THE EFFECT OF DIAGENESIS AND FACIES DISTRIBUTION ON RESERVOIR QUALITY IN THE PERMIAN SANDSTONES OF THE TOOLACHEE GAS FIELD, SOUTHERN COOPER BASIN SOUTH AUSTRALIA

awarded 12.2.91

by David Barry Alsop (B.Sc.)

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AUGUST 1990

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STATEMENT OF AUTHENTICITY AND AVAILABILITY

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University. To the best of my knowledge and belief the thesis contains no material previously published or written by another person, except where due reference is made in the text.

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ABSTRACT

The Toolachee, Brumby and Munkarie Fields in the southern Cooper Basin of north-east South Australia contain wet gas in the Permian Patchawarra and Epsilon Formations. The diagenetic effects on reservoir quality are important in predicting sites of good quality reservoirs and in using stimulation techniques for enhanced recovery of gas from existing wells.

The aims of the study are: to characterise chronostratigraphic facies and distribution of Permian sandstones, to determine the paragenesis of the Toolachee, Epsilon and Patchawarra Formations, to investigate the effect of diagenesis on reservoir quality, and to define and predict potential reservoir sands in the region.

A total of 1296 feet of slabbed conventional core was geologically logged. There were 128 core samples and 25 cuttings samples examined by thin section, X-Ray diffraction (XRD), and scanning electron microscope (SEM). In addition, 20 samples were studied using cathodoluminescence.

The Toolachee Gas Field is located approximately sixty kilometres south-east of Moomba, on a structural high, the Toolachee Trend. The structure is a north-oriented trend situated immediately east of the Tenappera Trough. Brumby Gas Field is approximately 20 kilometres east of the Toolachee Field and comprises eight localised highs forming a broad structure. Munkarie Gas Field is located on a fault-dependent, north-south elongate structure which is 15 kilometres south-east of the Toolachee Field.

The Toolachee and Patchawarra Formations consist mainly of fine to coarse sandstone of point bar origin and fine-grained flood plain deposits, while sediments of the Epsilon Formation accumulated in a deltaic environment.

The main diagenetic effects acting on sandstones (sublitharenites) in the study area are early quartz cementation, porosity dependence on diagenesis, microporosity associated with authigenic dickite, formation of micritic and sparry siderite and the dissolution of mineral grains to form secondary pores. Hydrocarbon migration occurred after the last phase of diagenesis.

The main influences affecting reservoir quality are a combination of environmental and diagenetic controls. The main environmental controls are grain size, sorting, and mineralogy of the detrital grains and clays. The grain size of the initial sediment is an important factor with the medium to coarse-grained rocks of the Patchawarra Formation exhibiting the best porosities and permeabilities throughout the Toolachee, Brumby and Munkarie Fields. Sorting also plays a role in reservoir quality with well-sorted sandstones (sublitharenites) in the medium grain size range often having better porosity than the more poorly-sorted sandstones in this range. Primary intergranular porosity is dominant with subordinante secondary oversized pores and microporosity in dickite.

CHAPTER 1 INTRODUCTION

1.1 PREFACE

The Cooper Basin is an elongate Permo-Triassic intracratonic basin located in the north-east corner of South Australia and south-west corner of Queensland (Figure 1.1). The basin covers an area of 127,000 square kilometres and contains up to 1500m of sediment in the Nappamerri Trough (Battersby, 1976). These sediments consist of sandstones, siltstones, shales and coals deposited in fluvial, deltaic, and lacustrine environments. Permian sediments unconformably overlie the Lower Cambrian to Devonian (Roberts et al, 1990) metasediments and volcanics of the Warburton Basin and underlie the thick and extensive Eromanga Basin sequences of Jurassic to Cretaceous age (Buger, 1986) (Figure 1.2).

Approximately 25 million barrels of recoverable oil and an estimated 7.5 TCF original gas in place have been found in 50 fields within the Cooper Basin making it the most prolific hydrocarbon-producing basin onshore in Australia (Marcus, 1987).

Understanding the diagenetic history of sediments and the effect on reservoir quality in the Cooper Basin has become increasingly important over the last decade as the search for new hydrocarbon fields and the delineation of existing fields has become more critical to the nation's economy. The diagenetic processes, acting on sediments during burial, affect hydrocarbon migration pathways and the fluid storage capacity of its pore spaces. To comprehend the nature of the diagenetic changes that have taken place and their relationships to sedimentary facies, it is therefore important to be able to predict sites of good quality reservoirs in a field. Authigenic minerals occluding pore spaces and replacing minerals during diagenesis are of utmost importance to the petroleum engineer in using stimulation techniques to gain enhanced recovery from the wells within a field. These minerals may adversely influence certain techniques in use.

In this study the author investigates the diagenetic history of the Permian reservoir sandstones in the Toolachee Gas Field region of the Southern Cooper Basin, South Australia. This study is part of NERDDC project N0 1175, being undertaken by the National Centre for Petroleum Geology & Geophysics, to gain an understanding of factors controlling porosity

