The Geology of the Eastern Mt. Babbage Block and a study of the genesis of the Jurassic and Cretaceous sediments of the Southern Eromanga Basin.

by

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ABSTRACT

Mesozoic sediments in the Southern Eromanga Basin reflect the change from fluvial deposition in the Jurassic to shallow marine deposition with the onset of an Early Cretaceous transgression.

Rocks of the fluvial Algebuckina Sandstone outcrop around Mt. Babbage, in the Northern Flinders Ranges. They consist of several cycles of coarse, pebbly sandstones and conglomerates that fine upwards into well-sorted fine to medium-grained sandstones that are crossbedded throughout and represent a braided stream environment. An upper silicified sandstone contains numerous fossil-wood and leaf impressions which allow correlation of the sequence with those observed elsewhere around the Basin margins.

Further out into the Basin, the Algebuckina Sandstone is a well-sorted, fine to medium-grained sandstone that represents an alluvial plain environment. The overlying Cadna-owie Formation forms the transition between this and the marine Bulldog Shale above. This change is reflected in the decrease in grain-size of the sediment and the transition from kaolinite-dominated assemblages in the fluvial sandstones to marine clays of the Bulldog Shale containing predominantly montmorillonite.

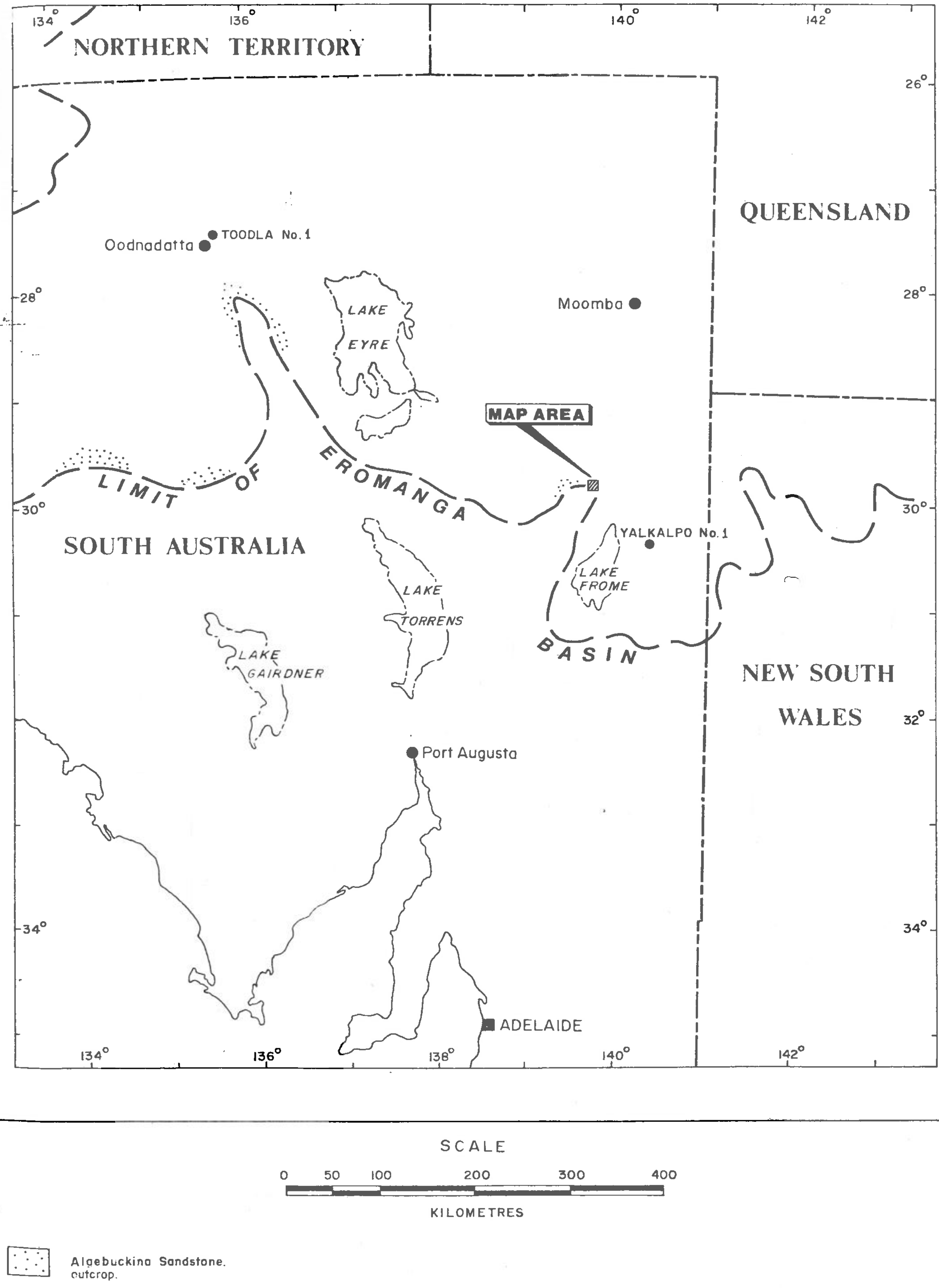
Most of the material supplied to the Algebuckina Sandstone and Lower Cadna-owie Formation was derived from the Gawler Range Volcano-plutonic Province and the Mt. Painter Province to the south.

The occurence of such a thick sequence of montmorillonitic silts and clays containing high-silica zeolites and authigenic quartz may represent a change to a volcanogenic source.

As the terrigenous supply was waning, with the onset of the marine transgression, volcanogenic detritus may have been supplied by a volcanic arc system that was developing to the east.

PART 1

The Geology of an area north of Mt. Babbage with a detailed study of the Jurassic sequence.



LOCATION MAP

FIG. 1a

INTRODUCTION

Location of the Area Studied

Jurassic and Cretaceous rocks outcrop along the edges of the Flinders Ranges, in the far north-eastern portion of the Mt Painter Province.

The map area, of approximately 30 square kilometres lies in the eastern Mt. Babbage Block, 10 kilometres northwest of Moolawatana Station, between latitudes 29^{o} 50' amd 29^{o} 55' south and longitudes 139^{o} 35' and 139^{o} 45' east.

The Jurassic rocks form part of the southern edge of the Eromanga Basin, a region of the larger Great Artesian Basin (Figure 1a). These sedimentary rocks lie unconformably upon Proterozoic basement, as valley fills or low relief mesas upon basement highs. Ephemeral streams have eroded much of these relatively unconsolidated sediments, leaving behind much of the coarser fraction to form alluvial gravels.

Regional Geology

The Mt. Painter Province comprises a lower Proterozoic sequence of metasedimentary and metaigneous rocks, the Radium Creek Metamorphics and the overlying Adelaidean metasediments of the Yudnamutana Sub group (Coats and Blissett, 1971).

Two intrusive events produced an "older" granite suite of Carpentarian age and a "younger" Ordovician suite of granodiorites and pegmatites. Much of the Mt. Babbage block is composed of members of this "older" granite suite (Coats and Blissett, 1971).

Several major phases of deformation caused the uplift of these rocks to form the ranges and Thornton (1980) suggested that the regional east-west foliation was produced during the Delamerian Orogeny, the second major phase.

Deposition of the overlying sediments commenced during the late Jurassic. The Algebuckina Sandstone (Sprigg et al, 1958) lies unconformably upon pre-Jurassic rocks and consists of a sequence of fine to coarse, gritty, kaolinitic sandstones and conglomerates, deposited in a fluvial environment (Wopfner et al, 1970). The overlying Cadna-owie Formation (Early Cretaceous), a finer grained transitional paralic phase, separates it from the shallow marine Bulldog Shale. (Freytag, 1966).

This sequence has been described by a number of authors (Wopfner and Heath (1963), Sprigg et al (1958), Wopfner et al (1970), Forbes (1982) from the Oodnadatta region, and also from the central Eromanga Basin, Ambrose et al, (1982) where it can be correlated with the Namur Sandstone member of the Mooga Formation, the Transition Beds and the Bulldog Shale.

Mesozoic sediments in the area around Mt Babbage, have been described by Woodard (1954) and correlated with the Blythesdale Sandstones, which encompass both the Cadna-owie Formation and the Algebuckina Sandstone (Freytag et al., 1967). Wopfner et al. (1970) later equated the sandstones at Mt Babbage with those of the Algebuckina Sandstone section at Mt Anna, but Forbes (1982) indicated that the Algebuckina Sandstone is absent around the northeast Flinders Ranges due to non-deposition or erosion.

The lithologies of the Algebuckina Sandstone and the Cadna-owie Formation appear very similar in outcrop along parts of the Eromanga Basin margin, hence the presence of either, or both formations was to be substantiated by a study of the geology, with emphasis on the stratigraphic position of the sediments and their depositional environment. A similar study was undertaken to the northwest, around Prospect Hill, by Phillips (1983), as part of a second Honours project incorporating these Eromanga Basin sediments.

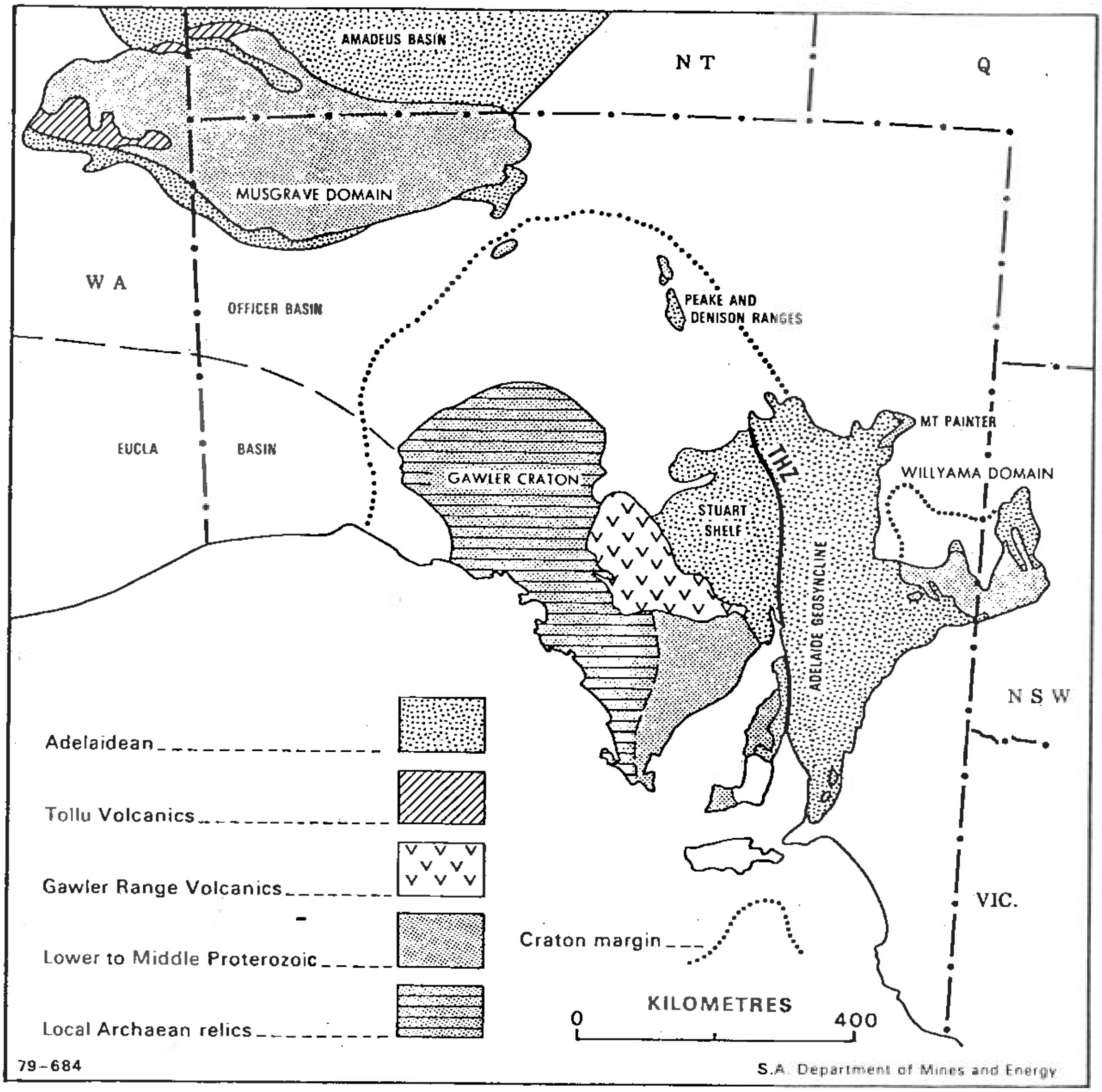


Fig. 1b The distribution of Precambrian rocks in South Australia showing the approximate limits of the Gawler Craton as defined by magnetics. THZ - Torrens Hinge Zone.

(from Parker, 1979)

STRATIGRAPHY

Introduction

The Jurassic sediments outcropping around Mt. Babbage, attain a maximum thickness of about 36 metres, and consist of three cycles of coarse to fine, gritty sandstones and conglomerates which fine upwards. Here, these cycles have been divided into three informal units, illustrated in Figure 2 and which also appears on the map in Figure 1c. The four sections shown in Figure 2 are the most informative of those studied, as most of the area shows poor outcrop and extensive erosion of the upper units.

A stratigraphic cross-section is given in Figure 3, and the location of this and the lithological sections is given in Figure 1c.

This sequence around Mt. Babbage was described by Woolnough and David in 1926 as Tertiary, Eyre Series but later recognised as late Jurassic to Early Cretaceous, on the basis of fossil evidence, by Woodard (1954). Wopfner et al (1970) considered the section at Mt. Babbage to be equivalent to the Algebuckina Sandstone section at Mt. Anna in the Peake and Denison Ranges, on the basis of lithological and environmental evidence.

The sandstones and conglomerates at Mt. Babbage are predominantly medium to coarse grained, lack sediment finer than silt size, are crossbedded, and of a fluvial braided stream environment.

Secondary ferruginization has produced a brown to purple discolouration of finer grained material and hard dark brown to black discontinuous ironstone grits in some of the coarser grained beds.

The uppermost unit contains a hard, grey silicified sandstone that has abundant fossil wood impressions (Glaessner and Rao, 1955); it has been equated with that described from the Peake and Denison Ranges (Wopfner et al 1970).


1


2


3

PLATE 4: Ferruginization, Unit 2

PLATE 5: Unit 2

PLATE 6: Unit 2


4


5


6

PLATE 7: Channel Scour, Unit 3

PLATE 8: Fossil Leaf Impressions, Unit 3

7

8

PLATE 9: Algebuckina Sandstone, Mt. Babbage
Rounded detrital kaolinite grain.

PLATE 10: Algebuckina Sandstone, Mt. Babbage
Detrital feldspar grain showing the unweathered form and lack of authigenic kaolinite.

