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THE UNIVERSITY OF ADELAIDE

ASPECTS OF THE GEOLOGY
OF THE STUART CREEK AREA,
NORTH OF LAKE TORRENS,
SOUTH AUSTRALIA.

by

Michael F. Vnuk, B.Sc.

December, 1978

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This thesis is submitted as partial fulfilment of the requirements for the Honours Degree of Bachelor of Science in Geology at the University of Adelaide.

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ABSTRACT

An area to the north of Lake Torrens, encompassing the newly proclaimed Stuart Creek Precious Stones Field, was studied, with particular reference to the opal-bearing Cretaceous sediments.

The pre-Mesozoic basement consists of Adelaidean rocks of the Wilpena Group in the east, separated from Lower Cambrian rocks by the Arthur Fault.

The relatively flat-lying Cretaceous sequence consists of two mappable units. The lower unit, called the "Stuart Creek Beds" in this thesis, is probably a transitional unit marking the transgression of the Lower Cretaceous sea. The early Aptian Marree Formation comprises bioturbated brown montmorillonitic muds with sandy and conglomeratic beds more prominent near the base. Scattered "erratics" occur. The original sediment, deposited in a marginal marine environment was black, pyritic and carbonaceous. It has been affected by a number of weathering events during the Tertiary. The uppermost portion has been very heavily weathered and bleached. Only a thin remnant exists now, due to erosion prior to Tertiary deposition.

The Tertiary sediments are mostly sands with some clays, silts and limestones. Milky quartz pebbles are a common characteristic. The sediments are non-marine, dominantly fluviatile. Silicification is common but variable. The sequence is correlated with the Mount Sarah Sandstone of Miocene age.

Opal, occurring throughout the area, is believed to have formed associated with silicification of the Tertiary. The precious opal is notable in that it occurs within relatively fresh sediments, rather than highly weathered rocks as elsewhere in South Australia. Precious opal is only found on the Field, but all the Cretaceous must be considered potentially opal-bearing until further work is done.

CONTENTS

	Page
ABSTRACT	
INTRODUCTION	
Location and Access	1
Previous Investigations	1
Aims and Method of Study	2
REGIONAL GEOLOGY	3
STRATIGRAPHY	
Pre-Mesozoic	5
Cretaceous	
Introduction	8
"Stuart Creek Beds"	9
Marree Formation	13
Tertiary	19
POST-DEPOSITIONAL ALTERATION	21
OPAL	
Opal Types and Occurrence	27
X-ray Diffraction Studies	29
Discussion	29
SUMMARY AND CONCLUSIONS	31
REFERENCES	33
ACKNOWLEDGMENTS	35
APPENDIX A: Photomicrographs	
APPENDIX B: Thin Section Descriptions	
APPENDIX C: Bulk and Clay Fraction Mineralogy	

List of Tables and Figures

Table 1	S.C.C. 19 - silicate analysis, bulk mineralogy and clay fraction mineralogy	Following page 22
Table C1	Bulk and clay fraction mineralogy	Appendix C
Figure		Following page
1a	Locality Map	1
1b	Mesas	1
2a	"Stuart Creek Beds" - Yarra Wurta Dam section	9
2b	"Stuart Creek Beds" - basal lithologies	9
3a	"Stuart Creek Beds" - clay clast conglomerate	10
3b	"Stuart Creek Beds" - sands with wood fragments	10
4a	Marree Formation - brown muds	14
4b	Lower Marree Formation, exposed in bulldozer cut	14
5a	Float derived from Marree Formation	15
5b	Bleached Marree Formation	15
6a	Tertiary/Cretaceous contact	19
6b	Tertiary sands	19
7a	Opals	27
7b	Opal from Stuart Creek	27
8a	Opal in situ - Charlie Swamp	28
8b	Opal Breccia - Charlie Swamp	28
9	Geological Map of the Stuart Creek Area (1:25000)	In pocket at back
10	Summary of level data from backhoe trenches, Calweld shafts and measured sections	In pocket at back
A1a	"Stuart Creek Beds" - basal lithology	Appendix A
A1b	Marree Formation - bioturbation	"
A1c	Close-up of bioturbation	"
A2a	Folds in opal	"
A2b	Opal from Andamooka	"
A2c	Opal from Andamooka	"

INTRODUCTION

Location and access

The study area lies to the north of Lake Torrens, nearly 700 km by road from Adelaide. (See Fig. 1a for Locality Map.) The area is dominated by several elongate north-south mesas, rising 30-40m above gently undulating plains (Fig. 1b). The ground slopes away to the south towards the lake margin, while to the north lies an extensive field of sand dunes, 5-10m high. The average rainfall is 125mm, but this is irregular. The native vegetation is sparse.

The study area encompasses the Stuart Creek Precious Stones Field (proclaimed in the Government Gazette of 16th March 1978) which lies in the northeastern corner of the map area. This can be reached by a four-wheel drive track from Andamooka, 55km to the south, or via graded station tracks from Farina. Major workings centre on a portion of a mesa ("Split Hill"*) and nearby in the valley. Several parties were active during 1978. Other abandoned opal diggings, including those near Yarra Wurta Cliff, occur outside the Precious Stones Field, mostly on mesa flanks. Another group of deserted opal diggings lies about 20km to the northeast at Charlie Swamp.

Previous Investigations

The area studied in this thesis was mapped on a regional scale by Johns (1966) for the ANDAMOOKA 1:250000 Geological Sheet and was reported briefly, in his summary of the ANDAMOOKA-TORRENS area (Johns, 1968).

Geological investigations by the South Australian Department of Mines in 1977 for the purpose of proclaiming a Precious Stones Field are reported in Barnes and Scott (1978). Their report also covers opal occurrence at Charlie Swamp and Yarra Wurta Cliff, besides Stuart Creek. All early references to opal in the area are included, (Brown, 1904, 1908; Howchin, 1919; Anonymous, 1949). In addition Barnes and Scott incorporate a summary of previous Department of Mines' investigations in the area, which had been conducted mainly as an adjunct to more detailed work at Andamooka. (Carr, et al., 1978 (geology and opal occurrence), Hannah and Lindsay, 1977 (micropalaeontology)).

*Names in inverted commas are informal and for this thesis only. Their location is shown on the map in the back pocket.

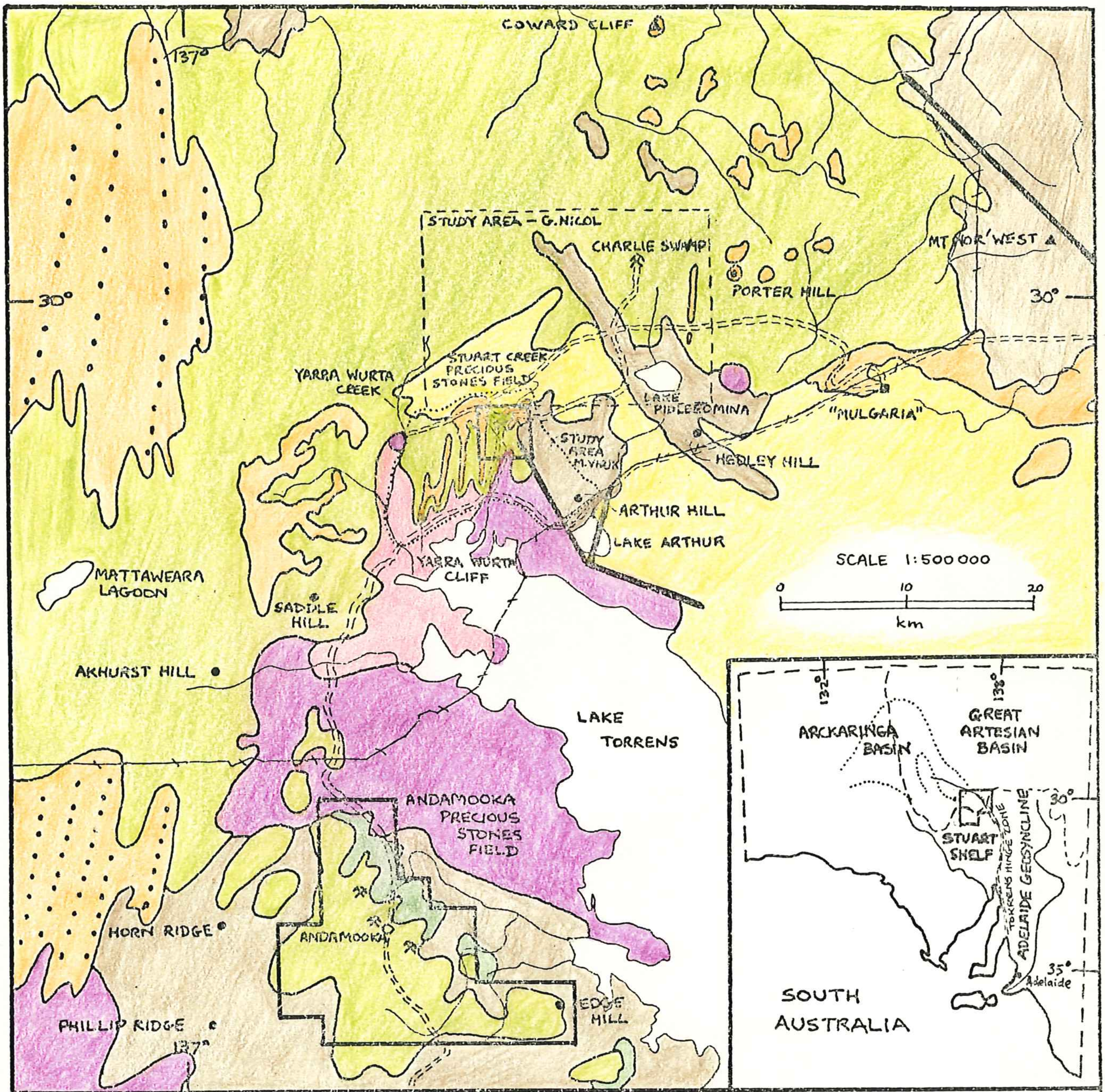


FIGURE 1a. LOCALITY MAP.

CAINOZOIC – Quaternary		Sand dunes and spreads. Not shown over older units.
CAINOZOIC – Tertiary		Mainly sands, variably silicified and ferruginized. Old ridge system (schematic).
MESOZOIC – Cretaceous		MARREE FORMATION: Brown and grey claystone with silt lenses. Sandy boulder beds near base.
MESOZOIC – Jurassic		ALGEBUCKINA SANDSTONE: Medium to coarse quartz sandstone. Pebbly sandstone.
PALAEOZOIC – Cambrian		YARRA WURTA SHALE: Red and green shales and siltstones.
		ANDAMOOKA LIMESTONE: Massive grey and brown limestone.
PRECAMBRIAN – Adelaidean		Quartzite, siltstone, shale, dolomite.

Fault Track Vermin Proof Fence

ADAPTED FROM BARNES AND SCOTT (1978). M.F. VNUK. 1978

Figure 1b   Mesas

View of mesas, looking west, from Farina turn-off. Yarra Wurta Cliff on left. White colouration on mesa flanks is bleached Marree Formation. Note very flat surface of the Tertiary capping on the mesas.

FIG. 1

b

Aims and method of study

This study is a follow-up to Barnes and Scott (1978). The main aims were to map the area of Cretaceous sediments (known to be opal-bearing in this area and elsewhere in South Australia) and to investigate opal occurrence. An area was chosen which contained mostly Cretaceous sediments, based on the ANDAMOOKA Geological Sheet (Johns, 1966). At the same time other aspects of the geology of the area were investigated including the Tertiary sequence and post-depositional alteration. Pre-Mesozoic basement was only cursorily examined.

For this project mapping was at a scale of 1:25000 using Department of Lands' aerial photography. The map, (Fig. 9) is included in the back pocket. All diggings in the area were examined and Charlie Swamp and Andamooka visited for comparison. Rock and opal samples were examined in the laboratory by thin sections and X-ray diffraction studies. Clay mineralogy and silicate analysis were determined for selected samples. Nearly thirty backhoe trenches, funded by the Department of Mines, supplemented the poor exposure. All backhoe trenches and other selected points were levelled by the Department of Mines.

A similar project covering an area to the north and northeast, including the Charlie Swamp diggings, was undertaken by Geoffrey Nicol (in prep.), also from the University of Adelaide.

Unless otherwise stated, all specimens referred to in this thesis are prefixed by an accession number, 546, and are held at the Geology Department, University of Adelaide.

REGIONAL GEOLOGY

This chapter is taken mostly from Johns (1968) and Parkin (1969). Refer also to the locality map (Fig. 1a).

The study area lies at the eastern margin of a stable region known as the Stuart Shelf. Upper Proterozoic equivalents of the Umberatana and Wilpena Groups overlie a concealed basement with an overall gentle dip to the north. Lower Cambrian sediments (limestones followed by red bed clastics) unconformably overlie the Precambrian sediments and form the oldest Stuart Shelf rocks in the study area. Dips are generally low.

The Stuart Shelf is separated from the more deformed Adelaide Geosyncline by a complex zone of faulting and folding named the Torrens Hinge Zone. In the study area this is represented by a major fault - the Arthur Fault of Murrell (1977). Cambrian sediments are downfaulted to the west while a broadly folded sequence of Wilpena and Umberatana Group sediments is exposed to the east.

The Permian Arckaringa Basin extended over parts of the northern Stuart Shelf but its limits are believed to be about 100km west of the study area.

Scattered non-marine sands of probable Upper Jurassic age appear to have filled in topographic depressions prior to a Lower Cretaceous marine transgression. Lower Cretaceous rocks contain sands and boulder beds passing up to mainly clays and claystone. The Upper Jurassic to Lower Cretaceous sediments form the southwestern margin of the Great Artesian Basin. It covers only the northern portion of the Stuart Shelf but thickens rapidly to the north where Upper Cretaceous non-marine sediments can also be found. All precious opal found at Andamooka and Stuart Creek has been within Cretaceous sediments, though this only sets a lower limit on its age of formation.

A break exists before the deposition of non-marine Tertiary sediments, again better represented in the northern part of the Stuart Shelf. Much of the Tertiary expresses itself as low arcuate silcreted ridges, centred on the Millers Creek area, and is best seen on aerial photographs. The mesas in the study area were probably developed by stream erosion channelled between these ridges. Though generally thin, the Tertiary sequence is quite thick beneath Lake Torrens which was subsiding during the Tertiary, perhaps due to rejuvenation of faults within the Torrens Hinge Zone.

Quaternary dune sands, lake sediments, alluvium and colluvium are thinly spread over much of the area.

During the Cainozoic and perhaps the Late Cretaceous a number of weathering and silicification events took place. They may or may not be related to each other and to opal formation.

STRATIGRAPHY

Pre-Mesozoic

The Precambrian and Cambrian sediments were only looked at briefly to establish the nature of their unconformable contact with the overlying Cretaceous sediments.

The Precambrian forms part of a large anticline of Umberatana and Wilpena Group sediments, of which the upper portion of the western limb lies in the eastern part of the study area. This comprises the Brachina Formation, the A.B.C. Range Quartzite and the Bunyeroo Formation. They have a general strike of northwest to northnorthwest, and a variable, usually moderate, dip to the west.

Only the upper part of the Brachina Formation, which consisted of poorly outcropping green and purple submicaceous siltstones, was inspected. This passes gradationally into the A.B.C. Range Quartzite. The more resistant lithology produces a prominent ridge, called the "Arthur Ridge" in this thesis. It differs from the mesas to the west, in that it is wider, is oriented subparallel to the Precambrian trends, rather than north-south, and is not capped by Tertiary sediments.

The quartzite is poorly outcropping, especially on the top of the "Arthur Ridge", which was mapped as Marree Formation by Johns in 1966, probably only on the basis of photointerpretation. A number of exposures, (e.g. near the southeast corner of the Precious Stones Field), show it to be thin bedded, white to grey quartzite, sometimes arkosic, interbedded with softer sandstones, siltstones and shales, that are more susceptible to erosion. Numerous sedimentary structures can be seen in the quartzite, including crossbedding, clay galls, ripple marks and synaeresis cracks, indicative of a very shallow water origin.

The structure is not always simple, and numerous folds were observed in the quartzite in some areas, which are probably related to the Arthur Fault.

Within the study area Johns (1966) had not mapped Bunyeroo Formation, believing the top of the A.B.C. Range Quartzite to be truncated by faulting. Murrell (1977) has mapped Bunyeroo Formation south of the study area in the Lake Arthur area. In this study probable Bunyeroo Formation was encountered in the northern part of the study area. Opal miners had deepened two bulldozer cuts below the basal boulder bed of the Marree Formation, exposing fissile red and green micaceous siltstone with fine laminations and crosslaminations. (See TS 546/17, in Appendix B.) When further exposed, (Backhoe Trench 101 (BHT 101)), bedding was measured and found to be consistent with the Precambrian structure, suggesting that these rocks belong to the Bunyeroo Formation. Subsequently, fragments of probable Bunyeroo Formation were found in the creek to the west. The Arthur Fault must then pass under "Split Hill" or to the west or die out.

Within the study area, Lower Cambrian rocks form the pre-Mesozoic basement for the area west of the Arthur Fault. However, they are only exposed in the southern half of the map area. The Cambrian sequence was defined and described by Johns (1968). He divided it into two formations: the Andamooka Limestone and the Yarra Wurta Shale, which he equates with the Ajax Limestone and the Billy Creek Formation of the Adelaide Geosyncline.

The Andamooka Limestone consists mostly of limestones and dolomites, commonly grey, brown, or yellow-brown. The limestones are laminated to massive, sometimes sandy, and with thin clastic interbeds. The base is truncated by the Arthur Fault to the east. However, Johns considers that a fairly complete section is exposed with a thickness of approximately 300m. The Andamooka Limestone is upturned near the fault, producing dips of 30° or more. It rapidly shallows and most of the limestone is dipping a few degrees to the west.

Features of the limestone include intraformational breccias, ooidstones (often silicified) and chalcedonic nodules. These nodules can be red, yellow, black, white or grey and are commonly banded or concretionary. They can be referred to as poor quality, coarse-grained agate, (see Crettenden and Barnes (1978)). They weather out of the limestone, of which they are a good indicator where outcrop is poor. They are especially common south of the Field. The limestone also contains Archaeocyatha. In fact, the first undoubted Cambrian rocks, west of Lake Torrens, were recognised by Archaeocyathinae fragments, found in bore chippings from the now abandoned Yarra Wurta Bore (Jack, 1926). Unfortunately, the location of the bore is not known accurately.

The uppermost Andamooka Limestone contains stromatolites, as exposed where the road crosses the creek, west of the Farina turn-off, between TBM 466 and 483 (TBM: temporary bench mark). An example is figured in Johns (1968) Plate XIII, Fig. 2.

A gradational contact with the overlying Yarra Wurta Shale is exposed nearby. The Yarra Wurta Shale is a sequence of red-brown, pale green and yellow brown shales and siltstones, which are often micaceous and calcareous. The rocks are fissile and thinly bedded, and often show good laminations, crosslaminations and ripple marks - for example, in creek exposures on the Andamooka track near TBM 486 and 487. Sandy beds and shale chip conglomerates were also seen. Outcrop is variable but usually subdued. The beds are gently undulating, with the dip and strike quite variable even over short distances. It is quite possible that small-scale faulting exists in the Yarra Wurta Shale and the underlying Andamooka Limestone. Johns (1968) records a thickness in excess of 100m, though the top is eroded. The uppermost Yarra Wurta Shale is commonly softened by weathering.

The Cambrian probably developed its present structure when the Arthur Fault was active, (during the Cambrian (Murrell, 1977)). A possible basin is indicated on the ANDAMOOKA geological map. Subsequent erosion cut across the tilted Cambrian sediments, producing a surface of low relief, as evidenced by outcrop, level data and photointerpretation.

Cretaceous

Introduction

Cretaceous sediments are present over much of the central and northern portion of the study area. Tertiary and Quaternary cover reduces the exposure while the nature of the Cretaceous itself, mostly soft mudstones, means that outcrop is poor, and useful sections minimal. The upper portion found on the flanks of the mesas is commonly weathered and silicified which detracts from the better exposure. (The effects of weathering and silification of the Cretaceous sediments are discussed in a later chapter.) Excellent exposures produced by the activities of opal miners - Calweld shafts, bulldozer cuts and backhoe trenches - are unfortunately concentrated in one small area. A series of nearly 30 backhoe trenches were dug to obtain additional information.

Two mappable units were recognized in the Cretaceous during this study. The lower unit was not recognized by Johns (1966) in his regional map due probably to the paucity of outcrop and scale of his map. It was previously recorded in one Calweld shaft by Barnes and Scott (1978), but this was not enough exposure to assign a confident age.

For the purposes of this study the lower unit is referred to as the "Stuart Creek Beds". The age and correlatives of this unit are discussed after a more detailed description of the unit.

The upper unit was mapped as an equivalent of the lower part of the Marree Formation by Johns (1966, 1968) and this usage is maintained in this study. Its age and lithology allow it to be correlated with both the Marree Formation of Forbes (1966) and the Bulldog Shale described from the Oodnadatta area by Freytag (1966). Though the Bulldog Shale is equivalent to the lower part of the Marree Formation, the term Marree Formation is preferred due to the proximity of the type section.