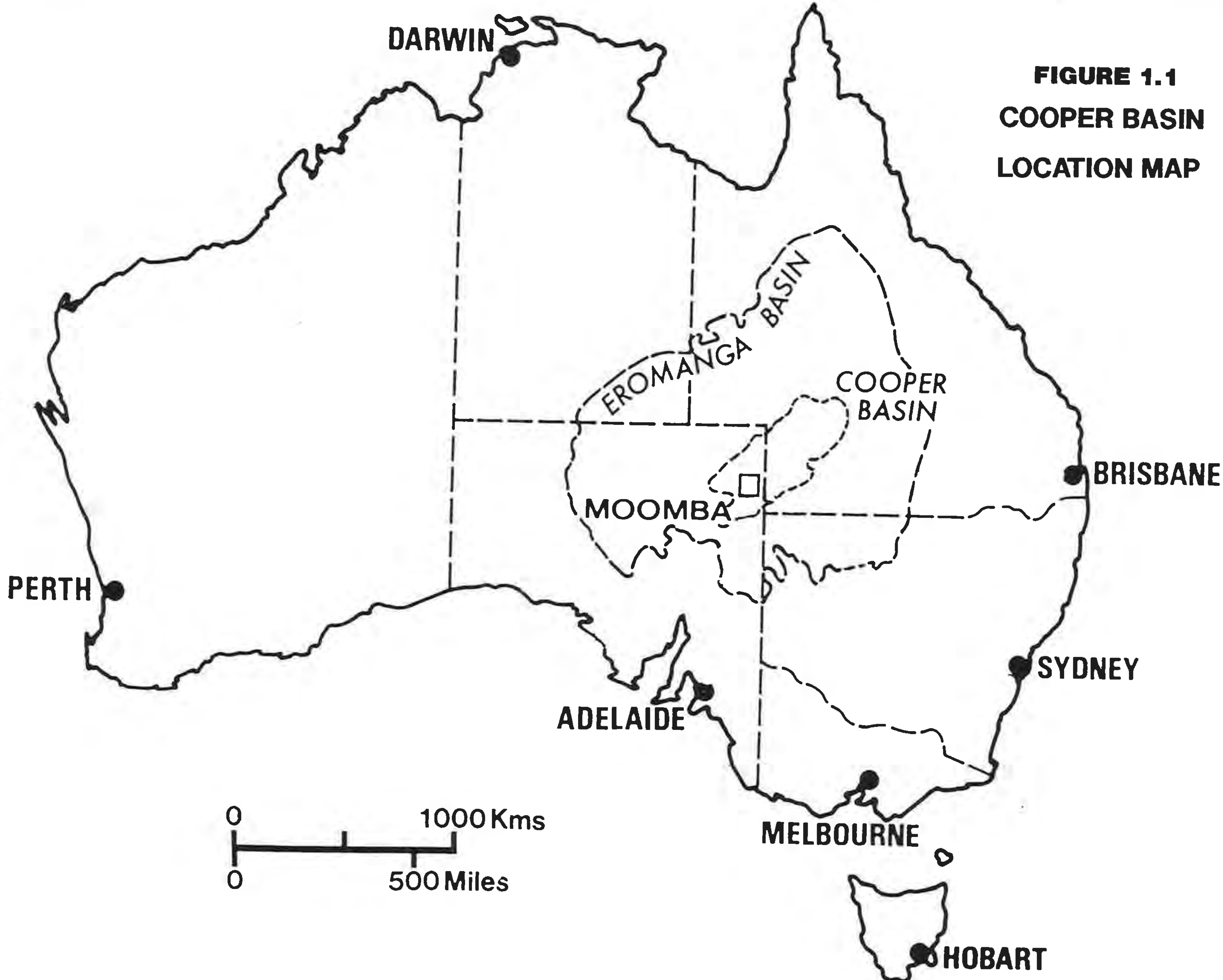
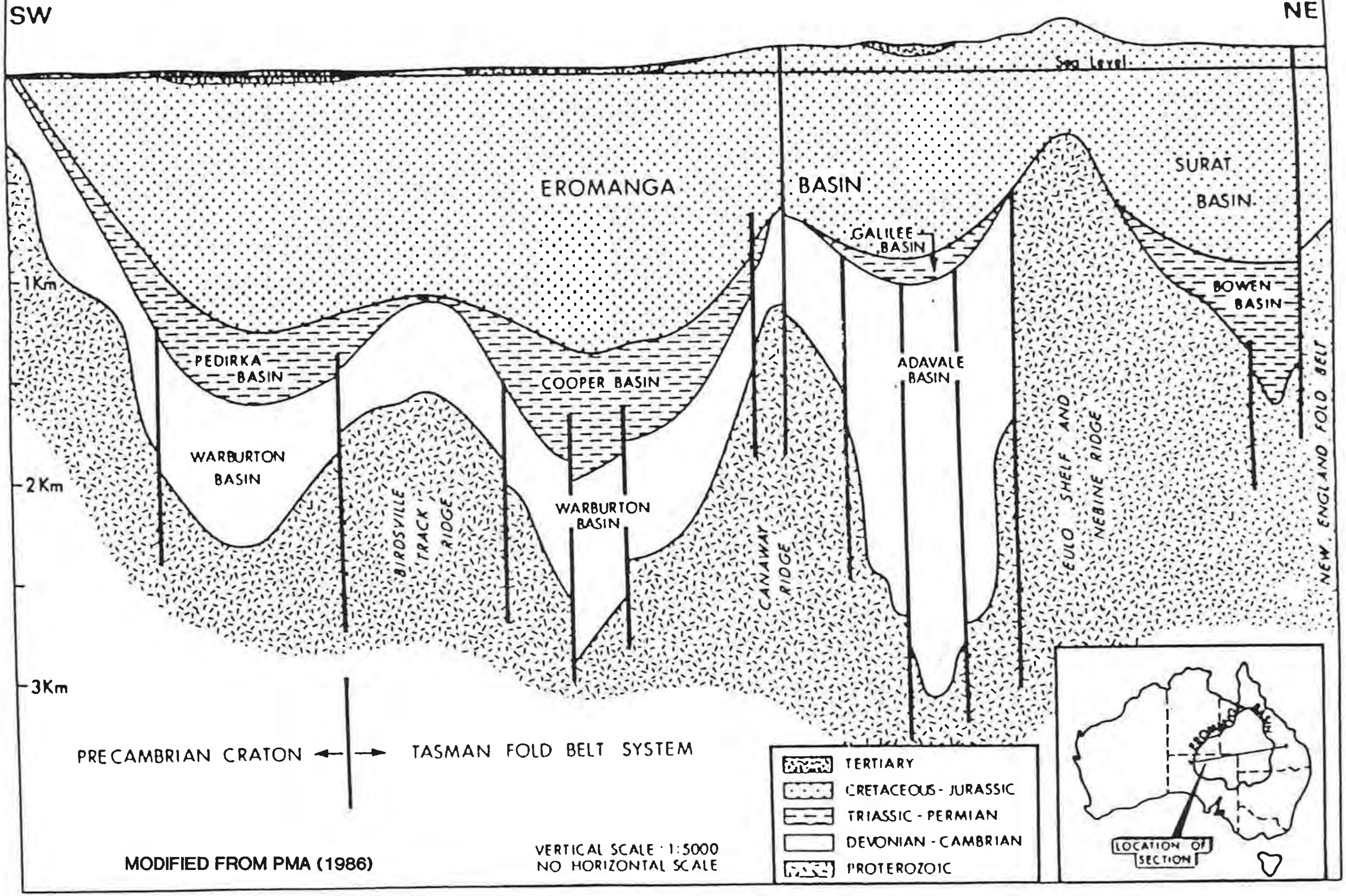


FIGURE 1.1
COOPER BASIN
LOCATION MAP
DARWIN
EROMANGA BASIN
COOPER
BASIN
MOOMBA
BRISBANE
PERTH
SYDNEY
ADELAIDE
MELBOURNE
HOBART
0
1000 Kms
0
500 Miles

FIGURE 1.2 : COOPER EROMANGA REGIONAL CROSS SECTION



and permeability in these Permian sandstones and providing industry with information vital to the prediction and location of reservoir quality sandstones.

1.2 AIMS

The aims of this thesis are:

a) To characterise the sedimentary and chronostratigraphic facies, the distribution and nature of the Permian sandstones.

b) To determine the diagenetic histories of the Toolachee, Epsilon and Patchawarra Formations.

c) To define and predict the best reservoir sands in this region, based on their depositional environment and diagenetic histories.

d) To investigate the effects of diagenesis on reservoir quality.

1.3 STUDY AREA

The study area encompasses the Toolachee, Brumby and Munkarie gas fields in the south-eastern Cooper Basin.

The Toolachee Gas Field is located approximately sixty kilometres south-east of Moomba (Figure 1.3), on a structural high, the Toolachee Trend (Battersby 1976). It is a north-south oriented field situated east of the Tenappera Trough. Gas production is from the Patchawarra and Epsilon Formations.

Brumby Gas Field is approximately twenty kilometres east of the Toolachee Field (Figure 1.3). The field is located on a broad structural high consisting of eight localised highs. The field is slightly elongate in a north-south direction cut by six north-south oriented normal faults. Brumby Field produces gas from the Patchawarra Formation.

The Munkarie Gas Field is located fifteen kilometres south-east of the Toolachee Field (Figure 1.3). The field is located on a north-south elongate structural high with several relatively long north-south normal faults. There are two localized structural highs cut by north-east to south-west faults in the south-eastern part of the field.