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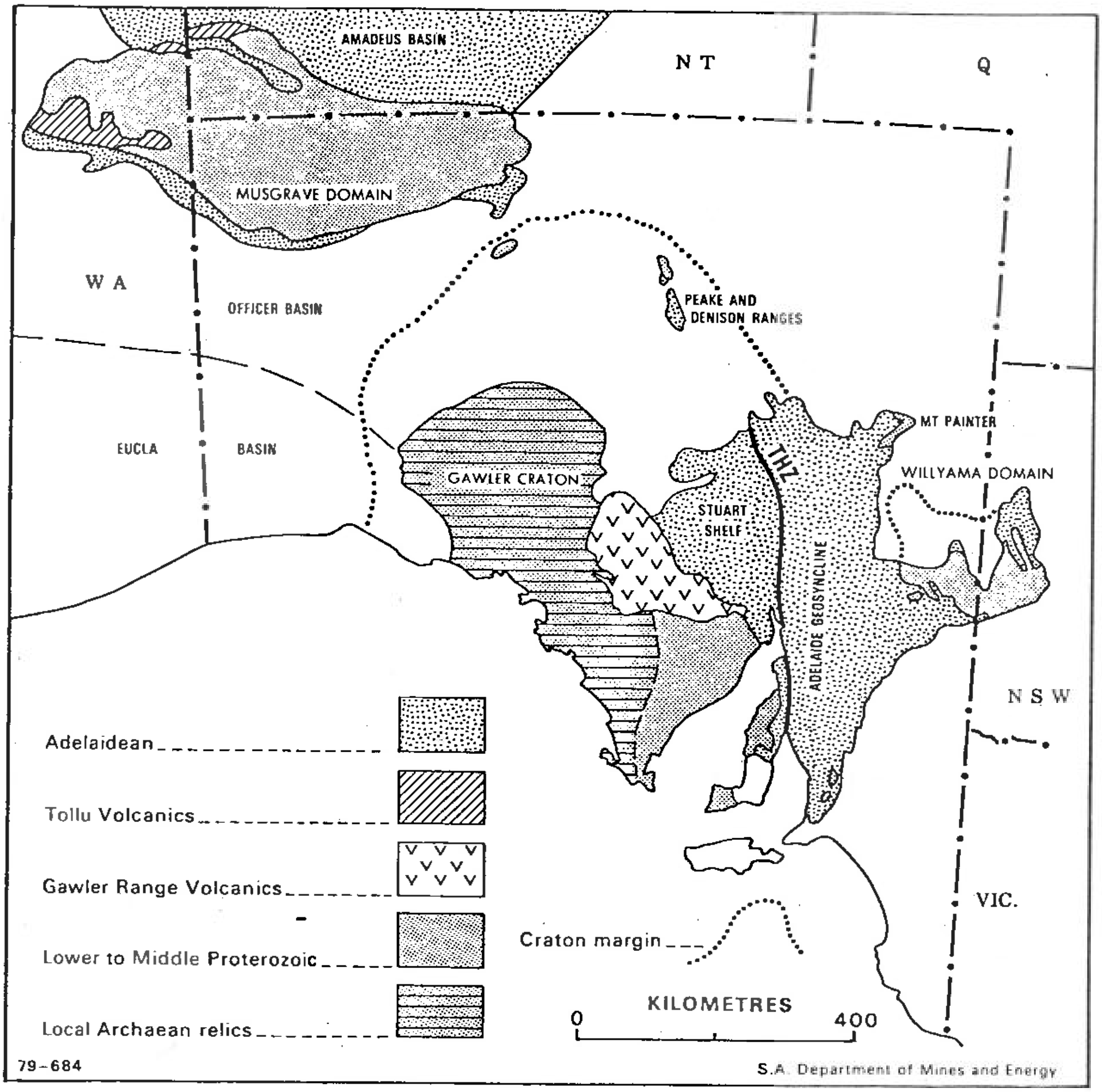

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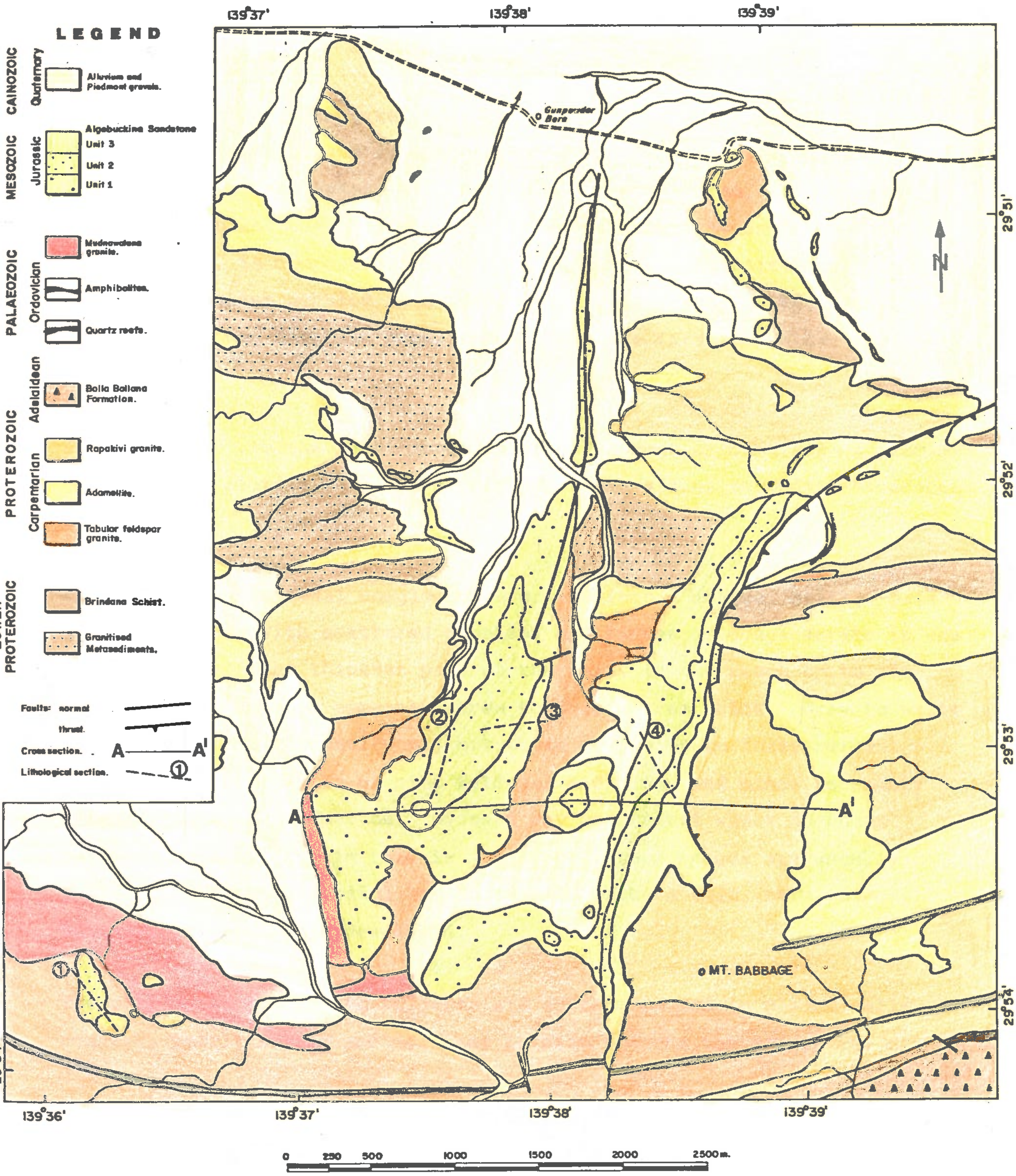
MT. BABBAGE BLOCK

MT. PAINTER PROVINCE, S.A.



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MAP OF STUDY AREA SHOWING LOCATION OF CROSS SECTION AND LITHOLOGICAL SECTIONS.

FIG. 1C

Lithological Descriptions

UNIT 1

The base of this unit marks the unconformity with the underlying Proterozoic basement and is commonly observed as a quartz pebble to cobble conglomerate (plate 1). Within the central area, the basement appears fresh and the overlying conglomerate, that may exceed two metres in thickness, is composed of rounded blue and grey to white quartz and quartz tourmaline pebbles in a predominantly quartzose silty, sandy matrix. Rounded basement pebbles occur but are rare and often very weathered.

Towards the north the basal conglomerate is absent or consists of pebbles of weathered biotite chlorite garnet schist in a fine to medium micaceous sandy matrix.

In all areas, the basal conglomerate grades into a coarse, gritty, pale grey sandstone, with scattered pebbles, and lenses of conglomerate in the lower part. In the thickest part of the Unit, it may reach up to six metres but it is more commonly three to four metres thick. Grey to white quartz is the main constituent, but there may be up to forty percent (coarse fraction) white or pink feldspar and mica, and minor accessory minerals such as tourmaline. Garnets may be present where adjacent basement schists contain them in abundance. Pore spaces are usually partly filled with detrital kaolinite. In parts a thin, hard, black, ferruginous matrix has developed.

The pebbles of quartz and feldspar are subrounded and in places well-rounded, poorly sorted and decrease in size towards the top of the unit.

Rare lag deposits of rounded basement pebbles can be observed along sharply erosional surfaces. The pebbles are commonly very weathered, indicating a period of non-deposition, and iron rich solutions have infiltrated along these erosional contacts leaving a thin, hard ironstone band.

Bedding within this lower part is absent, or where present, horizontal, but the sandstones become current bedded towards the top in the thicker parts of the sequence.

The contact with the uppermost clean, fine to medium grained quartz sandstone is commonly quite sharp (Plate 2). These cream to pale brown sands are trough crossbedded throughout, and contain stringers of small pebbles along crossbeds, ripples and erosional surfaces (Plate 2).

The crossbed sets range from a few centimetres to one metre thick and their consistant dip shows a northerly current direction.

Groups of locally derived basement boulders are occasionally observed within this upper well-sorted layer. The boulders, up to one metre long, show some rounding and due to their localized development and proximity to source regions were probably part of debris flows (Plate 3). The high energy flow of the river removed all but the coarsest material, leaving behind thin lenses of these boulders.

UNIT 2

There is a sharp contact between this unit and the underlying clean well sorted sandstone of Unit 1. However this contact does not appear to be erosional.

To the southwest of the area, Unit 1 is absent and Unit 2 lies directly upon granodioritic basement rocks. This is deeply weathered, and the basal conglomerate developed upon this surface contains up to eighty percent basement pebbles, with rounded white quartz pebbles forming the remainder of the coarsest fraction. The matrix is also composed of coarse feldspar and biotite with minor quartz grains (Figure 2, section 1).

The lower part of this unit generally resembles that of Unit 1. Coarse, gritty, feldspathic sandstones, showing little stratification, are overlain by medium-grained trough crossbedded sandstones with abundant stringers and lenses of fine pebbles.

This unit shows great variation within this portion, due to the lateral movement of channels and bars across the active river tract (Rust, 1978) (Plate 5). Several smaller incomplete cycles, fining upwards, are present within the middle of this unit, due to vertical accretion upon bars. This produces the intertonguing effect of the fine to medium well-sorted sandstone with the coarser pebbly sandstone seen in Figure 2, (sections 2 and 3).

Dark grey carbonaceous mudstones were only observed at the top of one cycle as an overbank deposit. This bed attains a maximum thickness of one metre and shows a fine lamination at the base and becomes gradational with the overlying fine sandstones. A sharp erosional contact separates this from the overlying very coarse gritty sandstones of the next cycle.

The general lack of very fine sediment such as muds within the upper parts of these cycles indicates a consistant high energy flow. Muds deposited upon the upper bars protect them from subsequent erosion when water levels rise (Taylor & Woodyer 1978). Hence, the large number of erosional surfaces within this part of the unit and the number of incomplete cycles indicate a wide active channel.

As the channel began to fill, finer, well-sorted sandstones were deposited. These sandstones are extensively crossbedded (Plate 6). Trough sets range from a few centimetres to eighty centimetres in height and show erosional bases.

Horizontally stratified fine micaceous silty sands occur towards the top of Unit 2. Ferruginization has produced colours varying from pale brown to dark purple (Plate 4). These thin, discontinuous layers pass upwards into medium-grained well-sorted pale brown to cream sandstones.

Horizontally stratified beds, with small scale ripples, alternate with 10 cm layers containing fine planar ripples.

The current directions indicated, vary from southwest to northwest, but the flow direction is consistantly to the north in the overlying larger channel current beds. These beds tend to be finely trough cross-laminated with vertical heights of about seventy centimetres. Rib and furrow structures can be observed on the upper weathered surface.

UNIT 3

This upper unit represents the last fining upward cycle of the Algebuckina Sandstone in the Mt. Babbage area.

The lower part of this unit is a coarse gritty, pebbly sandstone containing abundant feldspar pebbles. Rare lenses of conglomerate contain sparse rounded to angular basement clasts, as well as the common, rounded white and grey quartz cobbles.

Unlike the bottom portion of each of the lower units it is generally trough crossbedded.

In the most complete, although not the thickest section (Figure 2, section 4), the bed overlying this lower part is a massive, clean, well sorted, quartzose sandstone up to 2 metres thick, with rare lenses and stringers of pebbles. It contains abundant vertical burrows, up to one centimetre in diameter, that penetrate up to thirty centimetres from the upper surface.

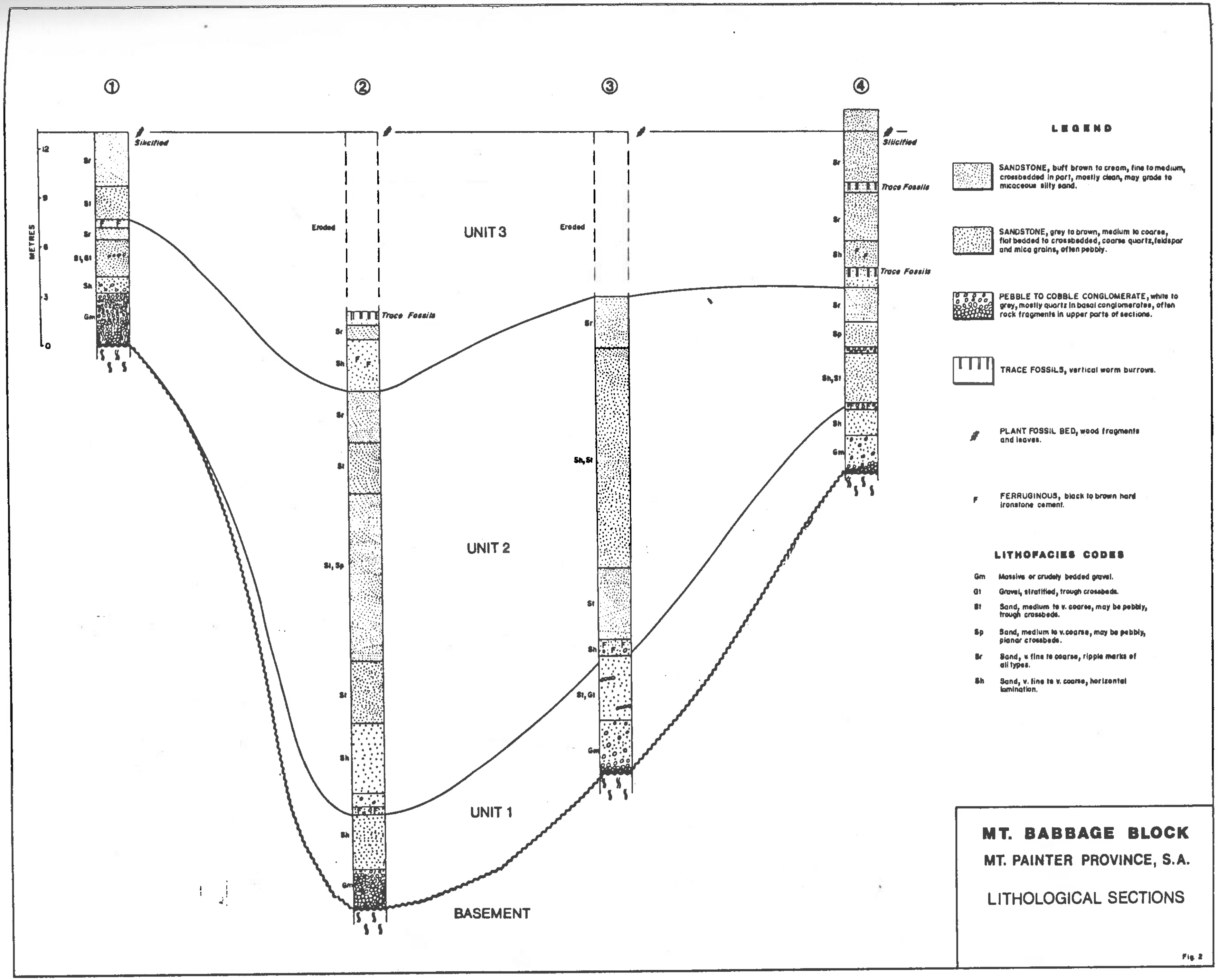
Fine white to purple micaceous silty sands overly this, commonly interbedded with clean, medium grained quartz sandstone. A ? Rhizocorallium burrow was observed on the upper weathered surface of these sands.

Large trough crossbeds can be observed throughout this well-sorted sandstone and in many cases they show sharp erosional bases (Plate 7).

A second bed of vertical burrows occurs above this, the sandstone being pebbly and friable and lacking in any other internal structure.

The overlying sands are predominantly horizontally stratified with thin interlayers that have fine ripple marks and pebble lenses.

