sand bodies were deposited in a meandering, braided, or anastomosing system, is of critical importance to understanding the distribution and connectivity of the sand bodies and how the sand bodies might be connected (Table 3). For example, meandering streams typically consist of single cycle sand bodies with thickness to width ratios of 1: 100, therefore a 10 m sand body should be correlatable between holes up to one km apart. If such correlation is not possible, then the sand bodies are likely to be from an anastomosing system, which have thickness to width rations of 1:10. Braided stream sand bodies can be correlated for distances of ~500 times their thickness. Anastomosing units are polycyclic, but are generally only 10 times wider than thick. Most sand bodies (see Appendix 1) in the area consist of polycyclic channel sands with poor correlation between holes, suggesting anastomosing architecture with some braided units. The width to thickness ratios in Table 3 also suggest that isolated sand bodies found in drill holes several km apart are unlikely to be correlates.

Table 3. Sand unit thickness likely to create connectable stratigraphy between holes (ratios after after Payenberg and Reilly 2004, and Makaske 2000)

Hole spacing	Meandering thickness (1:100 thickness: width ratio)	Braided thickness (1:500 thickness: width ratio)	Anastomosing thickness (1:10 thickness: width ratio)
1 km	10 m	2 m	100 m
2km	20 m	4 m	200 m
4 km	40 m	8 m	------
10 km	100 m	20 m	------

There are several ways at determining the width of sub surface sand bodies. The modern record (Kernich *et al.* 2003) shows that the ribbon sands associated with contemporary and recent channels on the Balonne fan are all 1-2 km wide. Some of the older surfaces (i.e. the Maranoa) have wider sand bodies but even these are less than 5 km. Sub surface sand bodies may be of similar width.

The sand bodies in the drill and gamma logs shows that both single and multi-cycle sand bodies consist of predominantly upward fining cycles ranging from 1-11 m thick, with an average thickness of 2.1 m, this giving a typical channel depth during deposition. Theoretical studies of width to thickness ratios of individual channel bodies show that these vary considerably (Fielding and Crane 1987), with the upper limit for unconfined (i.e. braided) streams having a width = 513 X depth$^{1..35}$. With the average channel being 2.1 m deep and the maximum 11 m, this gives an average channel width of 1396 m and a maximum of 13061 m. Meandering and anastomosing channels are narrower, following the lower and upper relationships of 0.95 X depth$^{2.07}$ and 64.6 X depth$^{1.54}$, high sinuosity streams with channels depths of 2.1 m and 11 m would have widths of between 4.4 and 136 m and 203 and 2594 m, respectively.

Thirdly, the total sand body thickness to width ratio can be used, using the ratios of Payenberg and Reilly (2004) for meandering and braided systems and of Makaske (2001) for anastomosing systems. Out of a subset of 100 sand units identified from drill logs, 35 consisted of multi-cycle sand bodies the range was 2 m to 20 m, with the average being 7.6 m. This suggests sand body widths of the order of 20-200 m for anastomosing systems 200-2000 m for meandering systems, and 1000-10000 m for braided systems, with average widths of 76, 760 and 3800 m respectively. This is consistent with what is seen in the contemporary landscape.

These data all point towards the fluvial architecture being characterised by a mixed channel style, with the single cycle beds pointing towards meandering or anastomosing systems and the multi-cycle beds towards braided or anastomosing systems. The fact that only a few areas show good correlation between holes over distances greater than a few km indicate that braided systems are rare. Sand bodies are mostly a few 100 m to a few km in width, rarely more.

6. RESULTS

6.1 0-15 m Aggregate layer

Most of the fabric visible in the AEM LEI slices of this aggregate layer corresponds closely to what can be seen in the ternary radiometrics image (Figure 3 andFigure **4**). The most obvious features are the two areas of very shallow high conductivity. One is in the north east of the study area and correlates with the Goondoola Basin (see Wilkinson 2003). The other lies to the south and occurs in an area of sodic and/or saline soils and shallow groundwater (probably perched) discharge along the edge of the Maranoa surface, referred to in some older reports as the Maranoa Fan. With the exception of the Goondoola basin, these conductive areas appear to lie above the regional water table. The conductivity highs along the edge of the Maranoa surface appear to be associated with localised perched water tables associated with clay horizons and overlying gypsum-rich soils. These are located well above the regional water table (typically 20-40 m below surface). Areas of very shallow or exposed bedrock are revealed by moderate conductivity. The Maranoa surface (sometimes known as the Maranoa fan) and Balonne-Moonie fans can be distinguished by subtle changes in conductivity. Several highly resistive areas are also present. One of these, on the Maranoa surface, correlates well with a large surface sand body. Others, smaller bodies on the Maranoa, Balonne, and Moonie fans show similar correspondence to channels sands of the modern Moonie and Balonne rivers.

A significant variation to the fabric is the presence of an interpreted dendritic drainage pattern in the northern part of the study area where there is exposed or shallowly buried bed rock. The headwaters of these drainages occur in the modern hills and extend out into the subsurface. The pattern is defined by areas of low conductivity, and, where occurring under cover, is not reflected by the contemporary surface drainage. The sedimentary fill of this palaeodrainage network need not be coarse grained and, in such a low relief setting, is dominated by clays and silts. Nor does an apparently strong AEM pattern indicate great thickness. Sandy body widths are unlikely to be more than a few km, and are generally less, as shown by the pattern of resistive units in Figure 4 that are thought to follow the shoe string channel sands. As the sediments of this aggregate layer occur above the water table the sand bodies provide mainly vertical flow down through the shoestring sand bodies to the unconfined water table. This is supported by the vertical extent of highly resistive units beneath the channels visible in the AEM sections in Appendix 1. The relatively high thickness of the sediments, their poor lateral connectivity and their good down channel connectivity results in a strongly anisotropic character to the water flow patterns.

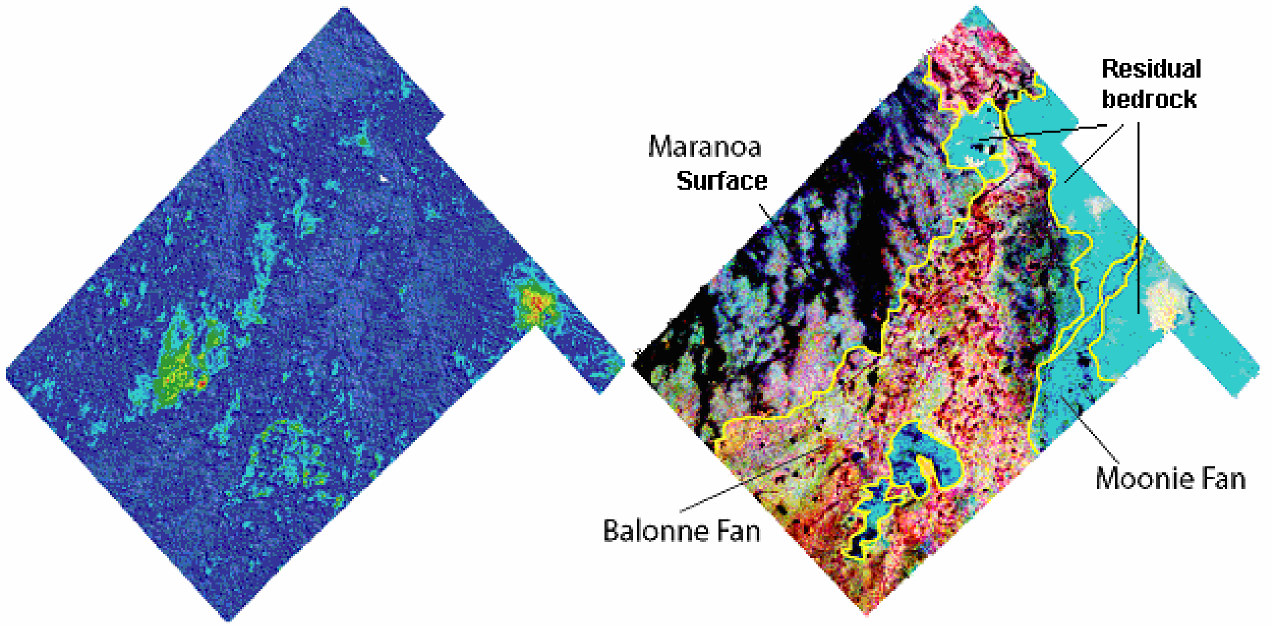

Figure 3. Comparison of representative (0-5 m) LEI of the 0-15 m aggregate layer, (left) with airborne radiometrics image, (right).

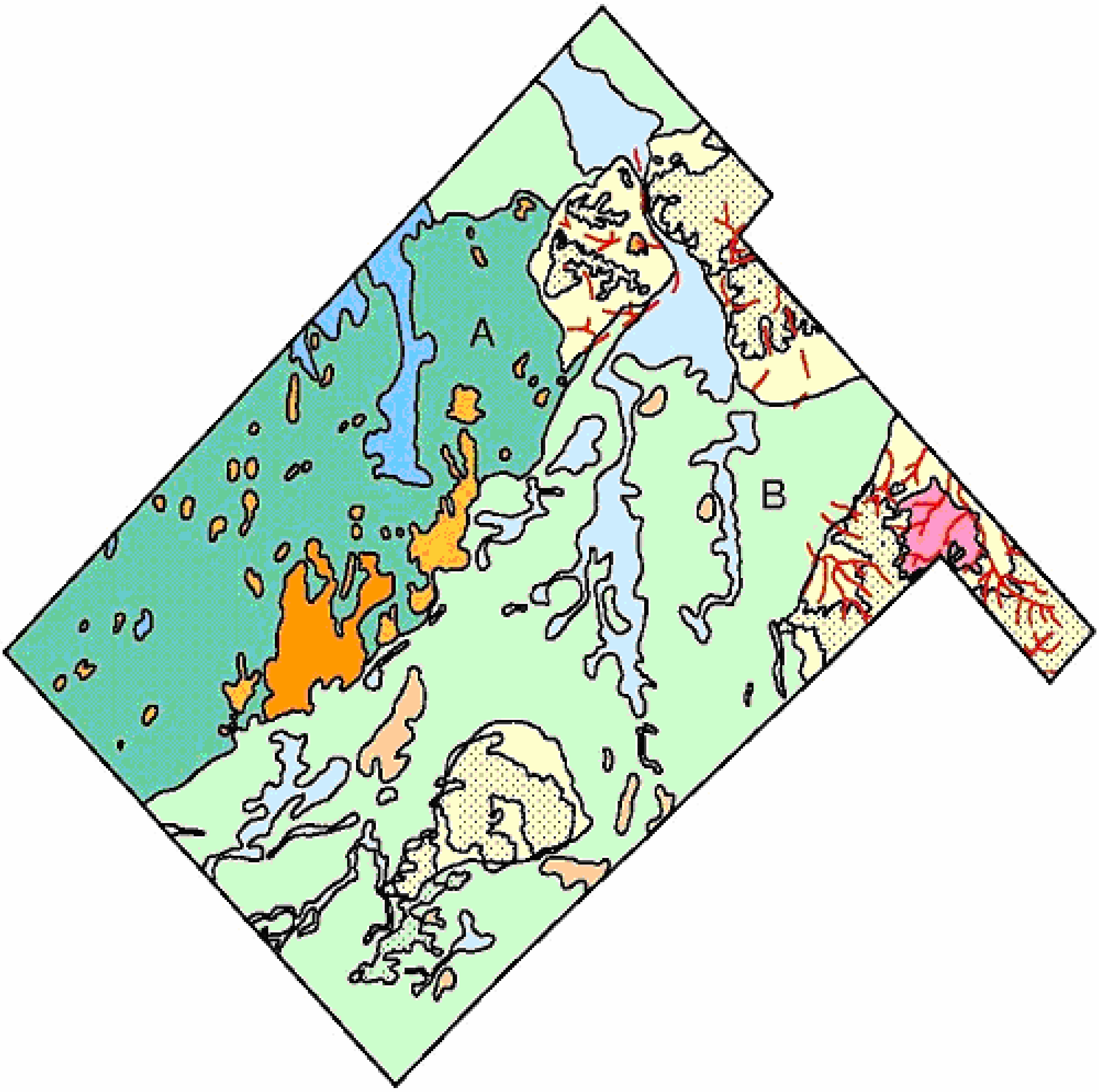

Figure 4. Interpreted architecture of 0-15 m aggregate layer. A Maranoa surface (dark orange = highly conductive areas, orange = moderately conductive areas, dark green = slightly resistive areas, blue = resistive areas). B, Balonne and Moonie Fans (orange = conductive areas, light green = slightly resistive areas, blue = resistive areas). Yellow = conductive bed rock, pink = Goondoola discharge area, stipples = hills, red dendritic pattern = inferred palaeodrainage network. A larger 1: 250 000 scale version can be found in Appendix 3.

6.2 The 15-40 m aggregate layer

The fabric of this aggregate layer (Figure 5) is characterised by four areas of relatively high conductivity, separated by areas of lower conductivity. The higher conductivity areas are interpreted as areas of weathered bedrock or bedrock, while the low conductivity areas are interpreted as thick sedimentary fill. There are three main areas of sedimentary deposition, a western area (palaeo-Maranoa), a central-northern area (palaeo-Balonne), and an eastern area (palaeo-Moonie).

The palaeo-Maranoa is characterised by very poor correlation between drill holes. The holes in this area are well spaced and the sand thickness typically 10-20 m. The sands provide the main aquifers, including the unconfined aquifer which occurs in this interval, while the surrounding clays and silts the aquacludes. Given the relationship between thickness and correlation (Table 2) it is likely that the channel types in this system are either meandering or anastomosing. Thus connectivity is likely to be poor laterally but good along the length of the channel.

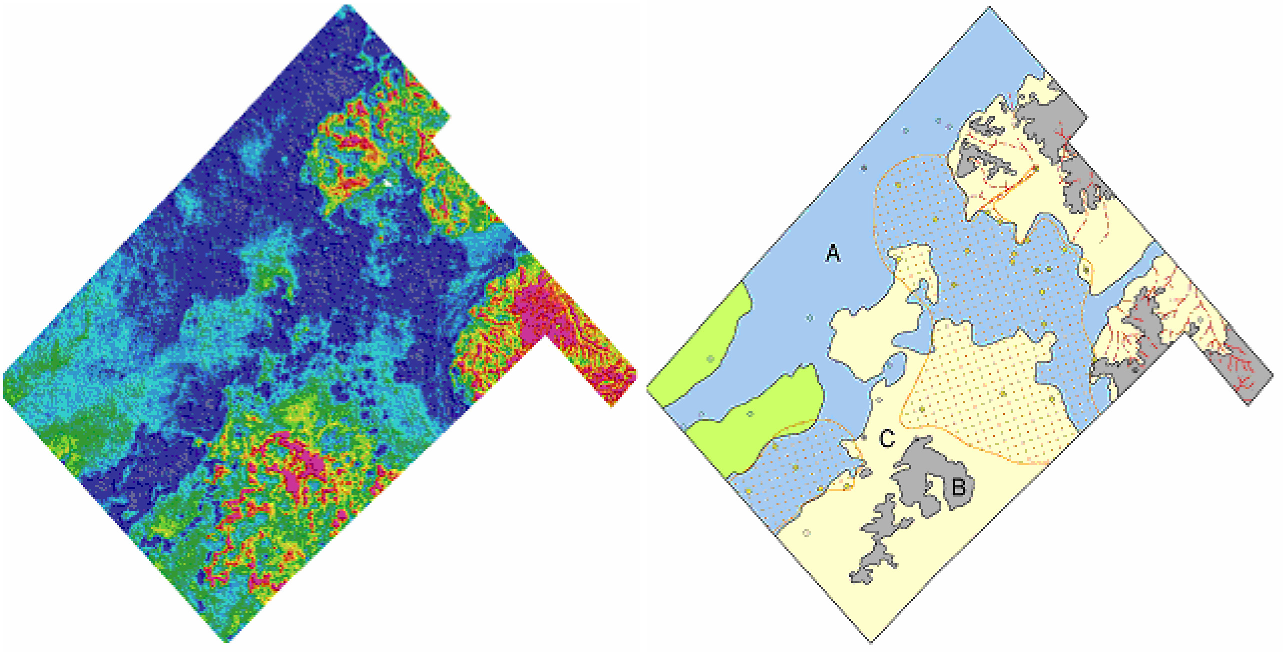

Figure 5. Architecture of the 15-40 m aggregate layer. Representative 20-30 m LEI slice (left). Interpretation (right): A. sediments covering both relatively shallow bedrock >40 m below surface and thicker palaeovalley fill successions (resistive). B. Weathered bedrock beneath extant hills. C. Areas of weathered bedrock (conductive) within 40 m of surface. Red lines are interpreted drainage networks in surface and sub surface. Orange stipple represents interpreted extent of shallow (between 0 and 40 m) more or less continuous braid plain sands (from drilling). Green areas are relatively conductive sediments. A more detailed version of the interpreted architecture (1:250,000 scale) can be found in Appendix 4.