The Cretaceous sediments lie unconformably upon Cambrian or Precambrian rocks. The unconformity surface is relatively flat with total relief of less than 20m. The basement appears to be higher near the southern ends of the mesas and slopes away to the north. Basement also rises to the west - probably in relation to the ancient fault scarp of the Arthur Fault. The unconformity surface appears to be somewhat more irregular over the Andamooka Limestone - understandable in view of the modern rugged outcrop.

The "Stuart Creek Beds" are not present on the basement highs and appear to be confined to topographic lows. The two known areas of occurrence are near Yarra Wurta Dam (in the northeast corner of the map area) and in the south central part of the Precious Stones Field and to the south. Sedimentation was probably continuous between the two areas and it may be present elsewhere (e.g. between "First Mesa" and "Second Mesa"). However, the unit was only adequately recognized late in the study, when sufficient exposure was obtained using the backhoe, and time did not permit revisiting all localities with this new unit in mind.

"Stuart Creek Beds"

The "Stuart Creek Beds" comprise a number of lithologies and description of several sections will serve to illustrate the features of this unit.

The thickest measured section comes from S.C.C. 16, a Calweld shaft located near the southern margin of the intensively worked area of the Field and logged by Barnes and Scott (1978). (Note: all Calweld shafts logged by Barnes and Scott are prefixed by S.C.C. Relevant shafts are marked on the map, Fig. 9)).

The section is nine metres thick, though the base was not penetrated. The bottom two metres of the shaft is within a stiff red-brown (with pale green patches) slickensided mud containing scattered sand grains and small clasts, mostly shale, (angular and rounded, generally <5mm across). Glauconite* occurs as small (<0.5mm) irregularly distributed grains. (See Fig. 2b.) It passes up gradationally into approximately 50cm of similar mud, but pale green in colour, due probably to the oxidation state of iron. A thin section of the red material shows it to have a very disrupted appearance with just a hint of possible bedding. (TS 546/2, Appendix B and Fig, A1a, Appendix A.)

This is overlain by approximately six metres of mainly white to yellow friable clayey sands and silts with pebbles and cobbles, and some grey clay beds. The clasts are distributed irregularly; in places they are close-packed while in others they are rare. They comprise quartzite, sandstones and some shale clasts, and vary from rounded to angular.

The top 40cm of the section is a pale grey brown, clayey silt to fine sand containing abundant very dark brown wood fragments.

An irregular, possibly channelled, contact exists with the overlying boulder bed, basal to the Marree Formation.

At Yarra Wurta Dam a section is exposed (Loc. F11) near the northwest corner of the dam where an overflow channel has deepened an old creek bed. Approximately six metres is present though the upper portion is poorly exposed and the base unexposed. (See Fig. 2a.)

*Identified by XRD.

Figure 2a "Stuart Creek Beds" - Yarra Wurta Dam section

Lower portion, looking west Probable regolithic or reworked Yarra Wurta Shale (red) overlain by pale green clay clast conglomerate, with thin, crossbedded and gypsified sand beds. (Rounded quartzite fragments derived from nearby Marree Formation can be seen near the top).

Figure 2b "Stuart Creek Beds" - basal lithologies

Left: Taken from near base of S.C.C. 16.
Note the very mixed nature of the rock, containing assorted clasts, sand grains and glauconite grains in reddish clay.
Probable reworked Yarra Wurta Shale with other detritus that has been exposed to some marine influence.
(Colour poorly reproduced).
(See thin section description (TS 546/2) in Appendix B).

Right: Taken from near base of Yarra Wurta Dam section. (See Fig. 2a).
Portions of this silty red clay show good laminations whereas other parts are disturbed or contain clasts (e.g. bottom right-hand corner). Probable reworked or regolithic Yarra Wurta Shale.

Similar lithologies found elsewhere.

FIG. 2

a

b

The lowest rock-type is again a stiff slickensided red-brown clay with clasts and occasional pale green patches. Glauconite is absent. Samples from near the base show what appear to be patches, up to a few centimetres across, of well-laminated reddish shales and siltstones, sometimes deformed, in a structureless red clay matrix. This is strongly suggestive of partly reworked Yarra Wurta Shale or at least a regolith developed on the shale. An example is shown in Fig. 2b.

Approximately 50-70cm of red-brown material is exposed which passes upwards into a pale green to grey, clay clast conglomerate, with sand bands, approximately 1.8m thick. The clay clasts are generally pale green ranging in size from less than 1mm to about 2cm. They are commonly rounded and flattened in shape. The Yarra Wurta Shale is the most obvious source of the clasts. The matrix is grey to pale green silty clay. Figure 3a shows a typical example.

Within this unit there are three sand beds, generally about 10cm thick. However, thickness varies somewhat, since they are crossbedded, often in a herringbone pattern, suggesting a tidal environment. The sandstones consist of dominantly well-sorted quartz sand ranging in size from coarse to fine. Roundness varies from subangular to very well-rounded, probably indicative of many sources including, perhaps, aeolian. Pale green clay is also present and some small clay clasts, especially between the sandy laminae. The two lower sand beds are strongly gypsified, filling in the original porosity.

The clay clast conglomerate passes gradationally over about 10cm, into a dark brown silty clay with abundant very dark brown to black wood fragments. This unit is poorly exposed. Digging shows that the unit is fairly similar up sequence, with perhaps some sand or silt interbeds but always with characteristic wood fragments. This unit is 4m thick and is succeeded by the Marree Formation. No major break is indicated, though exposure is poor.

North and south of the dam similar wood-bearing muds, clast-rich conglomerates and sands can be found, poorly exposed beneath the Marree Formation.

The sections at Yarra Wurta Dam and S.C.C. 16 can be grouped together on the basis of partially similar lithologies. The same lithologies (with a few variations) were found in backhoe trenches in the southern part of the Precious Stones Field and to the south. Though limited sections only were obtained, the association of the various lithologies in different combinations allows one to confidently group them all into the one packet of sediments beneath, and distinct from, the Marree Formation. For instance, the inter-relationship

Figure 3a "Stuart Creek Beds" - clay clast conglomerate

Pale green to grey, clay clast conglomerate. Abundant clasts commonly rounded within a slightly silty clay matrix. Sample from Yarra Wurta Dam section. (See Fig. 2a).

Figure 3b "Stuart Creek Beds" - sands with wood fragments.

Pale brown, generally well-rounded, fine to medium-grained quartz sands with common lignitic wood fragments, often concentrated in certain layers. (BHT 118A, 2.4m).

FIG. 3

a

b

of the clay clast conglomerate and the brown sands and silts, with wood fragments, was clearly demonstrated in BHT 118A, where small lenses of the conglomerate were present within a sequence of wood-bearing sands, silts and clays showing bedding and low angle cross-stratification. A sample of wood-bearing sand is shown in Fig. 3b.

A further lithology was also exposed in BHT 102, 115, 116 and 117 - poorly bedded green clays, silts and sands with some quartzite pebbles. Colour variations were common.

Though the base was never penetrated, it appears that the red-brown clay with clasts is the common basal lithology of the "Stuart Creek Beds". This corresponds with its possible mode of origin - regolithic or slightly reworked Yarra Wurta Shale, with perhaps some marine influence. Furthermore, at some sites Andamooka Limestone outcrops were only a few metres away. The other lithologies are believed to represent the many facies that could occur in an area that is undergoing a transgression. The cross bedded sands of the Yarra Wurta Dam seem to point to some coastal process, while the presence of glauconite implies marine influence. A rapidly changing environment of lagoons, beach, swamps, and perhaps rivers is envisaged.

Clay mineralogy determinations were made for four samples from the "Stuart Creek Beds". These are tabulated in Appendix C. F11/H comes from the base of the Yarra Wurta Dam while 122 comes from near the base of S.C.C. 16. (Examples are shown in Fig. 2b.) F11/I is a clay clast conglomerate from Yarra Wurta Dam (as in Fig. 3a) and 105 is a silty fine sand with wood fragments from S.C.C. 16, just below the Marree Formation. Samples were dominantly mica/illite with kaolinite subdominant or accessory, except 105 where the reverse occurred. The dominance of mica/illite is to be expected since the samples contained shale clasts. The kaolinite is probably derived from the weathering that would have occurred prior to Cretaceous sedimentation. Using these limited samples, the mica/illite-rich "Stuart Creek Beds" can be easily differentiated from the dominantly montmorillonitic Marree Formation.

Samples of wood-bearing, dark brown to dark grey clay from BHT 118A were submitted to the Department of Mines in the hope that if any spores, pollen or foraminifera were present they might give some indication as to the age of the unit. Unfortunately the samples were barren, leaving the age of the "Stuart Creek Beds" open to some speculation. It is obviously younger than Early Cambrian, but not younger than Aptian (the age assigned to the Marree Formation at Stuart Creek). However, from the nature of its occurrence, as a thin unit not present on basement highs, with mixed lithologies, and with no marked break before the Marree Formation, the evidence suggests that it is a transitional unit, deposited prior to the onset of fairly uniform marine conditions that produced the Marree Formation. A Late Jurassic to Early Cretaceous age can then be proposed.

Using this age, equivalents within the Great Artesian Basin could include the Algebuckina Sandstone and the overlying Cadna-owie Formation both fully described from the Oodnadatta area by Wopfner et al., (1970). However, the Algebuckina Sandstone, and the equivalent Village Well Formation from the Marree area (Forbes, 1966) are dominantly sandstones and appear to be non-marine. They are considered not to correlate with the "Stuart Creek Beds". The Neocomian to early Aptian Cadna-owie Formation is described as a transgressional unit from its type area, comprising mostly sandstone. However, there is some quite marked variation, which could perhaps be accentuated closer to the basin margin, i.e. in the study area, to produce the "Stuart Creek Beds". The equivalent from the Marree area is the Pelican Well Formation, and again, given the transitional nature of the units involved, correlation on the basis of lithologies (in the absence of biostratigraphy) though suggestive, is not definite.

A further possibility is that the "Stuart Creek Beds" are really a basal member of the Marree Formation, since Forbes (1966) has defined two such units from the Marree area. The Trinity Well Sandstone Member is a basal sand, while the Wilpoorinna Breccia Member is a bouldery slate-pebble breccia, which Forbes considers to have formed during the later stages of transgression over basement highs. Again, the Wilpoorinna Breccia Member has some similarities to the "Stuart Creek Beds", especially to the clay clast conglomerate lithology. However, the author feels it wrong to correlate simply on the basis of lithology which, in these cases, could be so easily influenced by local basement outcrop at the time of deposition.

Thus, the "Stuart Creek Beds" are left as a transgressional unit, either below or at the base of the Marree Formation, Neocomian to early Aptian in age.

Marree Formation

The Marree Formation succeeds the "Stuart Creek Beds" with only a short break in sedimentation. It consists of poorly bedded, commonly bioturbated moist brown muds with thin sandy and conglomeratic beds plus scattered "erratics". Yellow alunite/jarosite veins are a common feature. Originally the Marree Formation was probably a black pyritic, carbonaceous mud - this is discussed further in the chapter on post-depositional alteration.

Within the study area the Marree Formation has a larger areal extent than the "Stuart Creek Beds". Prior to erosion, the Marree Formation extended across the northern two-thirds of the map area and probably in the south as well, but there erosion has proceeded below the basement contact. Sedimentation may have been continuous to Andamooka. Well to the north, northeast and northwest of the study area the Marree Formation gradually thickens into the Great Artesian Basin proper. To the east erosion has removed all trace of Cretaceous sedimentation. The Marree Formation thins rapidly across the Arthur Fault as the basement rises. The lower boundary of the Marree Formation appears to slope gently from south to north.

The maximum thickness of the Marree Formation present is approximately 30m as determined from shafts and level data, however the upper contact is erosional and one can only speculate on the original thickness. The upper unconformity is relatively flat in the south but becomes irregular to the north, where relief of over 10m is indicated.

As stated before, outcrop is generally poor and the upper, better outcropping sections of the mesa flanks are weathered and silicified. Most observations came from freshly exposed material in the worked area of the Precious Stones Field.

The dominant lithology of the Marree Formation, comprising at least 80% of the sequence, is a moist brown mud, i.e. clay, with a variable content of silt to fine sand-size quartz grains, with rare mica flakes, feldspar grains, heavy minerals, chert and rock fragments. Scattered "erratics" occur. The remainder consists of silts, sands and conglomeratic beds. No carbonate was observed.

Clay analysis of fresh brown muds show the less than two micron size fraction to comprise 50-60%. This is dominantly montmorillonite with kaolinite subdominant or as an accessory. Mica/illite and quartz are present in trace amounts. A more detailed analysis in Barnes and Scott (1978) shows the clay to approach the composition of a sodium bentonite different from the calcium bentonite recorded elsewhere in the Marree Formation of the Great Artesian Basin. The mud alters rapidly on exposure, a feature discussed in a later chapter.

A further characteristic of the Cretaceous muds, within the study area, is a distinctive texture which is most probably due to bioturbation. This can be seen in Fig. 4a, and also, as photomicrographs in Appendix A, Fig. A1b and Fig. A1c. It consists of small elongate streaks up to about 2mm or more in length but generally less than 0.3mm thick. These patches are roughly parallel but occasionally have curved or irregular shapes. In hand specimen they are generally lighter than the muddy matrix but may be darker. A thin section shows them to contain less iron oxides and silt than the surrounding sediment while the margins are sometimes slightly darker due to concentration of iron oxides. This type of bioturbation is quite common. It is best seen in fresh muds but can occasionally be picked out in weathered material. It forms a useful criterion for assigning a rock to the Marree Formation.

Bedding is not always obvious on a small scale. Microscopically the muds show partial bulk extinction implying sedimentation in a quiet environment. Compaction has probably enhanced this effect. When present the characteristic bioturbation roughly defines bedding. Thin silt lenticles are often present. Though variable, they commonly define small graded units a few centimetres thick, silty at the base and rapidly grading up to mostly clay.

As mentioned before beds composed mostly of silt and sand occur. Bedding tends to be better developed, especially if there is some interbedding with clayey units. Sand beds are rarely more than 30cm thick. A sand bed is exposed in Fig. 4b.

The presence of conglomeratic beds and "erratics" is another very distinctive characteristic of the Marree Formation in the study area. Elsewhere, though present towards the base, they are not always as well-developed. Conglomeratic beds range from a metre thick down to isolated pebbles which appear to lie on the same bedding surface. "Erratics" may represent an even more thinly dispersed conglomerate or they may be unrelated. Conglomeratic beds are generally 5-20cm thick and contain clasts of variable size. The matrix is generally sandy and silty with varying amounts of clay. They have a sharp base while the upper contact grades rapidly into sandy silts, then muds. Such graded muds with a basal conglomerate are usually 0.5-2m thick and are well-exposed in some bulldozer cuts.

Conglomeratic beds are often indurated or ferruginized, probably due to the sharp change in properties above and below the basal contact. Clasts rarely lie directly on the underlying mud; a thin layer of matrix (a few millimetres thick) is usually present. Clasts sometimes deform the underlying mud, however this could be due solely to compaction. Sediment draping can also be found. Similar structures were occasionally observed associated with "erratics".

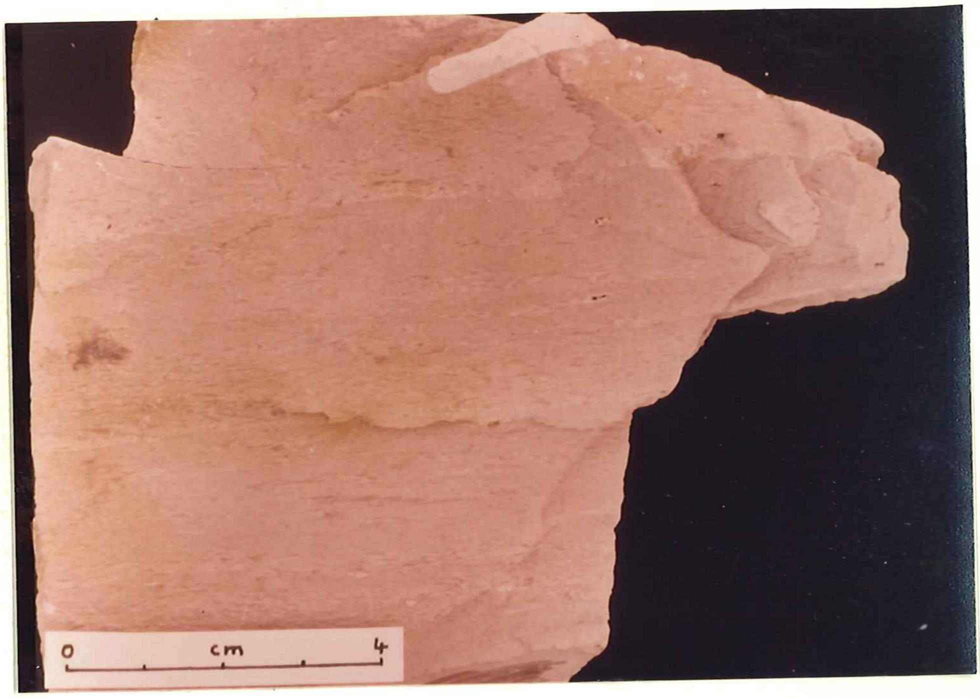
Figure 4a Marree Formation - brown muds

Typical mud, consisting mostly of clay with disseminated silt and fine sand. Silt sometimes forms a sharp base to fining-up sequences that rapidly grade up to mostly clay. Sample contains the characteristic bioturbation of the Marree Formation - small generally elongate streaks with somewhat variable shape. Mostly subparallel, roughly defining bedding. Note also an "erratic"; a bleached siltstone clast, rounded and flattened.
Sample has dried and colour reproduction is poor, but when fresh, the sample is medium to dark brown and moist.

Figure 4b Lower Marree Formation, exposed in bulldozer cut

Bulldozer cut, north of S.C.C. 16, northern wall.
Marree Formation a few metres above base. (Basal boulder bed is exposed in S.C.C. 16). Sand beds, as exposed here, are not a common feature of the Marree Formation. Pebbles and cobbles can be seen in the lowest sand bed, and also below. The typical brown muds have cracked and turned grey due to exposure. Note the extensive development of powdery yellow alunite in numerous joints and fractures. Gypsum veins are also present but are less common and less obvious in the photograph.

FIG.4



a

b

Clast size ranges from granule through to boulder. Boulders with longest dimensions in excess of 1m were observed in situ (e.g. Fig. 5b) and also on dumps, where the presence of other clasts cemented to the surface showed their origin. The largest "erratic" seen in situ was 60cm long. Larger boulders were observed that had presumably weathered out of the Marree Formation, however their origin as an "erratic" or conglomerate clast cannot be determined. The largest boulder seen was a quartzite at the rain gauge, near Yarra Wurta Dam. It had split into a number of pieces, the largest of which was 3.1m in length. "Erratics" and conglomerate clasts are generally sub-rounded to well-rounded. Truly angular clasts were not seen. Sphericity is variable from low to high. A number of lithologies are present, but, weathering rapidly breaks down all but quartzites. A false impression can thus be gained by examining float or even material on dumps. However, the presence of rounded quartzites in the float can be a useful criterion for the Marree Formation in areas of no outcrop (e.g. Fig. 5a). Care must be taken in that such boulders may be transported, or a lag deposit, or reworked into the Tertiary.

In freshly exposed areas the conglomeratic beds consist principally of quartzite, very fine-grained sandstone, siltstone and shale. Proportions vary, but no pattern was detected. Quartzites are mostly grey, pink or fawn and are often well-indurated. They are occasionally pebbly or arkosic. Sedimentary structures are commonly preserved. The siltstones and shales are often flattened parallel to their bedding. They commonly appear bleached, though black laminated siltstones with cubic cavities after ?pyrite were found. Other minor constituents include vein quartz, porphyries, chalcedony, pegmatite, limestone and possible schists. The porphyries are similar to those found in the Gawler Ranges (C. Giles, pers. comm., 1978). Rounded chalcedony fragments have many similarities to those found weathering from the Andamooka Limestone, as do rare silicified ooidstone pebbles. Limestone fragments were recorded by Barnes and Scott (1978), near the base of the S.C.C. 26.

Quartzite fragments with moulds of bivalves, brachiopods, tentaculitids, possible crinoid columnals and other unidentified fossils, were found scattered over an area of about 1km in the northeast corner of the map area, roughly centred on TBM 481. This area consists mainly of quartzite float derived from weathered Marree Formation. Similar fossiliferous quartzite fragments have been found elsewhere in S.A. and N.S.W., within Lower Cretaceous sediments (Campbell, et al., 1977). The fauna preserved has been matched with that of the Lower Devonian Amphitheatre Group and its correlatives which are only known to outcrop from western N.S.W. (Campbell, et al., 1977). The origin of these boulders will be discussed later in this chapter.

Figure 5a Float derived from Marree Formation

Typical float derived from Marree Formation, near Yarra Wurta Dam, looking southeast to northern extension of "Yarra Wurta Mesa". Float comprises dominantly quartzite clasts due to rapid weathering of other lithologies. Iron-stained due to exposure. Note general rounded form. (Largest boulder in foreground approximately 30cm in length).

Figure 5b Bleached Marree Formation

Bleached Marree Formation, a few metres thick, (locality B36, western side of "First Mesa"). The large quartzite boulder is within a yellow-stained sandy conglomeratic bed. This overlies relatively fresh mud, which however, is not exposed. Red-stained silcrete masses are weathering from the Tertiary, just out of view, at the top.

FIG.5

a

b

No marker bed or distinctly mappable facies was recognized within the Marree Formation. However, the uppermost Marree Formation exposed has a very strong weathering imposed on it. This is more fully discussed in a later chapter.