Above this the beds show variable degrees of silicification which has obscured much of the structure of the uppermost part of this unit and resulted in rocks approaching massive quartzites. The grey, massive, pebbly, silicified sandstone contains numerous wood and leaf impressions in several horizons (Plate 8). This fossiliferous quartzite-like sandstone horizon was observed by Wopfner & Heath (1963) in the Oodnadatta region. The detail preserved in these fossils indicates that silicification took place soon after deposition (Lange, 1978). The variability in extent of silicification is probably due to differences in porosity of the sandstones and its affect upon the circulation of silica-rich waters (Dapples 1967). The massive form it takes suggests precipitation from ground waters not from leaching conditions, i.e. it is not a columnar pedogenic type silcrete.



MT. BABBAGE BLOCK

MT. PAINTER PROVINCE, S.A.

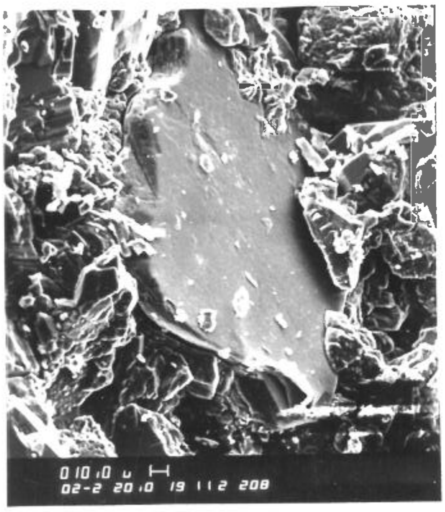
LITHOLOGICAL SECTIONS

Fig 2

PLATE 1: Basal Conglomerate

PLATE 2: Unit 1

PLATE 3: Boulder Bed, Unit 1



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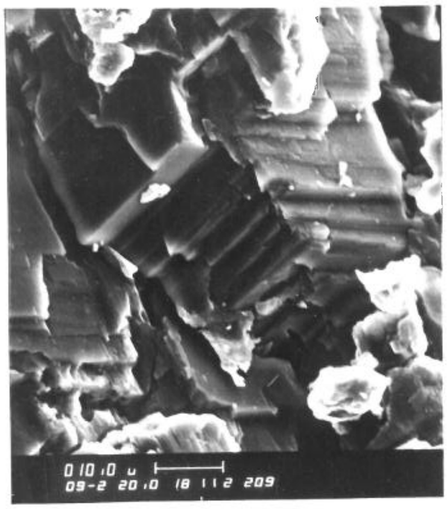

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STRUCTURE

Basement rocks within the area have undergone several periods of deformation, the most pronounced being the second that produced a regional eastwest foliation and has been assigned to the Delamerian Orogeny by Johnson (1980).

The main structural feature in the area is a large thrust fault, the "Mt Babbage Thrust" (Coats & Blissett, 1971) with a vertical displacement of about one hundred metres and which post-dates the Jurassic sedimentation (figure 3).

Previous mapping (Coats and Blissett, 1971) has indicated that the "Mt Baggage Thrust" is present through to the most northerly outcrop of the sandstone of Unit 1, but it was not observed there. Coarse, gritty sandstones lie directly upon the Proterozoic basement in an onlapping relationship.

A complete section of Jurassic sediments is observed on the downthrown side of the fault, with the basement granites and pegmatites lying directly above the sandstones of upper Unit 3. On the upthrown block only 5 metres of Unit 3, including the silicified fossiliferous beds, are present.

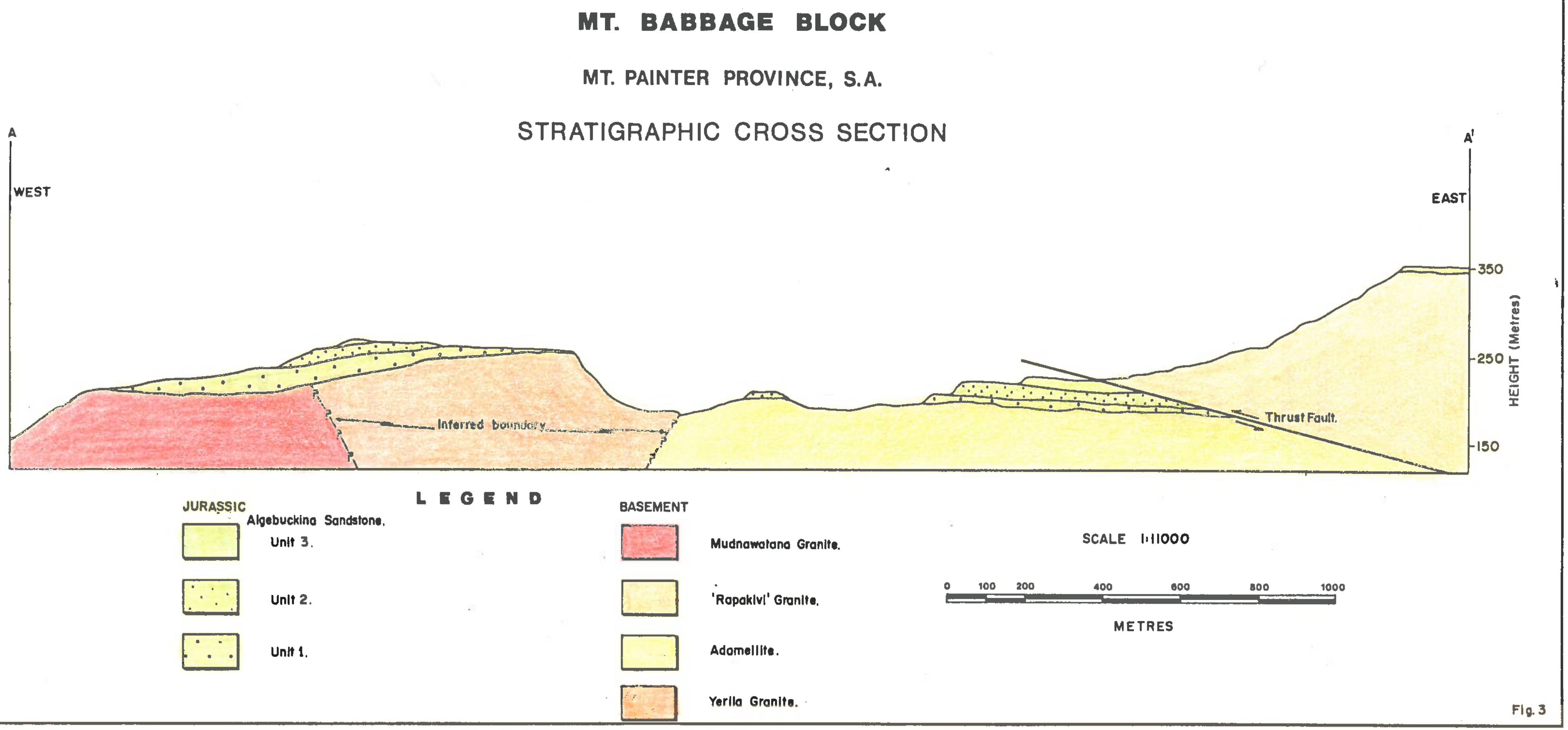
Thrust wedges, (repeated sections of Unit 2 sandstones) can be seen along the curved line of the fault in two areas, to the east and in the centre.

It appears to be very low angle from evidence of the relationships of basement pegmatites outcropping above the upper Unit 3 sandstones, but no fault breccia is observed.

A gentle folding accompanied the faulting, in response to the compressional forces (Figure 3), and dips range from 8^{o} west to 4^{o} east.

Two smaller faults occur on the western part of the area (Figure 1c). The lower unit is displaced but the rest of the sequence has not been penetrated, indicating instability of the older land surface during the time of deposition of the Algebuckina sandstone. The north-south trending fault is expressed as a thin fault breccia in the south and produces dips of about eighty degrees in the mostly flat-lying sandstones, towards the north.

Thus the thrust fault may have been active during deposition of the lower two Units for a period, evidenced by the thickness of sediments on the down-thrown side of the fault. Periodic movement and subsequent erosion of the upthrown block would explain the large proportion of fresh feldspar and mica contained within these sediments, and the occurrence of localized boulders within the upper Unit 1 beds.



MT. BABBAGE BLOCK
MT. PAINTER PROVINCE, S.A.
STRATIGRAPHIC CROSS SECTION
A
WEST
A'
EAST
350
250
150
HEIGHT (Metres)
Inferred boundary
Thrust Fault.
LEGEND
JURASSIC
Algebuckina Sandstone.
Unit 3.
Unit 2.
Unit 1.
BASEMENT
Mudnawatana Granite.
'Rapakivi' Granite.
Adamellite.
Yerila Granite.
SCALE 1:11000
0
100
200
400
600
800
1000
METRES

Fig. 3

DEPOSITIONAL ENVIRONMENT

The sequence around Mt Babbage was deposited in a braided fluviatile environment (Rust 1978). The coarse-grained nature of the sediments, the dominance of trough cross-stratified pebbly sandstones and the cyclic nature of the sequence resembles that of the Donjek type model of Miall (1977). The lack of facies Fl (fine silts and muds) at the top of the cycles indicates a constant rapid flow of water in the laterally migrating channels, transporting the finer material further out into the basin.

Periodic movement along faults may have caused slight uplift of the area, hence playing a major role in the development of the cycles.

The dominance of locally derived fresh pebbles of feldspar and mica and the presence of rare larger cobbles would also suggest uplift and subsequent erosion of the basement during sedimentation.

The Algebuckina Sandstone in the Peake and Denison Ranges (Figure la and lb) is characterised by medium to coarse sandstones and conglomerates that are variably kaolinitic and are current laminated and bedded, with occurrences of both trough and planar cross-bedding within the sequence. Three cycles, which fine upwards, consisting of coarse pebbly sandstone overlain by fine to medium thinly-bedded or current bedded silty sandstones, are also observed in the section at Mt Anna, described by Wopfner et al (1970).

The Cadna-owie Formation by comparison, is generally fine to medium grained with irregular gritty beds containing a carbonate cement in part (Wopfner et al, 1970). Boulder beds are widely distributed through the sequence. They are commonly composed of quartzite boulders, unlike those at Mt Babbage which are of granitic rock types and locally derived. The lower part of the Cadna-owie Formation is a fine grained sandstone with interbedded siltstones and carbonaceous claystones that contain small aggregates of pyrite concretious. At Mt. Baggage, limonite pseudomorphs of pyrite were observed scattered on the upper surface of Unit 3, but none were found in situ. The erosion of overlying beds (?lower

Cadna-owie) may have left these, and occasional well rounded red porphyry pebbles as the only indication of Cretaceous sediment in this area. The occurrence of pink porphyry, similar to that in the Gawler Ranges, is common throughout the Cadna-owie Formation.

Thus, the Algebuckina Sandstone is a coarser-grained formation with abundant cross-bedding, is kaolinitic and represents a braided fluvial system.

The Cadna-owie Formation is finer-grained, contains carbonaceous shales and siltstones with pyrite nodules and is often calcareous. This is more characteristic of a lower energy, near-shore or deltaic regime with local variations such as lagoons or shoreline facies.

PALAEOCLIMATE

A moist sub-tropical climate has been suggested for the Late Jurassic by Harris (1962) from the fern and cycad impressions observed in the upper silicified layer of the Algebuckina Sandstone.

A climate such as this is favourable for the formation of kaolinite during the weathering process (Velde, 1977) and would account for its presence as detrital grains, throughout the sequence. Small amounts may have formed in situ, but the feldspar grains present, appear to be quite fresh (Plates 9 and 10). The occurence of both fresh feldspar grains and detrital kaolinite throughout the sequence is indicative of a high relief source region, where both mechanical and chemical weathering take place at the same time.

PART 2

Mineralogy, Environments of Deposition and Source Regions for the Upper Jurassic-Cretaceous Eromanga Basin Sediments.

INTRODUCTION

Location of Wells and Aims of this Study

Three wells were studied, Yalkalpo #1 in the Lake Frome Embayment, CBH #2 from the northern Flinders Ranges and Toodla #1 in the Oodnadatta Region. All wells lie around the southern margin of the Eromanga Basin, and were chosen to observe any changes in mineralogy reflecting differences in source regions.

Core samples were taken at about ten metre intervals from three wells to examine the mineralogy within the Algebuckina Sandstone, the Cadna-owie Formation and the Bulldog Shale. The overall mineralogy, with particular emphasis on that of the clays, was viewed with the intention of determining the source regions and the possible volcanogenic origin of the marine shales. The authigenic minerals were studied to obtain information as to the presence of weathering or diagenetic changes within the samples and thus of their environments of deposition and burial.

Methods

Core samples were taken at ten metre intervals from the Algebuckina Sandstone, Cadna-owie Formation and the Bulldog Shale. Cuttings were not used, as contamination from up-hole and from the drilling mud would affect the results obtained. Thus, the upper part of the Bulldog Shale in Toodla #1 is not included. Core descriptions are given in Appendix 1.

Whole rock samples were hand crushed and the powder placed, as orientated specimens, on glass slides. The 2-5 μm fraction was then separated from the remaining coarser material by ultrasonic dispersion, and settling in cylinders. Both sets of specimens were examined by x-ray diffraction techniques, air-dried, and after addition of ethylene glycol.

A Philips diffractometer was used at $1^{o}/2\theta$min using graphite (monochromatised) CoK_{α} radiation.

Additional small pieces of the samples were coated with carbon and examined, using the scanning electron microscope. Elemental compositions of grains were obtained from the accompanying x-ray analyser.

The 63 µm - 125 µm fraction from some of the Bulldog Shale samples were examined with the election microprobe analyser to obtain quantitative elemental compositions of the larger detrital grains.

LITHOLOGIES

Algebuckina Sandstone

The Algebuckina Sandstone lies disconformably upon red and green Cambrian shales and sandstones in Yalkalpo #1 (Callen, 1973) and CBH #2 and upon supposed Ordovician quartzites in Toodla #1 (Griffiths, 1979).

The basal conglomerate consists of one to two metres of quartzite and underlying Precambrian Peake Series (Wopfner et al, 1970) clasts in a slightly kaolinitic silty, sandy matrix in Toodla #1. Porphyry clasts are predominant in Yalkalpo #1, indicating a source from the Mt. Painter Block (Giles and Teale, 1979).

Much of the core in Toodla #1 is missing over the interval above, due to washouts of the hole resulting in low core recoveries. The sections recovered were white, kaolinitic fine to coarse-grained sands interbedded with dark to light grey siltstones and clays that contain significant amounts of carbonaceous material. Pebble bands occur throughout the sequence. Cycles similar to those described in the previous section are observed, with predominantly trough cross-bedded gritty to fine sands which may occasionally be capped by thin claystones. Near the top of the sequence, traces of silicification can be observed and the increase in lithification may be equivalent to that exposed around Mt. Babbage.

In contrast to Toodla #1 and CBH #2, the sequence in Yalkalpo #1 is composed of interbedded pale grey siltstones and claystones with minor, thin coarse quartzose sandstone beds. The siltstones contain pebbles of grey quartz and pink porphyry. The fine-grained nature of the sediments suggests a low energy environment such as in a localized depression with a slow input of sediment (Truelove, 1980).

The lacustrine deposits probably received influxes of coarser material during periods of flooding.

PETROGRAPHY

Quartz

The major mineral in all samples, from the Algebuckina Sandstone through to the top of the Bulldog Shale is quartz, identified by sharp, symmetrical peaks at 4.3Å and 3.3Å, from x-ray diffraction profiles.

Selected diffraction profiles showing the mineralogy of all three formations is given in Figures 4a and 4b and a summary table is given in Appendix 2.

Kaolinite

Kaolinite, identified by strong, sharp peaks at 7.2Å and 3.58Å, is the dominant clay mineral within the Algebuckina Sandstone (Figure 5a and 5b). Within this formation however, the kaolinite shows varying degrees of crystallinity. In the well-crystallised samples the non-basal reflections can be resolved (Laughnan, 1974). The higher degree of crystallinity may indicate a higher proportion of authigenic kaolinite. Wilson et al, (1977) have shown that the majority of authigenic clays show sharp non-basal diffraction peaks and hence a high degree of crystallinity (Figure 6).