The exception to this is the areas to the north and south of the Noondoo Rises. These areas are characterised by thick, shallower sand units often 10 or more metres thick (Figure 5). Drilling has a relatively close spacing and good correlation between holes over distances of several km is evident. The multi-cycle nature of the sands points towards a braided channel system. Thick sands come to the surface along the southern margin of the palaeo-Balonne. The braided channel sands in the southern area do not have any surface expression. The sand sheet extends over 10's of km and is typically 20 m thick. The sand units of this aggregate layer, onlap the buried valley shoulders, providing the unconfined "upper aquifer" of McAlister (2000). The thick sand units between active and relict channels beneath the Moonie and Balonne fans provide the mostly likely recharge pathways for the upper aquifer.

A dendritic pattern is preserved in the AEM data in the higher elevation areas. These occur beneath the valley filling sediments, and are probably related to zones of deeper weathering beneath the old valleys systems. There is no evidence what so ever for palaeovalley filling sediments at this depth. The weathering nature of this pattern is reinforced by the fact that in this aggregate layer they are defined by high conductivity, more consistent with weathered rock (because of contained iron oxides and salts), than the low conductivity sediments found near the surface.

Also evident in Figure 5 is an area of moderately conductive sediment within the fill of the Dirranbandi Palaeovalley (see also Appendix 1 line 18). This occurs at some depth beneath the surface (20-80 m) is too deep to be a shallow salt store (as seen in 0-15 m aggregate layer) and it also extends beneath the water table. The most likely cause of the conductivity anomaly is a zone of conductive material in the sedimentary fill.

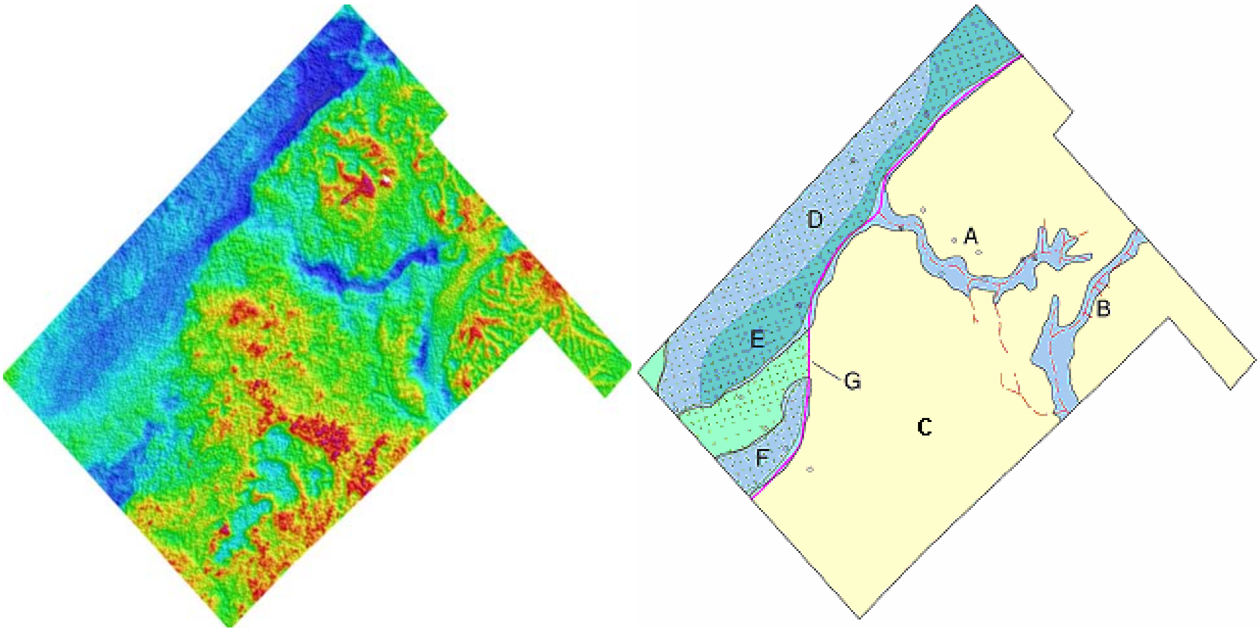

Figure 6. Architecture of the 40-160 m aggregate layer: representative 60-80 m LEI slice (left). Interpretation (right) A. Sediments filling incised valley. B Sediments filling incised palaeo-Moonie. Bedrock (variably weathered). D and E Thick sediments filling sub compartments of Dirranbandi Palaeovalley. F Resistive lobe (possibly from low salinity water in channel sands) within Dirranbandi Palaeovalley. G. Possible fault in underlying bedrock defining eastern margin of Dirranbandi Palaeovalley (purple line show sag along fault lines, not necessarily offset). Red lines are interpreted palaeodrainage systems. Yellow areas shallow conductive weathered bedrock at depth of <40 m. Blue areas are highly resistive thick sediments. Green areas are more conductive zones within the sediment fill. A more detailed version of the interpreted architecture (1:250,000 scale) can be found in Appendix 5.

6.3 40-160 m aggregate layer

The fabric in the AEM LEI slice of this aggregate layer (Figure 6) is dominated to the west by the Dirranbandi Palaeovalley and to the east by the incised valley systems of the palaeo-Balonne and palaeo-Moonie. The sediments of the Dirranbandi Palaeovalley and its tributary incised valleys are characterised by relatively low conductivity. The AEM signature of the interpreted incised valleys suggests that they are up to 160 m deep.

Drilling results in the Dirranbandi Palaeovalley indicates up to 200 m of sediment is present. Information on the fluvial architecture of the Dirranbandi Palaeovalley in the study area is very sparse, but the sections drawn further west by McAlister (2000) show poor correlation between drill holes, pointing towards an anastomosing channel style. The sand units are the main aquifers as in the previous aggregate layer, these show good connectivity parallel with the palaeovalley axis but poor laterally. The architecture of the sediments in the tributary palaeovalleys is much less understood as they have been penetrated by only a few holes.

The sand units of this aggregate layer, enclosed within the incised and buried palaeovalleys, provide the confined "lower aquifer" of McAlister (2000). Palynological data of Macphail (2003) shows that these sediments are derived by erosion of the Mesozoic in headwaters of the drainage basin. This suggests that sedimentary units of this aggregate layer extend well upstream into the catchment allowing recharge at higher elevations, explaining the subartesian nature of the "lower" aquifer.

Figure 7 NW – SE section showing change from an anastomosing to braidplain channel morphology. Inset – location of section within lower Balonne study area. Insert shows location of drill holes on section and others referred to in the text.

7. DISCUSSION

7.1 Bounding surfaces

The different aggregate layers represent major reorganisations in the horizontal fluvial architecture. However they are not accompanied by major incision. Therefore they are not driven by base level changes or tectonics. The 15-40 and 40-160 m transition coincides with of the incised valleys and the change to less confined sedimentation across the weathered surface. We suggest that this transition is due to the change from a depositional environment constrained by the palaeovalley margins to an largely unconstrained aggradational plain. The transition between the aggregate layers represents a change in fluvial architecture, possibly driven by the decrease in rainfall suggested by the palynology (Macphail 2003) of approximately 50% since the early Pleistocene. However, it may simply represent an autochthonous rather than an allochthonous change in the sedimentary dynamics, with changes in flow in the distributary fan systems (c.f. Miall 1996).

7.2 Sedimentary dynamics

Four types of depositional system predominate in the fluvial architecture of the study area. These are;

1) Incised valley fills. These are present in the deeper parts of the palaeo-Balonne and palaeo-Moonie systems. The detailed architecture, as noted previously, is not known.

2) Laterally extensive braided valley fills. These are characteristic of the higher parts of the palaeo-Balonne and palaeo-Moonie systems, stratigraphically above the incised valleys. They also occur stratigraphically higher in the section of the small sub-basin fill in the southern part of the study area.

3) Anastomosing or meandering valley fill in the Dirranbandi Palaeovalley and the southern sub-basin (some braided units may be present) and.

4) Anastomosing fan of the Maranoa system (some braided units may be present).

7.3 Sedimentary and Tectonic history

Palynology results suggest that the oldest sediments in the Dirranbandi Palaeovalley date from the Pliocene. This indicates 200 m of aggradation over the past 5 million years. This is high by Australian standards (for example, compared with 100 m of aggradation in 36 million years in Western Australian palaeovalley fill beneath salt lakes), and appears to be the result of neotectonics of the region, whether in the basin or the highland source areas in unknown. However, this equates to only 4 mm every 100 years, still relatively low by global standards.

7.4 Correlation of sand units

There is a tendency in the analysis of sparsely drilled Cainozoic fluvial sediments in inland Australian basins to over-correlate lithological units. This is shown in Figure 8, which compares the lateral correlations of sand units by NRM&E (Pearce *et al.* 2004) with the likely extent of anastomosing, braided, and meandering sand units. This illustration shows that sand bodies, even those deposited in systems with the greatest lateral extent relative to their thickness, are only rarely likely to appear in adjacent drill holes.

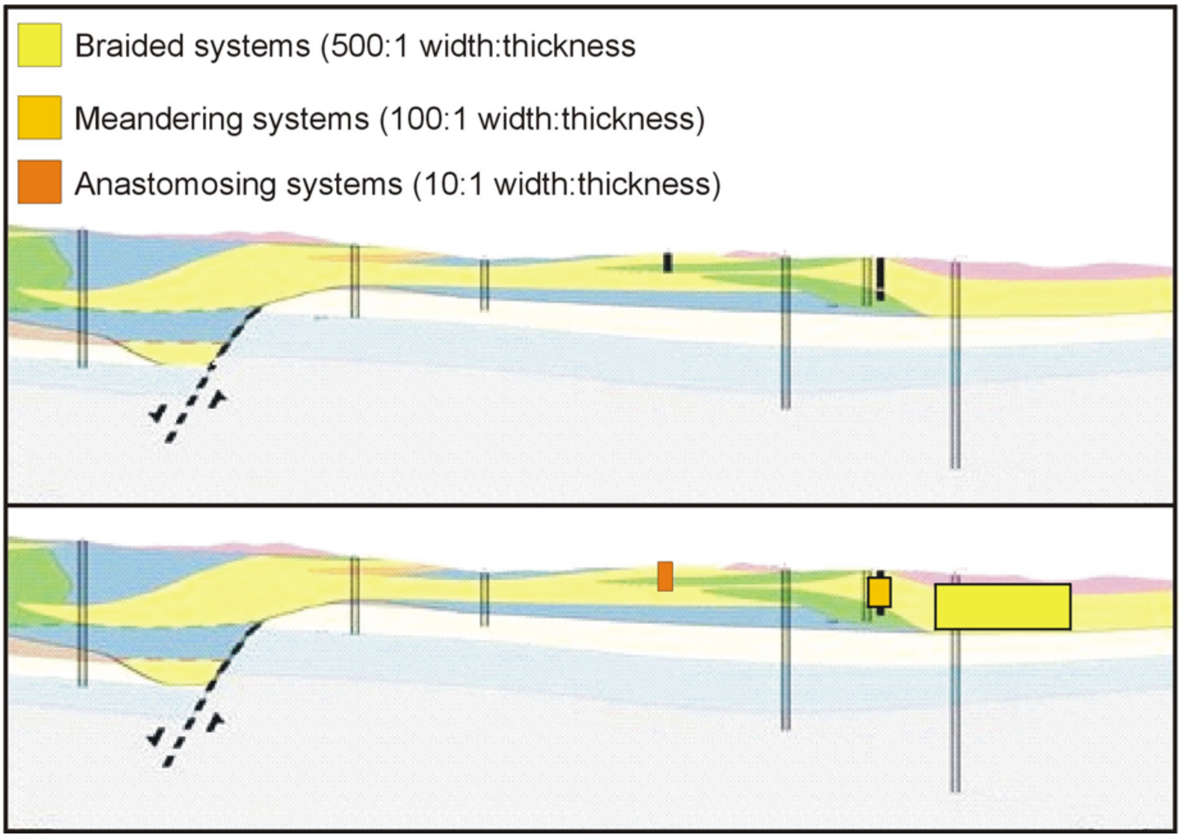

Figure 8. Comparison between previously interpreted lateral extent of sand bodies by Pearce *et al.* (2004) (top) with likely thicknesses of sand bodies deposited by fluvial systems of different architectures, cross section 9. Fault interpreted, Dirranbandi Palaeovalley may follow sag, rather than fault offset. See Appendix 1 for all interpreted sections using the more restrictive models of sand body geometry.

7.5 Hydrogeology

Depth to sand provides one indication of the recharge potential. Out of 56 holes, the depth varied from zero to 37 m, with the average depth being 5.4 m. Areas with less than this thickness of sediment over sand will have above average recharge, although, because of the clay dominated nature of the flood plain sediments, this will be still low except where sands intersect the surface. However, depth to sand should not be used in isolation, other factors are also important in the development of overall recharge potential, especially geomorphic context.

Of even greater importance is the fact that while only 18 out of 76 holes in the study area (24%) contain thick (more than 2 m) of sand, 50% of holes (5 out of 10) in the entire area described by Pearce *et al.* (2004) drilled into the main channels of the Balonne and Moonie rivers are immediately underlain by sand. As many of the holes starting in sand in the overall data set is likely to be in abandoned channels on the Balonne and Moonie fans, it is likely that most near surface thick sand bodies are associated with channels. Therefore much of the recharge to the unconfined water aquifer is going to occur preferentially via active or abandoned modern channels at the surface.

The three dominant styles of fluvial architecture present in the area (valley fill, braided, and anastomosing) have major implications for the hydrogeological properties of the sand bodies. Because the incised valley fills are narrow they probably have good lateral and excellent down channel hydraulic conductivity. Flow is likely to be comparatively focussed. Sand bodies are likely to show good connectivity, but the size of the aquifers is likely to be small, because of their constrained nature. The incised valley aquifers are deeply buried, meaning recharge is problematic. Several possibilities exist for recharge patterns. These include: lateral flow of water from the dendritic valleys in the hills and adjacent areas, advection from overlying sand units into the deeper sand bodies and flow out of saprolite along the palaeovalley margins into the sand bodies themselves. The presence of sub-artesian pressures in the deeper sand aquifers (McAlister 2000) suggests that advection from shallower sand units is not likely, however. Similarly, slug tests by BRS of the various hydrogeological units indicate that there is very little recharge of the cover sediments from the surrounding saprolites (Pearce, Wilkinson, pers. comm.)

The braided systems (mostly the upper part of the southern sub basin and the palaeo-Balonne and palaeo-Moonie sections, with a few small sections of the Dirranbandi Palaeovalley) will show good, though not excellent lateral hydraulic conductivity and connectivity. Conductivity and connectivity may be reduced because of the complex nature of sand bodies in braided systems that often contain thin silt or clay rich units that compartmentalise the overall system into smaller units. Overall aquifer volume will be high, because of the thick and laterally extensive nature of the braided sand units.

The anastomosing units include those flowing along the axis of the Dirranbandi Palaeovalley and those beneath the Maranoa surface. As anastomosing channels rarely migrate, there is little lateral connectivity and low lateral hydraulic conductivity between the major sand bodies, however longitudinal connectivity and hydraulic conductivity will be high (Figure 9). One complication is that although lateral extent of thick channel sand bodies is low in anastomosing systems, thin (less than 1 m thick) crevasse splay sands can extend over many km, connecting otherwise separate sand bodies. These sand sheets will be so thin they are unlikely to be recognised in RAB or RC holes and will be seen only in core. Volume of aquifers as a proportion of overall sediment volume will be low, because of the mud-rich nature of anastomosing fluvial systems. Recharge is only likely to occur from the surface or where sand bodies are close to the surface.