Otherwise, only a few comments can be made about the vertical and horizontal differences within the Marree Formation. An overall decrease in grainsize is indicated within the sequence. Fewer and thinner conglomeratic beds are found near the top of "Split Hill", than in the lowest workings on the flat. There are also more sand beds near the base. A basal boulder bed up to a metre thick is present in S.C.C. 16, BHT 101 and elsewhere. Continuations of this bed may be present at the base of a number of other shafts and bulldozer cuts. To the west, at Yarra Wurta Dam and in the vicinity of Yarra Wurta Cliff, the base of the Marree Formation is exposed, overlying the "Stuart Creek Beds" and Yarra Wurta Shale. In both places conglomerates are present, but not as thick. This could be due to local variations, or it may indicate an eastern source, thinning to the west.

Within the vicinity of Yarra Wurta Cliff a thin, indurated, pebbly, yellow sandstone with silicified wood fragments appears to mark the boundary between the strongly weathered and relatively unweathered parts of the Marree Formation. (See TS 546/A14/C in Appendix B.)

A conglomerate bed can be traced discontinuously along the eastern flank of the "Second Mesa" for over a kilometre. However, on the Field conglomerates are quite variable. Even with far better exposure, some conglomerates cannot be traced from one wall of a bulldozer cut to the other. It would seem that most conglomerates are lensoidal.

The Marree Formation appears to be relatively flat lying. Slight dips, generally less than 3^{o} to the west, were noted, especially in the Field. Due to two-dimensional exposure, the dip direction is open to much error. To what extent they represent initial dips is unknown. Dips of 10-20^{o} to the south-west were noticed in sandy beds in the vicinity of "Split Hill". Nearby sequences are flat-lying, hence it could be postulated that these dips are related to the Arthur Fault which probably passes close by. An initial dip is unlikely. A similar situation probably exists at Locality C1 where a dip of nearly 20^{o} to the southeast was seen in Cretaceous sediments. "Slips" and "slides" are miners' terms for small faults, with displacements of rarely more than 50cm, that occur within the Marree Formation. Bedding is not displaced when traced away from such a structure. They are common at Andamooka and elsewhere. It is considered by Carr, et al., (1978, p.22) that they are probably due to "expansional movements in the clayey sediments, resulting from variations in water content of the montmorillonitic clay".

Foraminifera from the area have been examined by Hannah and Lindsay (1977) and Harris and Cooper (1978). Most of these were agglutinated, with very few calcareous forms replaced by opaline silica. A decalcified marginal marine assemblage is indicated. The foraminifera provide only limited age information, suggesting a lower Aptian age.

During the course of this investigation some bivalve imprints were found within the muds. Some still had two valves joined, indicating either quiet conditions or rapid burial. A few bivalves of a different type were also found in the upper bleached Marree Formation.

Fossil wood (and rarely leaves) were found, either silicified, or as imprints in the upper bleached portion over a wide area. Fossil wood replaced by carphosiderite (a hydrated iron sulphate), silica and gypsum, was also found near the base of the Marree Formation at locality E4. Such remains are too poorly preserved for stratigraphic purposes; they are more of a sedimentological problem. Rarely, wood fragments were found as lignitic material similar to that in the "Stuart Creek Beds", while at the base of S.C.C. 19, in the least weathered section available, larger carbonaceous wood fragments were observed.

Besides the characteristic bioturbation, a number of other types were observed, especially in sandy beds. Red gypseous silt-infilled burrows, similar to those of Coober Pedy, were occasionally observed on the Field. They have been described as fossil termite burrows by Barker (in prep.).

The environment of deposition for the Marree Formation is not clear. The muds appear to have been deposited in a marginal marine environment, as evidenced from foraminiferal work, (Hannah and Lindsay, 1977). Probable glauconite, indicative of marine conditions, was also noted by the author in a few scattered occurrences. A reducing environment is indicated by carbonaceous remains within pyritic muds, at the base of S.C.C. 19 - the least weathered exposure of the Marree Formation. Partial bulk extinction of the clay, when viewed in thin sections, and the presence of bivalves with both valves intact, together point to quiet conditions during sedimentation. No ripple marks were observed, suggesting that the sediment was deposited below the wave base. This need not be so, as ripples do not always develop well in clayey material. Due to the vast extent of the Lower Cretaceous sea (forming part of the Great Artesian Basin), a fairly shallow water depth is most likely, especially since this area was probably near the margin of sedimentation.

Clinoptilolite was detected in the black muds from the base of S.C.C. 19 (see Table 1). Clinoptilolite is commonly associated with montmorillonite, in both marine and non-marine environments, as weathering products of volcanic ash (e.g. Reynolds, 1970), but no other evidence for a volcanic input is present, either in the study area or elsewhere in the Lower Cretaceous of the Great Artesian Basin.

The presence of coarser material within the Marree Formation is harder to explain, in the context of the above discussion of the fine-grained detritus. Conglomeratic beds imply that strong currents must have operated at certain times. Whether they are related to storms, floods, or some other agency (or agencies) is not known. Little channelling or scouring was observed.

"Erratics" within the system present another problem. They are common within the marginal areas of Lower Cretaceous sedimentation of the Great Artesian Basin, and there are many references to this feature within the literature, e.g. Woolnough and David, (1926); Parkin, (1956). Numerous suggestions have been put forward as to their origin. Glacial action can be dismissed, since no striated clasts have ever been found, and most clasts are rounded. Tree rafting can not explain the quantity, though it could be partly responsible, since wood is common within the Lower Cretaceous. Reworking of Permian till or other related deposits, is a possibility, since those sediments were generally poorly consolidated. The nearest known outcrop is approximately 100km to the west, but a closer source could easily have been completely eroded. The presence of the Devonian quartzites from New South Wales enhances the theory, though the lack of striated clasts is again pointed out. Wind moving boulders across a frictionless mud surface, was suggested by Barnes and Scott (1978). However, there is no evidence for any subaerial exposure. Ice rafting, by shore ice or river ice, as opposed to true glacial action, is another possibility. The general rounded nature of clasts could be due to the ice picking up unconsolidated river sediments or beach deposits. In that way, few striations would develop. Floods due to spring thawing (or warmer periods, on a larger time scale), could conceivably be responsible for the conglomeratic beds. Climatic information for the Lower Cretaceous is scarce. The only palaeotemperature data (Dorman and Gill, 1959) have been interpreted differently by different authors. Conditions do not appear to have been cold enough for glaciers, but this does not rule out shore or river ice. The problem of conglomeratic beds and "erratics" is further discussed in Nicol (in preparation).

Tertiary

The Tertiary sediments of the study area consist mostly of sands, with some finer and coarser clastics, and minor limestones. The whole sequence has been variably silicified. Correlation of silicified and unsilicified sediments is not always easy, and this, combined with poor outcrop, leads the author to group all the Tertiary sediments as one unit, the Mount Sarah Sandstone, of probable Miocene age. This is further discussed later.

The Tertiary is 5-10m thick on the mesas. The lower surface is fairly flat, and a typical unconformity can be seen in Fig. 6a. The upper surface is also very flat, and is probably related to a late Cainozoic peneplanation. Refer to the general view of the mesas, Fig. 1b.

North of the mesas the Tertiary has cut down below the highly weathered Cretaceous, e.g. BHT 112A, BHT 113. The relief on the unconformity is up to 20m or more. If the Tertiary everywhere was at least as high as the present tops of the mesas, a pre-erosional thickness of >30m is indicated.

The Tertiary has a number of distinguishing characteristics. Rounded, polished pebbles of milky quartz 5-10mm long are often present together with rarer chert and agate. They are a useful criterion for the Tertiary when outcrop is poor. Well-sorted coarse sands are commonly present as layers, or disseminated in much finer sands and silts. Rounded, polished pebbles of silcrete also occur. Though generally more common higher in the sequence, they were found near the base of the Tertiary on "Split Hill".

The only sedimentary structures seen were crossbedding and one isolated ripple-marked surface near Locality B44. Generally, crossbedding is at low angles or developed on a small scale as in Fig. 6b. However, large scale crossbedding is well exposed in bulldozer cuts on "Split Hill". (Figured in Barnes and Scott, 1978.) In many outcrops the Tertiary is flat-bedded (e.g. BHT 112B).

A wide range of non-marine environments is envisaged during Tertiary sedimentation. Fluviatile processes probably dominated, as evidenced by the coarse nature of much of the detritus and the types of crossbedding exposed. No evidence for aeolian origin was seen - the large crossbedded sands on "Split Hill" being coarse-grained and pebbly, and hence not formed by wind.

Clays and finer silts may have been deposited in lakes or swamps. Poorly outcropping limestones, generally silt or sand in a calcareous matrix, could also have been deposited in lakes. The calcium carbonate is probably primary, but this is not definite. (Thin section description, TS 546/A16/B in Appendix B.)

Figure 6a Tertiary/Cretaceous contact

Typical exposure of Tertiary/Cretaceous contact. The change from fresh to bleached Marree Formation can not be detected due to lack of outcrop. Bleached material is better indurated, and hence better exposed, towards the top. Abrupt change marks the Tertiary/ Cretaceous contact, however the Tertiary is not outcropping since it consists of silicified concretionary masses within unsilicified sands and silts. A change in silcrete type halfway up may indicate the presence of different units in the Tertiary. Tertiary is 8-10m thick. Photo taken looking south, on western side of "First Mesa"; Lake Torrens in background.

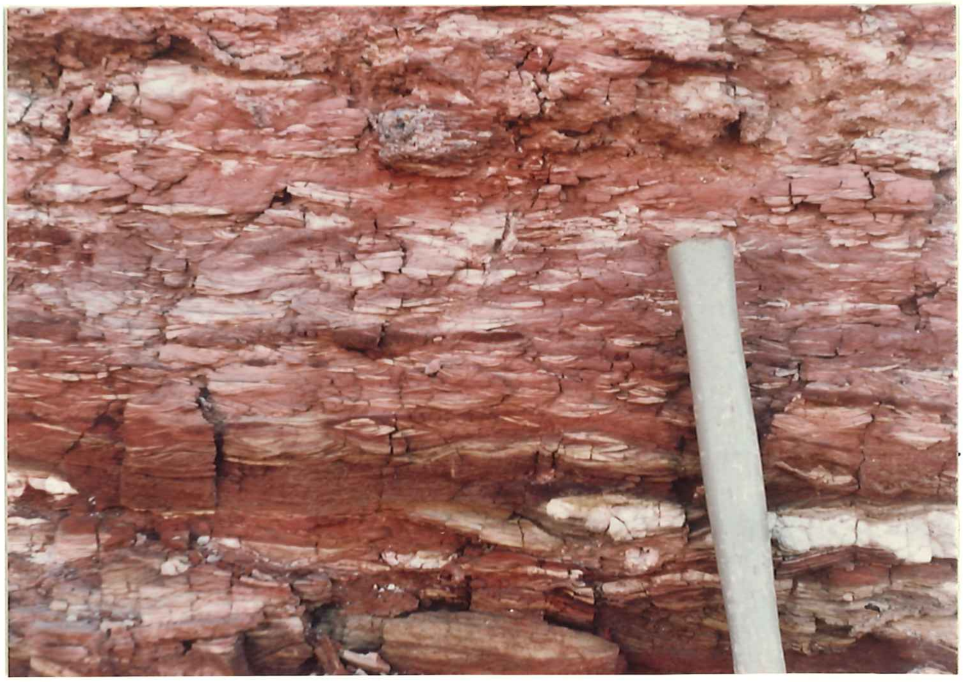
Figure 6b Tertiary sands

Semi-friable, ferruginized Tertiary sands; fine to coarse-grained with some clays and silts (white). Fine crossbedding suggests a fluviatile origin. (Locality A40, "Yarra Wurta Mesa").

FIG.6

a

Note: photo reversed during printing



b

Other rocks, mostly exposed on the flanks of "Arthur Ridge", are believed to be talus deposits, since they are poorly sorted and often contain angular and rounded quartzite clasts. The sandy matrix is silicified and/or ferruginized. Wood imprints were found at Locality C10. Due to the nature of the sedimentation, many breaks occur within the sequence. The clay mineralogy of six Tertiary samples appears to be dominantly kaolinite, with variable amounts of montmorillonite and mica/illite. This could be due to the weathered nature of the source, which probably included Cretaceous sediments, or due to weathering that occurred during the Tertiary.

The Tertiary sequence is correlated with the Mount Sarah Sandstone for a number of reasons. As defined in Barnes and Pitt (1977), the Mount Sarah Sandstone is a non-marine, mostly sand sequence, containing silcrete pebbles, that is itself silicified. It is the next packet of sediments deposited after the Lower Tertiary Eyre Formation. Furthermore, the Tertiary at Stuart Creek cuts down through the highly weathered Cretaceous. This major weathering is believed to be associated with the silicification of the Eyre Formation that produced the first silcrete. Hence the Tertiary at Stuart Creek is younger than the Eyre Formation. Barnes and Pitt (1977) suggest the Mount Sarah Sandstone to be late Oligocene to early Pliocene in age. They favour a Miocene age, and this age is adopted here, pending further evidence.

POST-DEPOSITIONAL ALTERATION

Post-depositional alteration (leaching, bleaching, silicification, ferruginization, etc.) is more common in the Cretaceous and Tertiary. However, even the Precambrian and Cambrian rocks have been affected. The Yarra Wurta Shale, Bunyeroo Formation and Brachina Formation are commonly softened, which sometimes makes distinction from weathered Cretaceous difficult. Whether this represents weathering prior to Cretaceous sedimentation or during a later weathering event, that also affected the Cretaceous, is not known.

The effect of weathering events on the "Stuart Creek Beds", apart from modern processes, is not known, due to poor exposure. No silicification was observed.

The Marree Formation has been subjected to a number of alterations. A major weathering event occurred prior to deposition of Tertiary sediments. This involved leaching and bleaching to produce a light, porous, bleached rock (See figs. 5b and 6a, also TS 546/19 in Appendix B). This alteration commonly has a sharply defined lower surface, sometimes marked by a conglomerate bed with fresher muds below. In outcrop these lower muds show some weathering effects as compared to typical brown muds. This may be due to a lesser effect from the main bleaching, or it may be modern in origin, developing due to exposure.

At Andamooka the fresh material, known as the "mud", is generally separated from the overlying "kopi" by the "level", a thin conglomerate band. Occasionally more than one "level" is present. Most opal is localized at the "level"-"mud" or "mud"-"kopi" interface. The "kopi" at Andamooka is mostly a light, white, sandy or silty claystone. The bleached rocks in the Stuart Creek area sometimes fit this description, but also include bleached clays or mud, since the distinctive bioturbation may be found.

The clay mineralogy of Andamooka "kopi" consists dominantly of montmorillonite with kaolinite subdominant, whereas limited work suggests kaolinite to be the dominant clay of the bleached rocks in the Stuart Creek area. This may reflect an original lithologic difference or a difference in intensity of alteration.

This major weathering event can be found over much of Central Australia. It could pre-date the deposition of the Palaeocene-Eocene Eyre Formation (i.e. probably the Late Cretaceous). The more commonly held view is that deep weathering occurred after deposition of the Eyre Formation (i.e. during the Oligocene), since that appears to be the time of the first major development of silcrete, a process often thought to be linked with deep weathering (see Barnes and Pitt, 1976).

In the study area the time of the deep weathering can only be established as prior to the Tertiary deposition, which is considered to be Miocene (see earlier Chapter). The two pieces of evidence are, firstly, the presence of bleached claystone clasts (of presumable Cretaceous origin) within the Tertiary, and secondly, the fact, that the Cretaceous rocks have been eroded into, prior to Tertiary deposition, removing the bleached rocks from some areas, and leaving only thin remnants elsewhere (<5m thick). Furthermore, the bleached zone probably had a relatively constant thickness over much of Central Australia of 25-50m (L. Barnes, pers. comm. 1978), thus indicating much erosion.

A second strong bleaching affecting Cretaceous sediments, is well-exposed at "Cockatoo Cliff", a few kilometres east of Charlie Swamp. It is considered a "late" event, and is described in Nicol (in prep.). No definite exposure of this bleaching was seen within the study area.

Another type of alteration is exposed in S.C.C. 19 (20.9m deep), where the Marree Formation changes in colour from pale grey at 2.5m (just below the Tertiary contact) to brown after a few metres. The muds darken until at about 17m they change to a dark grey, and then become black for the remainder of the shaft. (A thin section is described in Appendix B, TS 546/21.) Coarser beds are lighter in colour.

A series of samples was taken down the shaft and submitted to AMDEL for clay mineralogy and silicate analysis. The results are presented in Table 1. The samples were collected almost a year after drilling, and have probably suffered some alteration due to exposure. Mud samples were used, in the hope that they would be lithologically similar, and thus able to show the geochemical differences produced by alteration. Included in Table 1 for comparison, is a bleached white sandy claystone. Unfortunately, the extent of silicification was underestimated in the field, so that SiO_2 swamps the analysis. The silicification probably involved intense leaching, thus explaining why the minor amount of clay present is predominantly kaolinite.

It was expected that the lowest sample would show a high carbon content, since carbonized wood fragments were found elsewhere within the black muds. However, carbon is only present in trace amounts, and it would appear that the lowest sample probably derives its black colour from pyrite, which was detected in the bulk mineralogy. The changing colour from black to dark brown is probably due to oxidation of pyrite, while the gradual lightening of the brown muds is probably due to the leaching of total iron, which along with Na, K and Mg decreases up the shaft. The decrease in FeO/Fe_2O_3 may also have an effect. Though semiquantitative only, there is no change in clay mineralogy between the three lower samples, which adds further weight to the leaching

TABLE 1

S.C.C. 19 - SILICATE ANALYSIS, BULK MINERALOGY AND CLAY FRACTION MINERALOGY

	B4/B* silicified bleached sandy claystone	S.C.C. 19 2.5m grey mud	S.C.C. 19 12.75m brown mud	S.C.C. 19 16.85m dark brown mud	S.C.C. 19 19.8m black mud
SiO_2	77.68	58.44	55.13	54.33	58.53
TiO_2	.36	1.12	.70	.71	.57
Al_2O_3	4.44	25.22	18.18	17.59	14.49
Fe_2O_3	.31	.98	2.91	2.14	4.29
FeO	.01	.02	.07	.26	.56
MnO	<.01	.01	.01	.01	.01
MgO	.15	.59	1.28	1.32	1.54
CaO	1.81	.24	.34	.29	.20
Na_2O	.55	.74	1.90	1.94	2.27
K_2O	.60	.62	.85	1.13	1.60
P_2O_5	.03	.04	.04	.05	.17
H_2O^+	.84	8.14	5.47	4.95	3.71
H_2O	9.74	2.46	11.67	12.14	6.53
CO_2	.05	.10	.11	.07	.06
SO_3	2.38	1.10	.40	.85	3.96
Total	98.95	99.82	99.06	97.76	98.50
Bulk mineralogy	O D Q A Gy Tr-A K Tr M Tr	K D Q SD Mo A-SD M A Ha Tr	Mo D K SD Q A-SD M Tr-A Ha Tr Gy Tr	Mo D K SD Q A Gy A M A Ha Tr	Mo D Q A-SD Cli A M A Py Tr-A Ha Tr F? Tr Gy Tr
-2μm fraction - % of total		71	59	53	32
- mineralogy		K D Mo SD M Tr Q Tr	Mo D K A Q Tr M Tr	Mo D K A Q Tr M Tr	Mo D K A M Tr-A Q Tr

*Included for comparison, though silicified. Gypsum content prevented separation of -2μm fraction.

Mineral abbreviations

Cli	clinoptilolite
F	K feldspar
Gy	gypsum
Ha	halite
K	kaolinite
M	mica/illite
Mo	montmorillonite (smectite)
O	opaline silica
Py	pyrite
Q	quartz

Semiquantitative abbreviations used in table

D = Dominant. Used for the component apparently most abundant, regardless of its probable percentage level.

SD = Sub-dominant. The next most abundant component(s) providing its percentage level is judged above about 20.

A = Accessory. Components judged to be present between the levels of roughly 5 and 20%.

Tr = Trace. Components judged to be below about 5%.

Listed in order of decreasing abundance.

Taken from AMDEL Report GS 1081/79 by R. Brown.

hypothesis. It is not known whether the uppermost sample derives its grey colour from the different clay mineralogy (kaolinite dominant, montmorillonite subdominant) or whether it is due to more complete leaching of Na, K, Mg and total iron.

Al and Ti increase towards the surface, but there is not enough evidence to decide whether this is due to actual introduction of these elements, or an apparent increase due to removal of other elements. The second model is preferred, since the ratio Al/Ti remains roughly constant. Silicon content shows no trend, however, this is probably due to variable sand content. Gypsum is common throughout the Marree Formation, and it was expected that Ca and S content would show some correlation. However, this is not the case and no explanation for this behaviour can be offered. (High S in S.C.C. 19/19.8m is probably related to the pyrite content.) The cause of variations in H_2O^+ and H_2O^- is not known. They are probably particularly susceptible to post-digging alteration. Similar wide variations are to be found in analyses of muds from Andamooka and Stuart Creek (Carr et al., 1978). MnO and CO_2 show no trend. P_2O_5 is notably higher in the bottom sample than the three upper samples. Low totals in some analyses may be due to unanalysed chlorine present as halite.