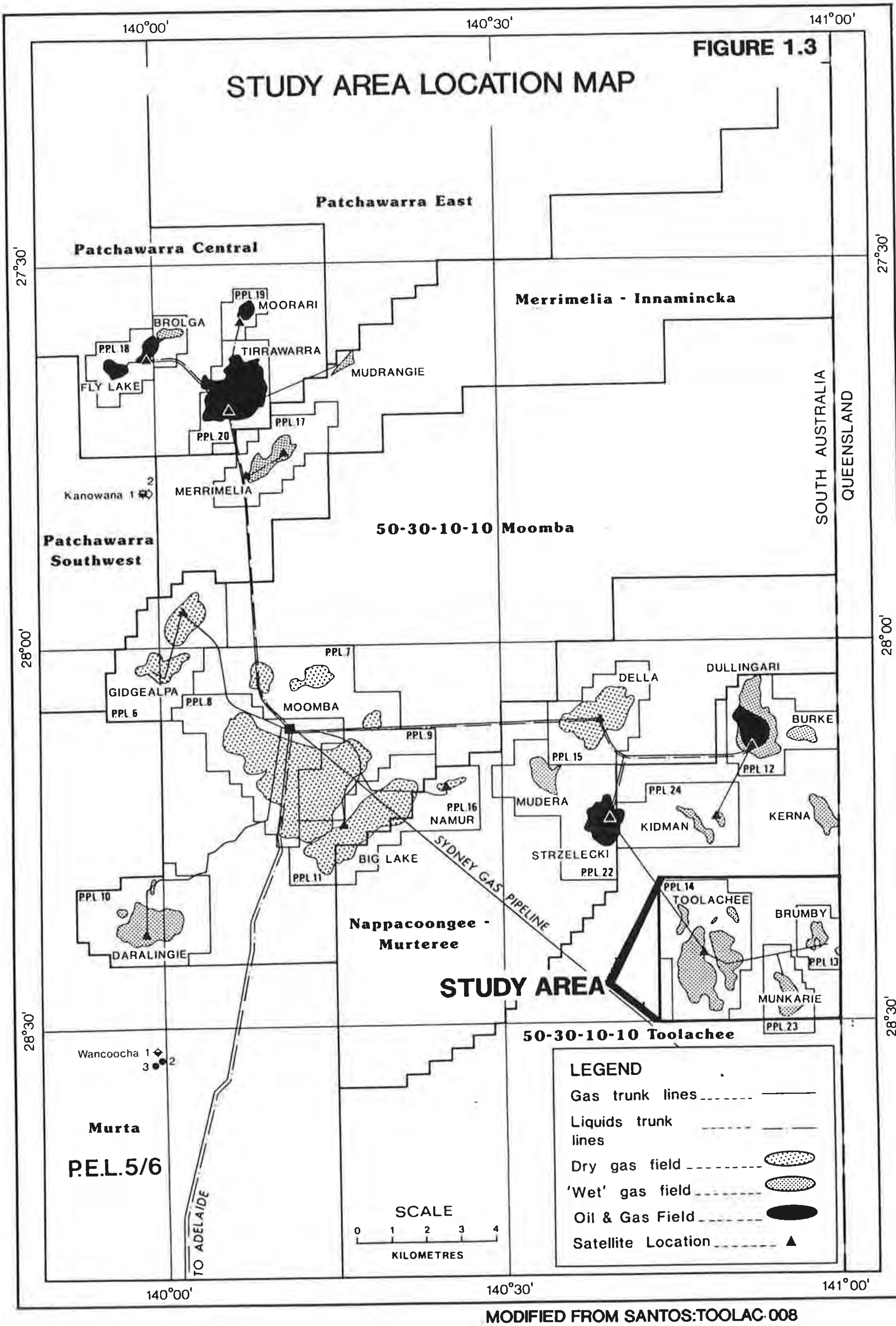


FIGURE 1.3

STUDY AREA LOCATION MAP

MODIFIED FROM SANTOS:TOOLAC 008

1.4 EXPLORATION HISTORY

The Toolachee 1 gas discovery well (Figure 1.4) was drilled by Delhi Petroleum in 1969. Since then, the Toolachee Trend structure has been extensively drilled with a total of forty wells drilled to date. The primary reservoir is in the Patchawarra Formation which produces gas with minor condensate. Some wells in the Toolachee Field also have gas production from the Epsilon Formation. Sandstone reservoir geometry of the sediments in the Toolachee Field was mapped by Devine and Gatehouse (1977).

The Brumby 1 gas discovery well was drilled by Delhi Petroleum in 1972 to test an anticlinal feature on a basement high. In 1988 Brumby 4, drilled by Santos Ltd., was cased and suspended as a Patchawarra gas/condensate well.

The Munkarie 1 gas discovery well was drilled by Delhi Petroleum in 1978 and, in 1984, Munkarie 4 was cased and suspended as a gas/condensate well from the Patchawarra Formation. Munkarie 6 was drilled in 1985 and was cased and suspended as an Epsilon/Patchawarra gas well.

Thornton (1979) produced regional paleogeography maps of the Gidgealpa Group within the Cooper Basin which included the Toolachee and Brumby Fields. Morton (1983) carried out a study into the geology and reserves of the Toolachee Field, producing isopach and paleogeography maps of the Toolachee and Toolachee East areas for the Patchawarra and Epsilon Formations. Crew (1985) investigated the stratigraphy and sedimentology of the Epsilon Formation in the Toolachee Field area with extensive logging of core from the Epsilon Formation in the Toolachee and Munkarie Fields. A study of the sedimentology and facies distribution of the Patchawarra Formation in the Cooper Basin was carried out by Faridi and Hunt (1987), during which isopach and paleogeography maps were produced for genetic associations identified within the Patchawarra Formation. This study included the Toolachee, Brumby and Munkarie Fields. Genetic associations of the Patchawarra Formation, which are identified by Faridi and Hunt (1987), are used in this thesis to produce isopach and total sand isopach maps. Smith (1987) reported on facies interpretation and genetic unit mapping of the Epsilon Formation in the Toolachee Field area and covered wells