Scanning electron microscope (SEM) work has shown that two types of kaolinite, detrital and authigenic, are present and are identified by their high Al and Si contents. The detrital grains are large and rounded, with little internal structure. The authigenic kaolinite grains consist of unorientated books of stacked pseudohexagonal flakes and free platy grains that fill pore spaces (Wilson et al 1977) (Plate 11).

Toodla #1 contains a higher proportion of authigenic kaolinite, as can be seen in the diffraction profiles in Figure 6. The higher porosity of the coarser-grained sandstones has allowed the movement of large amounts of ground water through the formation. This weakly saline water (Griffiths, 1979) has leached out the alkalis, leaving behind the Al and Si to form kaolinite. The Algebuckina Sandstone is as a consequence one of the major Mesozoic aquifers in the Eromanga Basin.

Illite

Illite, identified by small sharp peaks at 10.07Å is more abundant in Yalkalpo #1 in both the clay fraction and whole rock analyses than in Toodla #1. However, this peak is diminished in the settled samples and is reduced to about five percent of the clay mineral assemblages in both wells (Figure 5a, b).

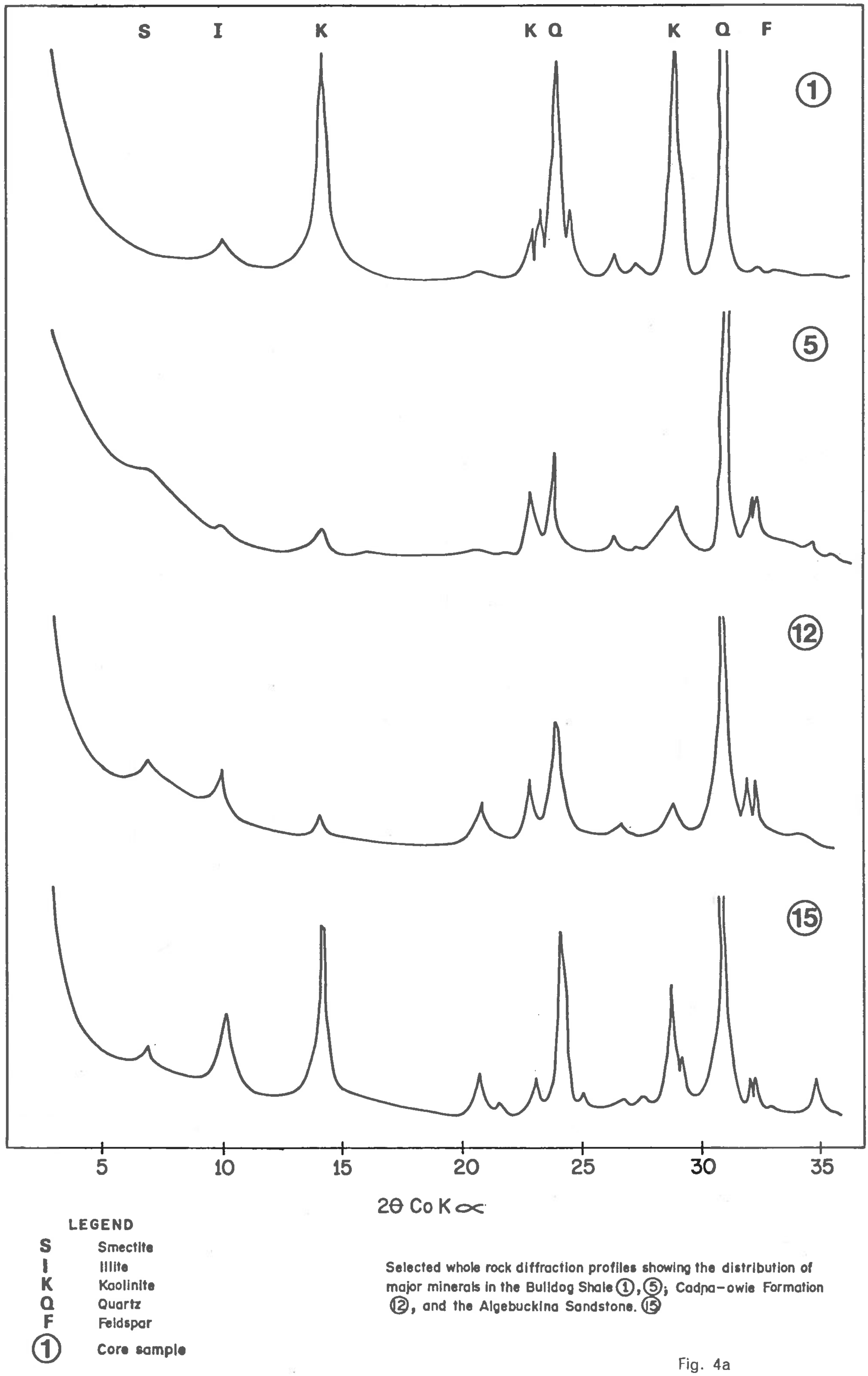
From this, it can be deduced that most of this fraction is coarse grained muscovite and biotite, that is removed during the settling process. Large platy grains can be seen with the SEM, throughout the samples, and the analyses show that both muscovite and biotite are present.

Feldspar

Again, Yalkalpo #1 contains much more feldspar than Toodla #1. The small asymmetrical peak at 3.22Å indicates the presence of plagioclase and one at 3.29Å, identifies potassium feldspar (Brindley and Brown, 1980)

These peaks remained on the trace after settling, hence, the feldspar is very fine grained, probably due to weathering effects and its conversion to kaolinite under the prevailing leaching conditions. Hence, this fine-grained feldspar may either be the cores left after weathering, or small authigenic feldspar crystals, formed by precipitation from circulating ground waters.

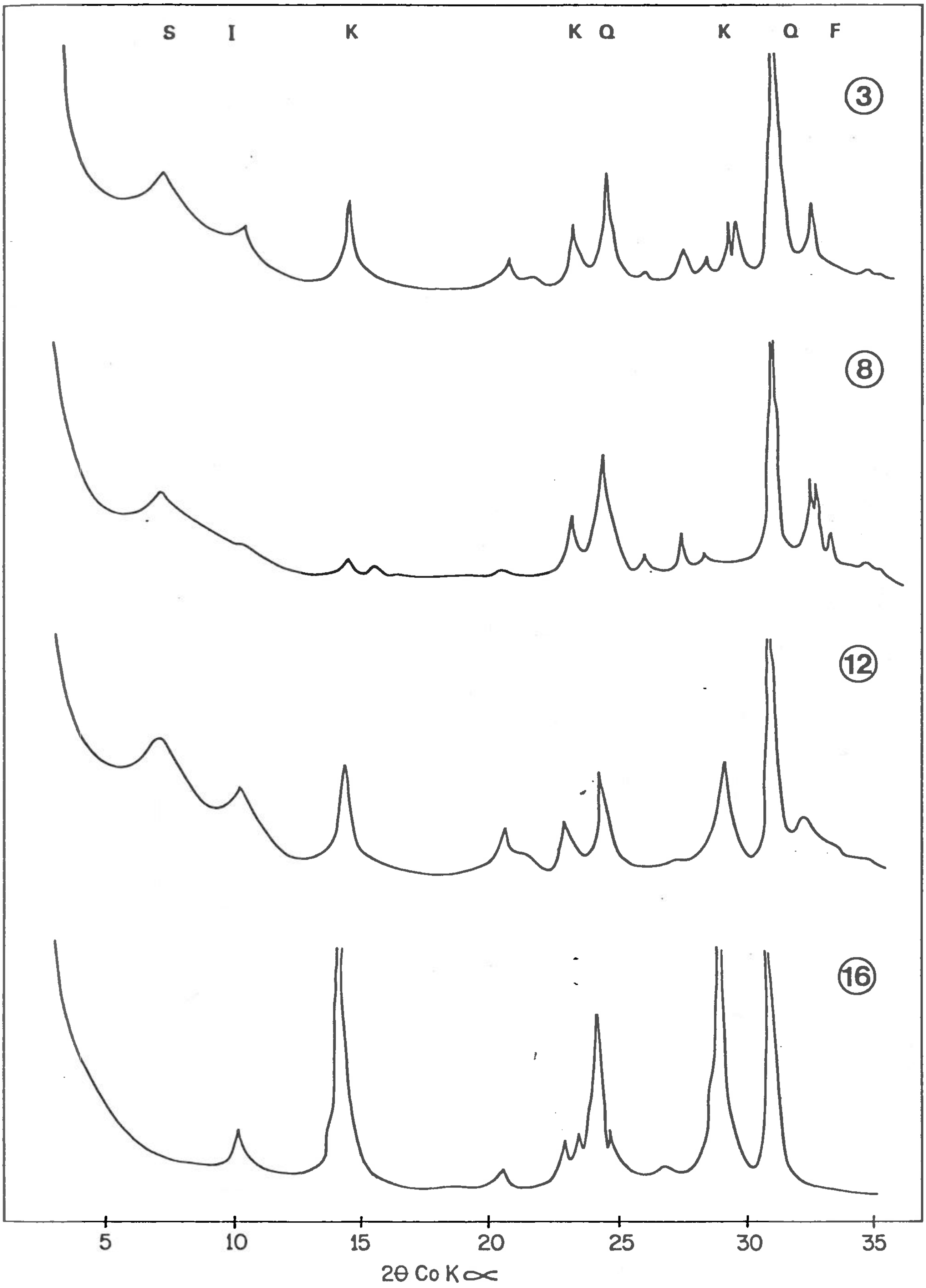
Yalkalpo No.1



Selected whole rock diffraction profiles showing the distribution of major minerals in the Bulldog Shale (1), (5); Cadna-owie Formation (12), and the Algebuckina Sandstone. (15)

Fig. 4a

Toodla No.1



LEGEND

- **S** Smectite.
- **I** Illite.
- **K** Kaolinite.
- **Q** Quartz.
- **F** Feldspar.
- ③ Core sample.

Selected whole rock diffraction profiles showing the distribution of major minerals in the Bulldog Shale ③, ⑧ ; Cadna-owie Formation ⑫, and the Algebuckina Sandstone ⑯
Notice the decrease in the proportion of feldspar with increasing kaolinite, indicating conversion of feldspar to kaolinite.

Fig. 4b

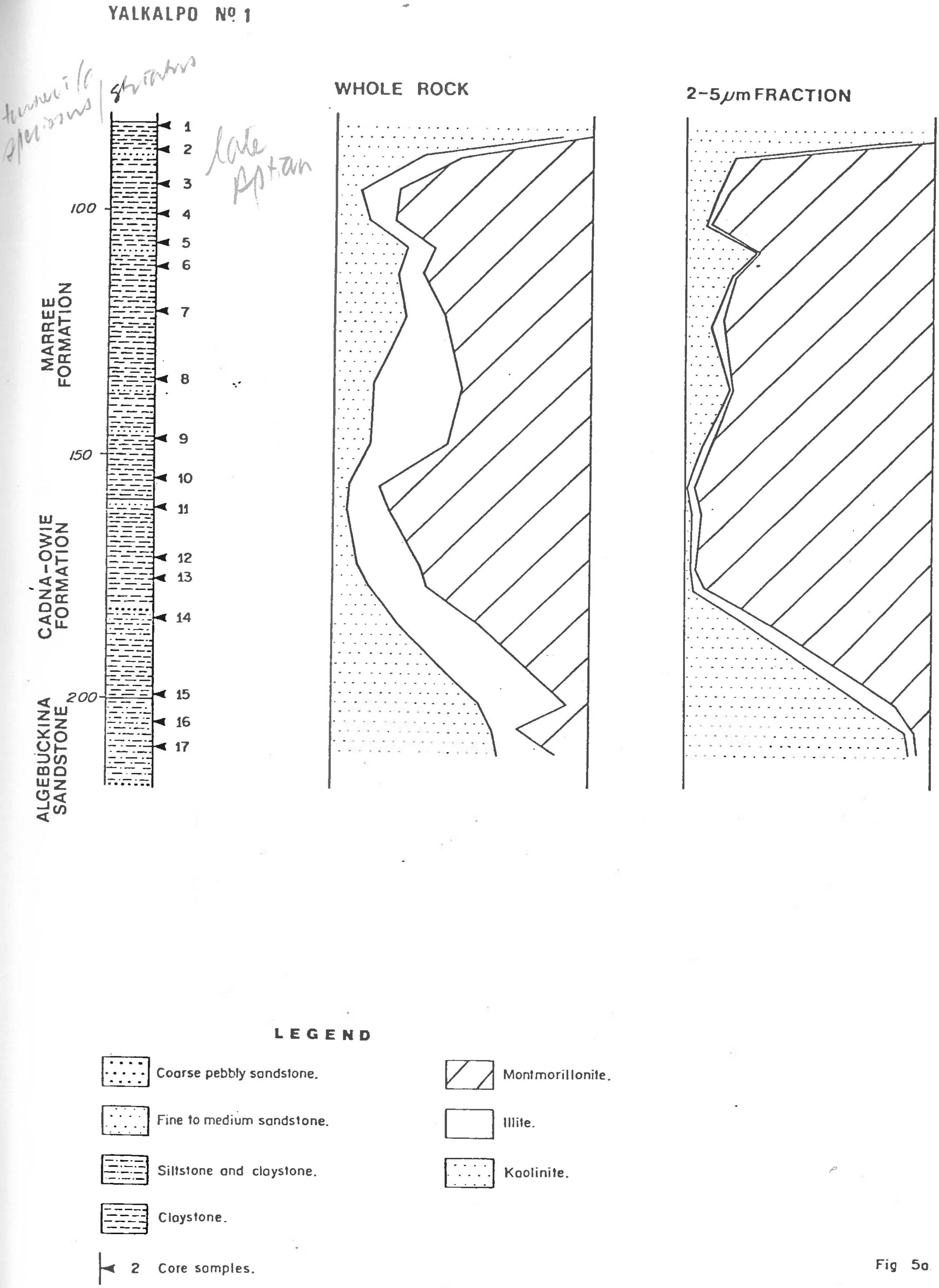
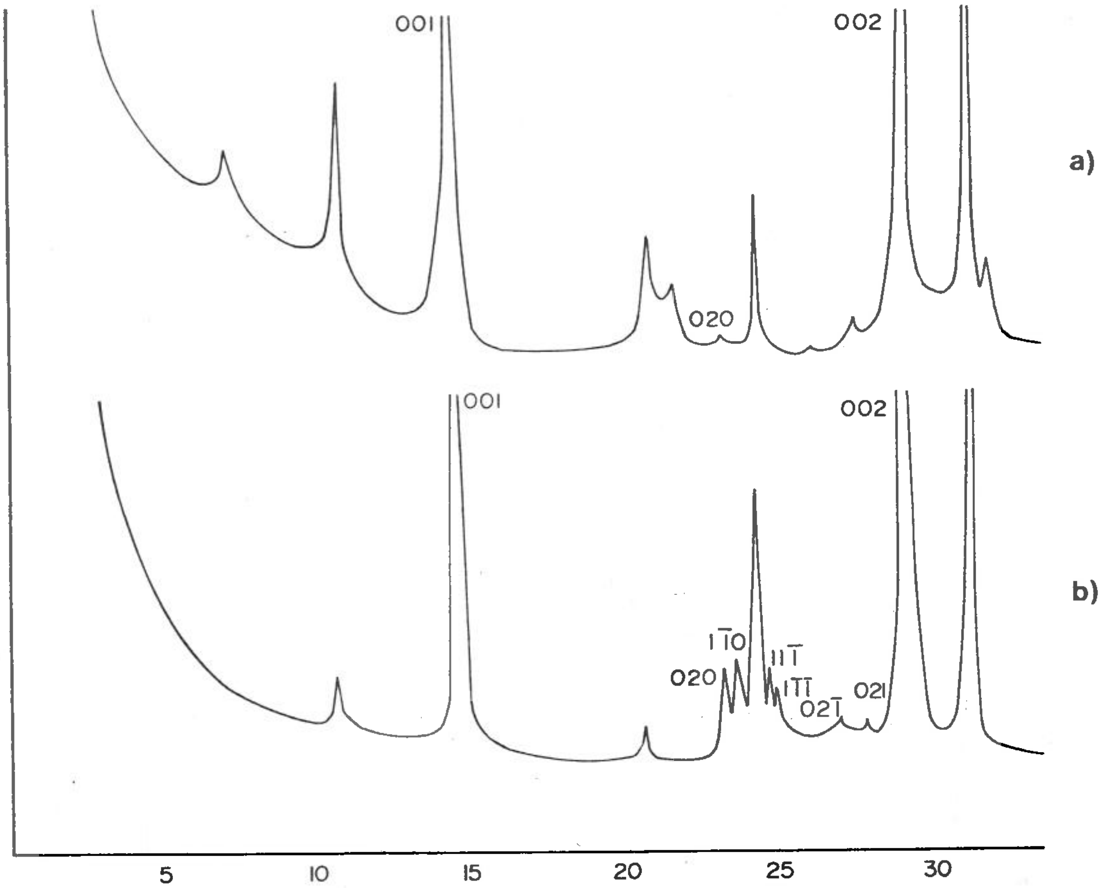

YALKALPO Nº 1
WHOLE ROCK
2–5µm FRACTION
late Aptian
100
150
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
MARREE FORMATION
CADNA-OWIE FORMATION
ALGEBUCKINA SANDSTONE
LEGEND
Coarse pebbly sandstone.
Fine to medium sandstone.
Siltstone and claystone.
Claystone.
2 Core samples.
Montmorillonite.
Illite.
Kaolinite.