It is felt by the author that a number of alteration processes have produced the profile as observed down S.C.C. 19. It is quite likely that the brown, darkening to black sequence, is a continuation of the first major weathering. Material examined from Coober Pedy drill core also showed a similar sequence. Intensely weathered rocks at the surface become similar to the base of S.C.C. 19 by about 50m. However, the base of S.C.C. 19 (∿83m relative to the Australian Height Datum (A.H.D.)) is well above the collar of other shafts which did not pass through black pyritic muds, but rather, only brown muds. Since S.C.C. 19 was the deepest shaft, and was sited over the centre of a hill, this suggests that the alteration is related partly to the modern topography, and hence is probably a continuing process.

The process which produced the stiff grey clay of S.C.C. 19/2.5m would seem to be related to a weathering event that also affected the overlying Tertiary. This is because grey clays were only noticed directly below Tertiary sediments, or where they had only recently been eroded, e.g. "Split Hill", BHT 105, BHT 112, BHT 113. Brown muds, never grey muds, were observed at the surface, in the valleys between the mesas, suggesting that the greyness was not just a surface process related to exposure. A clay analysis from near BHT 113 was also dominantly kaolinite.

At the surface bioturbation is difficult to distinguish within the grey mud, due perhaps to the change in clay type. It is the presence, then, of rare "erratics" which allows identification of the Marree Formation. The grey gradually changes to brown within a few metres.

Another alteration that the Marree Formation muds suffer is that when exposed they change in colour from brown through grey to off-white. At the same time they dry out, become lighter and more porous, and generally crack. This is presumably just due to loss of water.

Further evidence that the Marree Formation was probably originally pyritic comes from two sources:

(1) Spheroidal goethite concretions, often coalesced, from the Marree Formation at Locality E31, were probably originally pyritic.

(2) The presence and abundances of certain sulphates within the Marree Formation.

Besides ubiquitous gypsum, which could have a number of origins, veins of yellow powdery alunite are common and indeed characteristic of the brown muds of the Marree Formation. Some jarosite was reported in Barnes and Scott (1978), while Jones and Segnit (1966) record natrojarosite. During this study carphosiderite was found replacing wood fragments at Location E4 near the base of the Marree Formation. Dana's Manual of Mineralogy states that all of these minerals are often related to the weathering of pyrite. Jessup (1960) also discussed the alteration of pyritic Cretaceous sediments to produce alunite, ferruginous seams and gypsum. Alunite is formed by acid sulphate reacting with clays. The age of the alunite is not known, but it was probably associated with the first major weathering. It also pre-dates opal formation.

Silicification has occurred within the Marree Formation, but is more prominent within the Tertiary sediments. A problem exists, in that it is difficult to determine whether two expressions of silicification are part of the same silicification event, but differing due to different chemical or physical conditions at the time of formation. Silicification can differ in both morphology and mineralogy. The problem is further hampered due to lack of good sections. For this reason only a brief discussion of silicification will be given here.

The intensely bleached Marree Formation ("kopi") is commonly indurated by silica in the form of opal-CT, as determined by XRD. In places where "kopi" was originally mud one can see a progressive increase in induration, probably due to increasing opal-CT content, until finally the rock is a grey, non-porous rock, comprising quartz and opal-CT only (determined by XRD).

Commonly the overlying Tertiary sands and silt are unconsolidated. This may be due to silicification selectively affecting only clays. However, silicified mud pebbles appear in the basal Tertiary, suggesting silicification prior to Tertiary deposition. Whether this was related to the silicification of the Eyre Formation is not known. Thin section TS 546/B3/A (in Appendix B) describes such a contact.

Within the Tertiary, silicification is far more complex and expresses itself in a number of mineralogies and forms. All of these postdate an earlier silicification, (probably post-Eyre Formation) as evidenced by polished silcrete pebbles in these sediments.

No clear history for the Tertiary silicification can be determined, however at least two stages are implied by TS 546/B2/H. In this slide a silicified sandstone is broken up and resilicified.

The mineralogy of silicification is mostly chalcedony. However cementation by opal and quartz overgrowths also occurs (TS 546/36 and TS 546/B2/H respectively). Minute TiO_2 crystals are very common in some silcretes (e.g. TS 546/35).

The outward morphology of the silcrete varies considerably. Some sands were massively silicified whereas others were only partly silicified, with concretionary masses weathering out of unconsolidated sands and silts. On the mesas these types were more common at the base of the Tertiary, while at the top, nodular varieties were dominant. Whether this represents different expressions of the same silicification, or silicification at two different times is not known. Silicification may have proceeded prior to the end of the Tertiary deposition.

Other types of post-depositional alteration include ferruginization and gypsification. Ferruginization is common in the Tertiary, where iron oxides commonly form the only cement of the sands, e.g. at "Split Hill". See also Fig. 6b. Ferruginized Tertiary sands are described in Appendix B (TS 546/35 and TS 546/D3/A). Ferruginization has taken place prior to silicification in some localities, but little else can be stated about its time relationship(s) to other events, e.g. ferruginization within the Marree Formation. (See Fig. 7b and TS 546/84).

Gypsification is common throughout the area. Unfortunately, it is a very mobile substance as evidenced by the growth of gypsum in old diggings. For this reason, gypsification has little time significance. Gypsum probably developed from calcium, leached from original carbonate, and sulphate, weathered from pyrite, during the first major weathering event. There may also have been some original gypsum in the marginal marine Marree Formation.

Gypsum was present during precious opal formation, (Miocene, see next chapter), since it is often included in opal, making the stone worthless and subject to cracking.

OPAL

Opal Types and Occurrence

Opal at Stuart Creek, Charlie Swamp and Yarra Wurta Cliff is well discussed in Barnes and Scott (1978). For this thesis opal occurrence within the study area was examined. Opal at Charlie Swamp was looked at briefly for comparison purposes, and is covered in more detail in Nicol (in prep.).

Opal, especially precious opal, is rarely seen in situ. Thus one has to examine material on dumps, which, besides being non-representative, gives little information as to the mode of occurrence. Another difficulty arises when trying to watch miners at work or discuss their work with them, since they do not always like to give away much information.

Within the study area, opal can be divided into two categories - precious opal (and associated opal), and common opal.

Precious opal has only been recovered from "Split Hill" and from workings on the flat to the west. (See Fig. 7a (4,8)). There is an unsubstantiated report of precious opal being found at Yarra Wurta Cliff. The most notable feature is that precious opal is found within fresh sediments, rather than bleached, highly altered rocks as elsewhere in South Australia. At Stuart Creek precious opal occurs in two situations. (Terminology is that used by the local miners.)

(1) "Levels" - subhorizontal discontinuous veins at, or very close to, the contact of conglomeratic or sandy beds overlying muds. (See Fig. 7b, also TS 546/84 in Appendix B.)

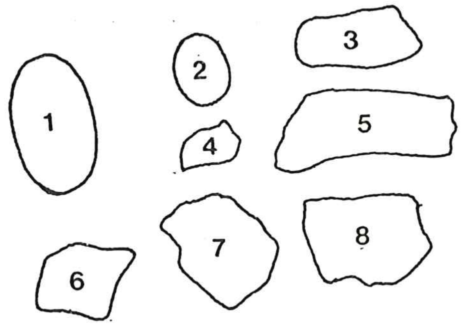
(2) "Verticals" - opal infilling joints, fractures or "slides" of any orientation, and commonly associated with alunite, iron oxides and gypsum.

Limited knowledge suggests that "verticals" are more common near the top of the exposed Cretaceous, just below the Tertiary (i.e. "Split Hill"), while "levels" are more productive near the lower part of the Marree Formation on the flat. Precious opal is thus found over a stratigraphic thickness of >25m.

Precious opal at Stuart Creek is said to commonly contain sand and/or gypsum, making the stone worthless or subject to cracking.

Associated with precious opal is potch, which is very similar, but has little or no "colour". A gypsum-shot sample of potch is shown in Fig. 7a (7). Another type of opal commonly associated with precious opal on the Field is called "amber potch" or "honey potch" due to its colour and transparency. It does not possess "colour", but some miners consider it a good sign of precious opal nearby.

Figure 7a   Opals



(Mineralogy in brackets determined by XRD).

1&2 Cut and polished samples of common opal, black. Charlie Swamp (Opal-CT).

3 Black and white laminated opal, (opal-A, opal-CT). 546/A6, southern end of "Yarra Wurta Mesa", sample from dump around old pits.

4 Uncut precious opal, sample from Stuart Creek Field.

5 Yellow to orange, semi-opaque common opal from adit below Yarra Wurta Cliff trig. Sample shows some irregular darker patches as if brecciated and recemented. 546/A14/L. (Opal-CT).

6 Grey common opal, "porcelain potch". Shallow bulldozer scrapes west of "Second Mesa". 546/E19/B. (Opal-CT).

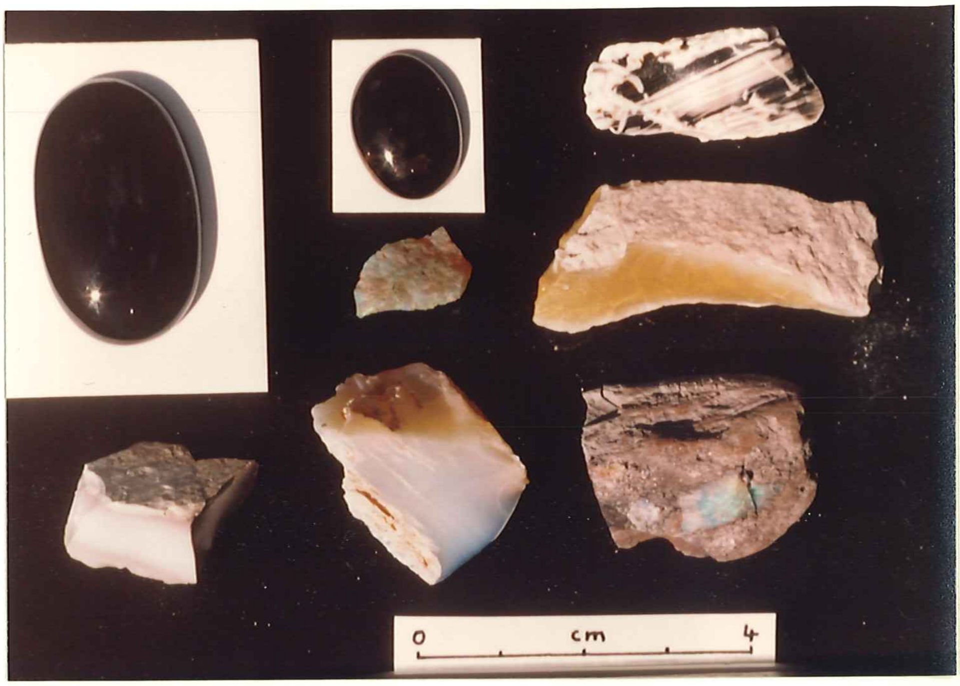
7 Gypsum-shot, milky potch with poorly developed blue "colour", (enhanced by photograph). From dump, Stuart Creek Field. 546/136. (Opal-A).

8 Precious opal from Stuart Creek Field.

Figure 7b   Opal from Stuart Creek

Thin discontinuous vein of poor quality precious opal located at the interface of a sandy layer (with some pebbles) over a mud; both ferruginized.
Sample from northwestern area of intensive workings on the flat, Stuart Creek Field.

FIG. 7



a

b

Common opal has a vitreous lustre and a conchoidal fracture like precious opal, but does not possess any "colour". See Fig. 7a, (1,2,3,5,6). Some miners use the term "potch" to include most non-precious opal that is described as common opal here.

Within the study area numerous varieties of common opal were seen. Colours included black, brown, dark blue, grey, orange, tan and white, while opacity varied from colourless to very opaque. Some samples were laminated (Fig. 7a (3)), while others had a brecciated appearance, e.g. Fig. 7a (5), from Yarra Wurta Cliff, and Fig. 8b, from Charlie Swamp. Other samples appeared similar to "amber potch" or potch from the Field, but never with any colour. Weathering tends to produce a paler coloured skin and cracks commonly develop. This is probably due to loss of water on exposure, but may be related to other factors. Though "colour" is lacking, some common opal is obviously a good ornamental stone. (Fig. 7a (1,2)).

Common opal generally occurs as veins of varying orientation, with thicknesses ranging from less than 1mm to 3cm or more. It is rare in "kopi" but can occur just below as at Yarra Wurta Cliff. Common opal appears to occur more often in fresh muds, e.g. Charlie Swamp (Fig. 8a), where the network of opal veins is particularly well developed. Within the study area, there are diggings in and around the intensively worked areas of the Field. Outside the Precious Stones Field upwards of fifty workings are present, mostly sited on the flanks of the mesas, particularly "Yarra Wurta Mesa". They consist of a few bulldozer scrapes, small shafts and adits, backhoe trenches and hand dug pits. Bulldozer cuts and pits occur outside the study area at Charlie Swamp. Nearly all of the workings are sited in fresh Marree Formation, probably on the basis of opal floaters found nearby by the miners. Some diggings, especially the shallow bulldozer scrapes in the Cambrian rocks are obviously exploratory only.

Common opal is not restricted to the Marree Formation and may occur elsewhere. Common opal occurs in the Tertiary as a cement in the sandstones, and also as completely silicified Cretaceous shale clasts. A pit near BHT 105 contained some of this material. (See TS 546/36 in Appendix B.) Opal may have been recovered from the Yarra Wurta Shale just below the Marree Formation at Yarra Wurta Cliff, based on the number of diggings. G. Nicol (pers. comm. 1978) also records common opal from the Precambrian near Charlie Swamp. Some common opal was found in the areas of intensive workings on the Field, which allows for the possibility that precious opal will be found where only common opal is found now.

Figure 8a Opal in situ - Charlie Swamp

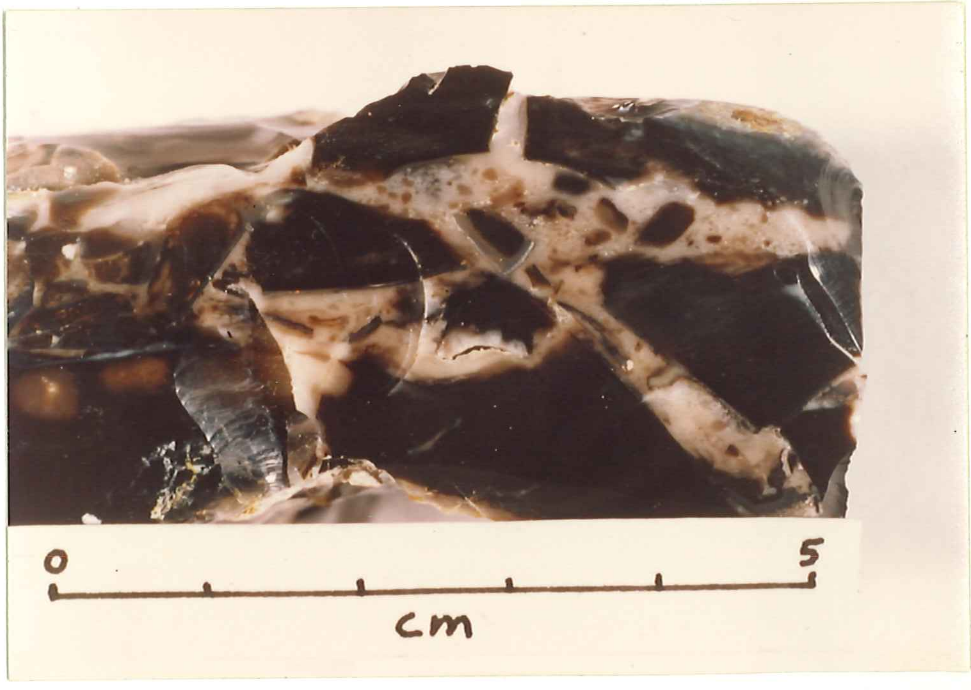
Black common opal forming an irregular network of veins within fresh brown muds of the Marree Formation at Charlie Swamp. (BHT 84).

Figure 8b Opal breccia - Charlie Swamp

Black common opal (mineralogy: opal-CT) brecciated and recemented by white material consisting of opal-CT and quartz. This provides evidence for at least two phases of opal formation at Charlie Swamp. Correct orientation of the sample is not known since it was recovered from a dump (BHT 84).

FIG.8

a



b

X-ray Diffraction Studies

Jones and Segnit (1971) have classified opal into three structural groups on the basis of X-ray diffraction patterns. Opal-A is almost amorphous, whereas opal-CT has a highly disordered low-cristobalite structure with some tridymitic stacking. Opal-C is a rarer form, not encountered in this study, which has a well ordered cristobalite structure.

Almost all precious opal is opal-A (Jones and Segnit, 1971). Precious opal contains minute silica spheres, 0.15 to 0.3 microns in diameter. When the spheres are well ordered and of even size, the resulting structure of regularly spaced voids acts as a diffraction grating. This produces the "colour" of precious opal - pure spectral colours that change as the specimen is rotated. The colours seen depend on angle of incident light and observation, size of spheres, void infilling and other factors. Potch opal occurs when spheres are too variable in size or poorly packed or some other property affects diffraction. Potch commonly shows poor development of "colour" in a milky background due to the scattering of light. The structure of precious opal is covered well in Darragh et al., (1976).

Thirty samples were examined by X-ray diffraction to determine the nature of the opal phase present. It was hoped that opal-A would be detected, thus possibly leading to precious opal nearby. Samples came from the Precious Stones Field, Yarra Wurta Cliff and elsewhere in the study area, besides Charlie Swamp. Only a few samples were not opal-CT, and nearly all common opal was found to be opal-CT. As expected, precious opal and potch from the Field were opal-A. Unexpectedly a mixture of Opal-A and opal-CT was found in "amber potch" and in the samples of laminated common opal. The significance of both of these occurrences is unknown. Perhaps "amber potch" is associated with precious opal due to its opal-A content. Further work is required to determine if the fine laminae in laminated opal are of different structure, since outwardly the samples look like common opal. An attempt was made to look for spheres in these two types of opal using the scanning electron microscope, but due to lack of time and experience the attempt was unsuccessful.

Discussion

Barnes and Scott (1978) discuss opal occurrence within the area. For the Stuart Creek occurrence they reject the hypothesis that precious opal is related to silicification in Early Tertiary times, associated with deep weathering (as put forward by Hiern (1965) and supported by Carr et al., (1978)). They would rather place opal formation as a younger event, associated with the silicification of the Miocene Mount Sarah Sandstone. Their main reasons are as follows.

Much of Central Australia appears to have had a bleached profile at least 30m thick, developed during the Early Tertiary. In the study area, erosion has left only thin remnants a few metres thick on most of the mesas, while at "Split Hill" this "kopi" is totally removed.

If opal formation is related to the bleached profile, then clasts of opal would be found in younger Tertiary sands, e.g. the Mount Sarah Sandstone. They are not, though milky quartz, agate and silcrete pebbles that probably derive from the Eyre Formation are common. (This feature is not confined to the Stuart Creek Field.)

Again, if opal is related to the bleached profile, then it would be expected to be concentrated at the "kopi"-"mud" interface as at Andamooka. This is not the case at the Stuart Creek Field, though common opal is found in this situation at Yarra Wurta Cliff, perhaps as a remnant of an earlier phase of opal formation.

If precious opal formed at about the same time as the major bleaching, then opal must have formed at least 50m below the surface (>25m of "kopi" plus >25m beneath the "kopi"). Barnes and Scott consider this unlikely if opal formation is related to descending groundwater, as this depth would be permanently below the water table.

Further to the above reasons, Barnes and Scott note the common presence of opaline silica as a cement in Tertiary sandstones.

These arguments, though not direct, appear to be quite sound and the author is in agreement with their theory, i.e. that precious opal formation at Stuart Creek is related to the silicification of Miocene sands. Whether this applies elsewhere in Australia needs further investigation. In either case, large areas must now be considered potentially opal-bearing.

The actual process of opal formation is probably deposition from silica-rich ground water trapped at a permeability interface or in cracks. (See e.g. Hiern, 1965; Darragh, 1976.) An example of microscopic folds and faults within common opal from Yarra Wurta Cliff (Fig. A2a) is quite good evidence to show the original gel-like consistency of opal prior to complete solidification.

If silicification of the Tertiary sands at Stuart Creek has comprised a number of events, then it is reasonable to expect several stages of opal formation to be present. This is well displayed in brecciated opal samples, especially one from Charlie Swamp (Fig. 8b), where an earlier opal is brecciated and cemented by later opal. A sample from Andamooka (see Fig. A2b,c) also shows a complicated history of opal deposition. An original carbonate rock (as evidenced by pseudomorphed rhombs) has been completely replaced by silica as quartz and opal. They have been deposited alternately in cavities. For both these examples one cannot determine the time breaks between each phase, or what factors control the opal deposition. One can only state that opal was not all formed during one phase.

SUMMARY AND CONCLUSIONS

An area north of Lake Torrens was studied, with particular reference to the opal-bearing Cretaceous sediments. The study area contains the Stuart Creek Precious Stones Field, which is presently being worked, and a number of other abandoned diggings, including those near Yarra Wurta Cliff.

The pre-Mesozoic basement consists of folded Wilpena Group sediments in the east (Brachina Formation, A.B.C. Range Quartzite and Bunyeroo Formation); separated by the Arthur Fault, from the gently dipping Andamooka Limestone and Yarra Wurta Shale of Lower Cambrian age, to the west. The northern extension of the Arthur Fault could not be traced.