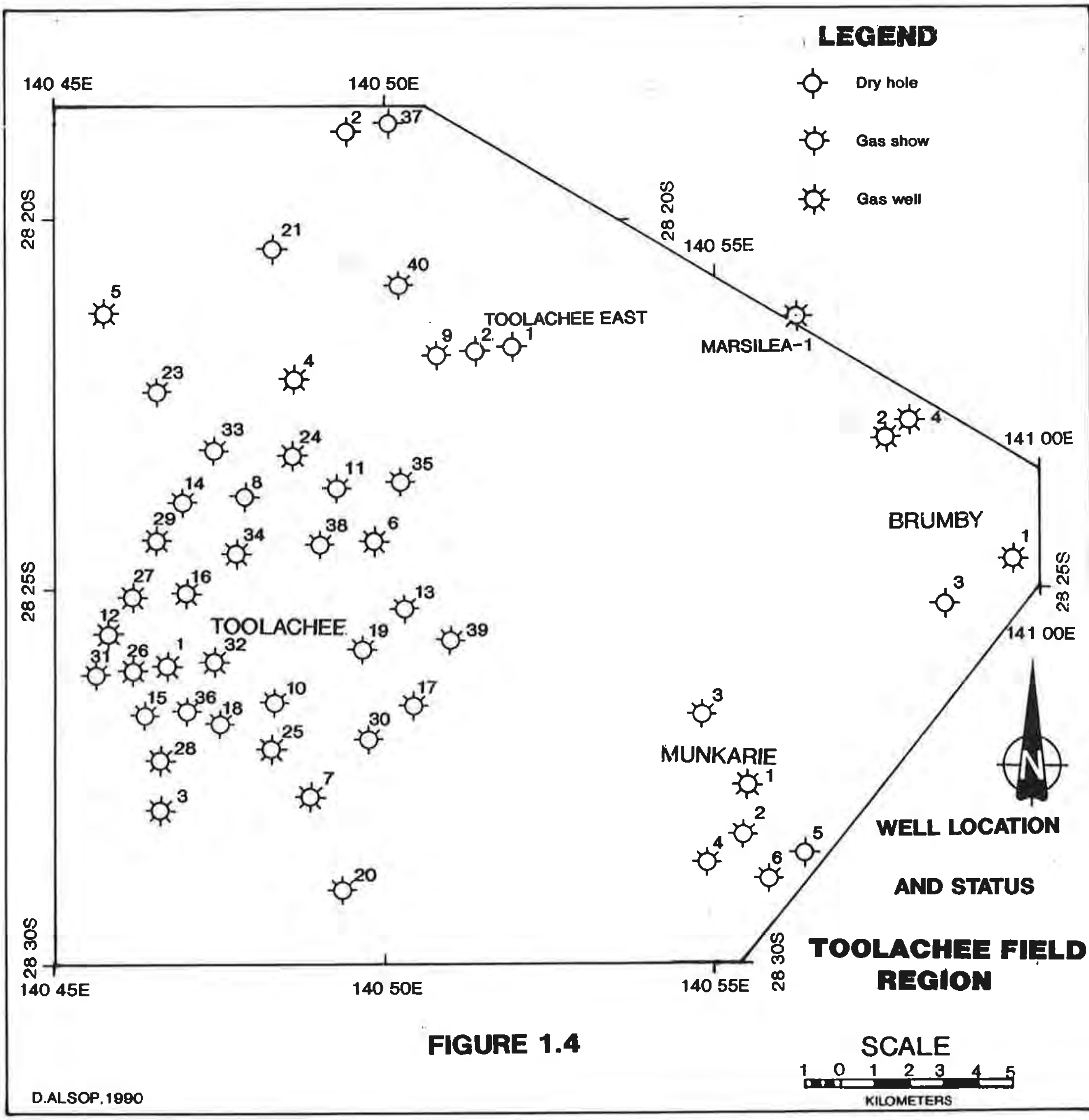

LEGEND
Dry hole
Gas show
Gas well
140 45E
140 50E
140 55E
141 00E
28 20S
28 25S
28 30S
TOOLACHEE EAST
MARSILEA-1
BRUMBY
TOOLACHEE
MUNKARIE
WELL LOCATION
AND STATUS
TOOLACHEE FIELD
REGION
SCALE
1 0 1 2 3 4 5
KILOMETERS
D.ALSOP, 1990

FIGURE 1.4

from Munkarie and Toolachee Fields. His genetic classification of the Epsilon Formation is used in this thesis for paleogeography and isopach mapping.

Grasso (1986) investigated the sedimentation history of the Brumby and Munkarie Fields using genetic sequences of strata. That study was used to construct paleogeographic maps for the Patchawarra Formation, the Epsilon Formation, the Daralingie Beds and the Toolachee Formation.

Martin (1984) conducted a petrological study of the Patchawarra 76-1 sand in Toolachee 19, using thin section analysis, X-ray diffraction and scanning electron microscopy to determine composition, diagenesis and reservoir quality within the Toolachee 19 well. This is the only previous study on diagenesis in the Toolachee Field.

CHAPTER 2 REGIONAL GEOLOGY

2.1 STRATIGRAPHY

The stratigraphic nomenclature used (Figure 2.1) is that introduced by Kapel (1966), formalised by Gatehouse (1972) and updated in O'Neil (1989). This groups the Cooper Basin sediments into nine formations which were deposited from the Late Carboniferous through to the Mid Triassic.

Economic basement in the Toolachee region is regarded as the pre-Permian metasediments of the Warburton Basin. These slightly metamorphosed sediments consist of dark grey, micromicaceous and pyritic metasiltstones, highly fractured shales, quartzite and interbedded phyllite (Toolachee 1 WCR, 1969, Brumby 3 WCR, 1984, Munkarie 5 WCR, 1985). The metasediments are often steeply dipping (Toolachee 1 WCR, 1969).

The Merrimelia Formation, of Late Carboniferous to Early Permian age, unconformably overlies the sediments of the Warburton Basin and consists of glacigenic and paraglacial sequences of tillites, fluvioglacial, glaciolacustrine and glacial-aeolian sediments (Williams et al, 1985). This formation is relatively thin (maximum known thickness:30m (100ft)) in the Toolachee region and generally onlaps the structural highs, from which it is absent (Williams et al, 1985).

The Tirrawarra Sandstone of Early Permian age is absent throughout the Toolachee, Brumby and Munkarie Fields. Elsewhere it consists of fine to medium-grained fluviatile sandstones, thought to disconformably overlie the Merrimelia Formation (Battersby 1976). This formation is generally restricted to the south to south-western parts of the Cooper Basin and in particular to those areas of thick sedimentation such as the Gidgealpa-Merrimelia-Innamincka (GMI) and Murteree Anticlinal Trends (Thornton 1979). Well data have shown that no anticlines were present in the area of these trends during the deposition of the Tirrawarra Formation and that they may have been areas of maximum sedimentation (ibid). The Tirrawarra Sandstone is almost entirely comprised of quartz sandstones, with only very minor intercalations of shale and coal (Thornton 1979). The sandstone has been interpreted by Thornton (1979) as having been deposited in a braided stream environment, however Gostin (1973) has indicated

STRATIGRAPHIC NOMENCLATURE - **SOUTH AUSTRALIA**

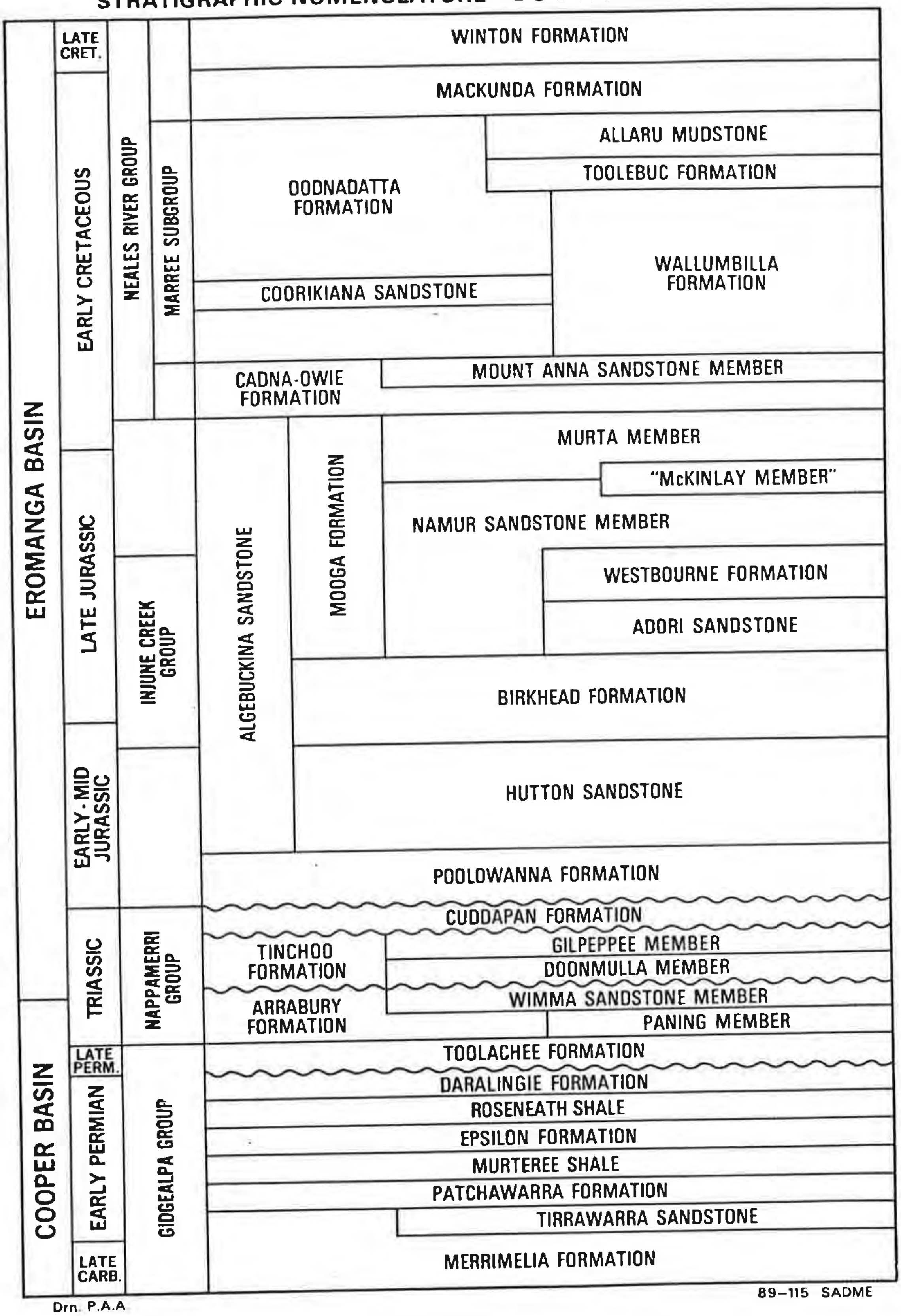


FIGURE 2.1

From O'NEIL (1989)

a gradation from braided to meandering fluvial systems based on lithologic interpretation from cores.