Fig 5a

TOODLA No. 1

Fig. 5b.

KAOLINITE CRYSTALLINITY



a) Yalkalpo No. 1 Sample 17.

b) Toodla No. 1 Sample 16.

Whole rock diffraction profiles showing poorly crystalline kaolinite in a), and non-basal reflections of crystalline kaolinite in b)
Both samples are from the Algebuckina Sandstone.

Fig. 6

Silica

Quartz occurs as both detrital grains and as authigenic crystals. Detrital grains are most commonly rounded and contain small abrasion pits. The authigenic crystals show well formed prism faces, and can be found as aggregates filling pore spaces.

Kaolinite

Poorly crystalline kaolinite is dominant, although some of the coarser sandy layers are predominantly composed of authigenic kaolinite (Plate 11). The detrital grains are large and rounded, often with platy morphologies. The association of these large grains with the upper-most marine clays indicates a continuing detrital input from the same source region.

Illite

Whole rock diffraction profiles show a much larger peak at about 10A than the settled sample profiles, hence much of this material is coarser than 5 μm and consists of muscovite and biotite. Examination with the SEM shows large, fresh platy grains as well as rare weathered grains, shown in Plate 14. The finer micaceous minerals are much more difficult to identify, but minor well-developed crystals (Plate 12) and irregular flakes with thin, elongate projections have been observed . They were identified as illites by their high Si, Al and K compositions.

Montmorillonite

The broad, asymmetrical peak observed between 10.3Å and 14.6Å, that upon addition of ethylene glycol, shifted to about 17.5Å and became noticeably sharper, was identified as a smectite. The 060 reflection at 1.496Å, from a randomly orientated powder sample, confirmed that it was dioctahedral and hence a montmorillonite (Brindley and Brown, 1980). The variation in the basal spacing and the broad nature of this peak before glycolation, is due to the differing interlayer water content of each sample. The montmorillonite structure contracts under conditions of low humidity (Mac Ewan, 1975).

The absence of non-integral reflections given by mixed-layer clays, such as montmorillonite/illite, indicates that the smectite is a pure montmorillonite (Mac Ewan, 1975).

SEM analysis has shown that it takes the form of thin crenulated crystals that have no well defined morphology.

Feldspar

The feldspars within the Cadna-owie Formation are dominantly potassium-rich, although more sodic plagioclases are also present. Most grains appear quite fresh in the less porous sections, and give sharp peaks on x-ray diffraction profiles.

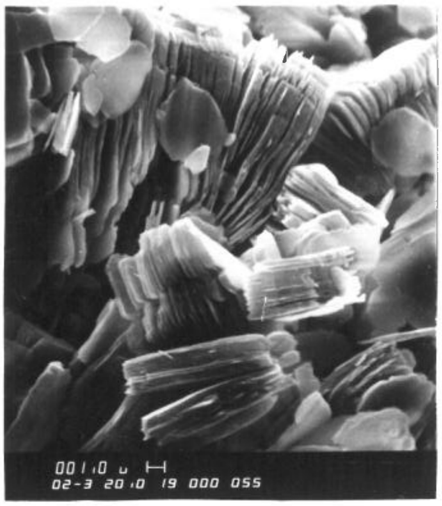
PLATE 11: Cadna-owie Formation
Stacked plates of authigenic kaolinite filling pore spaces in a sandstone bed.

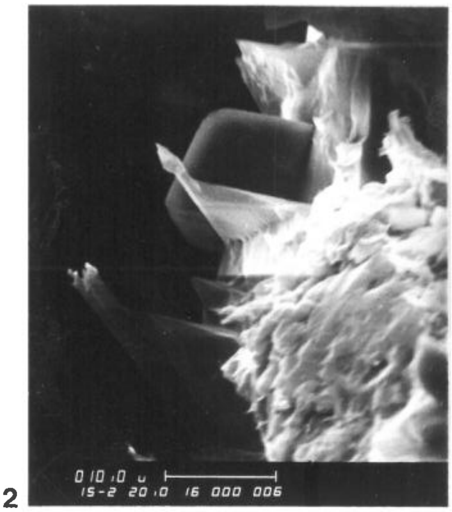
PLATE 12: Cadna-owie Formation
Platy crystals of authigenic illite filling a cavity.

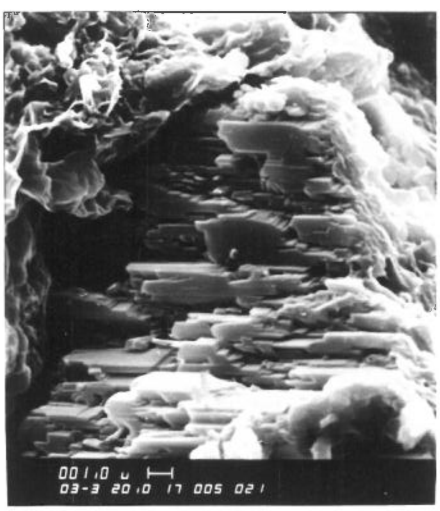
PLATE 13: Cadna-owie Formation
Partly weathered detrital feldspar grain with a coating of montmorillonite.

PLATE ~~14~~ 15: Cadna-owie Formation
Large detrital mica grain with fine outgrowths of illitic material.

PLATE ~~15~~ 14: Cadna-owie Formation
Cubic ferro-magnesian silicate crystal, detrital.


001.0 u
02-3 20.0 19 000 055
11


010.0 u
15-2 20.0 16 000 006
12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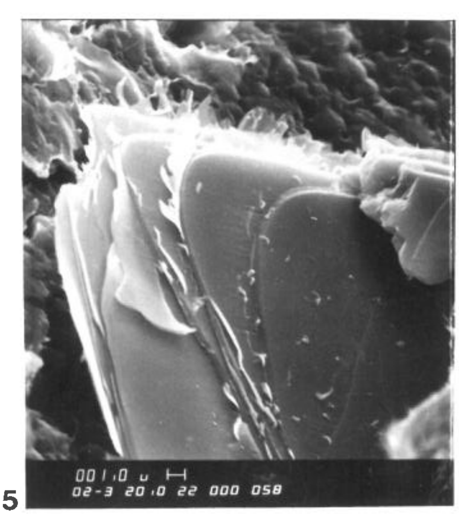
14


001.0 u
02-3 20.0 22 000 058
15

Bulldog Shale

The shallow marine Bulldog Shale consists of pale to dark grey siltstones and shales with minor fine to medium sandy laminations, and bands of carbonate.

The shales are finely laminated and grade down into the siltstones or sandstones over a few centimetres. Much of this lamination has been disturbed by burrowing organisms in the lower portion, and marine mollusc shells can be found scattered thoughout.

The siltstones and shales are pyritic, glauconitic and contain abundant carbonaceous fragments and marine fossils.

Griffiths (1979) suggested that the formation around Oodnadatta was deposited in an intertidal environment, with the coarser interbeds representing relatively more vigorous sedimentation in a tidal channel. The presence of graded bedding on such a small scale, however, may be indicative of density currents, that would spread a thin layer of coarser material further out in the shallow sea and deposit it under relatively quiet conditions.

PETROGRAPHY

Montmorillonite is the major clay mineral over this interval, but kaolinite percentages are greater in the more porous layers, (see Figure 5a) and become dominant near the contact of the upper Bulldog Shale and the overlying Oodnadatta Formation in Yalkalpo #1.

Montmorillonite

As before, the montmorillonite present contains no interstratification with illite, as indicated by the lack of non-integral reflections. The montmorillonites within the Bulldog Shale show no differences from those contained in the Cadna-owie Formation.

Illite

Very little 2-5 μm size illite is present within the samples although there is a large proportion of coarse-grained micas in Yalkalpo #1 (Plate 17).

The illite observed under the SEM shows that much of it has elongate neddle-like or platy forms.

Kaolinite

The kaolinite within the Bulldog Shale is mostly authigenic although there is some detrital component present (Plate 16). At the top of the formation in Yalkalpo #1, whole detrital ?feldspar grains have been replaced by books of stacked flakes that show orientation and the remnant shape of the parent grain (Plate 18).

Feldspar

Probe analysis of the coarse (63 - 125 + μm) fraction shows that the potassium feldspars are much more common than the plagioclase feldspars, due to the higher resistance to weathering of the potassium feldspars. Many of the plagioclase grains appear either pitted or fractured. Analyses are given in Appendix 3.

Many of the grains have a volcanic origin, indicated by zoned grains with cores of labradorite and rims of oligoclase or microperthitic textures of fine laminae in the potassium feldspars due to compositional differences (Plate 37) produced by the crystallization of both the potassium-rich and the more sodic feldspar at the same time.

Zeolites

The zeolites within the Bulldog Shale are of the silica-rich type, clinoptilolite, and are dominantly potassic. Identification from x-ray diffraction techniques was difficult due to the overlap of peaks from other minerals and the small size of the clinoptilolite peaks. SEM work showed that the crystals were prismatic, platy or tabular in form (Plates 24 to 29), and from optical microscope observations they appear to be clear. The crystals commonly form aggregates in pore spaces or cavities, left by the weathering of larger detrital grains. The more sodic varieties form elongate plates or laths and are most commonly found to fill these cavities as replacement minerals (Plate 24). Electron microprobe analyses are given in Appendix 3. The analyses of other high Si/Al ratio minerals are also given. Their composition varies from that of the clinoptilolites, and they are very soft. These unidentified minerals also fill pore spaces and may show tabular morphologies, but are more commonly irregularly-shaped.

Pyrite

Pyrite occurs throughout all samples from the Bulldog Shale and can be identified from x-ray diffraction profiles by small peaks at about 2.7Å and 2.4Å. Much of the organic matter has been replaced by pyrite, such as fecal pellets observed around worm burrows (Plate 19). The octahedral crystals contained within these spherical bodies have, in some samples been replaced by silica (Plate 20). The most common form of pyrite is the framboidal type in which the spheres are about 10 μm in diameter and are composed of smaller equigranular crystals that may also occur singly, scattered over grain surfaces (Plate 21).

Pyrite has characteristic S and Fe peaks and is easily identified.

Accessory Minerals

Rare occurances of other detrital grains were observed on the SEM, which included well-formed crystals of chromite; a chrome spinel, small irregular grains of apatite, octahedral grains of magnetite, triangular grains of ilmenite and a cubic grain of an Fe rich silicate.

Rock Fragments

Igneous rock fragments were observed (using the electron microprobe) within the coarse (63 - 125 +μm) fraction. Many of these grains have been weathered, leaving only the K-feldspar-rich matrix showing the relict textures of the original grains (Plates 34, 35); or have an infilling of chlorite as aggregates of elongate radiating needles (Plates 38, 43). Altered glassy fragments and shards were observed, which are shown in Plates 40, 41, 42. The shards have been replaced by minerals that are more resistant to transport and weathering, such as pyrite. Other rock fragments include those of ignimbrites and microcrystalline quartz-feldspar rhyolites showing graphic textures and small accessory apatite and zircon grains (Plates 32, 33).

The fragments are predominantly of acid volcanics and most probably weathered from the Gawler Range Volcanic Complex, where rocks of this type have been described by Turner, (1975).

PLATE 16: Bulldog Shale

Large rounded detrital kaolinite grain.

PLATE 17: Bulldog Shale

Partly weathered detrital biotite grain.

PLATE 18: Bulldog Shale

A detrital ?feldspar grain completely replaced by stacked books of authigenic kaolinite. This is indicative of intense leaching after deposition.

PLATE 19: Bulldog Shale

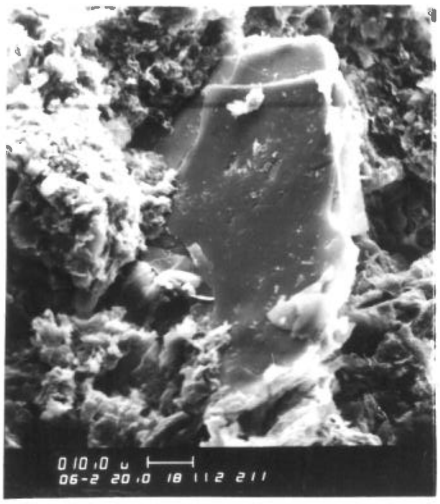
Worm burrow with spherical silica globules contained within.

PLATE 20: Bulldog Shale

Close-up of a silica spherule showing the octahedral shape of the individual crystals. The silica has probably replaced the original pyrite grains, seen in other samples.

PLATE 21: Bulldog Shale

Framboidal pyrite occurs throughout most samples. Pyrite also occurs as single rounded grains.



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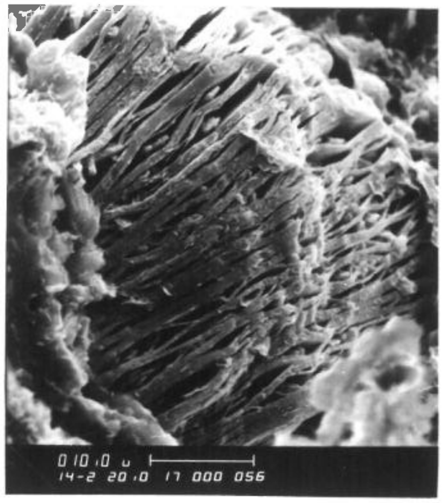

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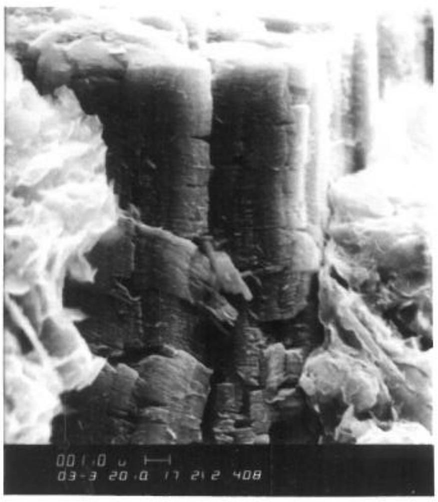

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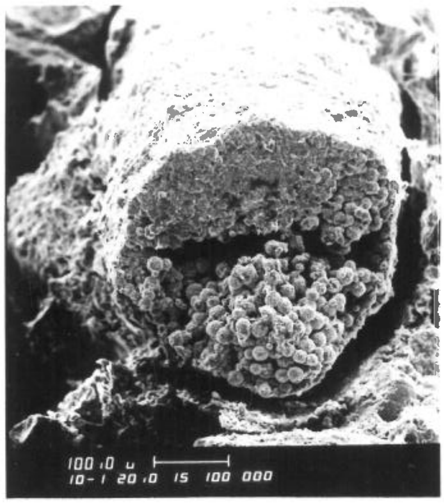

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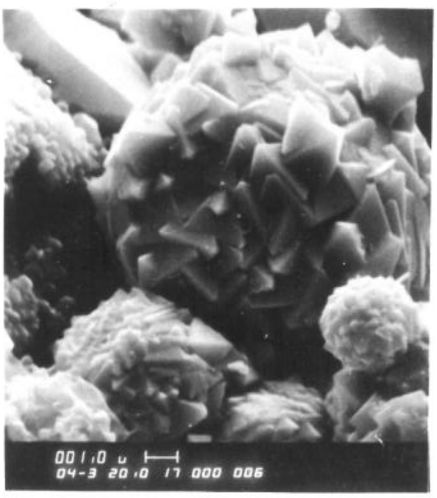

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PLATE 22: Bulldog Shale

Pyrite also occurs as octahedral crystals. Zeolite crystals can be seen in the lower left-hand corner.