A relatively flat unconformity exists, overlain by essentially flat-lying Lower Cretaceous sediments. The unconformity rises slightly to the south and rapidly to the east (across the Arthur Fault). The Cretaceous sediments consist of two units: a transgressional unit, called the "Stuart Creek Beds" in this thesis, and the overlying marginal marine Marree Formation.

The "Stuart Creek Beds" appears to be confined to topographic lows, with a maximum thickness of about 10m. It comprises a number of characteristic lithologies clearly distinguishable from the Marree Formation. The basal lithology is a reworked or regolithic Yarra Wurta Shale. Other lithologies include: pale green clay clast conglomerates; brown sands, silts and clays with abundant lignitic wood fragments; pebbles and cobbles in friable silty sand; and poorly bedded greenish clays, silts and sands. Glauconite occurs in places, suggesting some marine influence. A number of transitional environments are envisaged for the deposition of this unit.

No evidence was seen of a major time break before the Marree Formation. For this reason the "Stuart Creek Beds" can probably be correlated with other basal units of the Great Artesian Basin, e.g. the Cadna-owie Formation, the Pelican Well Formation, the Trinity Well Sandstone and Wilpoorinna Breccia Members of the Marree Formation. A Neocomian to early Aptian age is thus implied.

The overlying Marree Formation is early Aptian in age from foraminiferal evidence. It is approximately 30m thick, but the upper contact is erosional. It consists mainly of brown montmorillonitic muds with a distinctive bioturbation. Sandy and conglomeratic beds occur throughout the sequence, but are more prominent towards the base. Scattered "erratics" of unknown origin also occur. Veins of alunite and gypsum are common.

Up to 20m of Tertiary sediments unconformably overlie the Cretaceous. The contact is fairly flat, where exposed on the mesas, but to the north there is more relief, indicating more irregular erosion. The Tertiary consists mainly of sands, but conglomerates, pebble layers, silts, clays and minor limestones also occur. It is dominantly fluviatile in origin. The sequence is correlated with the Miocene Mount Sarah Sandstone on the basis of the presence of rounded silcrete pebbles, believed to be derived from the Lower Tertiary weathering of the Eyre Formation.

The rocks of the study area have undergone a number of phases of post-depositional alteration. The Lower Tertiary intense weathering event is believed to be responsible for two features - an upper intensely bleached profile ("kopi"), of which only thin remnants exist on most of the mesas (but not "Split Hill"), while below, the original black pyritic muds have been altered to brown muds, probably due mainly to oxidation and loss of iron. The brown Cretaceous muds rapidly pale, dry out and crack on exposure. Alteration associated with silicification of the Tertiary is probably responsible for partial silicification and kaolinization of the "kopi", while in areas where no "kopi" is present the muds underlying the Tertiary are grey with a higher kaolinite content. Silicification is quite variable and takes on a number of forms in the Tertiary. At least two phases are present.

Common opal is widespread within the study area, but precious opal has only been mined in the Precious Stones Field. At Stuart Creek precious opal is found as "levels" and "verticals". Particularly significant is the fact that the precious opal occurs in fresh Marree Formation, rather than in bleached material as elsewhere in South Australia. Much more of the Cretaceous within and outside the study area (and presently almost untested), now becomes potentially opal-bearing. It appears most likely that the formation of precious opal at Stuart Creek is related to the silicification of the Tertiary sands. This sets its age as Miocene or younger. However, the deposition of opal is probably far from simple, since at least two phases of common opal formation can be seen in brecciated samples.

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ACKNOWLEDGEMENTS

This thesis would not have come into being but for the help and encouragement of many people.

Thanks are due to the following:

- Geoff Nicol, who put up with me for many weeks in the field, and who helped me in many ways.
- Lew Barnes of the Department of Mines, and Dr. John Jones and Dr. Brian Daily of the Geology Department, for their supervision of the project and helpful discussions throughout the year.
- Jeff Olliver, Doug Scott, Peter Crettenden, Steve Ewen, Graham Krieg and others from the Department of Mines, who assisted in a variety of ways.
- Andamooka Area Officer, Dick Betterman and his wife Maureen.
- Rudi and Inge Duke of Andamooka.
- Clarry Findlay of Andamooka.
- The miners at Stuart Creek, particularly Jake, John and Cliff.
- Members of the academic and technical staff of the Geology Department, particularly Dr. Gostin, Margy Wright, Rick Barrett and Evert Bleys.
- Backhoe operator, Ted Havers, and his brother Mike.
- Fellow honours students.
- My family.
- Sue Brockhouse and Joan Brumby, for skilful typing.

APPENDIX A

Photomicrographs

Figure A1a "Stuart Creek Beds" - basal lithology

(TS 546/2, plane polarized light, field of view = 3.2cm)
Poor bedding can be distinguished in this slide. Note the mixed nature of the rock which includes shale clasts, sand grains and glauconite. A slickenside can be seen, running from top to bottom, near the centre of the photo.
Taken from the base of S.C.C. 16.
(Cracking due to drying out)

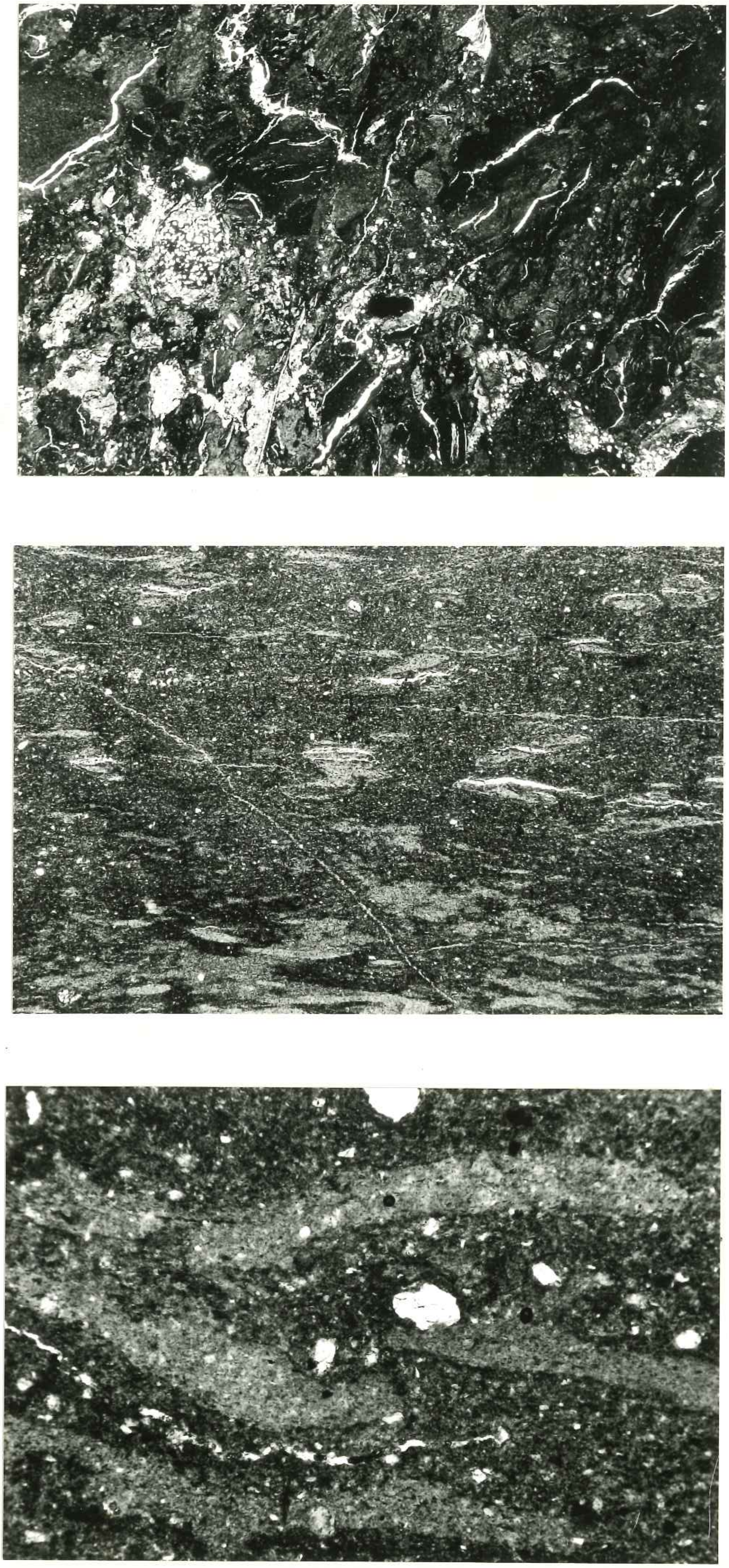
Figure A1b Marree Formation - bioturbation

(TS 546/8, plane polarized light, field of view = 1.5cm)
Paler streaks partly define bedding. Note disseminated silt and sand.
(Cracking due to drying out)

Figure A1c Close-up of bioturbation

(TS 39310 (Department of Mines sample P1230/77), plane polarized light, field of view = 2.7mm)
Paler streaks due to bioturbation, contain less silt and almost no iron oxides. Iron oxides are sometimes concentrated at margin.

FIG. A1



a

b

c

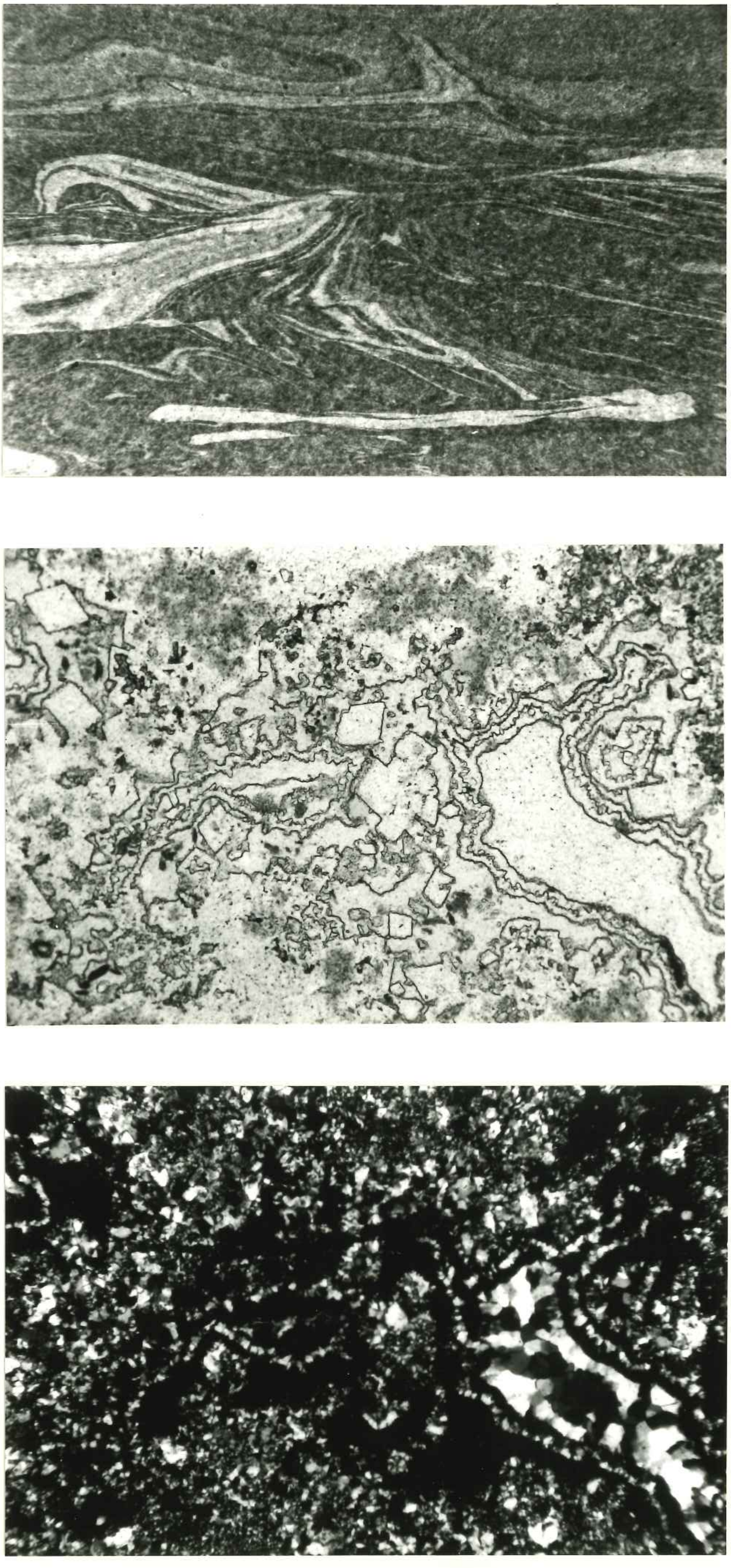
Figure A2a   Folds in opal

(TS 35275 (Department of Mines sample P1/76), plane polarized light, field of view = 2.7mm)
Common opal from Yarra Wurta Cliff.
Microscopic folds and faults suggest some movement of a gel-like substance prior to solidification.

Figure A2b,c Opal from Andamooka

(TS 546/61, (b) plane polarized light, (c) crossed polars, field of view = 2.7mm)
Thin section cut from a grey siliceous rock, containing some precious opal, from Andamooka. (Sample owned by C. Findlay).
The rock was originally a carbonate, since the outline of calcite or dolomite rhombs can still be seen. It has been completely replaced by silica; quartz (or chalcedony) and opal (isotropic). The complicated nature of deposition of opal can be seen in the right hand corner where a cavity has been infilled by quartz and opal alternately.

FIG. A2



a

b

c

APPENDIX B

Thin section descriptions

Approximately forty thin sections were examined, but only the more important ones are described here. Another twenty thin sections from earlier sampling by the Department of Mines were also examined. These are fully described in Barnes and Scott (1978). Hand specimen descriptions are a quick summary only, and include mostly features not otherwise apparent in the thin sections.

All of the following slides have been cut and numbered by AMDEL (number in brackets). They were stained by alizarin red, which stains only calcium carbonate pink.

TS 546/2 2 large thin sections (TS 40588, TS 40589)

Location: S.C.C. 16, 14m.

HS : Red to red-brown clay with occasional pale green patches. Contains small, angular shale clasts, quartz grains and grains of a green mineral (.2-.5mm) identified as glauconite by XRD. Slickensides common. No structure visible.

TS : The rock is mostly composed of brown or grey clay minerals often stained red by iron oxides. It has a brecciated and disturbed look which may be due to bioturbation in places. It appears to contain shale clasts. Sometimes the boundaries of the clasts are sharp, other times they grade into the matrix and can only be distinguished by subtle colour and textural differences.
Angular quartz grains, comprising less than 5% of the slide, are generally fine-grained to silt-sized. They are irregularly scattered throughout the slide.
Displacements of the order of a few millimetres correspond to slickensides in the hand specimen.
Glauconite occurs as very fine-grained material in patches 0.1 to 0.5mm across. The patches sometimes appear to be rounded or replacing ?organic remains. Mostly they are irregular in shape. Glauconite comprises less than 5% of the slide but most of this is confined to a couple of bands.
Under very low magnification appear to have poor but disrupted bedding.

Comments: Lower Cretaceous. Lowermost "Stuart Creek Beds". A common lithology for this unit. The presence of glauconite implies a marine environment of deposition, however, the very mixed nature of the sediment, including clasts, suggests a nearshore marine origin. Perhaps the glauconite developed in the sediment after a marine transgression covered a partly reworked soil or regolith (presumably derived from Yarra Wurta Shale). The cause and age of the slickensides is unknown but is unlikely to have caused all the brecciation in the rock. See Fig. 2b (similar hand specimen); Fig. A1a (thin section); and Appendix C, sample 105 for bulk and clay fraction mineralogy.

TS 546/8 — 2 large thin sections — (TS 40590, TS 40591)

Location: An unmarked Calweld shaft near S.C.C. 2.

HS : Brown muds with typical Cretaceous bioturbation. Bedding defined by silty layers and bioturbation. Soft and damp when fresh; pales, dries out and cracks on exposure.

TS : Visual estimate - brown clay >90%
quartz < 5%
iron oxides < 5%
minor flakes of mica

Quartz as angular silt to fine sand, mostly disseminated through the clay. Appear to have fining up cycles, 1 to 3 cm thick - silty clay layers passing up to dominantly clay. The remainder of the slide is composed of brown clay with iron oxides (disseminated fine grains, often in clusters or streaks). The clay shows partial bulk extinction indicating deposition in a relatively quiet environment.

The bioturbation of the hand specimen comprises paler elongate streaks (1-2mm long) generally parallel to bedding, though some have irregular shapes or appear to be coalesced. Lighter colour due to less iron oxides, though sometimes concentrated at the margins. Also contain less silt. Clay has a slightly different texture.

Comments: Lower Cretaceous, typical Marree Formation mud with characteristic bioturbation. Probably deposited in a quiet marine environment. See Fig. 4a (similar hand specimen); Fig. A1b,c (thin section showing bioturbation); and analyses of similar brown muds in Table 1.

TS 546/17 — (TS 40561)

Location: East of "Split Hill", base of pit that had passed through Marree Formation basal boulder bed. (NE of BHT 101).

HS : Red, finely laminated micaceous siltstone, fissile along bedding planes.

TS : Visual estimate - quartz 50%
muscovite/sericite 10%
iron oxides 40%

Laminations due to variations in content and grainsize of quartz. Laminations <0.5mm thick. Quartz is angular silt.

Comments: Bunyeroo Formation on lithological and structural grounds.

TS 546/19 (TS 40562)

Location: Eastern side of "First Mesa".

HS : Indurated claystone with minor sand and silt. Very pale pink-brown when fresh; weathers cream to very pale orange yellow. Light and very porous (sticks strongly to the tongue). Breaks with a conchoidal to irregular fracture. Occasionally typical Cretaceous bioturbation is visible.

TS : Visual estimate - matrix (opal-CT, kaolinite) 95%

Visual estimate -	matrix (opal-CT, kaolinite)	95%
	quartz	5%
	chert, ?feldspar, ?rock fragments	< 5%

Quartz, and other minor constituents, mostly angular, but some more rounded grains ranging in size from silt to fine sand. Scattered through the slide but sometimes grouped together in small closer-spaced clusters - due to ?biological activity.
Matrix - shown to be opal-CT and kaolinite from XRD and clay analysis. Shows some bulk extinction and typical Cretaceous bioturbation, both found in unsilicified Cretaceous mud of 546/8.

Comment : Slightly sandy bleached claystone typical of rocks in uppermost portion of Cretaceous sequence. Appears to be a highly weathered (i.e. leached and bleached) and silicified mud/clay of the same type as the fresh material in the field and elsewhere. It can be equated with the "kopi" of Andamooka. See analyses of similar sample (B4/B) in Table 1.

TS 546/21 (TS 40563)

Location: Near base of SCC19 (depth approximately 20m).

HS : A black to dark grey sandy and silty clay with a sulphurous smell.

TS : Slide has cut through a very sandy layer.

Visual estimate -	quartz	50%
	clay (iron stained)	40%
	chert, feldspar, and altered rock fragments	< 5%
	organic matter (localized)	< 5%
	Mica	< 2%

TS 546/21 (cont.)

Quartz mostly as angular fine to very fine sand with some silt. Rare rounded coarse grains. Other grains have similar size and shape. Sand within a brown (iron-stained?) clay matrix. Bedding poorly defined by localized patches of black carbonaceous? material and occasional less sandy areas. Small patches of quartz-free clay appear churned up, suggesting bioturbation.

Comment : A carbonaceous, reducing environment is indicated. May represent original sediment type of Maree Formation, protected by depth from weathering. See analyses of similar material (S.C.C. 19/19.8m) in Table 1.

TS 546/35 (TS 40564)

Location: Approximately 30m west of SCC 25.

HS : Rounded and angular quartzite fragments (sometimes showing bedding) up to 10cm or more across, within a very pale olive gray sandy siliceous matrix. No structure. Conglomeratic silcrete.

TS : Visual estimate - quartzite fragments 25% (variable)

quartzite fragments	25% (variable)
quartz	60%
matrix	15%

minor heavy minerals and chert grains.

Quartzite fragments, variable roundness and size. Not adequately represented.

Quartz ranging from silt to very coarse sand, but mostly fine to medium sand. Commonly angular, but coarser grains tend to be rounded or well-rounded. Quartz overgrowths on quartz grains probably prior to this cycle.

Matrix - extremely fine grained (< 0.005mm) mass of crystals (brownish in plane polarized light, opaque yellow-brown in polarized light). Probably TiO_2 with some quartz, since Tio_2 indicated by XRD. Titaniferous matrix in some cracks and interstices in quartzite fragments.

Comments : Tertiary titaniferous conglomeratic silcrete, perhaps a silicified talus deposit.

TS 546/36 (TS 40565)

Location: 50m northwest of SCC 25.

HS : Medium to coarse-grained very well-rounded sandstone, each grain with thin black haematite coating. Pore spaces filled by orange-red clay.

TS : Visual estimate - quartz 80%

quartz	80%
iron-stained clay	15%
haematite	5%

Well-rounded quartz and chert grains ranging in size from medium to coarse and some very coarse. Some angular very fine sand trapped in interstices. Each quartz grain has one, and often two, thin (<0.02mm) coatings of haematite, (red when viewed at thin margins), which also acts as a cement.

A thin very irregular clay layer probably explains why the second haematite layer is less uniform in thickness and distribution than the first. Poorly packed finely crystalline brownish clay fills most of the interstices.