The Early Permian Patchawarra Formation unconformably overlies the Merrimelia Formation in the Toolachee region (Devine and Gatehouse 1977). The sequence consists of fluvial sandstones, siltstones, shales and coals which were deposited in channels, point bars, crevasse splays, overbank and backswamp environments of a meandering fluvial system. The energy of the fluvial environment generally decreases towards the top of the formation. The sandstones are generally fine to coarse-grained sublitharenites, interspersed by siltstones, shales and coals.

The Murteree Shale represents a thick non-marine lacustrine environment, conformably overlying the Patchawarra Formation (Thornton 1979) consisting of buff to light grey siltstone. The Murteree Shale is interpreted by Thornton (1979) as being deposited in a permanent body of water fed by sediments from an onshore deltaic alluvial plain. This lake, assumed to have advanced from the east, deposited a uniform suite of shales with minor amounts of interbedded siltstones and fine-grained sandstones. The thickest section of the Murteree Shale (88m) occurs in the Toolachee East 1 area (ibid). The lake marks the maximum extent of the lacustrine transgression which interfaced with the top of the Patchawarra Formation (ibid) on a very subdued topography. Stuart (1976) has suggested that the shale was deposited in an open basin with restricted access to the sea, justified by its regional relationship with facies within the basin.

The Epsilon Formation conformably overlies the Murteree Shale and, in turn, is overlain by the Roseneath Shale (Thornton 1979). The stratigraphic distribution of beds comprising these formations represent a lacustrine/marine retreat followed by a lacustrine/marine advance. Deltaic deposition of the lower part of the Epsilon Formation followed the easterly retreat of the Murteree Lake and hence the eastern part was the last to be exposed and the first to be inundated again with the onset of the next lacustrine/marine advance (ibid). The Epsilon Formation consists mainly of siltstone to fine sandstones with minor coarser-grained sandstone and coal, deposited in a fluvio-lacustrine to fluvio-deltaic environment (Smith 1987).

The Roseneath Shale which conformably overlies the Epsilon Formation is a lacustrine sequence similar to the Murteree Shale with a thick sequence of dark grey carbonaceous siltstone and minor sandstone. It has a local maximum thickness of 88m at Toolachee East (Thornton 1979). The shale was deposited in one large lake which transgressed from the east and was either a large inland body of fresh water or had restricted access to the sea (ibid).

Conformably overlying the Roseneath Shale is the Daralingie Formation which consists of interbedded shales, siltstones, sandstones and coal development associated with backswamp areas. The top of the Daralingie Formation is considered an erosional surface. The Daralingie beds are interpreted as a regressive succession laid down by two delta systems encroaching from the south into the retreating Roseneath Lake (ibid). The base of the Daralingie Formation is a lithologic time marker based on a thin band of siltstones and coals (Thornton 1979). The basal contact and the effects of erosion on the top contact are shown well in the Toolachee 1,3 and 7 wells, with erosion removing an unknown thickness of Daralingie Formation, especially from the tops of anticlines (Thornton 1979). The unit is generally very thin except in the deeper parts of the Nappamerri Trough.

The Toolachee Formation consists of a thick sequence of interbedded siltstones, sandstones and coals which unconformably overlie the Daralingie Formation. This formation is similar to the Patchawarra Formation, but has better developed coals and more poorly developed sandstones. These sequences represent deposits of fluviatile, point bar, overbank, and back swamp origin. In the Toolachee region, lithofacies boundaries parallel the major north south fault, with Toolachee East 1, on the downthrown side of the fault. Toolachee East 1 penetrated a thicker sedimentary sequence than any other Toolachee Field well (Thornton 1979). Thornton (1979) has interpreted a downwarp across the fault which affected the major facies distribution.

The Nappamerri Group consists of sandstone, siltstone, and shale deposited in fluvial lacustrine conditions during the Early to Mid Triassic. They are distinct from the Gidgealpa Group because they are redbeds. Powis (1989) has divided the Triassic sequence into three main units; the Early Triassic Arrabury Formation, the Middle Triassic Tinchoo Formation and the Late Triassic Cuddapan Formation. In this classification the Arrabury and Tinchoo and Cuddapan Formations are contained within the Nappamerri Group. This subdivision of the Triassic was done only in the northern part of the basin and will not be discussed further here.

2.2 STRUCTURE

The Cooper Basin is a north-east/south-west trending intracratonic basin which was initiated by epeirogenic downwarping of the craton in the late Carboniferous to Early Permian (Battersby 1976). However, Kuang (1985) has suggested that reactivation of major south-west to north-east striking thrust faults of the underlying Warburton Basin caused the development of the Cooper Basin.

The main structural elements of the southern Cooper Basin (Figure 2.2) are the Tennapera, Nappamerri and Patchawarra Troughs, which are separated by the Toolachee, Nappacoongee-Murteree and Gidgealpa-Merrimelia-Innamincka structural highs. The troughs are the major depocentres of sediment in the basin with onlap onto adjacent highs. Structural highs are predominantly controlled by normal faults as well as some wrench-related reverse faults (ibid).

The main sequence of events affecting the Permo-Triassic Cooper Basin sedimentation were;

1) Epeirogenic downwarping in the Late Carboniferous to Early Permian.

2) Permian Deposition with contemporaneous faulting along major pre-Permian structural trends.

3) Downcutting of Daralingie unconformity in Late Permian.

The Toolachee Trend is a north-south oriented structural complex (Figure 2.3) controlled by a horst structure (Figure 2.4) with north-south flanking faults. The Toolachee Trend is composed of two northerly striking, block faulted anticlines with several northerly