PLATE 23: Bulldog Shale

Pseudohexagonal grain of authigenic apatite.

PLATE 24: Bulldog Shale

Elongate laths of Na zeolite. These crystals often replace larger weathered detrital grains or fill cavities.

PLATE 25: Bulldog Shale

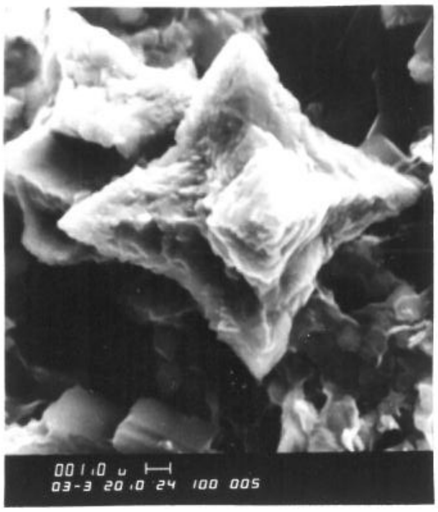
K rich zeolites and montmorillonite filling a cavity.

PLATE 26: Bulldog Shale

Large striated crystals of clinoptilolite.

PLATE 27: Bulldog Shale

Clinoptilolite crystals often form long strands and have this platy morphology. Other crystals may form prisms or cubes.



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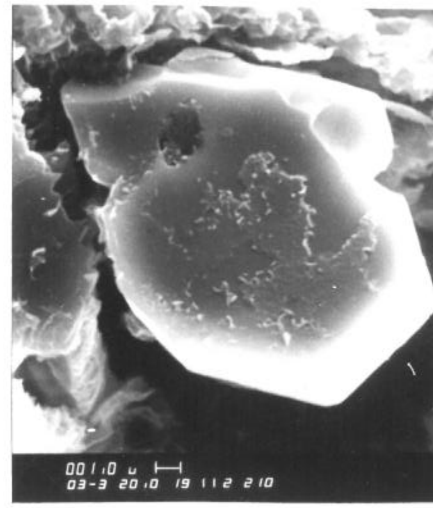

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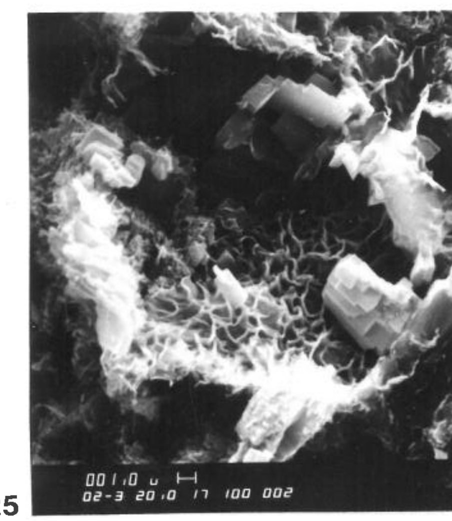

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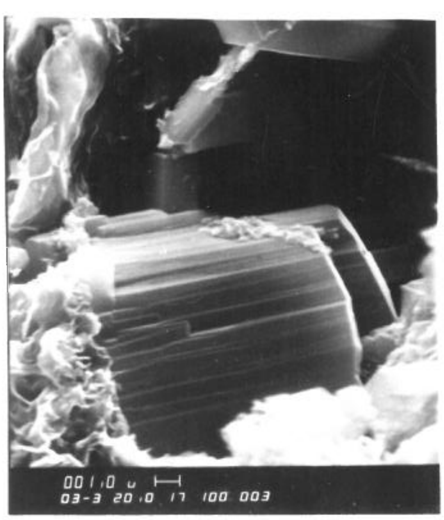

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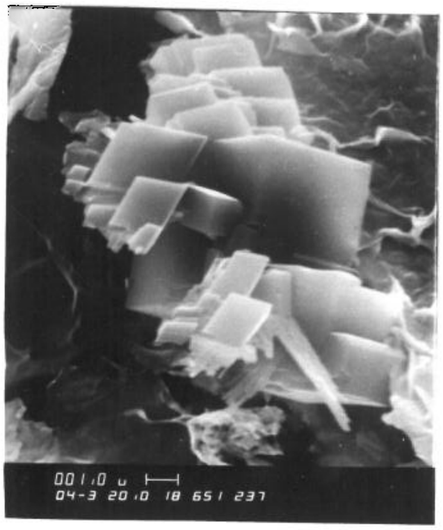
PLATE 28: Bulldog Shale
Aggregate of clinoptilolite crystals in pore spaces and cavities, note the variety of shapes.

PLATE 29: Bulldog Shale
Prismatic clinoptilolite crystals.

PLATE 30: Bulldog Shale
Authigenic quartz crystals showing well-developed prism faces. Montmorillonite fills the cavities above.

PLATE 31: Bulldog Shale
Authigenic quartz crystals showing well-developed prism faces. Montmorillonite fills the cavities above.


28



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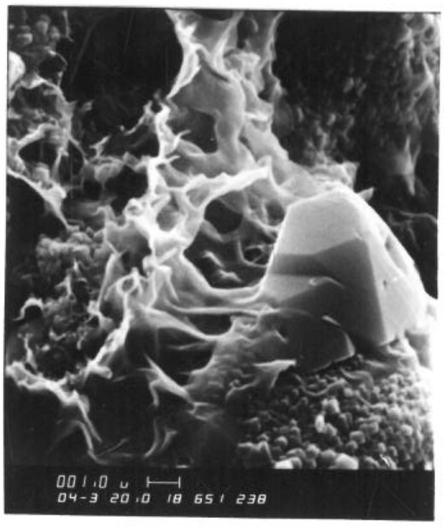

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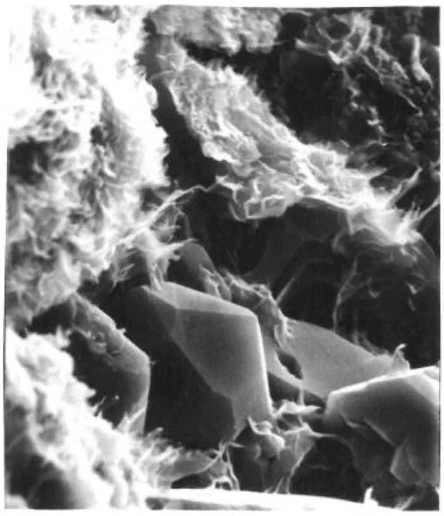
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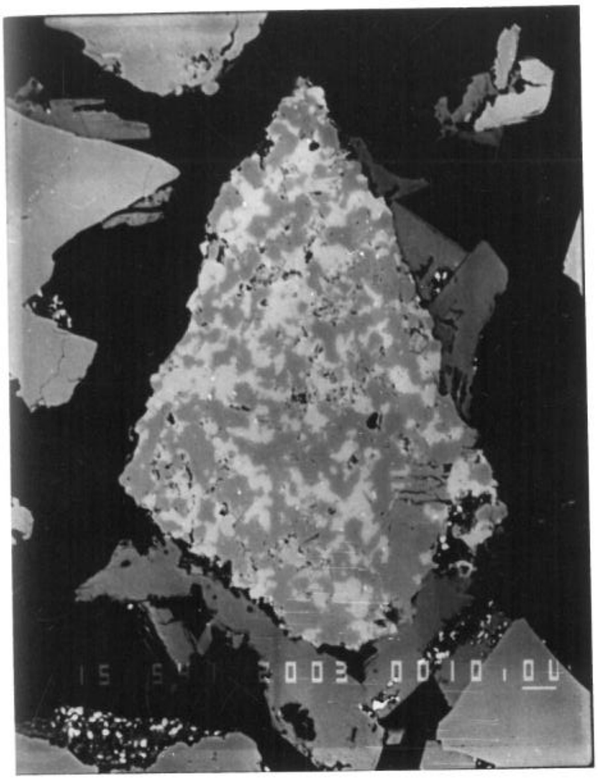
PLATE 32: Bulldog Shale, Yalkalpo #1
Angular acid volcanic rock fragment showing the graphic texture of K-feldspar and quartz.

PLATE 33: Bulldog Shale, Toodla #1
Compare with above. Bright spots are ilmenite and apatite.

PLATE 34: Bulldog Shale, Toodla #1
Rock fragment, K-feldspar has replaced the original crystals, but the igneous texture can be seen quite clearly.

PLATE 35: Bulldog Shale, Toodla #1
Igneous rock fragment.



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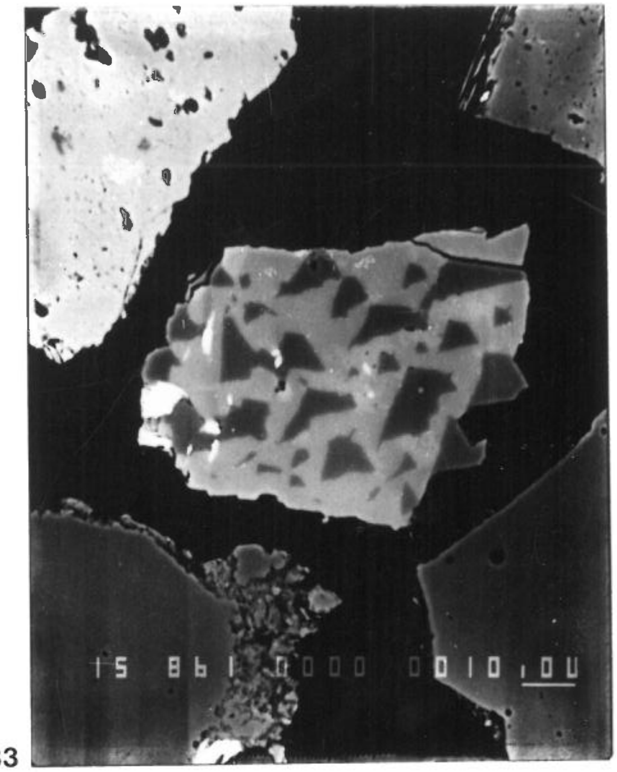

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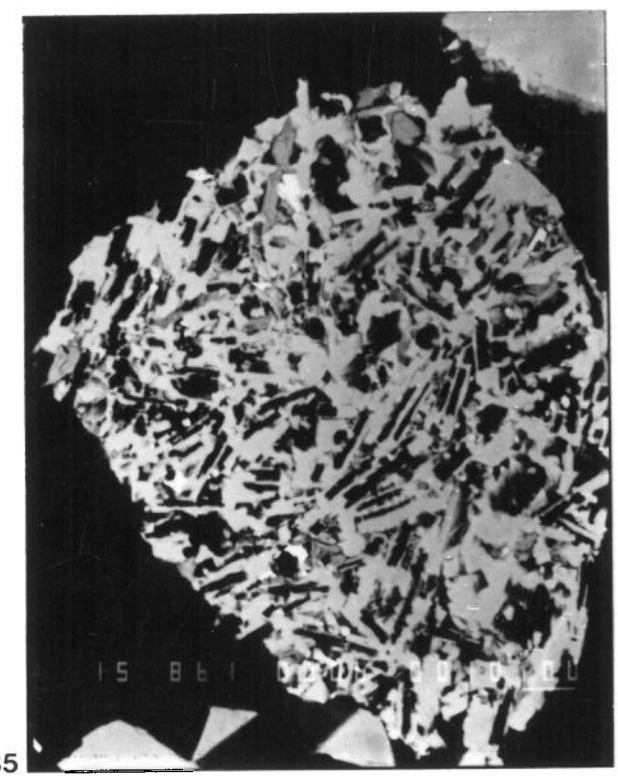

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PLATE 36: Bulldog Shale, Toodla #1

Rutile replacing a grain, a secondary silicate forms the matrix.

PLATE 37: Bulldog Shale, Yalkalpo #1

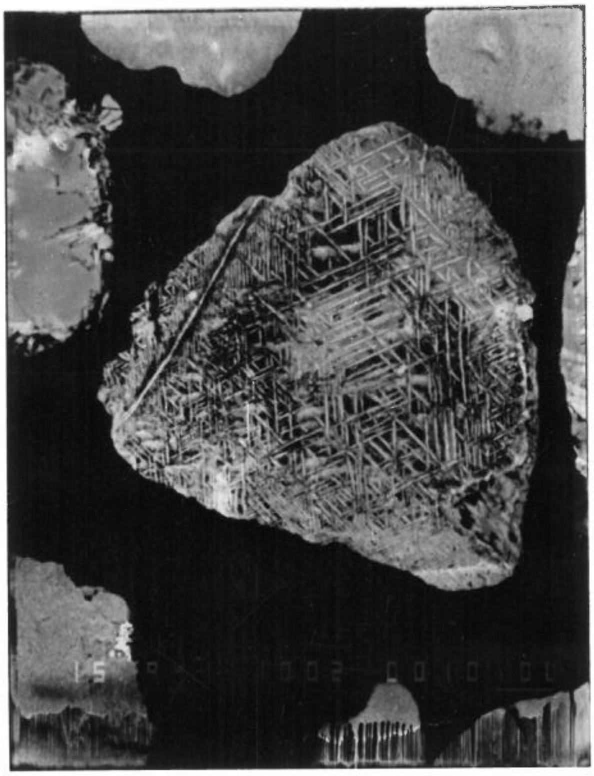
Igneous feldspar grain, predominantly K-feldspar with more sodic laminations.

PLATE 38: Bulldog Shale, Toodla #1

Glass fragment replaced by radiating chlorite needles. The rounded edges of the grain and the texture suggest the glassy origin.

PLATE 39: Bulldog Shale, Yalkalpo #1

General view, showing the abundance of volcanic fragments. Notice the angularity of many grains.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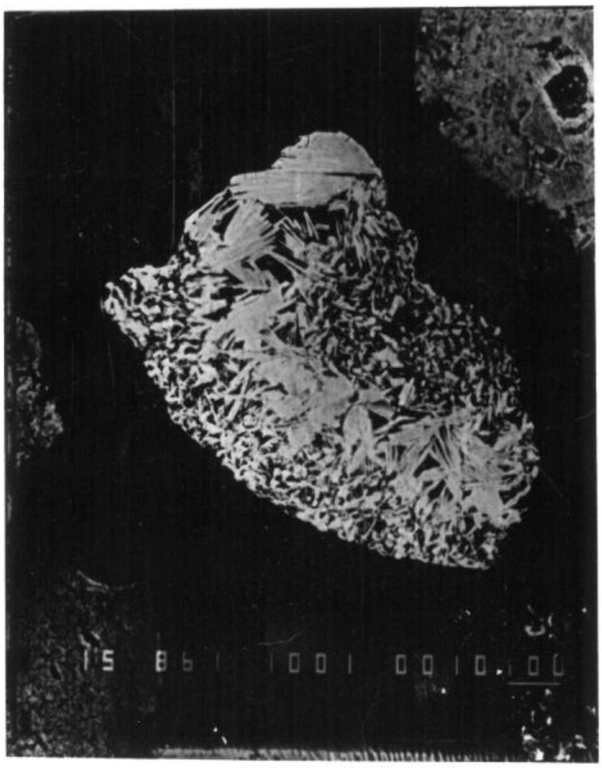
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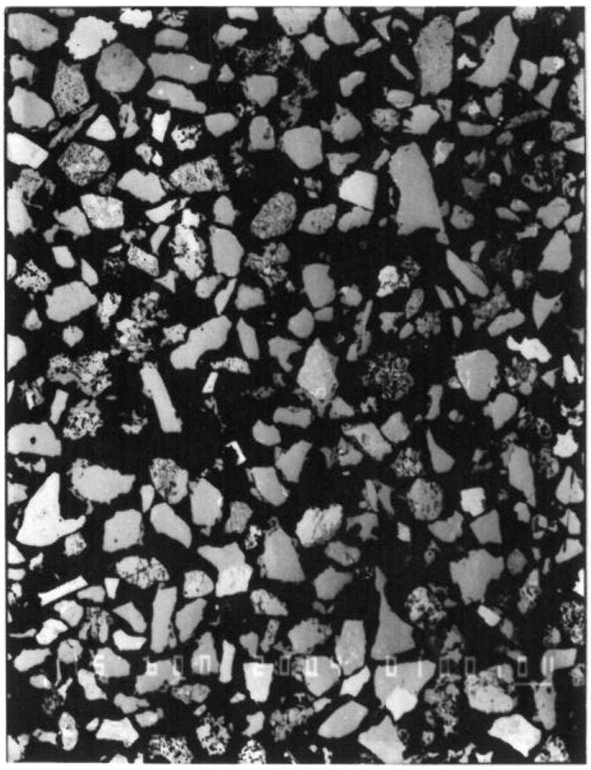
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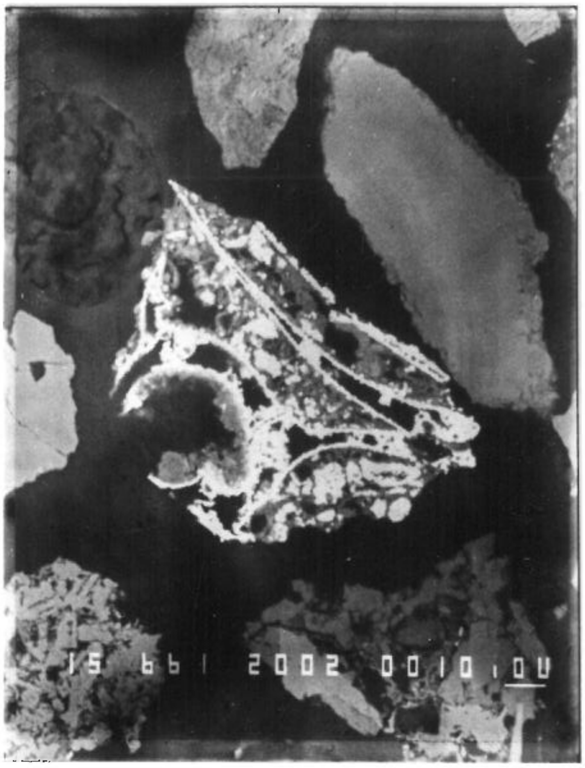
PLATE 40: Bulldog Shale, Toodla #1
Devitrified glass fragment,

PLATE 41: Bulldog Shale, Yalkalpo #1
Glass shard replaced by pyrite, zeolites fill the cavities.