Comments : Tertiary ferruginized sandstone. The size, sorting and roundness, suggest it to be fluvial in origin.

TS 546/38 (TS 40566)

Location: Small pit on top of ridge, 200m north of BHT 105.

HS : Silicified sandstone containing fragments of white material which appears similar to poor quality potch. No structure visible in hand specimen.

TS Visual estimate -

quartz	60%
opal	35%
chalcedony	5%

Quartz as medium to coarse sand grains, angular to well-rounded, Minor fine sand.

Matrix is opal, since isotropic and pale brown in plane polarized light. Some minor variations in colour, perhaps due to clay or iron oxide content, occur. "White potch" fragments in hand specimen appear to be all opal, sometimes with approximately 10% quartz grains randomly scattered throughout. (Fine to medium, angular to rounded). Distinct from remainder of rock by slightly lighter colour of opal matrix. Opal in fragments is opal-CT (by XRD) and

TS 546/38 (cont.)

presumably so is matrix of sandstone.
Two generations of chalcedony can be seen in the sandstone filling cavities. The first is brownish in plane polarized light and forms as thin colloform layers in cavities. It is length slow and appears to grade into the opal matrix. It is only tentatively identified as chalcedony. The second is colourless, length fast, fibrous and generally fills cavities, including those partly filled by the first generation.

Comments: "White Potch" fragments are probably bleached clasts of Cretaceous sandy clay now completely silicified. The opal matrix and two generations of chalcedony suggest a complicated history of Tertiary silicification events.

TS 546/84 (TS C20333)

Location: Northeast part of worked area, Stuart Creek Opalfield.

HS : Thin discontinuous seam of opal, clear to amber, with some "colour" (mostly purple and green), at or near the contact of a clay and an overlying muddy sand occasionally with granules or pebbles - both heavily iron-stained. The clay is dark purple, while the sand is lighter due to sand content. Thin films of gypsum occur in cracks in the mud.

TS : The opal is present in the slide as a vein 2mm thick. It appears that the opal occurs slightly above the contact between the clay and the overlying sand. The clay is brownish in plane polarized light. However, detail is obscured by the presence of many small clusters of iron oxides (0.02mm across) probably haematite, comprising up to 60% of the mud, though distribution is variable. There are minor scattered silt-sized quartz grains.
The sandy layer is similar but contains 30-40% mostly angular quartz grains, mostly very fine to fine with some medium sized grains. Feldspar, rock fragment and mica grains also occur.
The opal-sediment contacts are sharp and fairly smooth.
See similar sample in Fig. 7b.

TS 546/A5 (TS 40576)

Location: Flank of "Yarra Wurta Mesa".

HS : A cream-weathering, pink, very fine-grained silicified sandstone, with some coarse to very coarse grains, either in thin layers or randomly scattered as individual grains, clusters or streaks. Layers define bedding in outcrop.

TS : Visual estimate -

Visual estimate -	quartz	80%
	TiO_2 rich matrix	10%
	chalcedony	10%
	heavy minerals	1%

Angular fine to very fine grained closely packed quartz grains with minor heavy minerals.
Matrix is brownish in polarized light, hence probably similar to TS 546/35. Sometimes reddish, indicating presence of iron; probably the cause of the pink colour of the hand specimen.
Matrix also includes fine-grained chalcedony (<0.01mm). Also has coarse to very coarse quartz grains scattered through the rock (as individuals and clusters) and also in bands.

Comments: Tertiary sandstone. Cause of coarse sand distribution unknown.

TS 546/A14/C (TS 40577)

Location: Indurated sandstone just above adit near Yarra Wurta Cliff trig.

HS : Grey to pale yellowish orange, finally laminated partly silicified impure sandstone with silicified wood fragments and occasional clay galls.

TS :

Visual estimate -	quartz	25%
	clay and iron oxides	45%
	opal	25%
	Fossil wood (variable)	5%
	Muscovite	< 1%

Quartz is angular silt to very fine sand, generally concentrated in thin laminae of the order of 1mm thick. Other less sandy laminae are composed of slightly coarser rounded grains, which appear to be mostly very fine-grained brownish clay with some iron staining. Larger clay grains and rounded clasts have been lost during grinding.

TS 546/A14/C (cont.)

Opal (isotropic, pale brown in plane polarized light) is the cement present in both sandy and clay-rich laminae. However its distribution is variable, perhaps due to solution, making the rock somewhat porous. Scattered muscovite flakes up to 0.2mm long occur.
Fossil wood, shown to be opal-CT by XRD, occurs as scattered fragments generally only a few millimetres long with one piece one centimetre long.

Comment : Cretaceous, Marree Formation. Presumably marine, since marginal marine foraminifera have been recorded from immediately below (Hannah and Lindsay, 1977). The presence of wood fragments also suggests closeness to a shoreline.

TS 546/A15/B (TS 40578)

Location: Float, Yarra Wurta Cliff area outcrop.

HS : Pale grey silcrete with lighter (more yellowish) "nodules", 2-20mm across, sometimes with a thin, irregular yellow grey skin. Sand grains can be seen throughout the rock, especially on the weathered surface which is stained red by iron oxides. Weathers irregularly, exposing "nodules".

TS : Visual estimate -

quartz	75%	
chalcedony	20%	
calcite	< 1%	(localized)
titaniferous matrix	2%	
heavy minerals and opaques	< 1%	
?opal	< 1%	

Quartz present as coarse to very fine sand size. Most grains are angular, though the larger grains are commonly rounded. The matrix is mostly fine-grained chalcedony, with occasional TiO_2 rich patches. "Nodules" comprise approximately 50% of rock, and are variable in composition, though roughly similar to the bulk of the rock. Others have a high concentration of minute brownish crystals of TiO_2, especially at the margins. Another nodule contains patches of calcite as matrix, while the rest is opal.

Comments : Tertiary. Nodular silcrete is common near the tops of the mesas.

TS 546/A16/B (TS 40579)

Location: Float, Yarra Wurta Cliff area.

HS : A micro-crystalline limestone with a high proportion of silt to very fine grained sand grains, and occasionally coarser grains. No structure visible, except solution cavities. Pinkish grey-brown when fresh.

TS : Visual estimate - calcite 43%

calcite	43%
quartz	55%
opaques	2%

Quartz is mostly present as angular fine to very fine sand (as are the opaques) with some larger quartz grains up to 0.5mm across. Larger grains are often rounded.

Matrix is calcite (stained pink with alizarin red) enclosing quartz grains. Grainsize approximately 0.3mm (cf. sand grains approximately 0.1mm). Some patchy brownish colouration may be due to included clay, iron oxides or organic material, and the distribution may be related to burrowing.

Elongate irregular quartz-free areas up to 1mm long may represent burrows in the sand.

Comments: A Tertiary limestone, possibly with primary carbonate.

TS 546/B2/G (TS 40582)

Location: Eastern flank of "First Mesa".

HS : A white to grey bedded partly silicified sandstone ranging in grain-size from fine to very coarse with some granules and pebbles, generally of milky quartz.

TS : Mostly quartz grains ranging in size from very fine sand to pebble size. In parts silicified by quartz overgrowths, other parts appear to have lost quartz by solution and have a thin coating of clay or iron oxides.

Scattered heavy minerals. Some TiO_2 localized in one layer.

Minor chalcedony, heavy minerals.

Comments: Tertiary partly silicified sandstone.

TS 546/B2/H (TS 40587)

Location: Float from "First Mesa".

HS : A pale yellow grey, very fine-grained siliceous rock that has been partially broken up and recemented by a grey sandy siliceous material.

TS : Quartz - angular silt to very fine sand is cemented by minor quartz and masses of minute brownish TiO_2 crystals responsible for pale yellow grey colour in the hand specimen. Rare angular coarser grains. This is broken up and recemented by a less well sorted sand. The sand is slightly coarser, (though still a very fine sand), with approximately 20% coarser grains, generally medium to coarse, and variably rounded. This sand is cemented by quartz overgrowths (in optical continuity with the original grains) and minor TiO_2. Rounded fragments of the first sandstone a few millimetres across can be distinguished within the second sandstone by the darker colour (due to more TiO_2). Boundaries are not sharp when viewed in detail. There is one thin bed a few millimetres thick, in which calcite is the cement.

Comments: A Tertiary silcreted sandstone. This slide shows that there have been at least two Tertiary silicification events.

TS 546/B3/A (TS 40585)

Location: Eastern flank of "First Mesa".

HS : A very pale grey brown microcrystalline siliceous rock overlain by a pale orange very fine sandstone. The sand fills cracks in the "chert" and rounded fragments of "chert" occur in the sandstone.

TS : Sandstone comprises angular very fine sand with rare coarser grains. Rare heavy minerals. Cemented mostly by chalcedony with very fine-grained brownish TiO_2 crystals. "Chert" shows bulk extinction, (overprinted by total extinction due to opal) hence possibly some remnant clay.

Opal-CT and quartz shown by XRD.

Burrows analogous to TS 546/8 and TS 546/19 are visible.

Scattered silt and fine sand grains <1%.

Cracks in "chert" contain sand grains.

A rounded clast has a different direction of bulk extinction to that of the sediment.

TS 546/B3/A (cont.)

Comment : Appear to have a Cretaceous mud almost totally silicified before erosion and deposition of a Tertiary sand that was later silicified, unless silicification produces different forms in different lithologies.

TS 546/D2/A (TS 40586)

Location: 300m northwest of Arthur Hill trig.

HS : A fractured quartzite, with the cracks partially filled by iron oxides and quartz fragments.

TS : A fine-grained quartzite, non-porous due to complete cementation by quartz overgrowths, but which has been brecciated. Many small scale fractures lined or filled by iron oxides. In wider fractures, angular quartz fragments, probably derived from the quartzite, are also present.

Comment: Probably a Tertiary weathering and ferruginization profile developed on Precambrian quartzite.

TS 546/D3/A (TS 40592)

Location: 400m northwest of Arthur Hill trig.

HS : Brownish black, fine to coarse sandstone, strongly cemented by iron oxides.

TS : Visual estimate -

quartz	80%
iron oxides	15%
porosity	5%

Poorly sorted sands, very fine to coarse, the coarser grains often rounded. Haematite and other iron oxides, irregularly coating grains and partly infilling interstices.

Comments: Ferruginized Tertiary sandstone.

APPENDIX C

Bulk and Clay Fraction Mineralogy

The following is taken from AMDEL report GS 1081/79. The investigation and report is by Dr. Roger Brown.

Subsamples of the clay samples were powdered and X-ray powder diffractometer traces of the bulk materials were recorded and interpreted.

Weighed amounts of the air-dry samples were dispersed in water with the aid of deflocculants and an electric blender and allowed to sediment for separation of representative -2 μm e.s.d. material by the pipette method. The resulting dispersions were examined by plummet balance to determine their solids contents, and were then used to produce oriented preparations on ceramic plates. Two plates were prepared for each sample, both saturated with Mg^{++} ions and one in addition treated with glycerol. These plates when air-dry were examined in the X-ray diffractometer. Extra diagnostic tests were applied to these samples as necessary, including examinations hot (130°C) and after heating for 1 hour at 550°C.

The results are given in Table C1. This lists for each sample the following:

(a) the mineralogy of the bulk sample, in approximate order of decreasing abundance, using the semiquantitative abbreviations given. This is to be regarded mainly as a source of information on the non-clay minerals.

(b) the proportion of the sample found to disperse into the -2 μm e.s.d. fraction.

(c) the mineralogy of the -2 μm e.s.d. fraction, again in order of decreasing abundance, using the same abbreviations. Detailed information on the clays should be taken from this section.

Semiquantitative abbreviations used in table

D = Dominant. Used for the component apparently most abundant, regardless of its probable percentage level.

CD = Co-dominant. Used for two (or more) predominating components, both or all of which are judged to be present in roughly equal amounts.

SD = Sub-dominant. The next most abundant component(s) providing its percentage level is judged above about 20.

A = Accessory. Components judged to be present between the levels of roughly 5 and 20%

Tr = Trace. Components judged to be below about 5%.

Mineral Key

A	Anatase
Cal	Calcite
F	K feldspar
Gy	Gypsum
Ha	Halite
K	Kaolinite
M	Mica/illite
ML	Mixed-layer clay of uncertain type - see clay fraction for details
Mo	Montmorillonite (smectite)
M/Mo	Regularly-interstratified mixed-layer illite - montmorillonite
O	Opaline silica
Q	Quartz
RI	Randomly-interstratified clay material of indeterminate type

TABLE C1

BULK AND CLAY FRACTION MINERALOGY

Sample	103		105		122		135		B49/B		S.C.C.19/2.0m	
Bulk mineralogy	Q	D	Q	CD	K	CD	Q	D	O	D	Q	D
	K	SD	K	CD	M	CD	Mo	SD	K	SD	K	SD
	Mo	A-SD	M	A-SD	Q	A-SD	K	A	Q	A	ML	SD
	M	Tr-A	Ha	Tr-A	Ha	Tr	M	A	Ha	A	Cal	A
	Gy	Tr					Ha	Tr	M	Tr	M	A
	Ha	Tr					A	Tr	Gy	Tr	Gy	Tr
	A?	Tr									F?	Tr
											A?	Tr
-2μm fraction - %	47		24		63		40		25		53	
Mineralogy	K	D	K	D	M	D	Mo	D	O	D	K	D
	Mo	A	M	SD	K	SD	K	A	K	SD	M/Mo	SD
	Q	Tr	Q	Tr	RI	A	M	Tr	M	A	M	A
	M	Tr			Mo	A			Q	Tr	Q	Tr

Sample	F4/A		F6/A		F6/B		F9/A		F11/H		F11/I	
Bulk mineralogy	K	D	K	D	Q	D	K	D	Q	D	Q	CD
	Q	SD	Q	SD	K	A-SD	Q	SD	M	SD	M	CD
	Ha	Tr	Mo	A	Gy	Tr-A	M	A	K	SD	K	CD
			M	A	M	Tr	Ha	Tr	Ha	Tr	Ha	Tr
			Ha	Tr-A					A?	Tr	A?	Tr
-2μm fraction - %	75		77		22		60		60		62	
Mineralogy	K	D	K	D	K	D	K	D	M	D	M	D
	Mo	Tr	Mo	A	Mo	A	Q	A	K	SD	K	SD
			M	A	M	A	M	Tr-A	Q	Tr	Q	Tr
			Q	Tr-A	Q	Tr						

Sample Description

103	?Tertiary. Pale green clay from S.C.C. 25, depth - approximately 4m.
105	"Stuart Creek Beds". Basal lithology of S.C.C. 16, red-brown slickensided clay, with sand, shale clasts and glauconite.
122	"Stuart Creek Beds". Wood-bearing silty brown muds. S.C.C. 16, depth - approximately 7m.
135	Marree Formation. Bleached muds, similar but not as strongly silicified as 546/B4/B in Table 1.
B49/B	?Tertiary. Pale grey clay with sand. Near northeast corner of Precious Stones Field.
S.C.C. 19/2.0m	Tertiary. Grey clay with some silt and sand.
F4/A	Tertiary. White silty, friable clay.
F6/A	Tertiary. Poorly laminated brown clay, with some fissility.
F6/B	Tertiary. Fine white clayey sands, 2m above F6/A.
F9/A	Marree Formation. Stiff grey clay. Tertiary approx. 1m above.
F11/H	"Stuart Creek Beds". Red regolithic Yarra Wurta Shale. Yarra Wurta Dam section.
F11/I	"Stuart Creek Beds". Green clay clast conglomerate. Yarra Wurta Dam section.

APPENDIX D

BACKHOE TRENCH DESCRIPTIONS

This material was only in a rough form when the thesis was submitted. It is included now since it is primary data relevant to the thesis. Also included are descriptions of sections at Yarra Wurta Dam (Locality F11) and Yarra Wurta Cliff (Locality A14).

A brief diagrammatic summary of the information contained in this appendix is contained in Figure 10 of the thesis.

The descriptions of the backhoe trenches are headed by the following information:

1. Backhoe trench number.
2. Elevation level (E.L.) of the top of the backhoe trench, relative to the Australian Height Datum.
3. Depth.
4. Stratigraphic unit(s) encountered. (The Tertiary unit is not named though it is probably the Miocene Mount Sarah Sandstone).

All samples referred to are kept in the Geology Department at the University of Adelaide, except where mentioned. Analyses are to be found in the thesis, Tables 1 and C1.

Michael Vnuk,
January, 1979.

BHT 101 E.L. 86.534m Depth 3.2m Marree Formation/ Bunyeroo Formation

The original bulldozer cut (approx. 2m deep) bottomed in a conglomeratic bed. Several others can be seen in the wall of the cut. The cut comprises typical flat-lying Marree Formation muds and silts, somewhat dry from exposure. The backhoe reveals the conglomeratic bed to be nearly one metre thick (from 1.8m to 2.7m deep). It is mostly framework-supported but contains some thin muds layers. Clasts are mostly rounded quartzite cobbles with some boulders. Siltstone is the next most common lithology.

Below the conglomerate is a thin grey green to grey brown mud with occasional pebbles. It passes up into the conglomerate. It is 10-20 cm thick due to the sloping and uneven contact with the Bunyeroo Formation below. The Bunyeroo Formation comprises laminated and finely cross-laminated siltstones and mudstones, mostly pale green but commonly red near the contact. They are micaceous with good to poor fissility along bedding planes. They are slightly softened due probably to weathering at an unknown time. Bedding was measured as striking 135^{o} and dipping 40^{o} west consistent with Precambrian trends. Assignment to the Bunyeroo Formation is on lithological and structural grounds.

Sample 546/17 and accompanying thin section came from similar Bunyeroo Formation below a conglomerate bed in a nearby cut.

BHT 102 E.L. 69.023m Depth 2.6m "Stuart Creek Beds"

40-50 cm of soil and alluvium overlie a conglomerate which contains granules, pebbles and cobbles within dry friable pale yellow silts to fine sands. Clasts comprise mostly quartzite, but also fine sandstone, siltstone and shale. Mostly rounded, some angular. The conglomerate is both matrix and framework supported.

At 2.2m this overlies a green glauconitic clay (occasionally yellow-stained or grey-green) which contains a few quartzite pebbles and cobbles.

A sample of each lithology was taken from the dump. Some drying from exposure has occurred (546/163 - upper, 546/162 - lower).

BHT 103 E.L. 71.589m Depth 2.5m Marree Formation

Apart from 80-90 cm of gypseous soil and alluvium the remainder of the trench contains weathered Marree Formation, i.e. grey to grey-brown silts and muds with much yellow alunite. A conglomeratic bed containing pebbles and cobbles is dipping approximately 10^{o} to the south. Unfortunately this trench was sited too high to reach the base of the Marree Formation.

BHT 104 E.L. 92.644m Depth 0.8m Recent

Abandoned in red soil containing rounded, angular and flaggy quartzite cobbles and boulders. Expect to have A.B.C. Range Quartzite below.

BHT 105 E.L. 88.853m Depth 2.8m Marree Formation

Deepening an old cut reveals 60-80 cm of infilling, then the remainder is Marree Formation. It comprises slightly silty clay with occasional scattered pebbles or cobbles. The colour of the mud varies from very pale grey darkening to grey brown at the base. Typical Cretaceous bioturbation can be observed in fresher samples. Iron-stained fractures are common.

BHT 106 E.L. 84.521m Depth 82.8m ?Tertiary

The top few centimetres of stream bed sands overlie a stiff very pale grey slightly silty clay which rapidly whitens on exposure (sample 546/160). Some pink colouration and small patches of red iron staining occur. No erratic pebbles, alunite or traces of bedding were seen. Some poorly defined bioturbation unlike that typically found in the Marree Formation was observed in 546/160. Lack of typical Cretaceous features and presence of Tertiary silicified sands a few metres away suggests a Tertiary age.

BHT 107 E.L. 90.660m Depth 2.6m Tertiary

10-20 cm of alluvium overlies bedded pale yellow to yellow sands with two beds (5 cm thick) at 0.8 m and 2.3 m depth. The sand beds are close to flat-lying, generally 5-10 cm thick but ranging from 2 to 20 cm thick. Beds contain low-angle cross stratification with differing directions between beds. The sands are generally well-rounded and well-sorted and range from coarse to fine with some finer material, especially as white silt and clay layers defining cross-laminae. The sand is free-flowing to semi-friable.

The pebble beds contain well-rounded to poorly rounded quartzite pebbles. A few other lenses are present.

BHT 108 E.L. 93.098m Depth 1.9m ?Tertiary

10 cm of alluvium overlies hard dry white to pink clay with minor silt. There is much irregular iron-staining both as patches and veins. Gypsification is also common.

Sample 546/159 is a hard white slightly silty clay. Samples 546/139 and 546/158 are hard pink clays with networks of fine iron-stained veins and fractures.

The lack of pebbles and characteristic Marree Formation bioturbation suggests this to be a Tertiary sediment, but it may be altered atypical Marree Formation. More typical Tertiary sands can be found a few metres higher close by.

BHT 109 E.L. 85.972m Depth 1.6m ?Tertiary

40-50 cm of alluvium then indurated white to yellow silty fine sands with some medium to coarse sands. The irregular contact with the lower lithology at 0.6 to 1.1m is dipping though no distinct structure can be seen in the upper or lower lithology. The lower lithology is similar to BHT 108 - a white to pink/iron-stained dry clay with minor silt and very fine sand, e.g. sample 546/157.

The sequence is probably Tertiary in age, but the lower lithology is possibly Cretaceous based on similarity to BHT 109. However, no undoubted Marree Formation characteristics are present.