In all of these systems, recharge is likely to occur by two mechanisms. Firstly: direct infiltration can occur where the sand is at or very close to the surface. This is mainly along the southern margin of the palaeo-Moonie and palaeo-Balonne systems, along the northern edge of the Noondoo Rises. The second can occur where sands are relatively close to the surface (<5 m) and flood waters can flow down deeply cracked clay-rich sediments of flood plains (Galloway *et al.* 1974) and intersect sand aquifers in the subsurface.

Some unexpected features of the fluvial architecture are that, despite the major changes in palaeogeography, some sand bodies continue throughout the sedimentary succession, for example in hole RN 49199 (Figure 7), which has essentially continuous sand (with minor interbedded clay) from 15 to 100 m. This is a minimum thickness because the hole bottomed in transported cover. Another example is provided by hole RN 42220139 (also Figure 7), where sand extends from 5 to 50 m. This thick sand unit cannot be easily correlated with sands of similar thickness in nearby holes, supporting the anatastomosing model which predicts such thick but narrow sand bodies. The hydrogeological implications of sand units of such geometry is that they facilitate vertical movements by rising or descending groundwater. Given the fact that the modern river channels are underlain by often thick bodies of sand, it is likely that most recharge of the upper, confined, aquifer, occurs through them.

Percentage of sand and gravel units in the holes gives an indication of the aquifer potential of that hole. It also gives an indication of the likely architecture, with braided systems being sand-rich and meandering or anastomosing being sand-poor. Out of a subtotal of 56 holes, the average sand content was 22.5%, and varied from zero to 78%. This suggests that the architecture is predominantly clay-silt dominant and anastomosing, with some braided units. The relatively small percentage of sand in the succession supports the prediction of poor aquifer connectivity. Theoretical studies of Allen (1978) showed that at least 50% sand was required in a succession to achieve high connectivity levels.

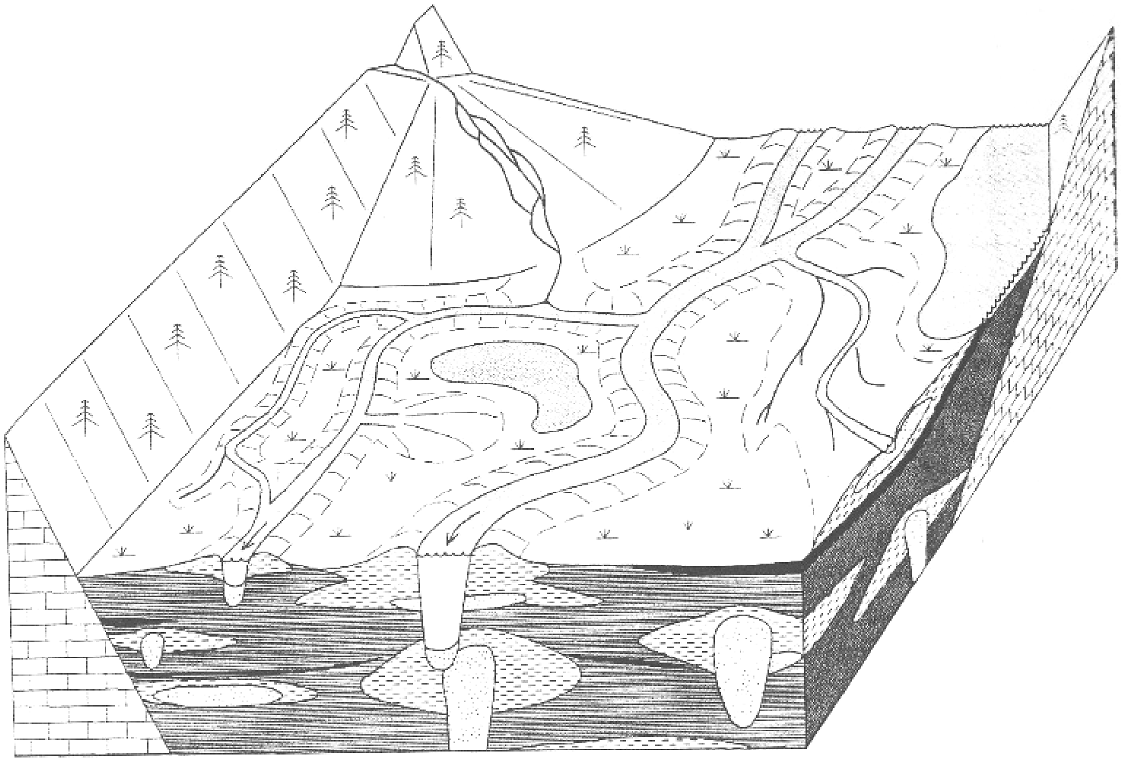

Figure 9. Schematic fluvial architecture of anastomosing systems (from Makaske 2001). Dark shading = organic rich sediment (swamps and lakes). Horizontal lines = mud (floodplains). Dashed horizontal lines = silt (levee bank deposits). Dots = sand (river channels). Brick pattern = bedrock.

7.6 Architecture of weathered Cretaceous sediments

Section 5.4 recommends an architectural rather than lithostratigraphic approach be used for regolith terminology rather than the widely used informal four-fold division of the weathering profile by a number of workers into upper and lower mottled zones separated by a the bleached zone (Kellett and Mullen 2003, Pearce *et al.* 2004). Comparison of the AEM sections with drill data reveals that there are large areas of highly conductive weathered Cretaceous sediment that are coincident with ferruginous development. However there is only one such horizon most localities, rather than two. These data indicate that the correlations of weathering zones between holes kilometres apart are largely spurious. Rather than a succession of zones, the data points to a single widespread but patchy ferruginous zone that has been variably identified as either upper or lower mottled zones. In other areas, well documented ferruginous material has a relatively resistive signature. In outcrop these coincide with silicification. The apparent correlation between ferruginisation and AEM conductivity anomalies and the apparent destruction of conductivity by overprinting silicification is an area for further research.

8. SUMMARY AND CONCLUSIONS

- The fluvial architecture of the St George study area consists of three vertically stacked systems, each with its own distinctive fabric in the AEM LEI slices.
- The deepest LEI slice with an interpretable fabric (40-160 m aggregate layer) consists of the fault controlled Dirranbandi Palaeovalley to the west and the incised valleys of the palaeo Balonne and Moonie rivers to the east. Sediment patterns in the incised valleys are not known, but those of the Dirranbandi Palaeovalley appear dominated by anastomosing patterns

- Above this (the 15-40 m aggregate layer) the fabric is composed of wide aggrading alluvial surfaces, characterised by the anastomosing channels of the Maranoa Fan encroaching from the west, and braided systems of the palaeo-Balonne and palaeo-Moonie rivers.
- The shallowest pattern (0-15 m aggregate layer), corresponds to the current system, with the Maranoa Fan now relict and the development of the Balonne and Moonie Fans.
- Despite the changes in palaeogeographic architecture, some sand bodies, especially in the Dirranbandi Palaeovalley region, continue from the surface through to depth, indicating good vertical connectivity for both rising and descending round water flow, at least within the constrains of each of the three main aquifer units (shallow unconfined and the intermediate and deep semi-confined aquifers).

Each of these units has its distinctive hydraulic properties. The braided units are the best aquifers because of their extent, connectivity, and volume. They are followed by the anastomosing systems and last by the incised valley fills. The incised valley fills have, however, had a very significant local influence on groundwater movement.

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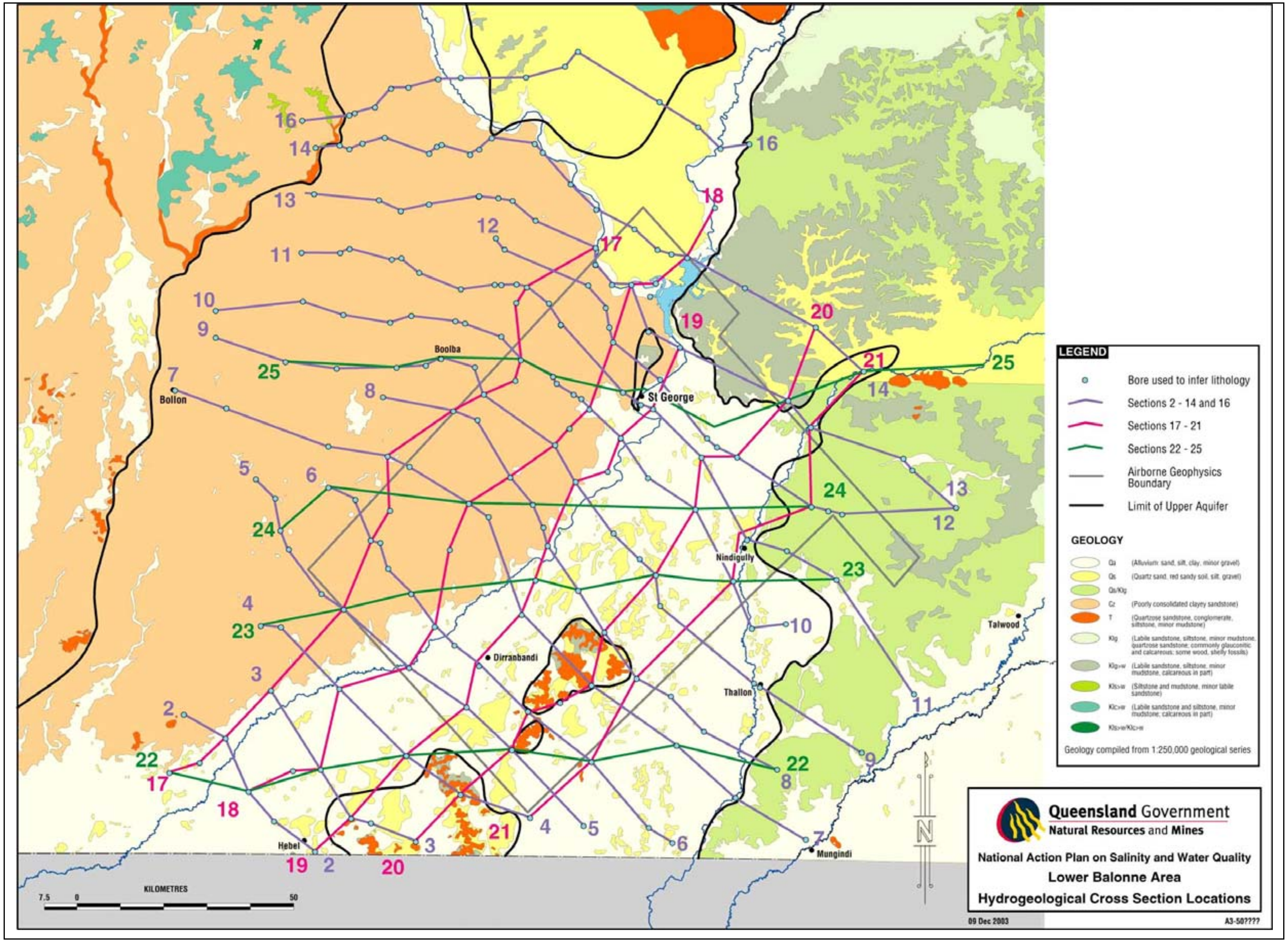
APPENDIX 1. COMPARISONS BETWEEN INTERPRETED DRILL CROSS SECTIONS AND VERTICAL AEM SECTIONS

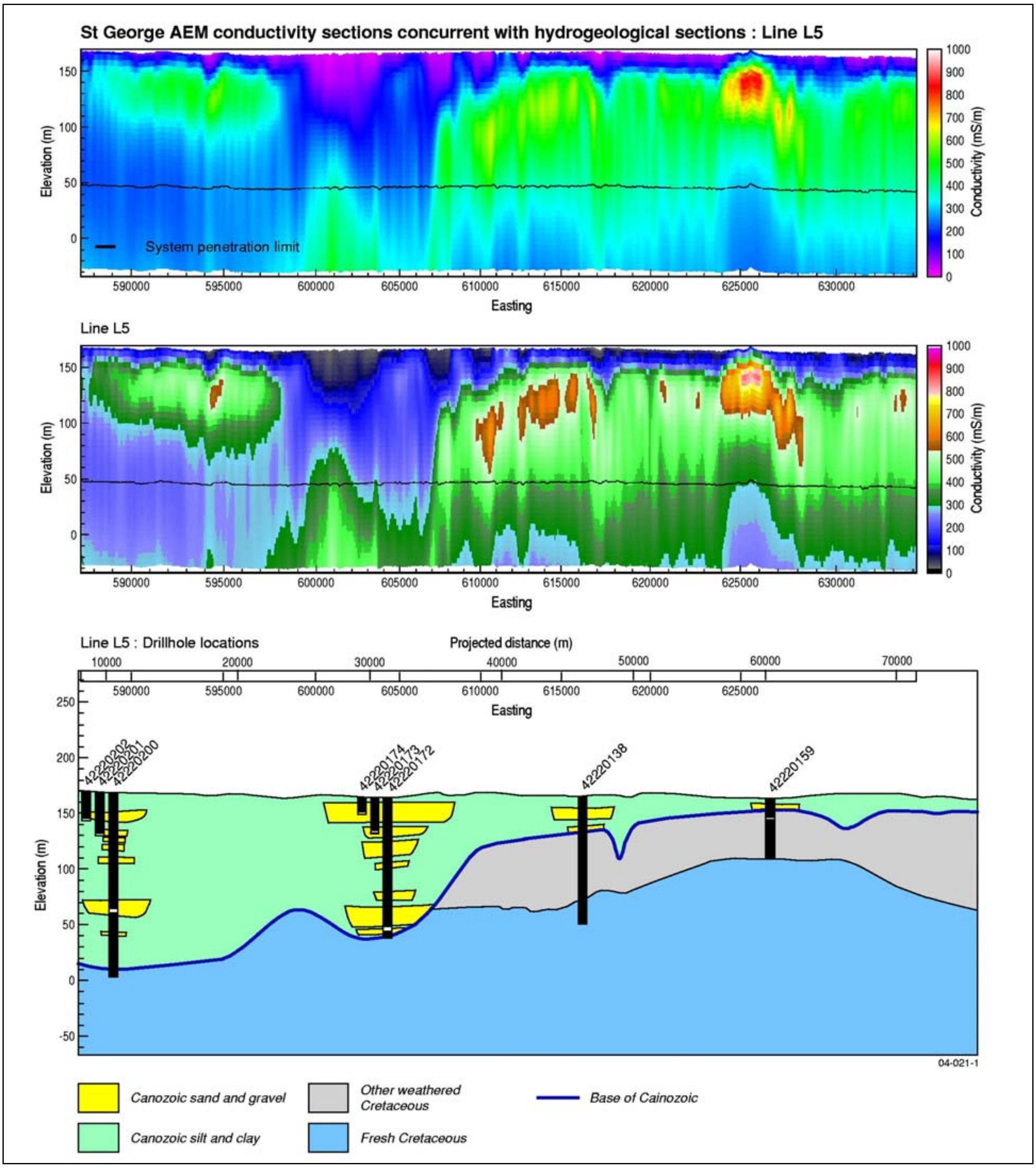
This appendix contains comparisons between interpreted drill cross sections and vertical AEM sections and a map showing their location. The drill holes and section lines are the same as those in Pearce *et al.* 2004), which is also the source of the location map. The drill lines are clipped to the study area, compared to the more extensive sections of Pearce *et al.* (2004). The AEM sections are generated to match the line of the drill sections and two different stretches are shown. Horizontal and vertical scales are the same in both the synthetic AEM and drilling sections. Black drill holes are government bores, those in outline are private bores. White areas in the bores represent screened intervals.