PLATE 42: Bulldog Shale, Toodla #1
Glass shard replaced by pyrite, chlorite fills the cavity.

PLATE 43: Bulldog Shale, Toodla #1
Glass fragment replaced by pyrite, with radiating chlorite needles and zeolites filling the cavity.

40



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SOURCE REGIONS

The Algebuckina Sandstone shows a decrease in grainsize from the section exposed at Mt. Babbage to the sections observed in the cores. The change from gravel-dominated to sand-dominated deposits, reflects the change from a braided river environment to an alluvial plain type further out into the basin, where it intertongues with shales and sands of the lacustrine Murta Member of the Mooga Formation (Ambrose et al, 1982).

Localized depressions on the basin margins accumulated a lacustrine sequence such as observed in Yalkalpo #1, while more active sedimentation continued in the other parts of the basin.

The Cadna-owie Formation is more variable, due to the onset of the Cretaceous transgression and the relative positions of observed rock units in relation to marine or non-marine deposition. Wopfner et al, (1970) attributed the variations observed within this formation to various sedimentary environments such as sheltered lagoons separated from the open sea by barriers. The high carbonaceous and pyritic components of parts of the sequence substantiate this. The coarser rippled sections may be due to the action of waves or currents in a near shore environment. The change in lithologies laterally and vertically may be in response to tectonic activity (Wopfner et al, 1970) or to differing depositional environments caused by waning fluvial inputs or the extent of marine transgression over the land surface.

The dominance of locally derived material within the Algebuckina Sandstone and the Cadna-owie Formation in all areas, indicates that the material weathering on the land mass was eroded and transported along river channels then deposited on alluvial flood plains, without long-distance transport. The northwards current direction observed at Mt. Babbage and the north-easterly directions observed around Oodnadatta support this. Much of the sediment received in the basin around the Peake and Denison Ranges has been derived mainly from the Gawler Range Volcanics as evidenced by the occurence of porphyry boulders and pebbles within the fluvial sandstones (Wopfner et al, 1970) (Figure 16).

Igneous rock fragments of this type were found throughout the Bulldog Shale and are given in Plates 32 to 43. The association of these fragments with the coarser laminations and graded beds containing detrital quartz, feldspar and mica suggests that they are also detrital and are part of density flows, that may have been initiated by movements along the basin margins.

The presence of such a large volume of montmorillonite within the Bulldog Shale however, is not as easily explained. It seems unlikely that it would have been produced by the weathering of the areas mentioned above, as interstratified montmorillonite/illite minerals are most commonly produced from continental weathering (Moberly and Jenkyns, 1981) under warm conditions, which prevailed during the Early Cretaceous. It appears, from the presence of large detrital kaolinite grains within the sequence, that much of the clay being produced by the land masses to the south was of this type, and not montmorillonitic.

This is reflected in the greater abundance of kaolinite with terrigenous material within Yalkalpo #1, which is located closer to its source region, the Mt. Painter Block. However, this may be a function of some sedimentary dispersal mechanism described by Gibbs (1977). Even so, the increase in montmorillonite with increasing distance from a river source would not account for the extremely large volume of montmorillonite-dominated sediment over such a wide area.

Therefore a second source must be considered.

Montmorillonite is a common product of the weathering of volcanic ash and glass at surface conditions and is the predominant clay mineral within volcanogenic sediments (Moberly and Jenkyns, 1981).

Volcanism during the Late Jurassic and Cretaceous, was associated with episodes of sea-floor spreading and the development of an arc system along the Eastern margin of Australia (Sutherland, 1978).

SUMMARY

The Upper Jurassic to Lower Cretaceous rocks of the Eromanga Basin span several depositional environments, from fluvial to shallow marine. The fluvial phase (Algebuckina Sandstone) consists of dominantly quartzose sandstones with all the detrital component derived from nearby older basement of the Gawler Ranges in the Oodnadatta region and the Mt. Painter Province in the Lake Frome Region. Its high porosity over much of the area makes it an important aquifer. The weakly saline waters circulating through the sandstones have produced the authigenic kaolinites that fill some of the pore spaces.

The transitional phase (Cadna-owie Formation) is in most part terrestrial in its lower portions in the southern basin, with a marine influence observed near the top. Much of the sediment is of the same origins as the Algebuckina Sandstone although minor volcanogenic influences are present, such as the abundance of montmorillonite towards the top, and the presence of potassium-rich zeolites.

The Bulldog Shale shows two types of sediment, terrigenous material derived from older basement rocks of the Gawler Ranges and Mt. Painter Province, and a volcanogenic fraction possibly derived from the andesitic pyroclastics of the volcanic arc developed along the eastern margin of Australia. The abundance of montmorillonite and silica-rich clinoptilolite suggests their formation from the devitrification of volcanic glass at surface conditions. The presence of devitrified glassy fragments and glass shards indicates a volcanic input but is inconclusive as to defining the source, i.e. the older basement or the Cretaceous pyroclastics.

Further work may reveal many of the answers regarding the definite source, or sources as suggested here, but it is beyond the scope of this paper.

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APPENDIX 1

CORE SAMPLE DESCRIPTIONS

YALKALPO #1

Sample 1

Massive pale grey clay, minor fine sandy, micaceous laminations. Minor carbonaceous fragments.

Sample 2

Massive dark grey clay, as above. Graded bedding up to 2 cm wide, fine clay clasts.

Sample 3

Massive pale grey clay with minor sandy laminations.

Sample 4

Pale grey clay with dark grey wispy laminations. Minor fine carbonaceous flecks and mica grains.

Sample 5

Dark grey massive clay with fine wispy laminations of coarser silt and sand. Carbonaceous fragments.

Sample 6

Massive pale to dark grey clay, thin dark green ?glauconitic sandy interbeds. Carbonaceous fragments, ?shelly fossils.

Sample 7

Dark grey clay, small pods and wispy laminations of silty sand. Small curved dark grey clay clasts. Trace carbonaceous material.

Sample 8

Very dark grey, soft, fissile sandy clay. Large mica flakes and thin sandy laminations.

Sample 9

Dark grey, massive clay. Wispy horizontal lamination. Bioturbated. Shelly fossil fragment. Fine sandy laminations.

Sample 10

Dark grey clay, as above.

Sample 11

Dark grey clay, as above, minor carbonaceous fragments. Micaceous. Layers of small square clay clasts, approximtely orientated parallel to bedding.

Sample 12

Pale grey, massive clay, as above.

Sample 13

Dark grey clay. Fissile in part. Very micaceous. Large carbonaceous fragments are common.

Sample 14

Massive pale grey clay. Minor thin lenses of very coarse sand. Minor carbonaceous material. Small green pebble of claystone.

Sample 15

Massive pale grey clay. Minor wispy laminations. Carbonaceous fragments.

Sample 16

Pale grey silty, clayey fine to coarse sand with scattered pebbles. Minor carbonaceous material.

Sample 17

Pale grey massive clay. Large carbonaceous fragments.

TOODLA #1

Sample 1

Pale grey silty sandy clay. Small lenses of quartz, mica sand.
Minor shell fragments.

Sample 2

Massive pale grey clay, scattered fine mica and quartz grains, finely laminated with very pale grey clay lenses.
Minor ?pyrite in pods 0.5 cm long.

Sample 3

As above, laminations at 90^{o} to core, grading from grey clay to pale grey silty clay, minor carbonceous flecks.
Sandy lenses.

Sample 4

As above, bioturbated sandy layers wispy lamination, very uneven bedding. Shell fragment. Clay clasts (very fine 0.5 cm) in the silty sandy layers.

Sample 5

Dark grey clay with silty sandy layers (1 cm) bioturbated in places, minor broken shell fragments. Carbonaceous fragment.

Sample 6

As sample 4 wispy laminations, bioturbated.

Sample 7

Well laminated, dark grey clays, silty laminations. Large bivalve shell fragment. Micaceous.

Sample 8

Dark grey clay and silt with bioturbated layers many small wispy sand lenses. Very sandy. Large carbonaceous fragments.

Sample 9

Green-grey clay, very finely laminated, fissile, minor sandy laminations, very thin, large 1 cm long cone shaped black fragment. Appears weathered, very soft crumbly, reduction spots.

Sample 10

As above, finely laminated, fissile. Minor sand. Lenses.

Sample 11

As above, less fissile, less weathered, smooth soapy fracture surfaces.

Sample 12

Pale to medium grey clay, minor sandy laminations, fissile.

Sample 13

Very pale grey kaolinitic sands, minor pale brown grey silty clay lenses, crossbedded. Very soft, micaceous.

Sample 14

Green grey coarse crumbly sands, very weathered, carbonaceous fragments, kaolinitic.

Sample 15

Pale grey fine kaolinitic sands with fine dark clay laminations, low-angle crossbedding. Carbonaceous.

Thin Section Descriptions

Plate 1 Yalkalpo #1

Sample No. 17

Fine-grained clay-rich sandstone. Micas show alignment with bedding planes. Small grains of feldspar are completely weathered.

Plate 2 Toodla #1

Sample No. 13

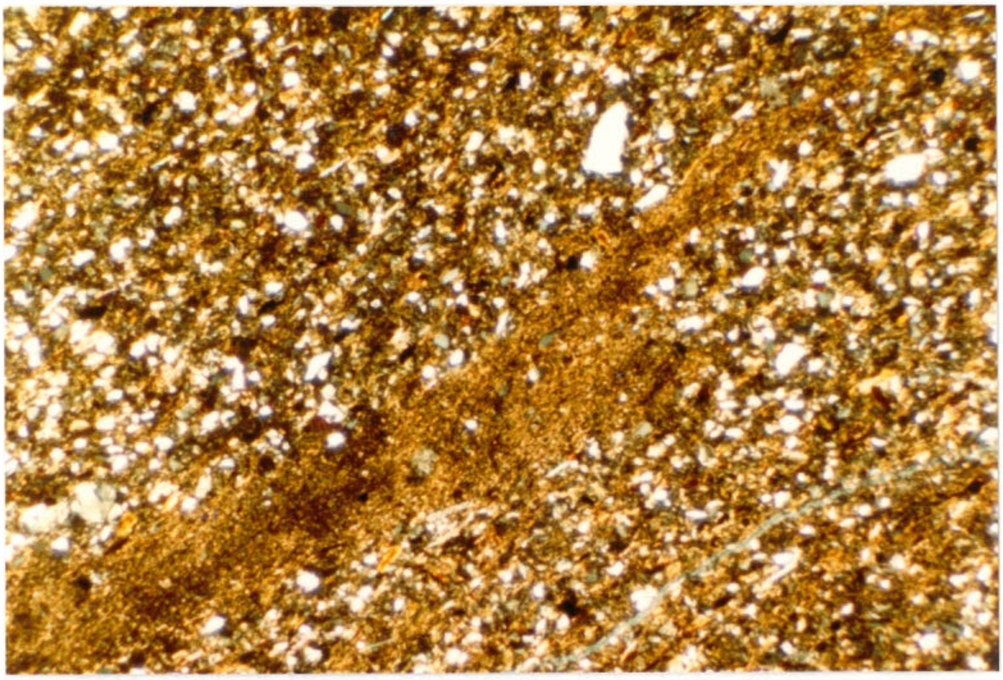
Fine to medium-grained quartzose sandstone, with much interstitial clay. Many feldspar grains have been very altered, and only the relict shape of the grain is left. Muscovite grains show alignment to bedding planes. Small rock fragments can be observed but are a minor constituent.

Plate 3 Toodla #1

Sample No. 14

Poorly-sorted quartz sandstone. Many of the grains show well-rounded forms. Many quartz grains show fractures and undulose extinction, and often have quartz overgrowths that are in optical continuity with the grain itself.