BHT 110	E.L. 80.629m	Depth 2.1m	Marree Formation

Alluvium 1.1-1.3m thick overlying typical Cretaceous silts and muds, grey at the top and becoming browner towards the bottom. Two pebble beds (5-10 cm thick) occur at 1.4m and 1.7m. The upper bed is discontinuous. Generally silt to fine sand between the pebble beds. Occasional "erratics" and yellow alunite veins.

BHT 111	E.L. 80.804m	Depth 2.2m	Tertiary

20-30 cm of sandy soil overlying white to grey clay with minor silt and sand (e.g. sample 546/168 at 0.5m).

Around 1.5m there is an irregular transition to pale grey to pale yellow semi-friable silt to very fine sand, (e.g. sample 546/167 at 1.8m).

No structure observed. Some iron-staining especially concentrated into bands 10-15 cm thick at 0.3, 1.0 and 1.9m.

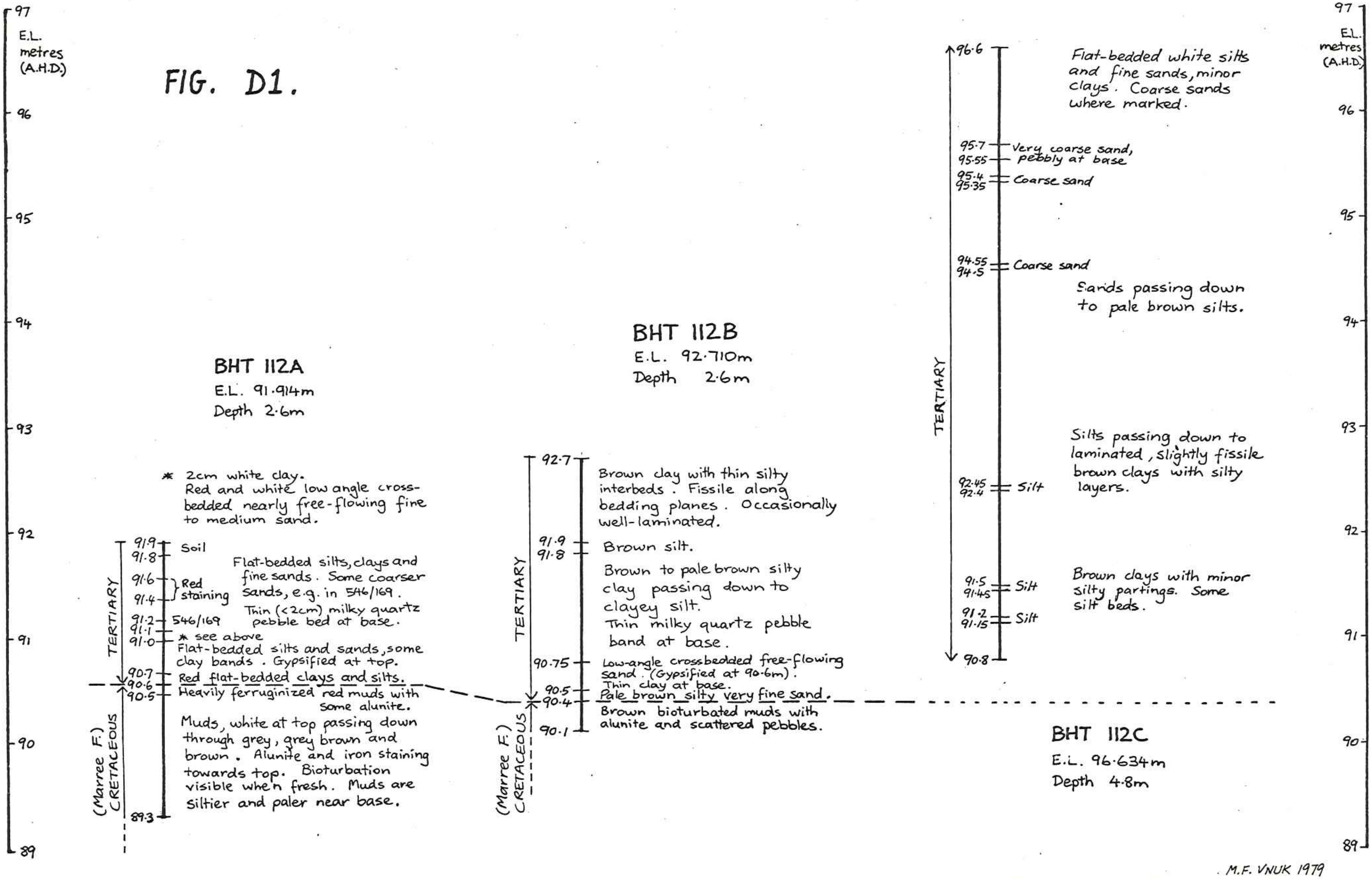
BHT 112A	E.L. 91.914m	Depth 2.6m	Tertiary/ Marree Formation
BHT 112B	E.L. 92.710m	Depth 2.6m	Tertiary/ Marree Formation
BHT 112C	E.L. 96.634m	Depth 4.8m	Tertiary

See Fig. D1

A group of three trenches within 50m (BHT 112C includes a scrape down an escarpment). All three backhoe trenches passed through flat-bedded Tertiary sediments with some layers almost completely clay. The clays can be distinguished from the Marree Formation because they were partly laminated and some exhibited good fissility. Furthermore when Marree Formation was reached (BHT 112A and 112B) it had the typical characteristics, i.e. conglomeratic beds, "erratics", bioturbated muds, alunite.

Two samples were submitted for bulk and clay fraction mineralogy (see Appendix C). 546/F6/A was a Tertiary poorly laminated brown clay with some fissility similar to those found in the lower part of BHT 112C while 546/F6/B comprised fine white silty and clayey sands (also Tertiary) similar to those from the upper part of BHT 112C.

FIG. D1.



E.L. metres (A.H.D.)
97
96
95
94
93
92
91
90
89
BHT 112A
E.L. 91·914m
Depth 2·6m
TERTIARY
CRETACEOUS (Marree F.)
91·9
91·8
Soil
91·6
91·4
Red staining
Flat-bedded silts, clays and fine sands. Some coarser sands, e.g. in 546/169.
Thin (<2cm) milky quartz pebble bed at base.
91·2
91·1
91·0
546/169
* see above
* 2cm white clay. Red and white low angle cross-bedded nearly free-flowing fine to medium sand.
Flat-bedded silts and sands, some clay bands. Gypsified at top.
90·7
90·6
90·5
Red flat-bedded clays and silts.
Heavily ferruginized red muds with some alunite.
Muds, white at top passing down through grey, grey brown and brown. Alunite and iron staining towards top. Bioturbation visible when fresh. Muds are siltier and paler near base.
89·3
BHT 112B
E.L. 92·710m
Depth 2·6m
TERTIARY
CRETACEOUS (Marree F.)
92·7
Brown clay with thin silty interbeds. Fissile along bedding planes. Occasionally well-laminated.
91·9
91·8
Brown silt.
Brown to pale brown silty clay passing down to clayey silt.
Thin milky quartz pebble band at base.
90·75
Low-angle crossbedded free-flowing sand. (Gypsified at 90·6m). Thin clay at base.
90·5
90·4
Pale brown silty very fine sand.
Brown bioturbated muds with alunite and scattered pebbles.
90·1
BHT 112C
E.L. 96·634m
Depth 4·8m
TERTIARY
96·6
Flat-bedded white silts and fine sands, minor clays. Coarse sands where marked.
95·7
95·55
Very coarse sand, pebbly at base
95·4
95·35
Coarse sand
94·55
94·5
Coarse sand
Sands passing down to pale brown silts.
92·45
92·4
Silt
Silts passing down to laminated, slightly fissile brown clays with silty layers.
91·5
91·45
Silt
91·2
91·15
Silt
Brown clays with minor silty partings. Some silt beds.
90·8
M.F. VNUK 1979

BHT 113 E.L. 75.589m Depth 2.0m Marree Formation

Marree Formation muds, nearly white at the top pass down through grey and grey brown to brown by approximately 50 cm. A conglomerate bed at 1m contains pebbles and cobbles in a matrix composed mainly of silt and clay with very little sand. Muds beneath this pass down to paler brown silts in the bottom 30 cm. Poorly defined bedding can be seen above the conglomerate where there is more silt to fine sand in the mud. "Erratics" are present and the typical bioturbation was also observed in the fresher muds.

Bulk and clay fraction mineralogy were determined for sample 546/F9/A which came from a poor outcrop a few metres away. The sample was very similar to the uppermost white to grey mud of the backhoe trench (see Appendix C).

BHT 114 E.L. 78.267m Depth 2.6m Marree Formation/ "Stuart Creek Beds"

A contact between Marree Formation and "Stuart Creek Beds" is probably exposed in this trench. However, weathering and alteration make definite stratigraphic assignment uncertain.

90-100 cm of creek alluvium and soil overlie weathered fine sands, silts and clays with alunite. These probably belong to the Marree Formation. A conglomerate bed occurs between 1.5 and 2.2m. The matrix comprises mainly clays and silts with minor sand. This is probably the basal boulder bed of the Marree Formation (see also BHT 101). Closeness to the base would explain the coarser than usual sediments above the conglomerate bed.

From 2.2m to the bottom of the trench (at 2.6m), is a fine white friable micaceous sand containing quartzite pebbles and cobbles. The clasts include rounded, angular and flaggy forms. This lithology is assigned to the "Stuart Creek Beds" on the basis of similarity to lithologies found in S.C.C. 16 and elsewhere.

No major time break is indicated between the Marree Formation and the "Stuart Creek Beds".

BHT 115 E.L. 67.468m Depth 3.1m "Stuart Creek Beds"

See Fig. D2

A thick conglomeratic bed appears to have a sandy interbed, all overlying very mixed sediments near the base. The dip of these lower sediments (approx. 110/40S) is difficult to explain, but may represent initial dips over a very irregular unconformity surface, or complex faulting related to the Arthur Fault that was covered elsewhere by later Cretaceous sediments.

The whole sequence is very altered under the thick creek alluvium.

BHT 116 E.L. 67.126m Depth 3.1m "Stuart Creek Beds"

See Fig. D2

A pebble bed in this trench exhibits a dip of 10-15° to the south. This may be due to similar reasons to those put forward in the description of BHT 115. Like BHT 115 there is thick creek alluvium and again the sediments are very weathered, with irregular veins throughout of white friable material which fizzes with acid. However the sediments do not closely resemble those of BHT 115.

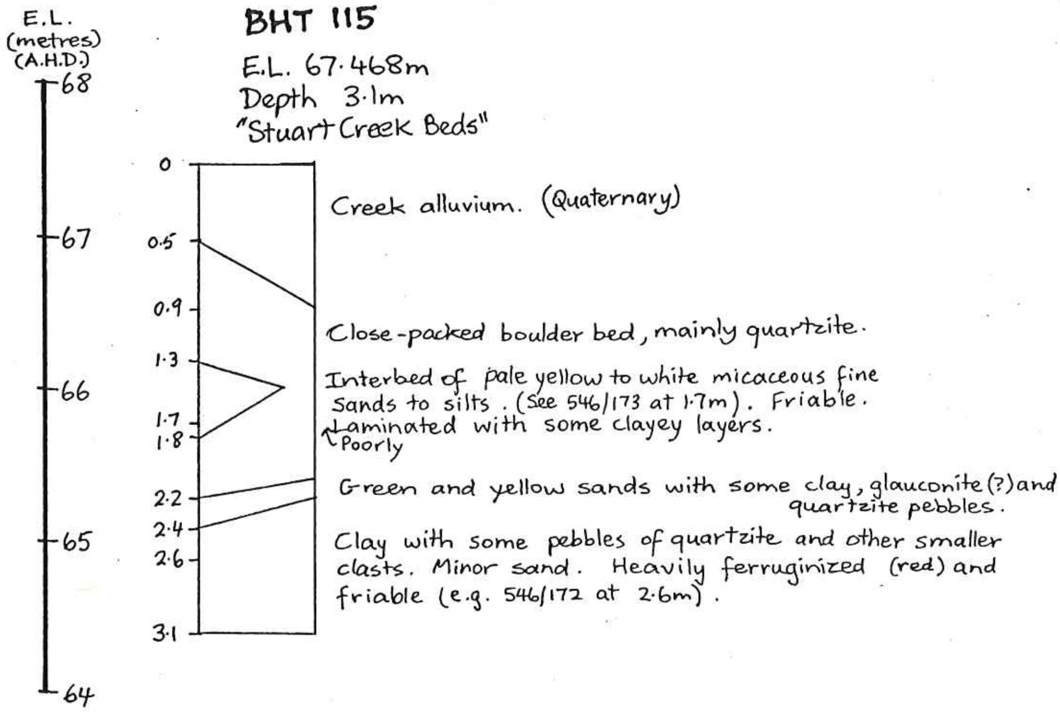
BHT 117 E.L. 70.289m Depth 2.4m "Stuart Creek Beds"

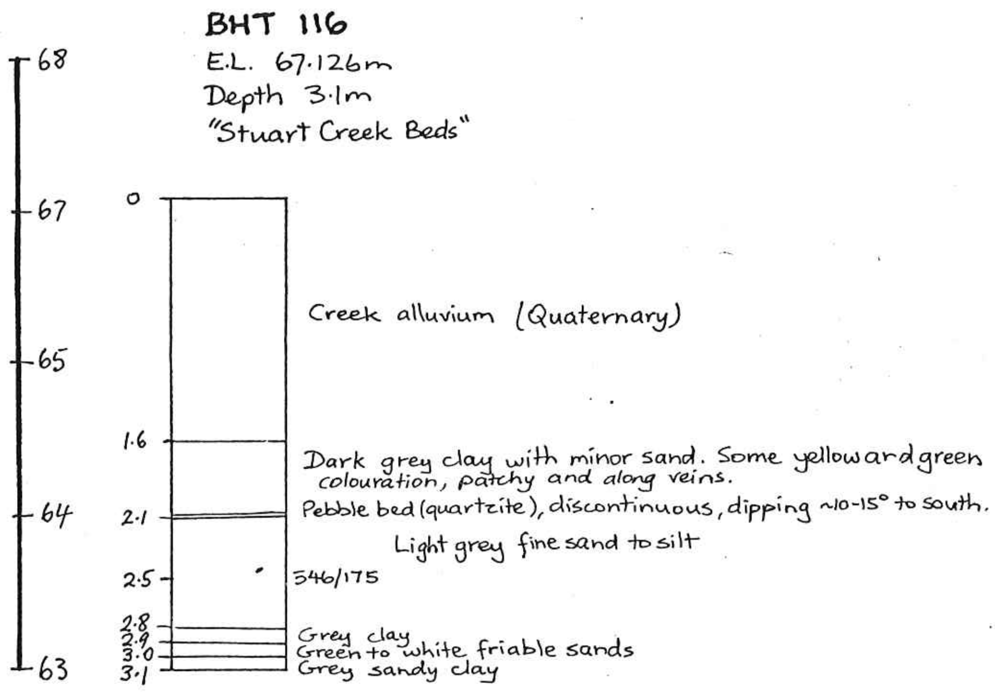
50 cm of soil and kopi (white powdery gypsum) overlies a weathered sequence of mainly greenish clay with yellow and grey colourations. It is slightly sandy, e.g. sample 546/177 from 1.5m. Scattered quartzite pebbles and cobbles (both rounded and angular) occur. Small clay clasts and possible glauconite can also be found. Hard white to very pale yellow nodules, a few centimetres across, occur near the top. A sample of this material (546/176 from 1.2m) was identified by X-ray diffraction as alunite. Other more yellowish veins of alunite are present.

The bottom 20-30 cm consists partly of sand of irregular distribution. It is nearly free-flowing in places but indurated elsewhere (e.g. 546/178). It is white to dark red in colour due to variable ferruginization. 546/178 contains iron oxide particles and some feldspar grains. It is mostly fine to medium-grained. The surrounding sediments are similar to those above and variably ferruginized.

Cambrian Andamooka Limestone outcrops nearby and BHT 117 probably almost reached the base of the "Stuart Creek Beds".

FIG. D2.





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<u>BHT 118A</u> E.L. 65.242m Depth 3.2m "<u>Stuart Creek Beds</u>"

<u>BHT 118B</u> E.L. 66.413m Depth 1.8m "<u>Stuart Creek Beds</u>"

See Fig. D3

BHT 118A consists of a scrape down an escarpment with a shallow trench at the base. BHT 118B was dug at the top to give a more complete section. Both show interbeds of green clay clast conglomerate with flat-lying brown sands, silts and clays commonly with lignitic wood fragments. Samples 546/184 and 546/185 were taken from dark carbonaceous clays in BHT 118A (2.6m and 1.8m respectively) and were unsuccessfully analysed for microfossils by the S.A. Department of Mines and Energy. (The samples are held at S.A.D.M.E.). A sample of the typical pale brown sands with wood fragments, 546/186 (BHT 118A, 2.4m) is shown in Fig. 3b.

Cambrian Andamooka Limestone outcrops <20m away at a level nearly a metre above the base of BHT 118A (by eye).

BHT 118B was more weathered than BHT 118A.

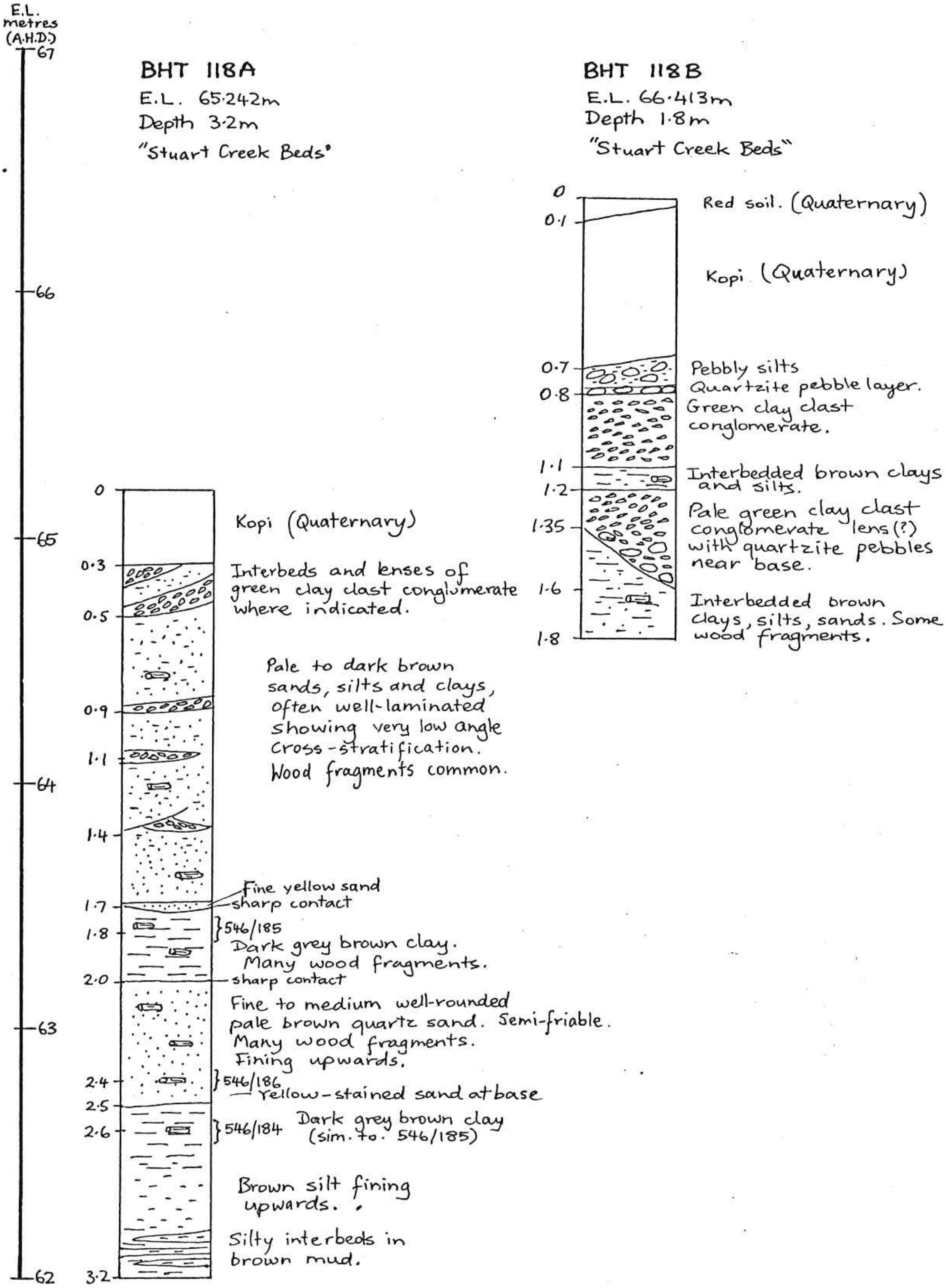
<u>BHT 119A</u> E.L. 69.105m Depth 3.5m "<u>Stuart Creek Beds</u>"

This trench includes a scrape down an escarpment. BHT 119B was dug at the top to provide a more complete section. The top 40 cm comprises mostly sands and silts as described in BHT 119B.