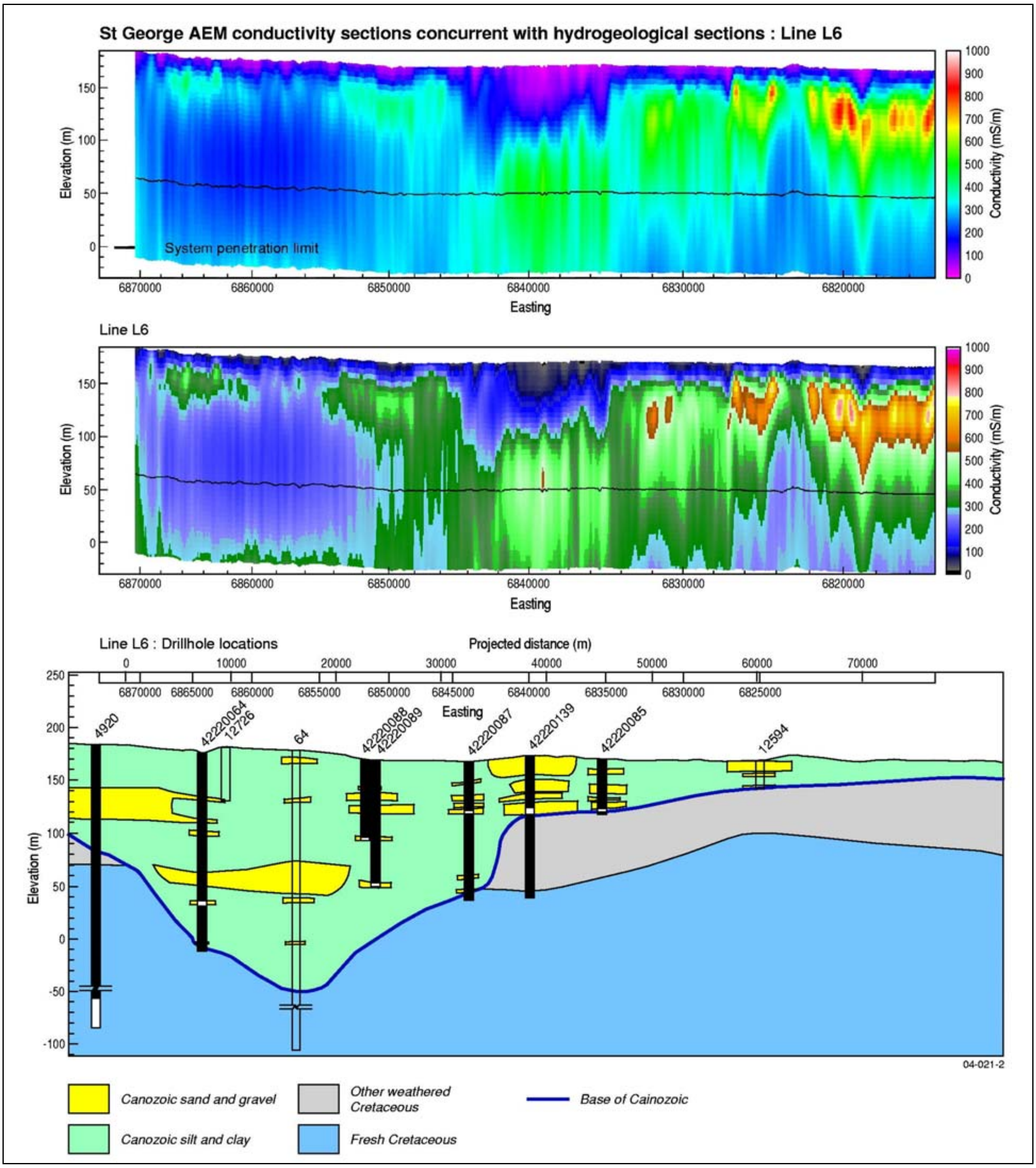
Compared with Pearce *et al.* (2004), the sections are interpreted differently using tighter limits on the lateral extend of sand bodies using AEM input. This is based on the likely extent of sand bodies as discussed in section 5.3 of the text. The extent used is the 1:500 thickness-to-width ratios of braided systems and so is quite optimistic. If the more constrained 1:100 or 1:10 ratios of meandering or anastomosing systems were used the reasonable extent of sand bodies would be even more limited. The sand bodies shown in these cross sections are those actually intersected by drill holes. We regard as highly likely that similar proportions of sand, though of different thicknesses and depths, would be encountered in holes drill between those already present.

The layout of the sections is shown below:

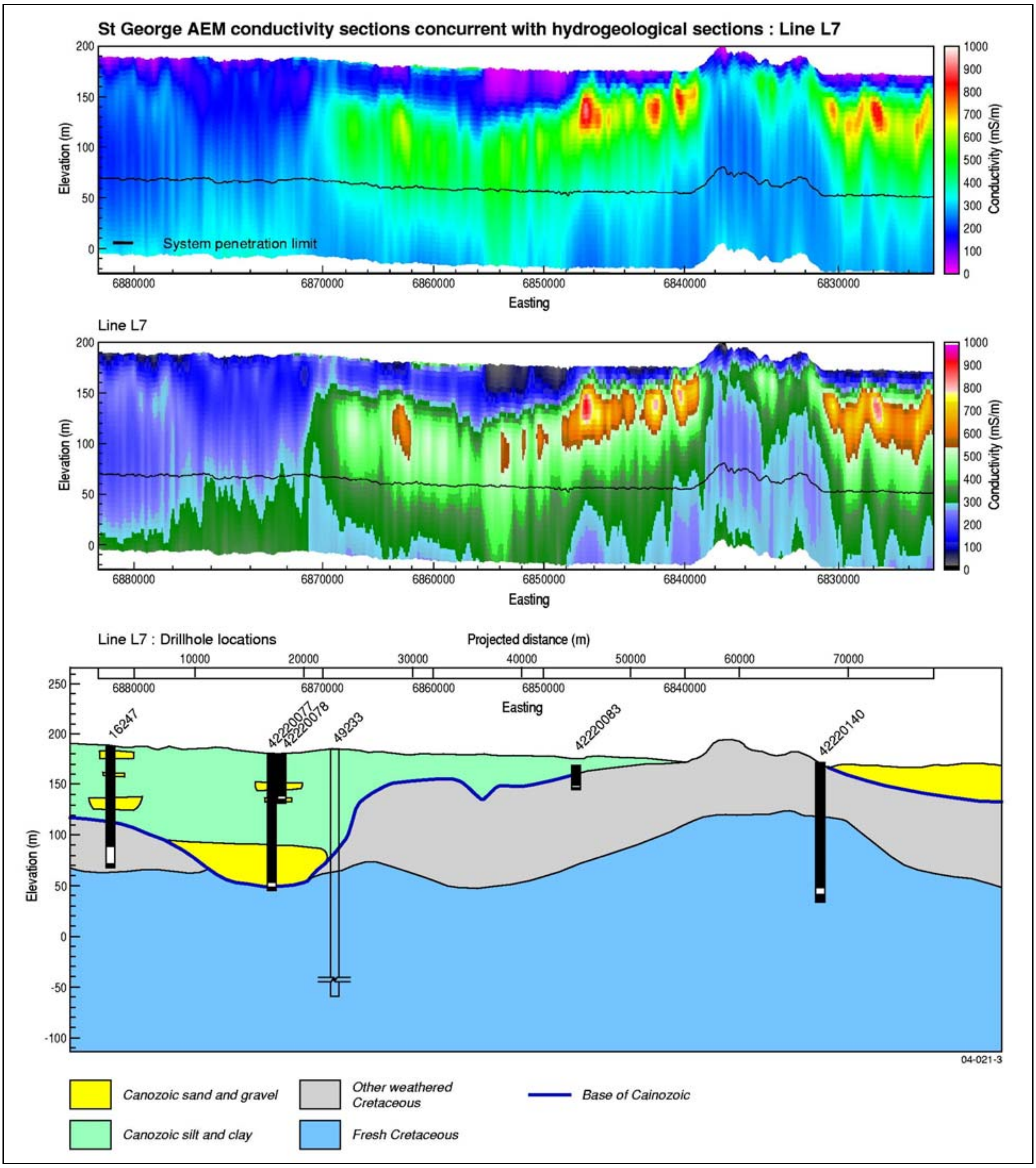
AEM section colour stretch 1
AEM section colour stretch 2
Interpreted drill cross section


LEGEND
Bore used to infer lithology
Sections 2 - 14 and 16
Sections 17 - 21
Sections 22 - 25
Airborne Geophysics Boundary
Limit of Upper Aquifer
GEOLOGY
Qa (Alluvium: sand, silt, clay, minor gravel)
Qs (Quartz sand, red sandy soil, silt, gravel)
Qs/Klg
Cz (Poorly consolidated clayey sandstone)
T (Quartzose sandstone, conglomerate, siltstone, minor mudstone)
Klg (Labile sandstone, siltstone, minor mudstone, quartzose sandstone; commonly glauconitic and calcareous; some wood, shelly fossils)
Geology compiled from 1:250,000 geological series
Queensland Government
Natural Resources and Mines
National Action Plan on Salinity and Water Quality
Lower Balonne Area
Hydrogeological Cross Section Locations
09 Dec 2003
A3-50????
KILOMETRES
7.5
0
50
St George
Boolba
Bollon
Nindigully
Dirranbandi
Thallon
Talwood
Hebel
Mungindi
N

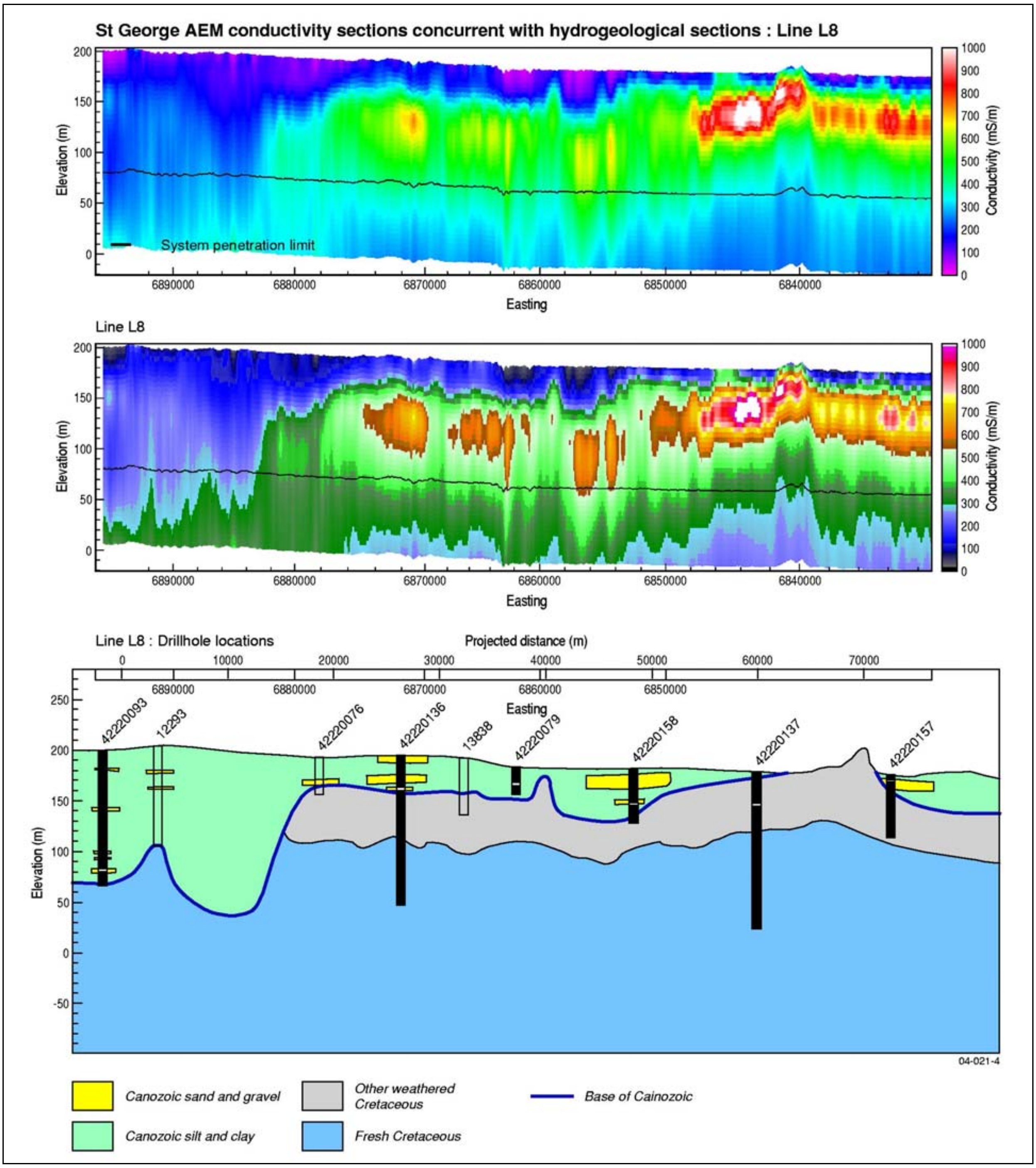

St George AEM conductivity sections concurrent with hydrogeological sections : Line L5
Elevation (m)
Conductivity (mS/m)
System penetration limit
Easting
Line L5
Line L5 : Drillhole locations
Projected distance (m)
42220202
42220201
42220200
42220174
42220173
42220172
42220138
42220159
04-021-1
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic

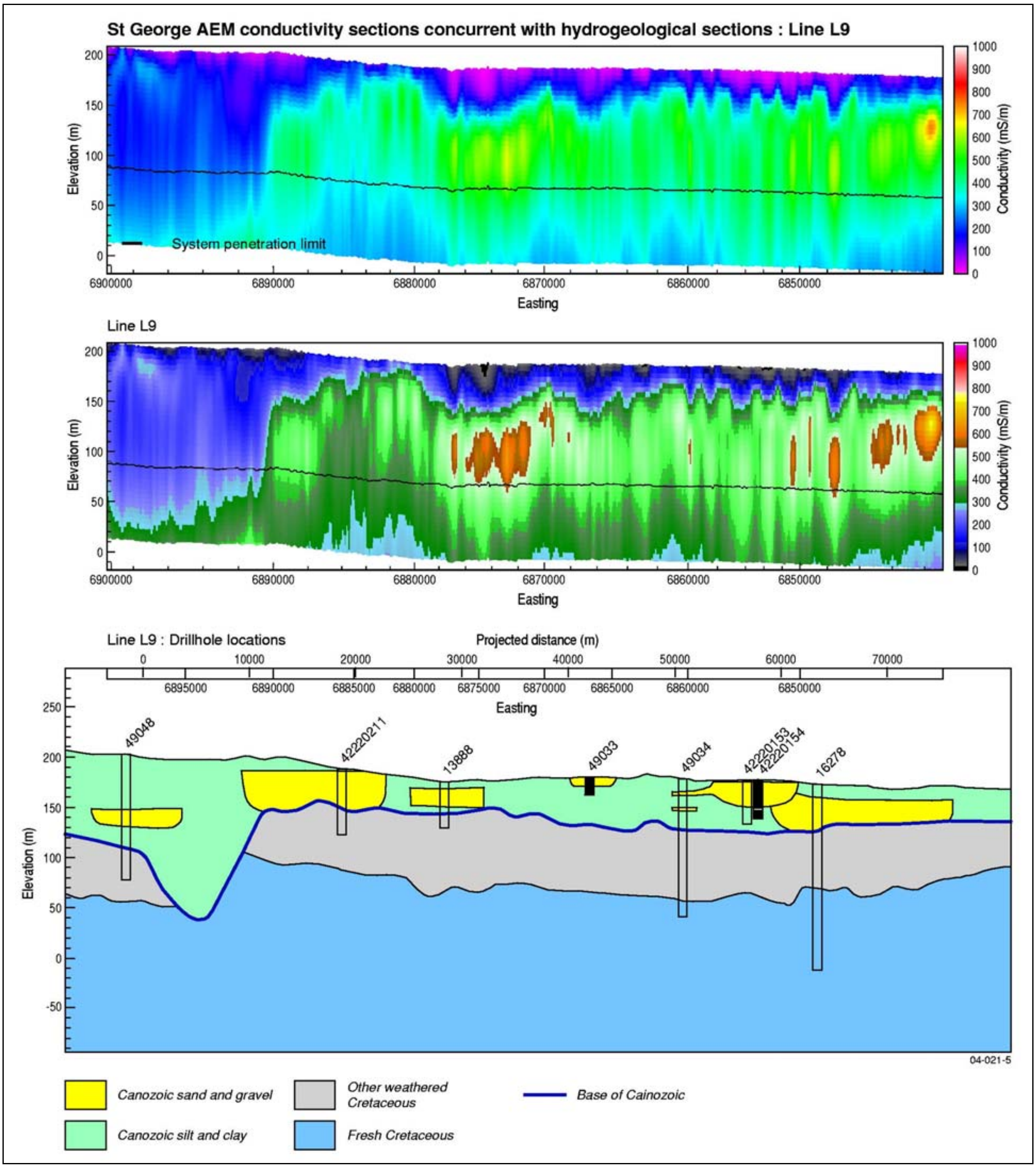


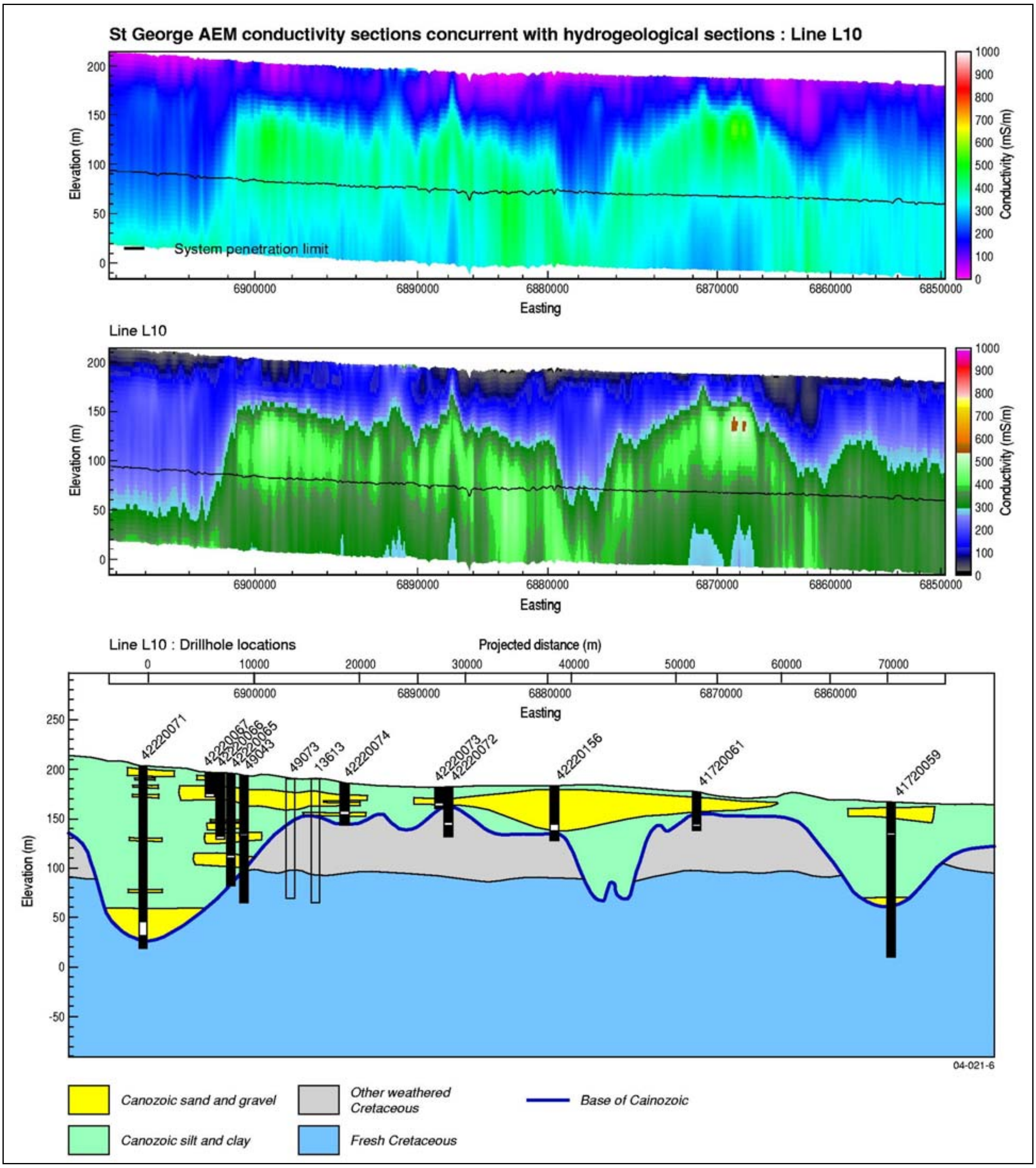
St George AEM conductivity sections concurrent with hydrogeological sections : Line L6
Elevation (m)
System penetration limit
Easting
Conductivity (mS/m)
Line L6
Line L6 : Drillhole locations
Projected distance (m)
4920
42220064
12726
64
42220088
42220089
42220087
42220139
42220085
12594
04-021-2
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic



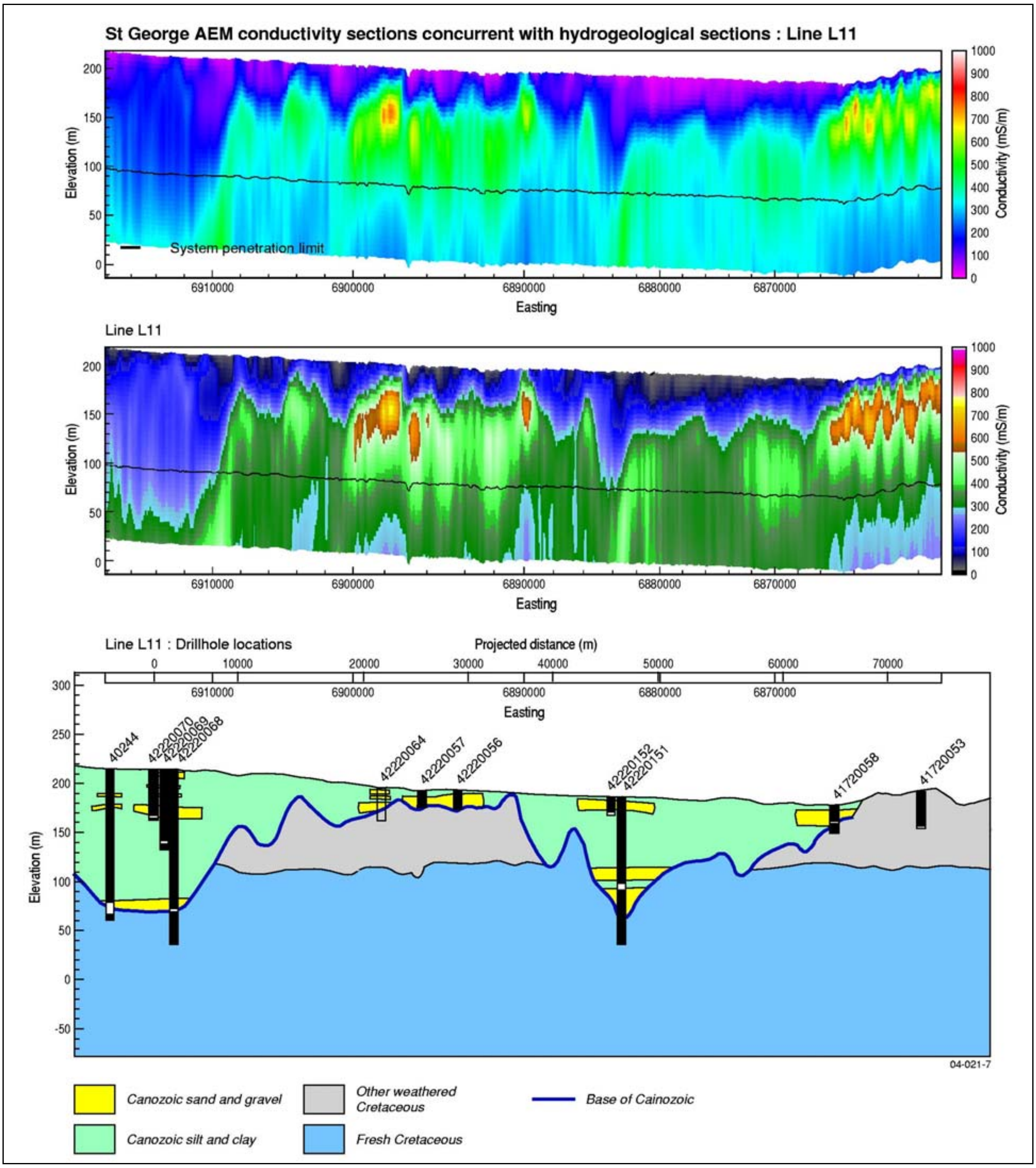
St George AEM conductivity sections concurrent with hydrogeological sections : Line L7
Elevation (m)
Conductivity (mS/m)
System penetration limit
Easting
Line L7
Line L7 : Drillhole locations
Projected distance (m)
16247
42220077
42220078
49233
42220083
42220140
04-021-3
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic

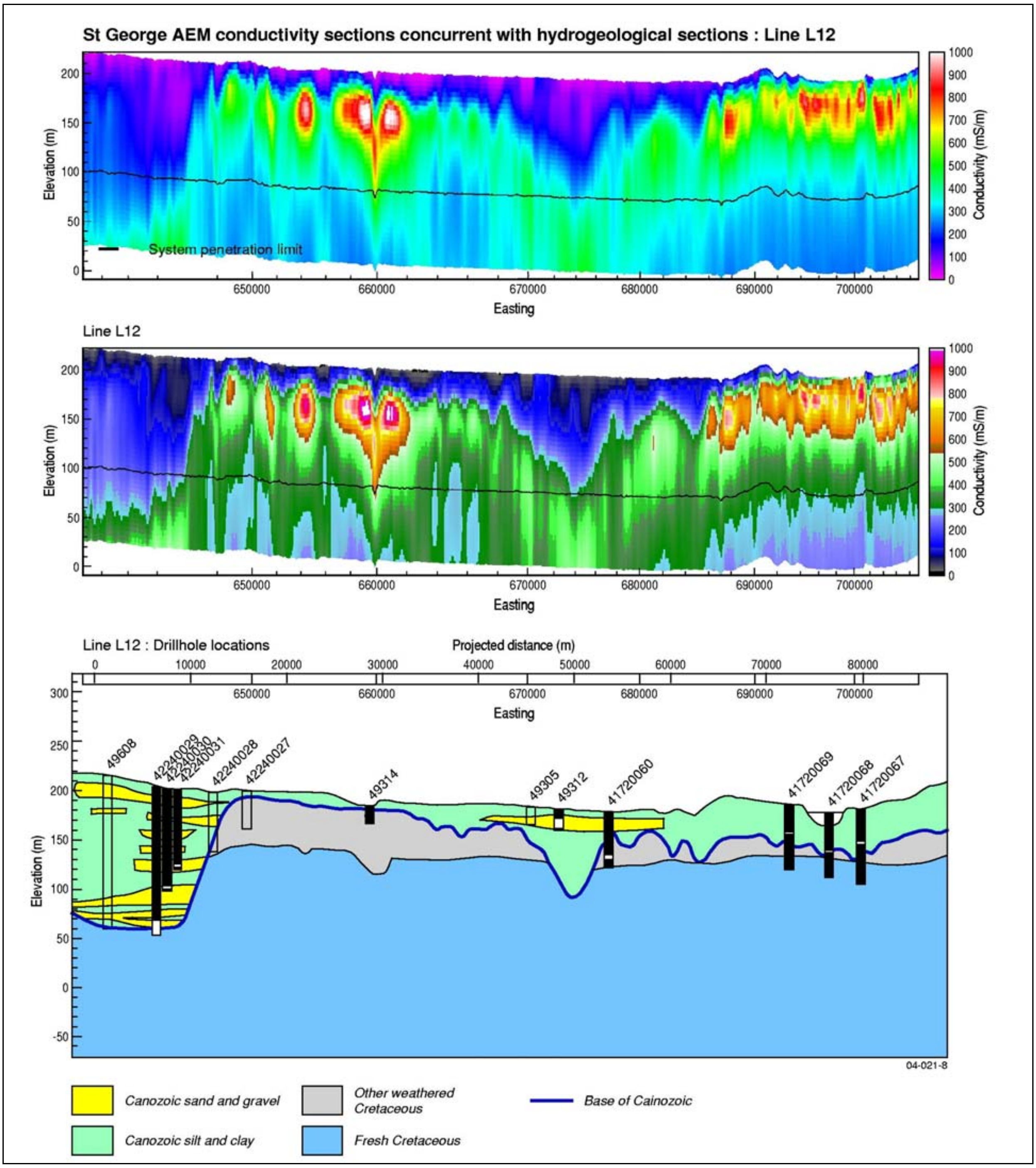

St George AEM conductivity sections concurrent with hydrogeological sections : Line L8
Elevation (m)
Conductivity (mS/m)
System penetration limit
Easting
Line L8
Line L8 : Drillhole locations
Projected distance (m)
42220093
12293
42220076
42220136
13838
42220079
42220158
42220137
42220157
04-021-4
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic

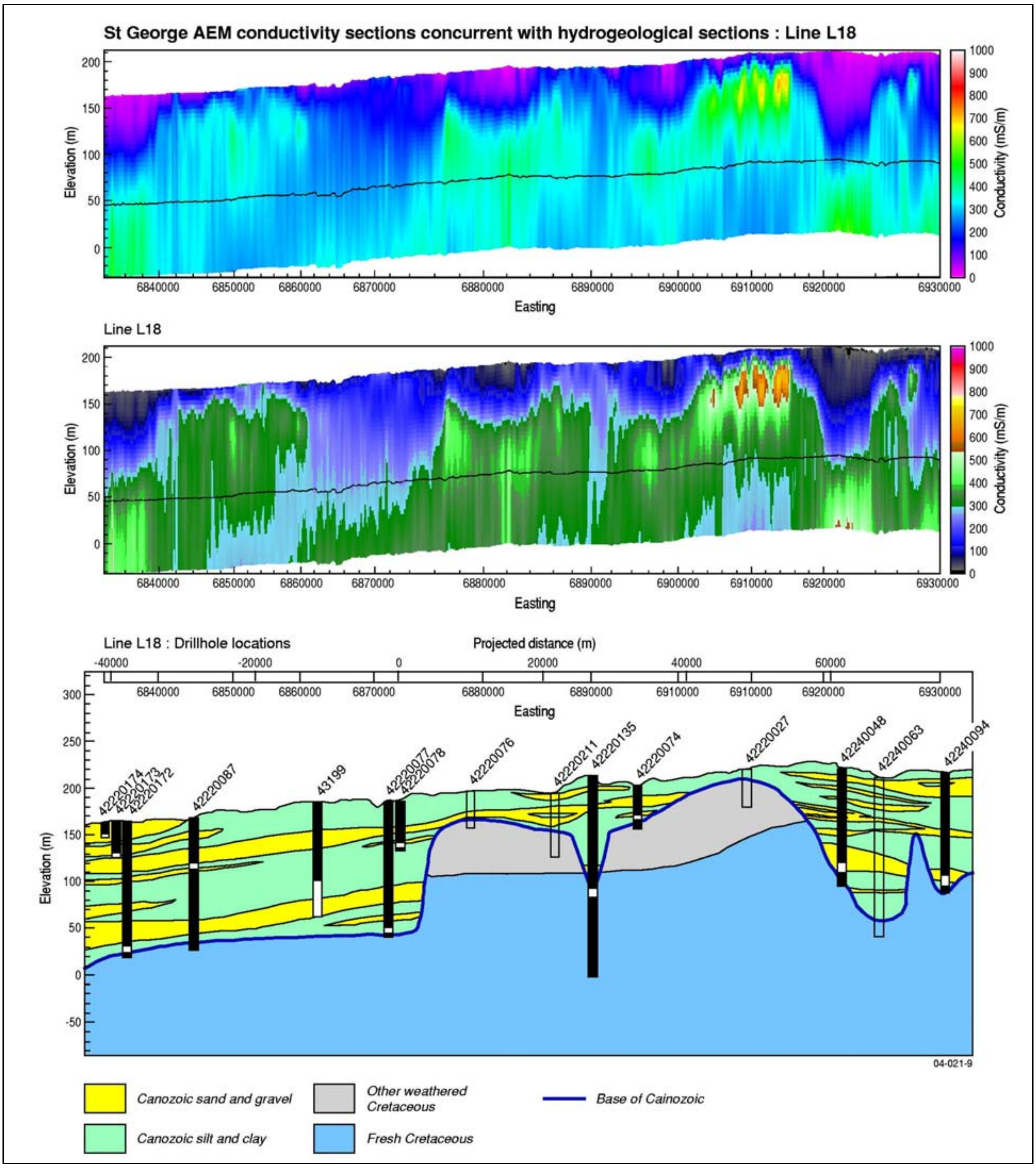

St George AEM conductivity sections concurrent with hydrogeological sections : Line L9
Elevation (m)
Conductivity (mS/m)
System penetration limit
6900000
6890000
6880000
6870000
6860000
6850000
Easting
Line L9
Line L9 : Drillhole locations
Projected distance (m)
0
10000
20000
30000
40000
50000
60000
70000
6895000
6885000
6875000
6865000
49048
42220211
13888
49033
49034
42220153
42220154
16278
04-021-5
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic



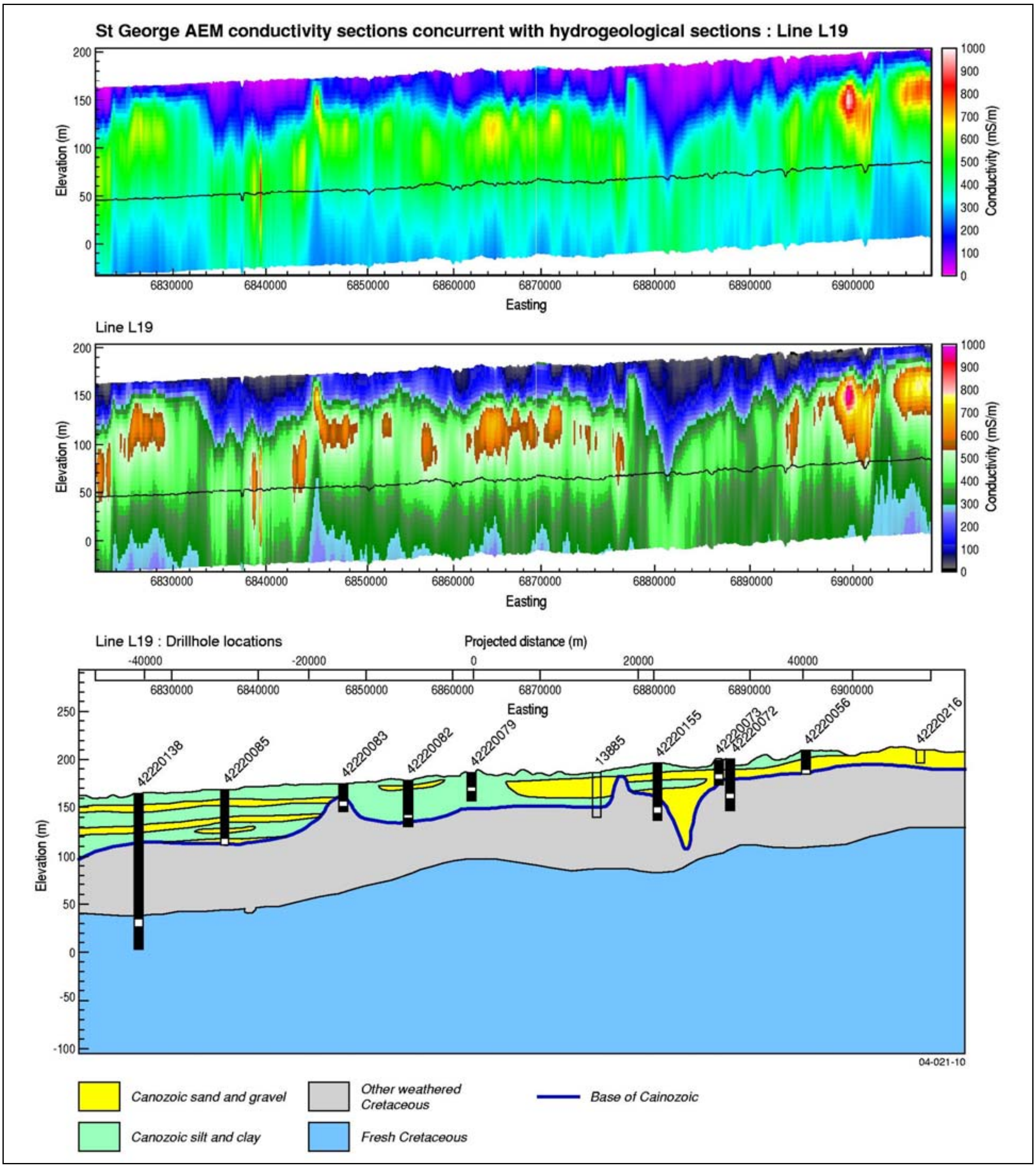
St George AEM conductivity sections concurrent with hydrogeological sections : Line L10
Elevation (m)
Conductivity (mS/m)
System penetration limit
Easting
Line L10
Line L10 : Drillhole locations
Projected distance (m)
42220071
42220067
42220066
42220065
49043
49073
13613
42220074
42220073
42220072
42220156
41720061
41720059
04-021-6
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic

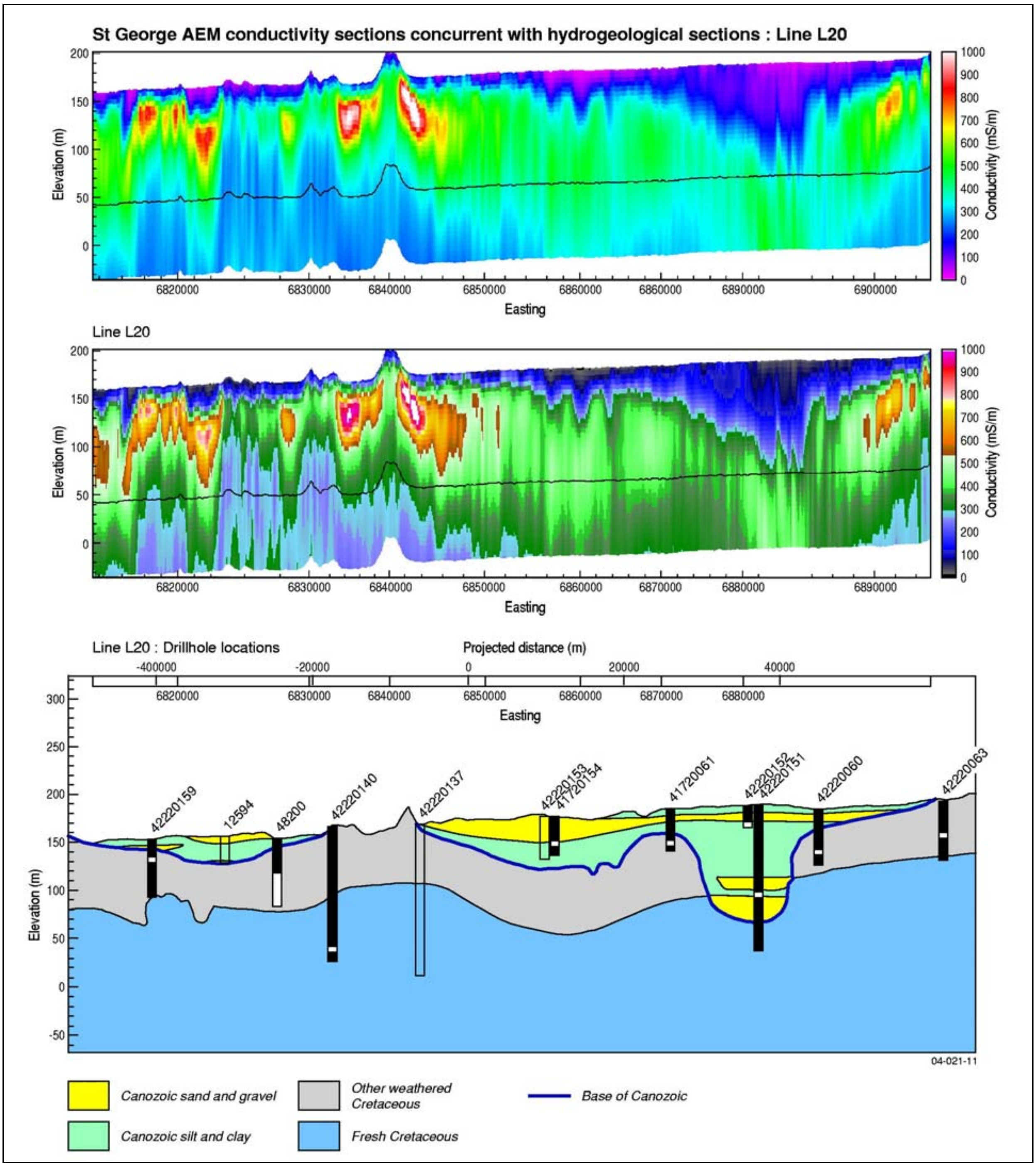

St George AEM conductivity sections concurrent with hydrogeological sections : Line L11
Elevation (m)
Conductivity (mS/m)
System penetration limit
Easting
Line L11
Line L11 : Drillhole locations
Projected distance (m)
40244
42220070
42220069
42220068
42220064
42220057
42220056
42220152
42220151
41720058
41720053
04-021-7
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic


St George AEM conductivity sections concurrent with hydrogeological sections : Line L12
Elevation (m)
Conductivity (mS/m)
System penetration limit
Easting
Line L12
Line L12 : Drillhole locations
Projected distance (m)
49608
42240029
42240030
42240031
42240028
42240027
49314
49305
49312
41720060
41720069
41720068
41720067
04-021-8
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic



St George AEM conductivity sections concurrent with hydrogeological sections : Line L18
Elevation (m)
Easting
Conductivity (mS/m)
Line L18
Line L18 : Drillhole locations
Projected distance (m)
42220174
42220173
42220172
42220087
43199
42220077
42220078
42220076
42220211
42220135
42220074
42220027
42240048
42240063
42240094
04-021-9
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic


St George AEM conductivity sections concurrent with hydrogeological sections : Line L19
Elevation (m)
Conductivity (mS/m)
Easting
Line L19
Line L19 : Drillhole locations
Projected distance (m)
42220138
42220085
42220083
42220082
42220079
13885
42220155
42220073
42220072
42220056
42220216
04-021-10
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Cainozoic


St George AEM conductivity sections concurrent with hydrogeological sections : Line L20
Elevation (m)
Conductivity (mS/m)
Easting
Line L20
Line L20 : Drillhole locations
Projected distance (m)
04-021-11
Canozoic sand and gravel
Canozoic silt and clay
Other weathered Cretaceous
Fresh Cretaceous
Base of Canozoic

APPENDIX 2. REGOLITH ARCHITECTURE IN SELECTED DRILL HOLES

These summary lithological descriptions are based on drillers logs and are therefore of variable and uncertain quality. See Appendix 1 for locations and context. The absence of a characteristic weathering "stratigraphy" is notable (e.g. distinct upper and lower mottled zones, bleached zone, etc.). Base transported cover and base saprolite is inferred by the author. Data below the first fresh rock interval is not recorded in this appendix.

Hole 13613 Line 9

0-0.91	Soil
0.91-10.67	Sandy clay
10.67-24.38	Sand
24.38-29.26	White clay
29.26-32.61	Sand
32.61-37.49	White clay
37.49-39.62	Hard pink sandstone
39.62-41.45	Hard white sandstone
41.45-43.89	Rock
43.89-51.82	White clay and ironstone
51.82-54.25	Clay and sandstone
54.25-59.44	Soft sandstone
59.44-76.81	Yellow sandstone

BASE TRANSPORTED COVER

76.81-85.04	Grey shale
85.04-85.95	Hard sandstone
85.95-99.06	Grey shale
99.06-100.28	Brown shale

BASE SAPROLITE

100.28-107.9	Grey shale and sand

Hole 49073 Line 9

0-0.91	Soil
0.91-12.19	Yellow and red clay
12.19-19.81	Dry sand
19.81-27.74	Gravely sand

POSSIBLE BASE TRANSPORTED COVER

27.74-38.10	Sandy clay
38.10-45.15	Hard rock

INTERPRETED BASE TRANSPORTED COVER ON SECTIONS

45.15-60.96	White clay
60.96-82.30	Yellow clay

BASE SAPROLITE

82.30-103.63	Blue sandy shale

Hole 41720067 Line 12

0-3.0	Hard
3.0-4.0	Fractured off white clay, hard
4.0-5.0	Grey white clay, hard
5.0-7.0	Weathered, limonite and reddish purple stained grey white clay
7.0-9.0	Slightly stained grey white clay, firm
9.0-11.0	Chalky grey white clay
11.0-13.0	Heavily limonite stained, grey white clay
13.0-14.0	Limonite stained grey white clay
14.0-16.0	Heavily weathered and limonite stained clay
16.0-17.0	Heavily reddish purple stained clay
17.0-18.0	Heavily orange/brown limonite stained clay
18.0-21.0	Heavily reddish purple stained clay
21.0-22.0	Heavily red/brown stained clay
22.0-23.0	Heavily orange/red stained clay
23.0-25.0	Heavily orange/red and red/brown stained, off white clay
25.0-26.0	Limonite stained off white clay
26.0-34.0	Heavily limonite stained clay
34.0-40.0	Strongly weathered olive brown siltstone
40.0-42.0	Strongly weathered olive grey siltstone
42.0-46.0	Strongly weathered olive grey siltstone, carbonaceous material
46.0-47.0	Less weathered olive grey siltstone, firmer
47.0-51.0	Limonite stained light grey shale/siltstone, carbonaceous material

BASE SAPROLITE

51.0-54.0	Medium grey shale

Hole 41720069 Line 12

0-1.0	bed brown silty soils then yellow brown silty clay
1.0-2.0	Yellow brown silty clay
2.0-7.0	Brown and reddish purple stained, off white clay, Mn stained
7.0-9.0	Limonite and pale red brown stained off white clay
9.0-10.0	heavily yellow brown to red brown limonite stained clay
10.0-12.0	Orange limonite stained clay
12.0-13.0	Pale yellow brown stained clay.
13.0-16.0	Red brown and yellow brown stained clay
16.0-17.0	Brown limonite stained clay
17.0-18.0	Purple stained clay
18.0-19.0	Red brown and yellow brown stained clay
19.0-20.0	Yellow brown stained clay
20.0-22.0	Red brown and yellow brown stained clay
22.0-29.0	Pale yellow brown stained clay
29.0-34.0	Weathered yellow brown shale
34.0-36.0	Weathered olive grey siltstone
36.0-39.0	Weathered olive grey siltstone, Mn bands
39.0-44.0	Weathered brown shale
44.0-47.0	Weathered olive brown shale/siltstone, firmer
47.0-51.0	Weathered olive grey shale/siltstone
51.0-53.0	Weathered greenish grey siltstone, Mn bands

BASE SAPROLITE

53.0-56.4	Greenish grey siltstone

Hole 42220136 Line 8

0-1.0	Orange brown very fine sand
1.0-2.0	Orange brown very fine to fine sand and minor red brown very fine sandstone
2.0-3.0	Yellow brown and light grey very fine sandstone, almost siltstone
3.0-4.0	Khaki brown and light grey brown very fine sandstone
4.0-5.0	Light grey and minor khaki grey brown very fine sandstone
5.0-6.0	Light grey very fine sandstone with red brown semi consolidated very fine sandstone
6.0-7.0	Light grey and red brown clay, sticky
7.0-11.0	Very stiff brown and light grey clay with very minor dark blue grey colouration
11.0-12.0	Brown and minor light grey silty clay
12.0-13.0	Brown and grey clay with minor carbonaceous clay layer
13.0-14.0	Very poor sample, either silt or sand layers
14.0-16.0	Brown and grey stiff clay with carbonaceous streaks
16.0-17.0	Buff grey sticky clay
17.0-18.0	Grey and brown silty clay with minor carbonaceous streaks
18.0-19.0	Very poor sample, either silt or sand
19.0-22.0	Poor sample, silt to coarse sand, rounded, predominantly quartz and feldspar
22.0-23.0	Medium to very coarse sand and fine gravel, rounded, quartzose, white grey, clay bound
23.0-24.0	Light grey sandy silty clay with some medium to coarse sand and pea gravel
24.0-25.0	Light grey silty clay
25.0-26.0	Poor sample, probably silt or very fine sand
26.0-27.0	Yellow brown and light grey sandy clay with brown indurated sandy clay and minor grey clay
27.0-28.0	Minor hard band at 28 m, light grey clay with yellow brown sandy clay and clay, minor broken siliceous clasts
28.0-29.0	Light grey claybound medium to coarse sand and pea gravel, rounded quartz dominant
29.0-30.0	Light grey claybound coarse sand gravel, quartz sand, lithic gravel, rounded to sub rounded