Width of view on all plates is 3 mm.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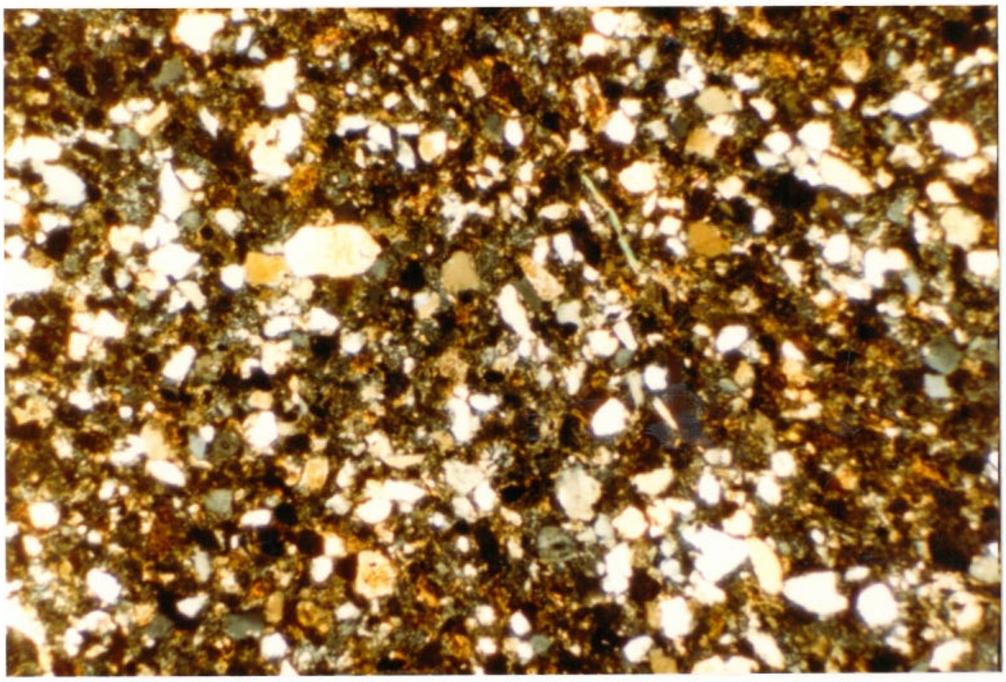
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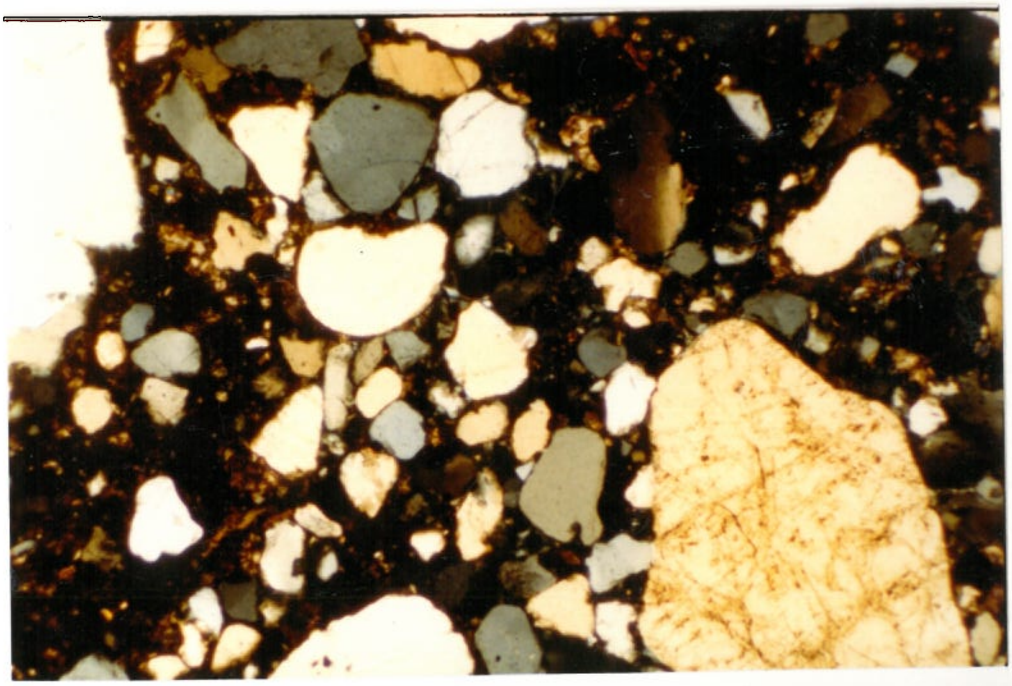
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Plate 4 Toodla #1

Sample No. 15

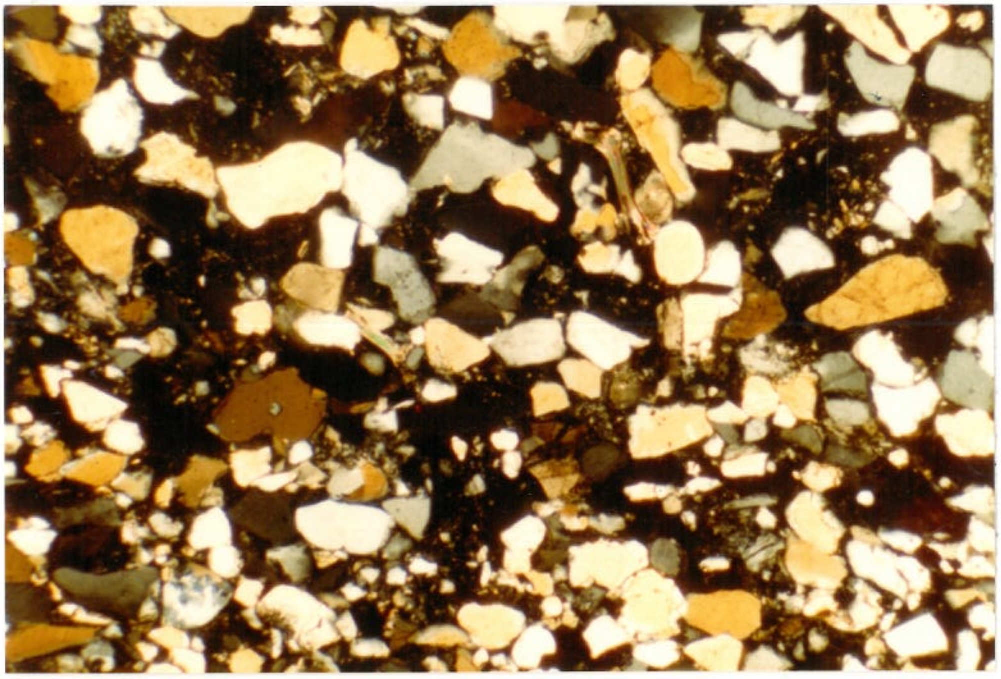
Well-sorted sandstone with clay-rich laminae. Aligned mica grains are concentrated in the clay layers. Quartz grains commonly show overgrowths that are in optical continuity. Rare feldspar grains.

Plate 5 Toodla #1

Sample No. 16

Moderately-sorted quartz sandstone. Many grains show well-rounded forms, but others are very angular. Quartz grains show overgrowths as above that are quite thick. Feldspar grains show a weathered rim but fresher cores. Mica grains show little alignment with bedding. Igneous rock fragments consisting of composite quartz grains and quartz-feldspar grains are common throughout.

Width of view on all plates is 3 mm.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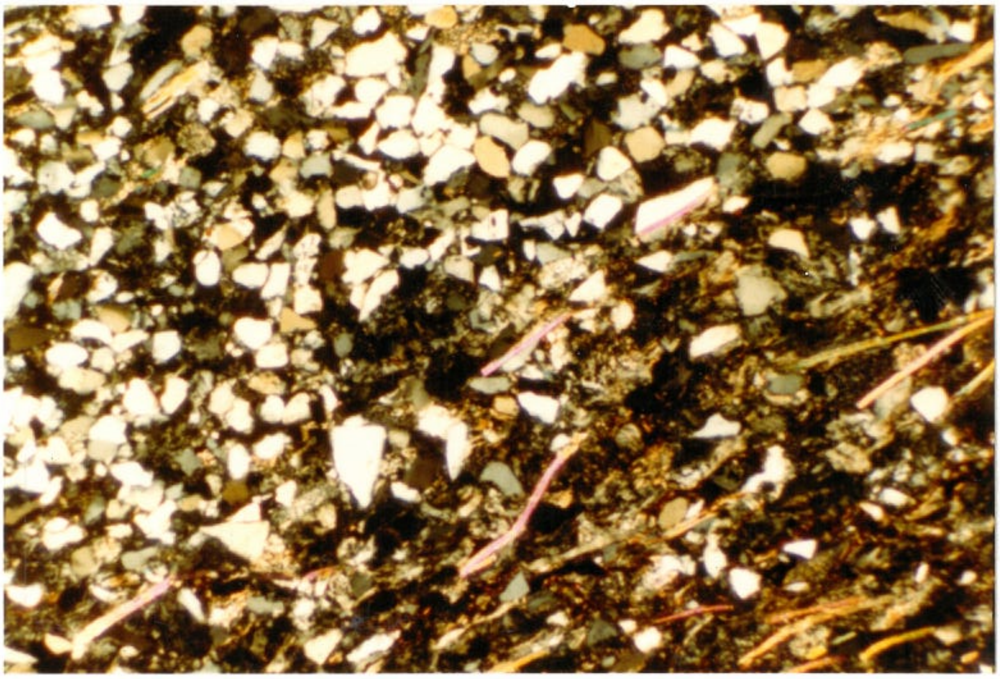
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APPENDIX 2

MINERALOGY

Well: Yalkalpo #1

Sample No.	Terrigenous Minerals				Secondary or Authigenic Minerals					
	Q	F	K	I	P	M	S	Z	C	SH
1	d	t	d	t		-	t	t	t	
2	d	t	c	t		d	t	t		
3	d	t	t	t		d				
4	d	t	t	t	t	d		t	t	
5	d	t	c	t		d			c	
6	d	t	c	t		d		t	y	?t
7	d	t	c	c		d			t	
8	d	c	c	a	t	d	t			
9	d	t	c	a	t	d		t	t	t
10	d	t	t	t		d				t
11	d	t	t	c	t	d		t	t	
12	d	t	t	c		d			t	
13	d	t	c	c		d			c	
14	d	t	c	a		d	t		t	
15	d	t	d	a		t			t	
16	d	t	d	t		c			t	
17	d	t	d	c		c	t		c	

d	dominant	Q	quartz)	
a	abundant	F	feldspar)	from x-ray
c	common	K	kaolinite)	analyses
t	traces	I	illite)	
		M	montmorillonite)	
		P	pyrite)	
		S	silica)	from optical
		Z	zeolites)	determination
		C	carbonaceous material)	(selected
		SH	shelly fossils)	samples)

Well Toodla #1

Sample No.	Terrigenous Minerals				Secondary or Authigenic Minerals					
	Q	F	K	I	P	M	S	Z	C	SH
1	d	c	t	t	t	d	t	t		t
2	d	t	c	c		d			t	
3	d	t	c	c		d			t	
4	d	t	c	c	t	d	t	t		c
5	d	t	t	t	t	d	t	t	t	
6	d	t	t	t	t	d		t		
7	d	t	t	t		d			t	c
8	d	c	t	t		d			c	
9	d	t	t	c		d				
10	d	t	t	t		d			t	
11	d	t	t	t	t	d		t	t	
12	d	t	c	c		d		t		
13	d	t	a	c		a			t	
14	d	-	d	t	t	-			t	
15	d	t	d	t		-			t	
16	d	-	d	t		t				

d	dominant	Q	quartz	)	
a	abundant	F	feldspar	)	from x-ray
c	common	K	kaolinite	)	analyses
t	traces	I	illite	)	
		M	montmorillonite	)	
		P	pyrite	)	
		S	silica	)	from optical
		Z	zeolites	)	determination
		C	carbonaceous material	)	(selected
		SH	shelly fossils	)	samples)

APPENDIX 3

ELECTRON MICROPROBE DATA

WELL: Toodla #1

Table 1

K-Feldspar

SiO_2	65.71	66.38	67.04	67.94	66.46	68.62	68.74	67.94
TiO_2	0.37	-	-	-	-	-	-	-
Al_2O_3	18.67	18.73	18.64	18.71	18.72	18.62	19.00	19.17
FeO	-	-	-	-	-	0.21	-	-
CaO	-	-	-	-	-	0.16	-	0.10
K_2O	14.83	14.34	14.24	13.25	12.09	11.44	10.73	10.13
Na_2O	0.54	1.22	0.49	1.03	1.62	2.52	3.98	4.02
TOTAL	100.11	100.67	100.41	100.94	98.89	101.57	102.45	101.26

Table 2

Plagioclase

SiO_2	68.23	67.62	70.16	63.21	66.20	62.58	57.39	55.71
Al_2O_3	19.70	20.34	20.22	23.87	22.63	23.78	26.78	28.99
FeO	0.35	-	0.31	-	-	-	-	0.14
MgO	0.24	0.18	-	-	-	-	-	-
CaO	0.14	0.13	0.18	4.75	3.16	5.29	8.64	10.84
K_2O	0.14	0.33	0.07	0.32	0.87	0.83	0.30	0.09
Na_2O	11.05	10.98	8.97	8.64	8.30	7.03	5.37	4.97
TOTAL	100.00	99.59	99.90	100.79	101.16	99.51	98.46	100.75

Table 3

Micas

	Biotite					Muscovite		
P_2O_5	0.20	0.14	-	-	-	-	-	-
SiO_2	31.22	36.04	31.05	31.75	35.83	36.55	37.24	46.15
TiO_2	3.71	1.97	1.98	2.84	1.69	0.23	0.58	-
Al_2O_3	13.90	13.42	11.86	18.90	18.78	24.75	26.28	36.37
Cr_2O_3	0.12	-	0.20	-	-	-	-	-
FeO	13.06	20.05	17.44	20.74	21.35	2.62	2.72	0.68
NiO	0.57	0.21	-	-	-	-	-	-
MnO	7.45	0.18	-	0.15	-	0.14	-	-
MgO	1.31	4.43	4.83	7.43	5.43	0.72	0.65	0.38
CaO	2.44	1.18	0.14	0.19	0.45	0.55	0.60	-
K_2O	1.42	2.08	6.72	3.56	0.79	8.05	8.36	7.04
Na_2O	-	-	-	0.74	0.24	-	-	0.58
TOTAL	75.41	79.71	74.23	86.32	84.56	73.60	76.42	91.20

Table 4

	Amphibole		Chlorite			Glauconite		
P_2O_5	1.08	1.95	-	-	-	0.11	-	-
SiO_2	49.61	49.11	27.88	26.79	25.00	53.00	52.03	53.24
TiO_2	1.45	1.26	-	-	-	0.52	0.42	0.45
Al_2O_3	15.91	19.16	19.26	18.65	22.42	16.64	16.60	18.82
FeO	13.99	13.22	26.53	32.28	26.22	16.15	14.99	13.30
MnO	0.14	-	0.50	0.31	-	-	-	-
MgO	5.75	5.42	10.81	7.35	13.87	3.22	3.59	2.62
CaO	1.94	3.03	0.13	0.14	-	1.12	0.94	0.79
K_2O	2.19	2.48	0.36	-	-	3.35	3.13	5.11
Na_2O	0.76	0.97	0.34	-	-	0.20	-	-
TOTAL	92.81	96.60	85.80	85.52	87.51	94.30	91.70	94.33

Table 5

	Ilmenite		Apatite	
P_2O_5	0.12	-	17.48	16.06
SiO_2	-	2.20	10.36	16.31
TiO_2	37.81	45.57	0.53	0.85
Al_2O_5	0.55	0.90	4.51	7.53
V_2O_3	-	0.29	-	-
FeO	51.98	43.55	8.46	20.64
MnO	0.49	0.54	0.42	0.37
MgO	2.34	2.18	2.81	2.53
CaO	-	0.20	26.33	22.82
K_2O	-	0.23	0.44	0.77
Na_2O	0.25	0.44	0.86	0.32
TOTAL	93.54	96.11	72.20	88.20

WELL: Yalkalpo #1

Table 1

Feldspar

	K-Feldspar							Plagioclase
SiO_2	68.93	69.18	64.88	65.68	62.19	66.80	66.49	69.31
TiO_2	-	0.17	-	-	-	-	-	-
Al_2O_3	18.82	17.74	8.15	19.39	16.35	19.91	19.04	20.50
FeO	-	-	-	-	2.06	0.25	0.29	0.15
MgO	-	-	-	-	-	-	0.12	-
CaO	-	-	-	-	-	1.04	1.29	0.31
K_2O	13.61	11.28	15.12	10.65	9.09	7.45	5.67	0.13
Na_2O	-	-	0.41	1.05	4.15	5.03	5.46	11.74
TOTAL	101.35	98.36	98.57	96.77	93.83	100.48	98.35	102.14

Table 2

Micas

	Biotite	Muscovite		Glauconite/Illite	
P_2O_5	-	-	-	-	0.35
SiO_2	21.47	47.50	50.16	52.75	54.05
TiO_2	2.34	-	0.42	0.31	0.19
Al_2O_3	9.95	36.08	31.35	11.79	15.06
FeO	10.69	0.96	2.43	17.09	11.20
MgO	9.08	0.64	1.78	3.13	2.34
CaO	0.54	-	-	0.33	0.52
K_2O	2.34	10.39	8.35	5.14	2.65
Na_2O	0.96	0.25	0.14	-	0.42
SO_3	0.96	-	-	-	0.21
TOTAL	58.35	95.83	94.63	90.54	87.00

Table 3

Zeolites

					Clinoptilolite			
SiO_2	55.60	71.24	64.26	64.66	65.57	68.44	64.95	62.14
Al_2O_3	9.81	12.95	13.25	13.50	12.52	13.03	12.02	13.86
NiO	-	-	0.19	-	-	-	-	-
Cr_2O_3	0.10	-	-	-	-	-	-	-
FeO	0.39	0.17	-	-	0.19	-	-	0.31
MgO	0.58	0.73	1.26	1.16	0.97	0.85	0.83	1.44
CaO	0.45	0.40	1.45	1.47	0.66	1.09	0.92	1.64
K_2O	0.57	0.33	0.90	1.01	1.54	1.54	1.51	0.85
Na_2O	0.60	0.38	1.76	1.80	2.61	3.17	4.10	4.51
SO_3	-	-	1.14	-	0.26	-	-	0.17
TOTAL	68.11	86.20	83.27	83.61	84.32	88.72	84.38	84.94