Most of the rest of the trench consists of clay, commonly slickensided and with a variable sand and clast content. Clasts are mostly clay or shale and can be both angular or rounded. They are generally less than 1 cm in diameter. In places the clasts are fairly obvious and look similar to the clay clast conglomerates of BHT 118A. But elsewhere clasts are difficult to see, especially since the sequence is patchily iron-stained with colours ranging from pale green to dark red-brown. This variation in colour is shown from 1.5-2.0 metres where one side of the trench is red-brown while the other side is green. From 2.0 to 2.4m there is much dark purple staining probably by manganese oxides. Sand patches are also present.

546/181 is a sample of dark red-brown clay with clasts from 2.9m. 546/180 is a sample of pale green clay with indistinct clasts from 3.2m. This sample also shows irregular white layers that may represent original bedding. Much of the bottom 40 cm consists of this material.

FIG. D3.



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BHT 119B E.L. 70.590m Depth 1.8m "Stuart Creek Beds"

Approximately 80 cm of red-brown soil and kopi overlies a semi-friable sand. The sand is pale green to grey green in colour but is more yellowish near the top, which also contains more clay patches. It is mostly fine-grained but it is not well-sorted and coarser and finer sand and silt comprise approximately a third of the sediment. Small clay clasts and quartzite pebbles (generally less than 1 cm in diameter) can be found. The trench is very weathered and bedding is very indistinct. Sample 546/179 is from 1.5m.

BHT 120 E.L. 61.416m Depth 1.8m "Stuart Creek Beds"

This trench contains mostly slickensided clays with minor silt and sand contents. Variable amounts of small shale clasts appear in the clay. Colours vary from pale green to red-brown and are patchily and irregularly developed (e.g. 546/182 from 1.3m).

A lens up to 15 cm thick of grey to green sandy clay appears 10 cm from the base (546/183).

BHT 121 E.L. 81.843m Depth 3.5m ?Tertiary

Originally the yellow, white and purple sands in this trench were thought to be Quaternary, i.e. a thick alluvial sequence, since the trench was sited in a stream bed. Considering the depth of the trench it is more likely that the alluvial sands pass down into Tertiary sands. However the trench was backfilled before this could be checked.

BHT 122 E.L. 82.868m Depth 3.1m ?Tertiary

Stream sands extend down to 0.8 to 1.4m. Below this irregular contact are mostly clays to 2.8m. The clays are grey and featureless near the top but are coloured irregularly red, yellow and pink towards the base (e.g. 546/171 at 2.7m). They are fairly pure stiff clays with a few minor sandy bands, especially around 2.3m.

From 2.8 to 3.1m the sediment is mostly pale grey quartz sands with some clay interbeds. The sands are mostly fine to very fine (546/170) and tend to be nearly free-flowing though sometimes held together by clay content.

Bedding in the trench (25 to 30^{o} towards 150^{o}) is mostly defined by the sand beds. It is inconsistent with nearby Precambrian outcrops which also do not have free-flowing sands. There are no Cretaceous characteristics in the sediments. Assignment to the Tertiary is on the basis of partial similarity to BHT 124 nearby.

BHT 123 E.L. 87.385m Depth 3.2m Tertiary

Apart from 50 cm of soil at the top this trench contains mostly flat-bedded (white to pale yellow) sands. These are mostly fine to very fine, with thin silty and clayey interbeds. They have similarities with BHT 107 though cross-bedding is less well-developed.

BHT 124 E.L. 85.516m Depth 2.1m ?Tertiary

60-70 cm of soil and alluvium overlies grey slightly fissile clay which appears flat-lying. At approximately 1m depth it passes into friable white to grey quartz sands exhibiting low angle cross stratification. Some thin clay interbeds and patches are present. The sands have a similar bedding orientation as those in BHT 122 (i.e. 25-30^{o} towards 150^{o}). The clays may be Tertiary but the age of the sands is uncertain.

Yarra Wurta Cliff Section

See Figure D4.

At Yarra Wurta Cliff is a section showing Tertiary sands and silcretes overlying Marree Formation sediments. The upper part of the Marree Formation has been strongly altered to "kopi". The lower part, "mud", is less affected. Common opal has been found just below the contact (see also Fig. 7a).

Yarra Wurta Dam Section

See Figure D4.

At Yarra Wurta Dam is a 6m section of "Stuart Creek Beds". Unfortunately, the base is not present, however the lower part is well-exposed. (See also Figure 2a, 2b and 3a).

FIG. D4.

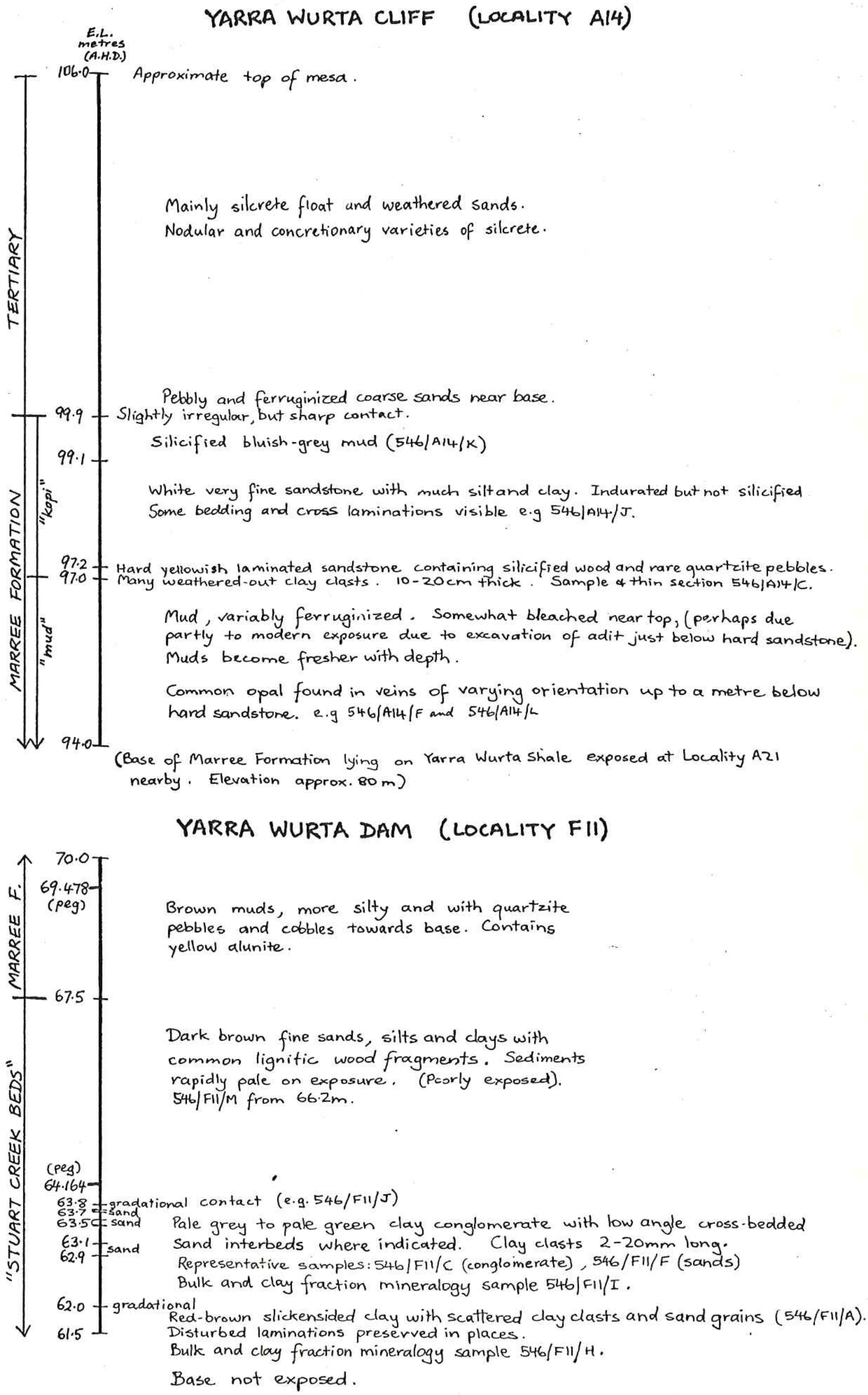

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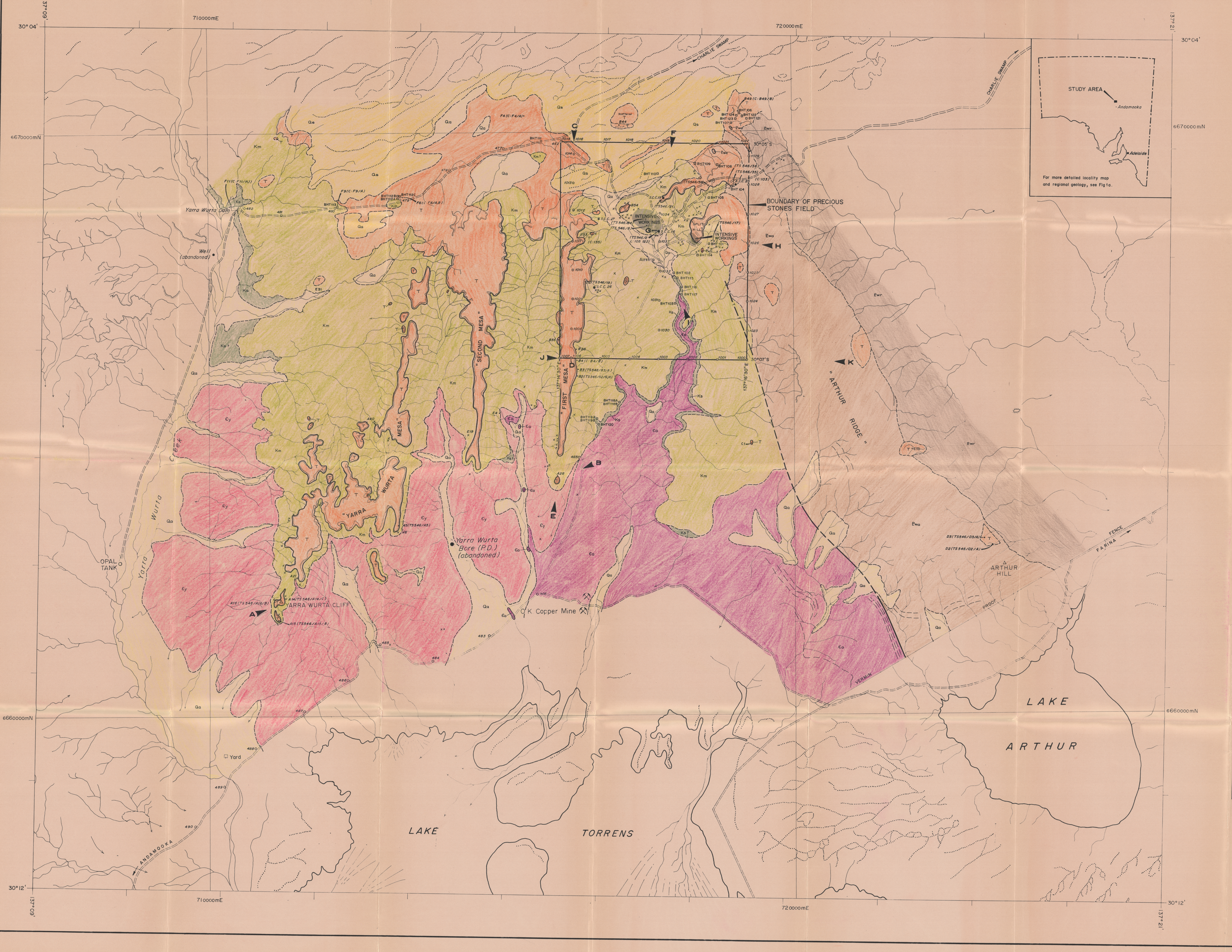
Figure 9.



LEGEND

CAINOZOIC	QUATERNARY	Qa	Alluvium and colluvium.
		Qs	Sand ridges and sand spread with claypans.
	TERTIARY	T	Probable MT. SARAH SANDSTONE of ? Miocene Age but may include other units. Sands and silts with minor clays and limestones. Common pebble layers of polished milky quartz and also reworked silcrete clasts. Variably silicified and ferruginised. Conglomeratic near "Arthur Ridge".
MESOZOIC	LOWER CRETACEOUS	Km	Lower part of MARREE FORMATION (Aptian). Brown to grey muds with sandy or conglomeratic beds. Characterised by the presence of 'erratics', distinctive bioturbation and yellow alunite veins. May be intensely weathered to light, porous, white rock in upper exposed portion.
		Ks	"STUART CREEK BEDS" Varied lithologies, including regolithic or reworked Yarra Wurta Shale at base (may contain glauconite); pale green, clay clast conglomerate; brown sands, silts and clays with abundant lignitic wood fragments; pebbles and cobbles in friable silty sand; and poorly bedded greenish clays, silts and sands. Poorly outcropping, hence boundaries somewhat speculative.
PALAEOZOIC	LOWER CAMBRIAN	Єy	YARRA WURTA SHALE Red and green, laminated shales and siltstones.
		Єa	ANDAMOOKA LIMESTONE Massive to laminated, grey to brown limestone with chalcedonic nodules.
UPPER PROTEROZOIC	ADELAIDEAN (WILPENA GROUP)	Ewb	BUNYEROO FORMATION Red and green micaceous siltstone.
		Ewa	A.B.C. RANGE QUARTZITE White to grey, crossbedded flaggy quartzite. Some interbeds of siltstone and shale. Clay galls common.
		Ewr	BRACHINA FORMATION Green and purple shales and siltstones.

- Geological boundary – observed.
- Geological boundary – inferred.
- Fault – observed.
- Fault – inferred.
- Fault – possible.
- Bedding trends.
- Calweld shaft (logged in Barnes and Scott, 1978)
- Backhoe trench.
- Bench mark.
- Temporary bench mark.
- Digging (not all shown on Field).
- Vermin proof fence.
- Sand ridge.
- Claypan.
- Creek.
- Trigonometric station.
- Locality referred to in thesis (TS - thin section, C - clay mineralogy).

NOTES :

(1) Names in inverted commas are informal and used for this thesis only.

(2) Due to recent activity in the area by Amoco, track information may be incorrect.

(3) P.D. implies position doubtful.

LEVEL INFORMATION

CALWELD SHAFTS

NUMBER	E.L.(m.)
S.C.C. 16	72·2
S.C.C. 19	94·4
S.C.C. 25	96·2
S.C.C. 26	82·3
S.C.C. 27	78·9

TEMPORARY BENCH MARKS

NUMBER	E.L.(m.)
462	81·655
465	64·848
466	46·164
477	84·186
478	92·767
479	92·484
480	75·803
481	70·202
482	64·714
483	42·747
484	41·758
485	43·826
486	43·823
487	44·339
488	41·621
489	38·680
490	38·099

BACKHOE TRENCHES

NUMBER	E.L. (m.)
BHT 101	86·534
BHT 102	69·023
BHT 103	71·589
BHT 104	92·644
BHT 105	88·853
BHT 106	84·521
BHT 107	90·660
BHT 108	93·098
BHT 109	85·972
BHT 110	80·629
BHT 111	80·804
BHT 112 A	91·914
BHT 112 B	92·710
BHT 112 C	96·634
BHT 113	75·589
BHT 114	78·267
BHT 115	67·468
BHT 116	67·126
BHT 117	70·289
BHT 118 A	65·242
BHT 118 B	66·413
BHT 119 A	69·105
BHT 119 B	70·590
BHT 120	61·416
BHT 121	81·843
BHT 122	82·868
BHT 123	87·385
BHT 124	85·516

BENCH MARKS

NUMBER	E.L. (m.)
1000	78·31
1001	
1002	
1003	68·80
1004	66·57
1005	72·31
1006	106·15
1007	86·98
1008	105·78
1009	105·62
1010	105·00
1011	93·72
1012	83·01
1013	79·37
1014	79·94
1015	81·54
1016	82·85
1017	85·43
1018	87·57
1019	88·60
1020	88·10
1021	91·32
1022	92·51
1023	87·04
1024	92·99
1025	89·62
1026	101·83
1027	104·98
1028	101·69
1029	102·97
1030	70·46
1031	71·68
1032	70·97
1033	72·18
1034	81·51

LEVEL INFORMATION RELATIVE TO AUSTRALIAN HEIGHT DATUM

METRES 1000 0 1 2 KILOMETRES

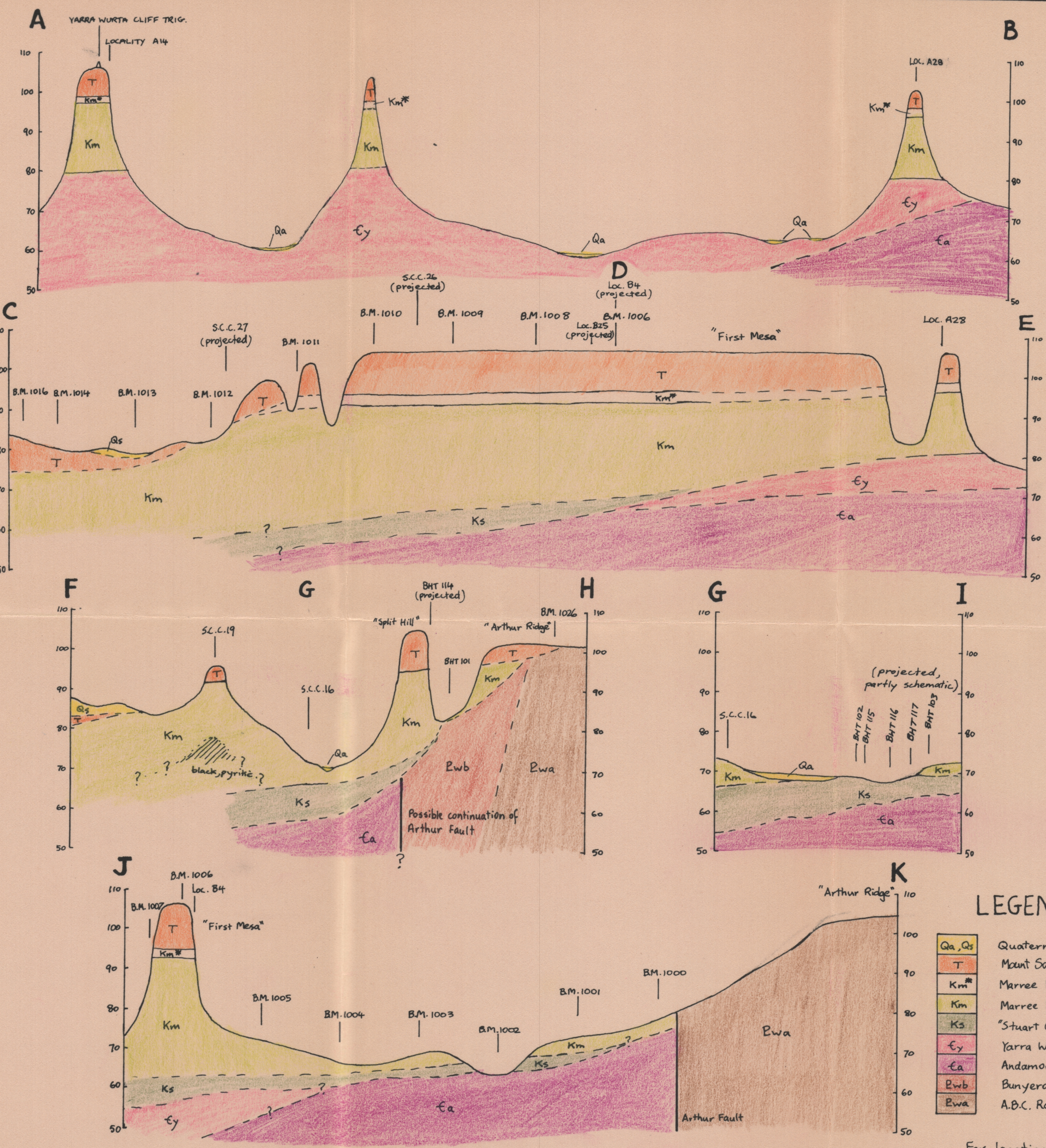
DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

STUART CREEK OPAL FIELD

GEOLOGICAL PLAN

	COMPILED M. VNUK	DRN N. S.	SCALE 1 : 25000	PLAN NUMBER 78-985
DIRECTOR GENERAL		CKD	DATE 18 - 12 - 78	

FIGURE 10. SUMMARY OF LEVEL DATA FROM BACKHOE TRENCHES, CALWELD SHAFTS AND MEASURED SECTIONS.



Notes.

Solid formation boundaries are derived from level data and hence are accurate.

Dashed lines have varying degrees of accuracy, and those at depth are somewhat speculative.

1:1000 used for the vertical scale to show the behaviour of very thin units.

Topography trends are correct, though absolute values are probably incorrect where there is little control.

Heights in metres, relative to Australian Height Datum (A.H.D.)

LEGEND

Qa, Qs	Quaternary alluvium and sands
T	Mount Sarah Sandstone
Km*	Marree Formation – "kopi"
Km	Marree Formation
Ks	"Stuart Creek Beds"
Ꞓy	Yarra Wurta Shale
Ꞓa	Andamooka Limestone
Ꞓwb	Bunyeroo Formation
Ꞓwa	A.B.C. Range Quartzite

For locations, see Fig. 9.

Vertical scale 1:1000

Horizontal scale 1:25000

Exaggeration $\frac{V}{H} = \frac{25}{1}$

FIG. 11. CROSS SECTIONS.

M.F. VNUK 1978