BASE TRANSPORTED COVER

30.0-32.0	Light grey sandy clay and grey stiff clay, yellow grey clay and minor carbonaceous streaks
32.0-33.0	Grey clay and red brown streaks
33.0-35.4	Grey and red brown clay, stiff
35.4-36.6	Grey red clay with very hard white yellow silicified siltstone
36.6-38.0	Pink grey silicified siltstone, hard
38.0-40.0	White light yellow grey silicified claystone, hard
40.0-41.0	White light grey silicified hard claystone
41.0-42.0	White sandy clay and clay with minor dark grey blue sandy clay
42.0-43.0	White silty clay and clay
43.0-44.0	White silty clay and clay and purple grey silty clay
44.0-49.0	White sticky clay
49.0-51.0	White sticky clay and very minor blue grey interbeds
51.0-52.0	Purple red cemented sandstone with white grey sandy clay and clay
52.0-53.0	White grey sandy clay and claystone and minor red brown sandy clay
53.0-54.0	Red brown silty clay with light grey and minor carbonaceous streaks
54.0-55.0	Light grey and red purple brown clay
55.0-57.0	Light grey clay, red purple brown silty sandy clay and minor yellow brown cemented sand
57.0-58.0	Khaki grey, minor red brown sandy clay and clay
58.0-59.0	Grey khaki sandy clay and silty clay
59.0-60.0	Grey clay
60.0-62.0	Grey green sandy clay
62.0-63.0	Khaki green sandy clay

63.0-64.0	Grey clay and khaki green sandy clay
64.0-66.0	Grey green silty clay with brown slightly carbonaceous mudstone
66.0-68.0	Grey brown mudstone with yellow brown mottling
68.0-69.0	Yellow brown purple brown mudstone, ironstone
69.0-69.8	Yellow brown silty mudstone

BASE SAPROLITE

69.8-73.0	Dark grey mudstone, slightly carbonaceous

Hole 42220137 Lines 8 & 20

0-1.00	Brown clayey soil
1.0-3.0	Limonite stained, off white clay, hard
3.0-4.0	Fractured, off white clay, hard
4.0-5.0	Grey white clay, hard
5.0-7.0	Weathered, limonite stained, grey white clay, firm
7.0-9.0	Slightly stained, grey white clay
9.0-11.0	Chalky, grey white clay firm
11.0-13.0	Heavily limonite stained, grey white clay
13.0-14.0	Limonite stained grey white clay
14.0-16.0	Heavily weathered and limonite stained clay
16.0-17.0	Heavily reddish purple stained clay
17.0-18.0	Heavily orange/brown limonite stained clay
18.0-21.0	Heavily reddish purple stained clay
21.0-22.0	Heavily red/brown stained clay
22.0-23.0	Heavily orange/red stained clay
23.0-25.0	Heavily orange/red and red/brown stained, off white clay
25.0-26.0	Limonite-stained off white clay
26.0-34.0	Heavily limonite-stained clay
34.0-40.0	Strongly weathered olive brown siltstone
40.0-42.0	Strongly weathered, olive grey siltstone
42.0-46.0	Strongly weathered, olive grey siltstone, carbonaceous material
46.0-47.0	Less weathered olive grey siltstone, firmer
47.0-51.0	Limonite stained light grey shale/siltstone, carbonaceous material

BASE SAPROLITE

51.0-54.0	Medium to dark grey shale

Hole 42220138 Lines 5 & 19

0-2.0	Light brown sandy silty clay
2.0-3.0	Light brown silty clay with calcite crystals
3.0-4.0	Light grey brown sandy clay
3.0-5.0	Light brown grey sandy clay with white crystals
5.0-6.0	Buff grey silty clay with white nodules and black carbonaceous streaks
6.0-8.0	Mottled light brown and orange brown sandy clay
8.0-9.0	Light brown sandy silty clay
9.0-10.0	Brown fine to medium sand
10.0-11.0	Fine to very coarse sand and gravel
11.0-12.0	Brown clayey fine to coarse sand and gravel
12.0-13.0	Light grey and orange brown sandy clay (fine to coarse)
13.0-14.0	Light grey and orange brown sandy clay (sandy fine to coarse with minor gravel)
14.0-15.0	Light grey sandy clay (sandy fine to very coarse, quartz dominant)

15.0-16.0	Light grey clayey sand (fine to very minor gravel)
16.0-17.0	Light grey with minor orange clayey sand and gravel (sand fine to very coarse with gravel)
17.0-18.0	Light grey clayey sand and gravel, fine to coarse sand
18.0-19.0	Light buff grey sandy clay (fine to coarse quartz dominant)
19.0-21.0	Grey light brown silty clay and clay with minor black carbonaceous streaks
21.0-25.0	Grey brown silty sandy clay and clay with minor black carbonaceous streaks
25.0-26.0	Grey brown minor orange brown sandy clay
26.0-27.0	Grey brown silty clay and clay
27.0-28.0	Grey and orange brown silty sandy clay
28.0-29.0	Grey dark grey brown silty clay
29.0-30.0	Grey red brown clay
30.0-32.0	Grey khaki brown mottled clay with minor black carbonaceous streaks
32.0-33.0	Grey brown khaki silty clay with black carbonaceous streaks
33.0-34.0	Grey brown red mottled clay
34.0-35.0	Light grey clay and silty clay
35.0-36.0	Khaki grey sandy clay
36.0-37.0	Khaki grey clay and silty clay

BASE TRANSPORTED COVER

37.0-38.0	Light grey clay, black coal and red orange khaki hard siliceous silcrete
38.0-39.0	Light grey clay with silcrete and red brown ironstone
39.0-40.0	White mudstone or claystone
40.0-41.0	White claystone with greenish tinge
41.0-45.0	White mudstone with minor red brown carbonaceous bands
45.0-46.0	White siltstone or sandy mudstone
46.0-47.0	Pink grey silty mudstone
47.0-52.0	Buff light grey with minor orange brown mottled mudstone
52.0-55.0	Light grey silty mudstone
55.0-60.0	Buff grey silty mudstone with minor yellow brown mottling
60.0-63.0	Grey brown and orange brown silty mudstone and siltstone
63.0-64.0	Grey brown and orange brown mottled siltstone
64.0-68.0	Orange brown grey brown silty mudstone
68.0-70.0	Grey brown and orange brown mudstone and minor siltstone
70.0-72.0	Orange brown silty mudstone
72.0-75.0	Mottled grey brown silty mudstone and silty mudstone
75.0-78.0	Dark grey and orange brown mudstone and silty mudstone
79.0-80.0	Khaki brown silty mudstone
80.0-83.0	Dark grey and khaki brown siltstone
83.0-84.0	Khaki brown siltstone

BASE SAPROLITE

84.0-85.0	Dark grey silty mudstone with minor carbonaceous streaks

Hole 42220139 Line 6

0-1.0	Dark chocolate brown clay
1.0-2.0	Dark chocolate brown clay with kaolin
2.0-3.0	Light orange-brown clayey sand
3.0-5.0	Light orange brown firm sand, silty clay with kaolin
5.0-6.0	Light brown fine grained reasonably clean cemented sand
6.0-10.0	Light brown fine to medium-grained sand, moderately sorted-rounded grains
10.0-10.2	Grey clay
10.2-11.0	Coarse-grained sand and fine gravel, moderately sorted rounded grains

11.0-12.0	Very coarse-grained sand and gravel, moderately sorted rounded grains
12.0-13.0	Very coarse grained sand and grey claybound waterworn gravel
13.0-14.0	Ferruginated and mottled grey/orange silty sandy clay
14.0-15.0	Very coarse-grained sand and fine gravel
15.0-16.0	Very coarse-grained sand and fine gravel, moderately sorted rounded grains
16.0-17.0	Fine to medium grained gravel
17.0-17.3	Moderately sorted rounded gravel
17.3-18.2	Mottled and ferruginated grey/orange clayey sand
18.2-19.0	Brown medium to corse grained dirty sand with interbedded laminar black carbonaceous clay bands
19.0-20.0	Interbedded orange brown and grey very fine-grained dirty cemented sands
20.0-21.5	Light brown medium-grained clean sand; moderately sorted rounded grains
21.5-22.0	Light brown-white fine-grained clean cemented sand
22.0-23.0	Interbedded orange-brown fine-grained cemented silty sand and grey-white fine-grained dirty cemented sand with dark brown carbonaceous silty clay bands
23.0-24.0	Interbedded red, orange and grey fine to medium-grained dirty cemented silty sands with dark brown carbonaceous bands
24.0-25.3	Light brown fine to medium-grained clean sand; moderately sorted rounded grains
25.3-26.0	Interbedded rusty reddish brown dirty silty sand and grey silty sand with minor dolomite bands
26.0-28.0	Grey-brown very fine-grained dirty firm semi-consolidated silty sands
28.0-30.0	Grey-brown very fine-grained sand with laminar grey clay interbeds and dolomite bands
30.0-31.0	Grey very fine-grained dirty sand with dolomite bands
31.0-32.0	Interbedded dark brown and blue grey silty sandy clay with black carbonaceous bands and dolomite bands
32.0-33.0	Interbedded orange-brown and white fine-grained silty sands with black carbonaceous bands and dolomite bands
33.0-34.5	Interbedded grey-brown and white fine-grained sands with dark brown carbonaceous clay bands and dolomite bands
34.5-36.0	Yellow-brown fine to medium-grained clean sand; moderately sorted rounded grains
36.0-37.4	White fine-grained dolomitised clean sandstone
37.4-38.0	Mottled grey/orange silty sandy clay
38.0-39.2	Mottled grey/orange silty clayey sand with black carbonaceous bands
39.2-40.0	Yellow fine to medium grained clean sand with orange clay; moderately sorted rounded grains
40.0-42.0	Light whitish brown fine-grained silty sand
42.0-44.0	Light whitish brown fine-grained silty sand with dark brown-grey-orange silty clay bands
44.0-45.0	Light brown fine to medium-grained clean sand; moderate sorted rounded grains
45.0-47.0	Interbedded light brown medium-grained clean sand and grey medium-grained dirty sand; moderately sorted rounded grains
47.0-48.0	Light brown fine-grained dirty silty sand and fine gravel
48.0-49.0	Light brown medium-grained dirty sand and fine gravel with interbedded laminar grey clay; moderately sorted grounded grains

BASE TRANSPORTED COVER

49.0-50.0	Interbedded orange, pink and light brown fine-grained silty sand
50.0-51.0	Interbedded orange and grey very fine-grained silty clayey sands
51.0-53.0	Mottled and ferruginated rusty reddish brown/orange/grey silty clay
53.0-54.0	Mottled and ferruginated rusty reddish brown/orange/grey clay
54.0-57.0	Mottled and ferruginated reddish pink/orange/white sticky dense firm plastic clay
57.0-58.0	Creamy white mudstone with interbedded orange-brown clay and carbonaceous grey-black clay
58.0-60.0	Creamy white mudstone with interbedded carbonaceous grey-black clay
60.0-61.0	Whitish light brown very fine-grained clean soft sandstone

61.0-62.0	Creamy white silty sandy clay with red mottling and interbedded carbonaceous grey clay bands
62.0-63.0	Whitish light brown very fine-grained soft dirty sandstone with interbedded grey-black carbonaceous bands
63.0-64.0	Very hard white silcrete with red and orange mottling and dendritic black manganese striations
64.0-66.5	Very hard white dolomitised fine-grained sandstone with red and orange mottling and dendritic black manganese striations
66.5-68.0	White very fine-grained clean sandstone
68.0-70.0	White very fine-grained clean sandstone with maroon mottling and iron staining
70.0-73.0	Interbedded white very fine-grained sandstones and siltstones with much maroon mottling and iron staining
73.0-75.0	Creamy white siltstone with maroon mottling and iron staining
75.0-76.0	Interbedded creamy white very fine-grained sandstones and siltstones with maroon mottling
76.0-77.0	Interbedded creamy white very fine-grained sandstones and siltstones with maroon mottling and iron staining
77.0-78.0	White very fine-grained sandstone with orange, red maroon mottling and iron staining
78.0-79.0	Interbedded yellow-brown very fine-grained sandstones and siltstones with orange and purple mottling
79.0-80.0	Interbedded light brown very-fine-grained clean sandstone and light brown siltstone with orange mottling.
80.0-81.0	Interbedded light brown very-fine-grained clean sandstone and light brown siltstone with red and orange mottling.
81.0-85.0	Interbedded light brown very fine-grained sandstone and light brown siltstone with orange mottling
85.0-88.0	Interbedded light grey brown very fine-grained sandstones and siltstones with orange mottling
88.0-89.0	Interbedded light grey brown very fine-grained sandstones and siltstones with orange and purple mottling
89.0-90.0	Greenish grey very fine-grained soft sandstone with minor orange mottling
90.0-94.0	Interbedded greenish grey very fine-grained soft sandstone and soft mustard siltstone with minor very fine grained sand
94.0-95.0	Soft light brown grey fine grained dirty sandstone with minor laminar interbedded mustard and purple siltstones
95.0-96.0	Mustard siltstone with minor very fine-grained sand and interbedded grey fine-grained soft laminated sandstone
96.0-97.0	Interbedded grey brown very fine-grained soft sandstone and mustard siltstone
97.0-98.0	Interbedded grey brown, purple and mustard siltstones
98.0-99.0	Interbedded grey brown and mustard siltstones
99.0-100.0	Carbonaceous blue-grey siltstone
100.0-101.0	Interbedded carbonaceous grey-brown siltstone and grey very fine grained dirty sandstone
101.0-102.0	Grey fine-grained sandstone with laminar interbedded brown siltstone and dolomite bands with red mottling
102.0-103.0	Blue grey very fine-grained dirty sandstone with laminar interbedded mustard and brown siltstones and dolomite bands with purple mottling
103.0-104.0	Dark grey fine-grained dirty sandstone with interbedded mustard and brown siltstones and dolomite bands
104.0-105.0	Dark grey fine-grained dirty sandstone with interbedded mustard and brown siltstones and dolomite bands
105.0-106.0	Grey fine-grained dirty sandstone with minor interbedded orange and brown siltstones
106.0-107.0	Grey fine-grained dirty sandstone with minor laminar interbedded brown siltstone
107.0-108.0	Interbedded grey fine-grained dirty sandstone and brown siltstone
108.0-109.0	Interbedded grey and grey-brown carbonaceous siltstones with minor fine-grained sand
109.0-112.0	Interbedded grey and grey-brown carbonaceous siltstones
112.0-113.0	Carbonaceous siltstones with minor very fine-grained laminated sandstone