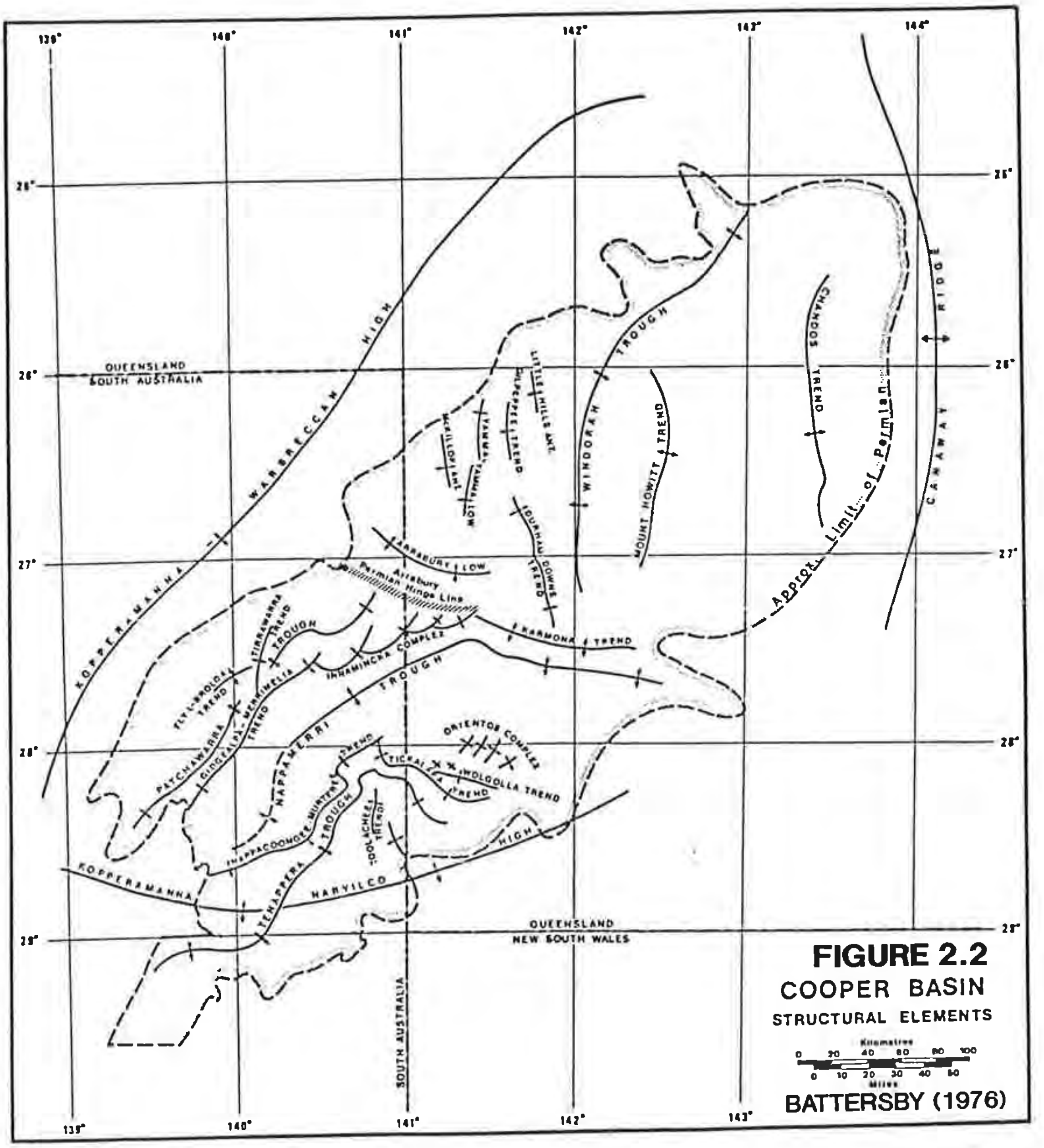


FIGURE 2.2
COOPER BASIN
STRUCTURAL ELEMENTS

BATTERSBY (1976)

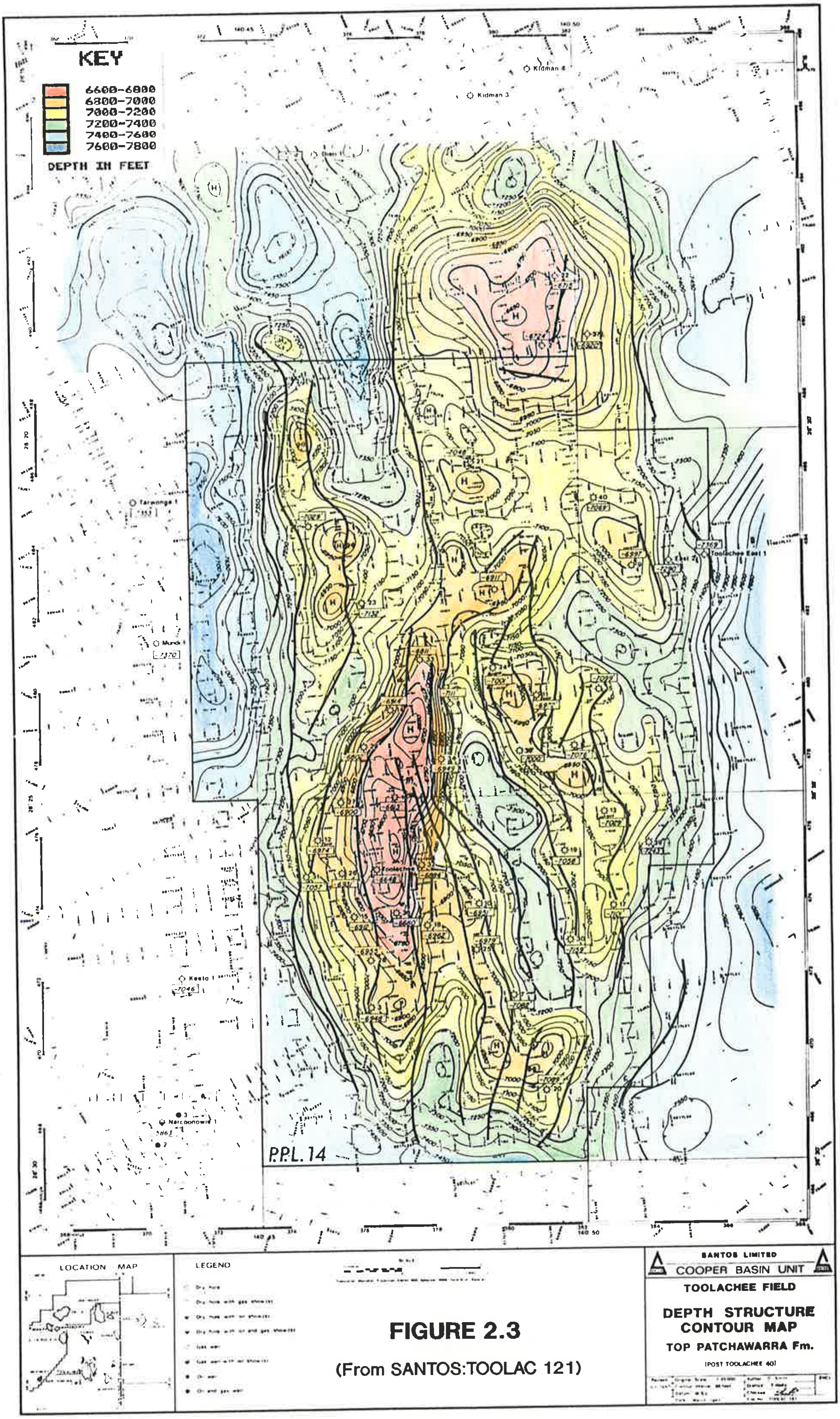
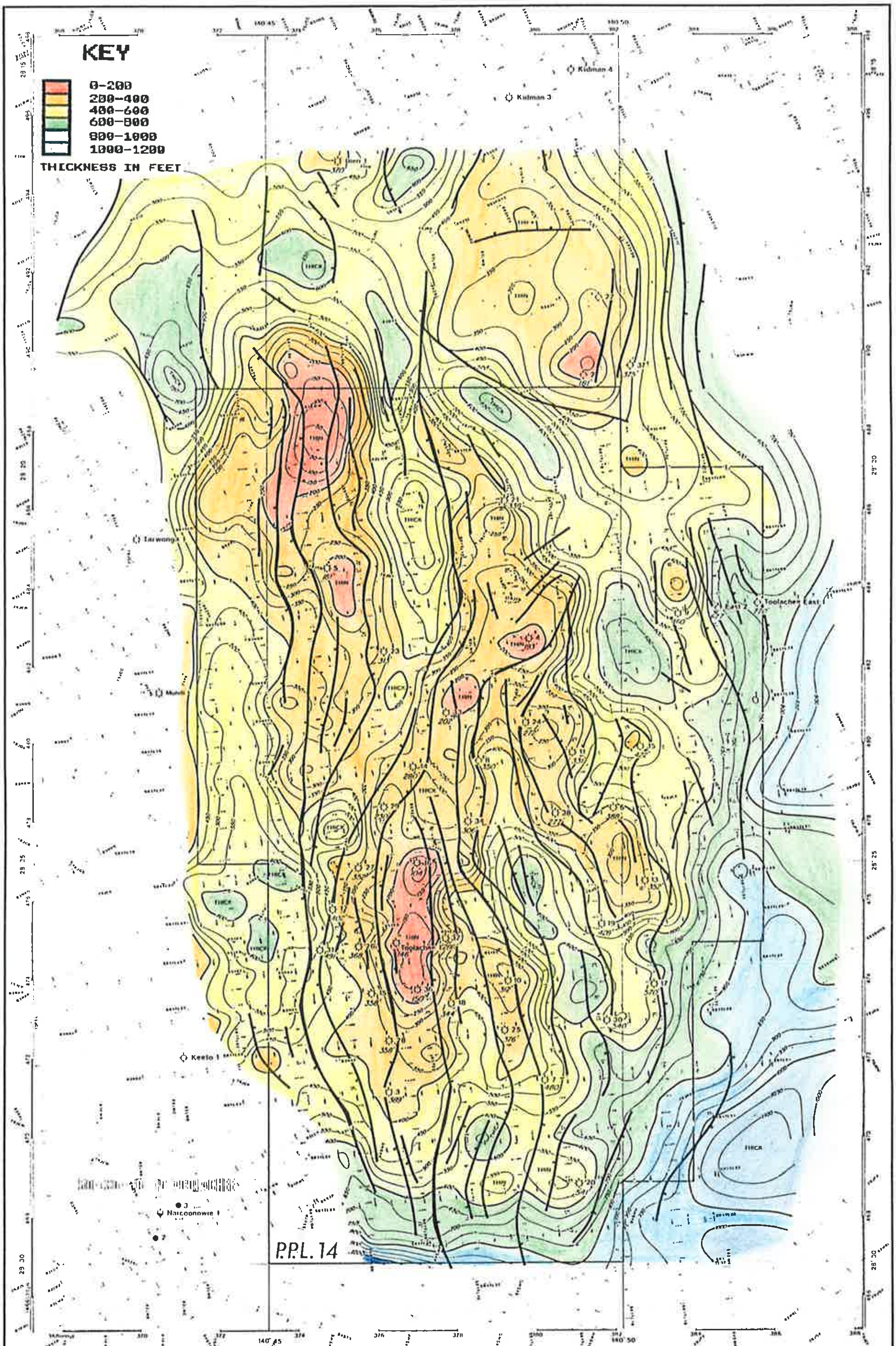
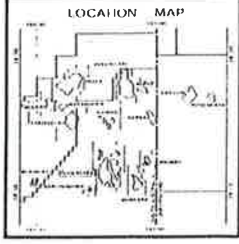


FIGURE 2.3

(From SANTOS:TOOLAC 121)





LEGEND

- Dry hole
- Dry hole with gas show(s)
- Dry hole with oil show(s)
- Dry hole with oil and gas show(s)
- Gas well
- Gas well with oil show(s)
- Oil well
- Oil and gas well

FIGURE 2.4

(From SANTOS:TOOLAC 120)

SANTOS LIMITED

COOPER BASIN UNIT

TOOLACHEE FIELD

ISOPACH MAP

BASE PATCHAWARRA Fm.

outlying anticlines. The north-south trend of anticlinal folds is in contradiction with the north-east fold trend more common in the basin (Stuart 1976). Stuart (1976) has recognised that the major faults separating the Toolachee area from the Epsilon area may have formed the boundaries of a stress-couple system or may be related to ancient structural patterns. Numerous faults within the Toolachee Trend and basement horst provide structural control for Early Permian sedimentation. Faults were active during the Early Permian but had mostly ceased to move by the time the upper Patchawarra Formation was being deposited (Devine and Gatehouse 1977). Minor post Patchawarra Formation faulting occurred, with some faulting lasting through to the Epsilon Formation (Figure 2.5). The Toolachee Formation shows no evidence of faulting (Figure 2.6). During Mesozoic times the sediments were draped over these pre-existing structures.

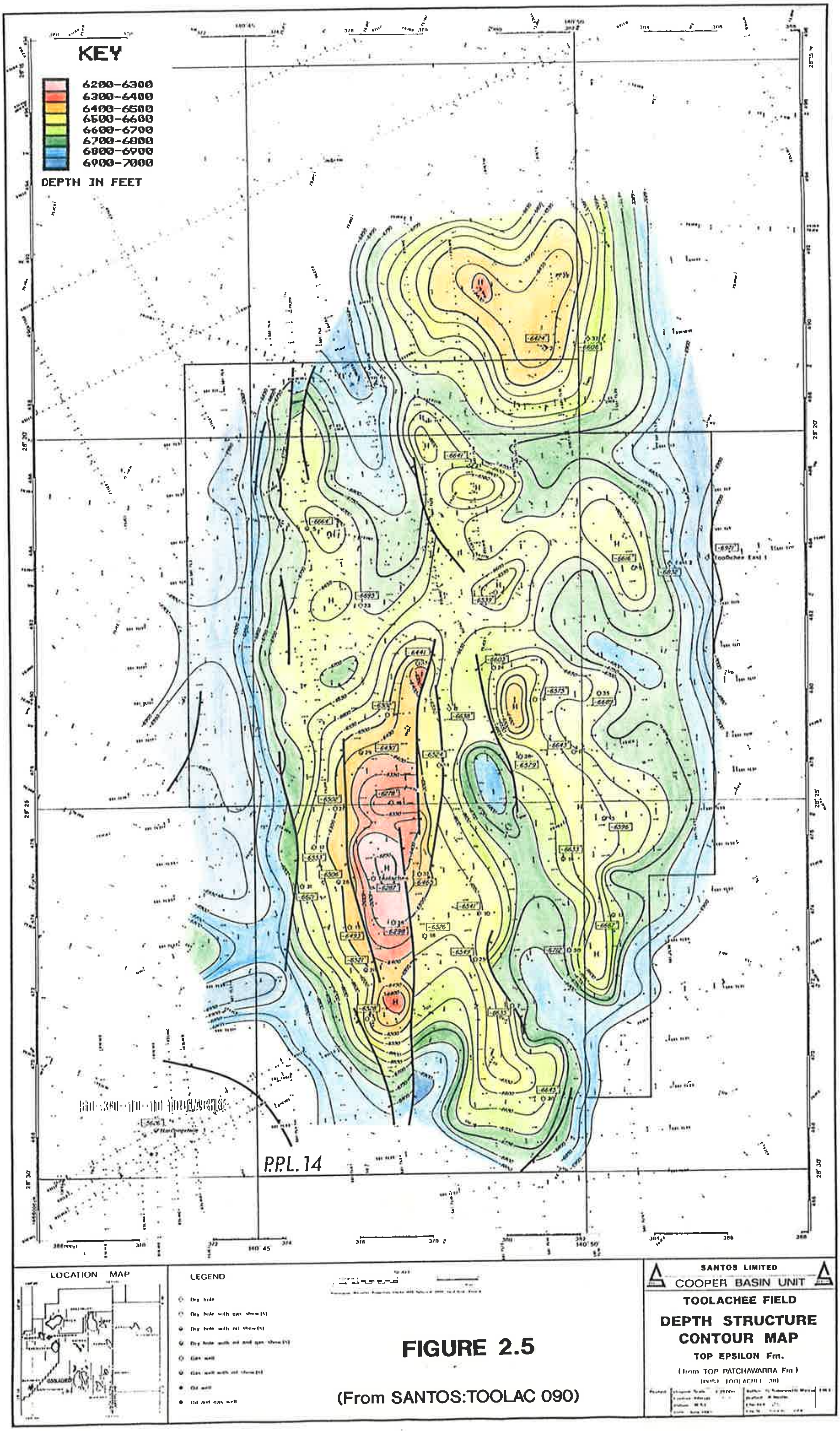
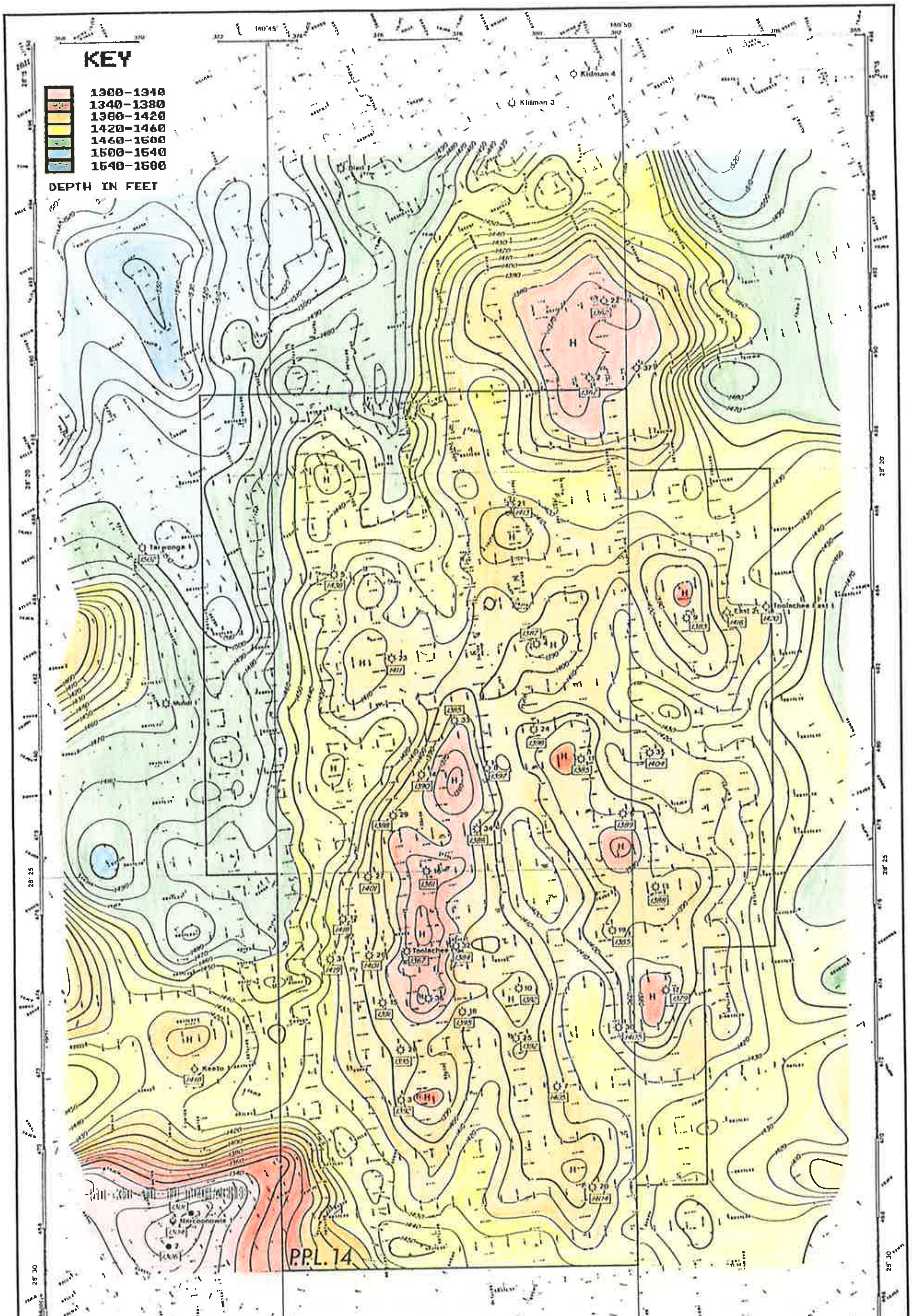
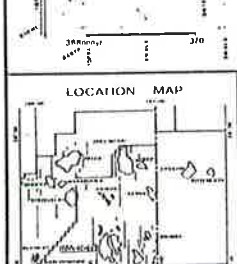