113.0-115.0	Interbedded grey and brown carbonaceous siltstone

BASE WEATHERING

115.0-120.8	Carbonaceous grey-blue siltstone

Hole 42220140 Lines 7 & 20

0-1.0	Light brown sandy loam
1.0-2.0	Multicoloured iron stained silcrete
2.0-4.0	Predominantly white iron stained silcrete
4.0-6.0	hard interbedded white very fine grained sandstone and silicified siltstone
6.0-11.0	Hard interbedded silicified white siltstone and white very fine grained sandstone with red mottling
11.0-15.0	White, very fine-grained sandstone and kaolinite
15.0-20.0	Interbedded light brown and white very fine grained maroon/iron stained sandstones and siltstones
20.0-24.5	Interbedded maroon stained very fine grained sandstone and white siltstone
24.5-28.5	Interbedded orange mottled light brown very fine grained sandstones and siltstones
28.5-29.5	Light grey-purple very fine grained dirty sandstone with black carbonaceous bands
29.5-30.0	Interbedded orange mottled purple light grey very fine grained sandstone and yellow siltstone
30.0-31.0	Interbedded orange-yellow very fine grained dirty sandstone and finely bedded light grey very fine grained sandstone with orange mottling
31.0-32.0	Interbedded white and orange-yellow very fine grained finely bedded sandstones
32.0-33.2	Light brown mustard very fine-grained sandstone with brown iron staining and mottling
33.2-34.0	Interbedded light brown-white very fine grained sandstones and siltstones
34.0-35.0	Interbedded medium brown very fine-grained sandstones and siltstones with white silcrete bands
35.0-37.0	Medium brown siltstones with minor very fine-grained sand and minor orange mottling
37.0-38.2	Interbedded white very fine-grained sandstone and medium brown mustard and purple siltstones with minor orange mottling
38.2-38.5	Very light brownish white siltstones with minor very fine grained sand
38.5-42.0	Greyish brown finely laminated mudstones and siltstones
42.0-47.0	Pale brownish grey and pale greenish grey interbedded fine sandstones and siltstones
47.0-48.0	Grey siltstones and mudstones with yellowish brown slightly ferruginised very fine sandstone bands
48.0-49.0	Brownish grey very fine sandstone with grey siltstone bands
49.0-50.0	Yellowish brown very fine sandstones and siltstones with minor dark purple thin hard ironstone bands
50.0-51.0	Pale brown interbedded fine sandstones and siltstones
51.0-52.0	Banded pale grey yellowish brown and pale green grey fine sandstone
52.0-53.0	Pale greenish grey fine sandstone with siltstone bands and trace of mica
53.0-54.5	Yellowish brown fine sandstone with grey siltstone bands
54.5-57.0	Bluish grey finely laminated siltstones and mudstones with dark brown carbonaceous siltstone bands

Hole 42220159 Lines 5 & 20

0-0.5	Reddish brown sandy clay loam
0.5-2.0	Light brown clayey sand
2.0-3.0	Light brown dirty fine cemented sand
3.0-3.5	Reddish brown dirty fine cemented sand with fine to medium poorly sorted waterworn gravel
3.5-4.0	Light brown dirty fine cemented sand with fine to medium poorly sorted waterworn gravel

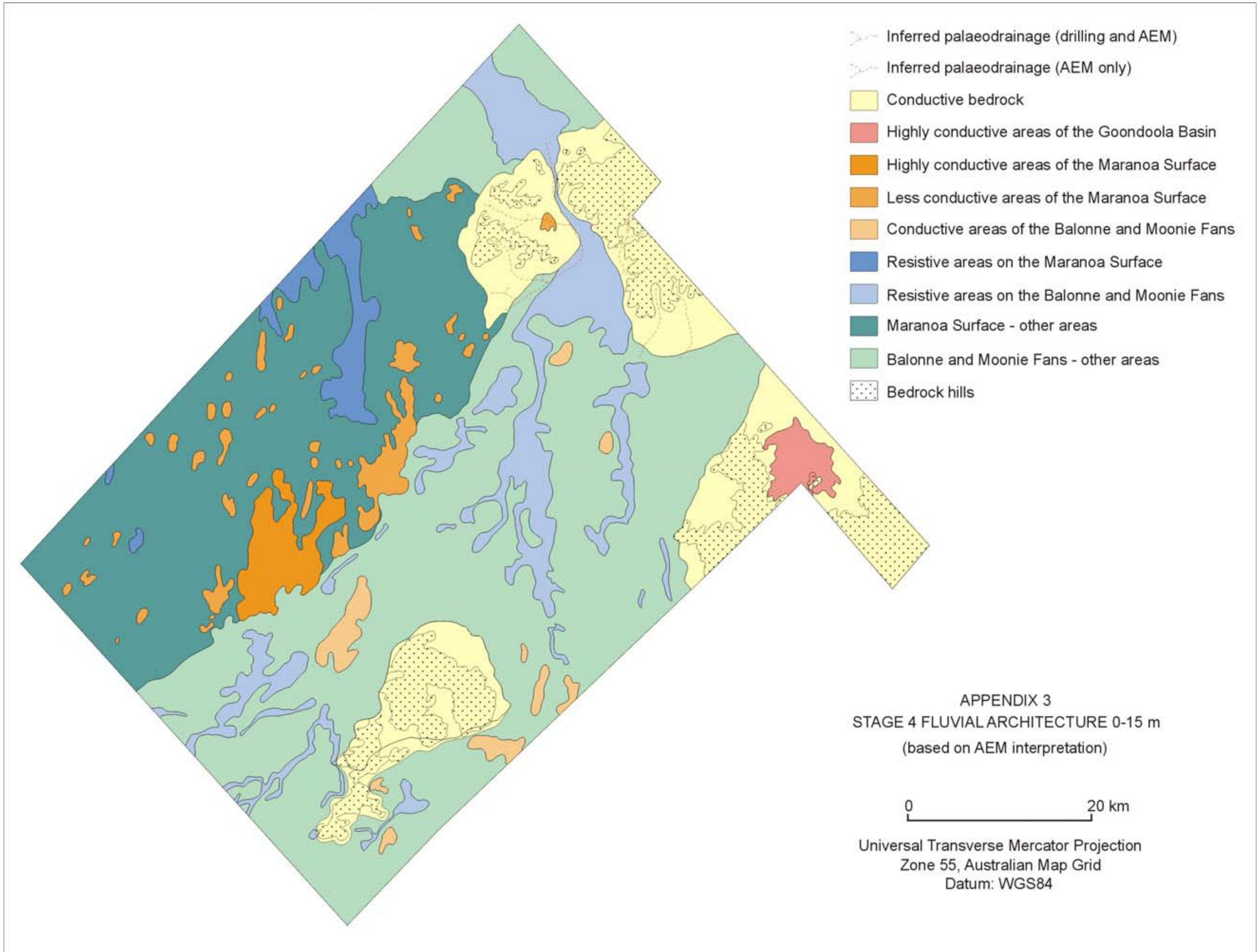
4.0-9.0	Light brownish white semi-consolidated fine and with grey silty clay bands and medium to coarse poorly sorted waterworn gravel

BASE TRANSPORTED COVER

9.0-10.0	Interbedded white and pink stained very fine sandstones, siltstones and kaolinite
10.0-11.0	Interbedded white and pink stained very fine sandstones, siltstones and kaolinite with blood red iron staining
11.0-15.0	Interbedded white pink stained and light grey very fine sandstones, siltstones and kaolinite with minor orange mottling
15.0-16.5	Interbedded white, pink stained, light brown and reddish brown very fine sandstones and siltstones with minor reddish pink mottling
16.5-17.5	Interbedded white and orange-white clean soft very fine sandstones
17.5-19.0	White clean soft fine sandstone
19.0-20.5	Light brownish white clean very soft fine sandstone
20.5-21.0	Light brownish grey siltstone with orange mottling
21.0-22.0	Interbedded brown and grey siltstones with minor very fine sand and minor orange mottling
22.0-23.6	Brown siltstone
23.6-25.0	Interbedded orange mottled brown siltstone and orange-brown sandy siltstone
25.0-26.0	Brown siltstone with minor orange mottling
26.0-27.0	Brown siltstone with minor orange mottling and laminar reddish brown siltstone interbeds with minor very fine sand
27.0-28.0	Interbedded light brown and orange siltstones with minor very fine sand
28.0-29.0	Interbedded very light brown grey and orange soft silty sandstones
29.0-31.0	Interbedded very light brown grey and orange soft silty sandstones and reddish black siliceous bands
31.0-32.0	Very light brown siltstone with reddish black siliceous bands
32.0-33.0	Interbedded very light brown siltstone and hard dark brown siltstone
33.0-34.0	Interbedded very light brown and orange siltstone with minor very fine sand
34.0-37.0	Interbedded grey and orange siltstones with minor very fine sand
37.0-39.0	Grey siltstone with minor laminar orange siltstone interbeds
39.0-40.0	Interbedded grey siltstone with lighter grey sandy siltstone with minor laminar orange siltstone interbeds
40.0-42.0	Interbedded orange and greyish brown siltstones
42.0-44.8	Interbedded grey and orange-brown siltstones with minor very fine sand

BASE SAPROLITE

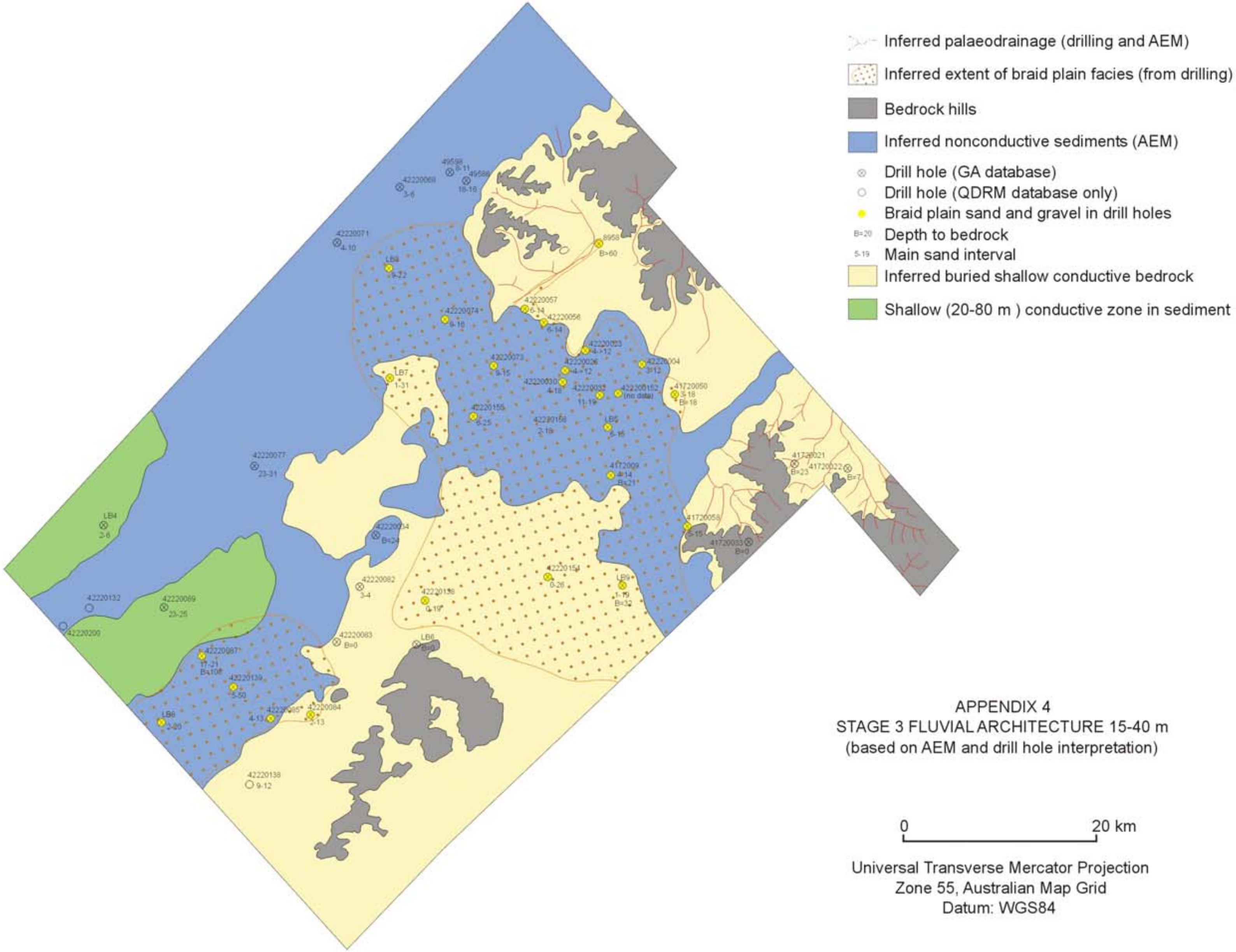
44.8-51.8	Blue siltstone with minor very fine sand



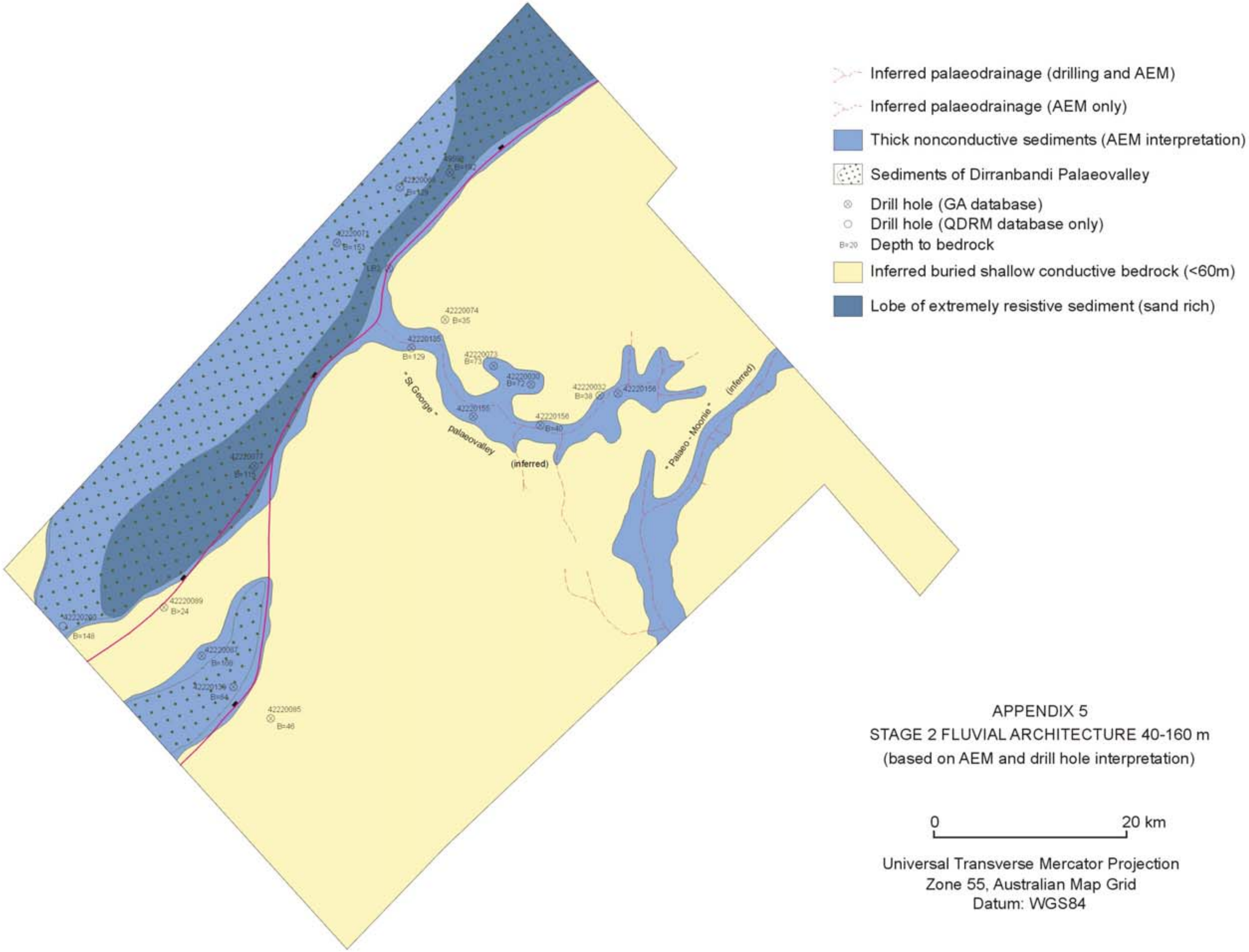
APPENDIX 3

STAGE 4 FLUVIAL ARCHITECTURE 0-15 m

(based on AEM interpretation)



APPENDIX 4
STAGE 3 FLUVIAL ARCHITECTURE 15-40 m
(based on AEM and drill hole interpretation)



APPENDIX 5
STAGE 2 FLUVIAL ARCHITECTURE 40-160 m
(based on AEM and drill hole interpretation)

0 20 km

Universal Transverse Mercator Projection
Zone 55, Australian Map Grid
Datum: WGS84