FIGURE 2.5

(From SANTOS:TOOLAC 090)





LEGEND

- Dry hole
- Dry hole with gas show(s)
- Dry hole with oil show(s)
- Dry hole with oil and gas show(s)
- Gas well
- Gas well with oil show(s)
- Oil well
- Oil and gas well

FIGURE 2.6

(From SANTOS:TOOLAC 112)

SANTOS LIMITED

COOPER BASIN UNIT

TOOLACHEE FIELD

TIME STRUCTURE CONTOUR MAP

TOP TOOLACHEE Fm.

(POST TOOLACHEE 35)

CHAPTER 3 METHODS

3.1 INTRODUCTION

The information available for this study was in the form of core and cuttings samples, wireline logs-usually a suite including Gamma Ray (GR), Self Potential (SP), Resistivity, Sonic, and seismic profiles. The full hole cores provided the best information for both sedimentological and diagenetic studies. Plugs cut from the core provided the basis for physical measurements of porosity and permeability. Details of all methods are available in Appendices.

3.2 FULL HOLE CORES

A total of 395m (1296 ft) of slabbed conventional core from the Patchawarra Formation was logged and sampled from 15 wells in the Toolachee Field, as well as 7.62m (25 ft) from one well in the Toolachee Formation. Patchawarra Formation core was also logged in Munkarie (14.6m, 48ft) and Brumby (46.3m, 152ft) Fields. Although samples (Epsilon Formation) taken from wells in the area have been logged by Smith (1987), additional core (66.8m, 219 ft) from 3 wells was sampled in this formation. Cores were logged to identify lithological characteristics and sedimentary facies and samples were taken for Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), core plug and thin section analysis. Appendix 1 contains the details of the logged core. From the detailed analysis of these cores, depositional environments were established for the samples taken and tied to the environments interpreted from gamma-ray logs.

3.3 CORE PLUGS

Core plugs have been taken from four cores and analysed by the Petroleum Services section of AMDEL Limited to determine porosity, permeability, bulk dry density and absolute grain density (Table 1). Samples were collected from sections of slabbed core in the zones of interest and were placed in a soxhlet extraction apparatus with a 3:1 chloroform/methanol solution to remove any residual hydrocarbons and salts. Porosity was determined using Boyles Law helium injection technique with mercury immersion to calculate the bulk volume. Permeability to air was determined by loading the sample into a Hassler cell and applying a confining pressure of 1750 kPa. The differential air pressure was then measured using a straight tube manometer. Additional porosity and permeability measurements from core plug analysis of the same form as described above were provided by Santos Ltd.

3.4 THIN SECTION ANALYSIS

3.41 PETROGRAPHY

Thin sections made from both core and cuttings were examined using an Olympus CN petrographic microscope. Porosity, grain size, mineralogy, textures, cements, dissolution features and other effects of diagenesis were observed. During thin section preparation, the araldite was stained with a blue dye to show porosity and five samples obtained from SAGASCO Resources Ltd were stained with alizaran red to show carbonate. Photomicrographs were taken of thin sections using a Zeiss Photo Microscope 3 with 100 ASA slide and print film. Thin section details are given in Appendix 2, with the results reviewed in the diagenesis and porosity sections.

3.42 CATHODOLUMINESCENCE

The cathodoluminescence microscope was used to differentiate between original detrital quartz grains and quartz cement. The Technosyn Cold Cathode Luminescence Microscope Model 8200 Mk 2 was used with a Leitz Orthomat E camera. Photomicrographs were taken of 20 polished thin sections using plane and luminescent light on 1600 ASA slide film and 1600 ASA Ektapress PPC print film at a respirosity setting of 4 at correction factor of D80. Currents were kept between 250-300 with kilovolt (kV) values between 15-20kV. General views were taken of each slide using the 4* lens and 8* zoom. Some slides were then photographed at higher magnifications for detailed work at up to 4* lens with a 12.5* zoom. Photographs at higher magnifications than 4* lens with a 12.5* zoom were not possible because of the poor focusing ability of the higher powered lenses in this set-up.

3.5 SCANNING ELECTRON MICROSCOPY

The Scanning Electron Microscope (SEM) allows a sample of rock to be viewed at high magnification with high resolution. This microscope was used to examine pore and grain relationships, mineralogy of cements and clays and how they affect pore spaces. The attached Energy Dispersive System (EDS) was used to determine mineralogy and produce an X-Ray energy spectrum of the mineral being identified.

A Phillips 505 Scanning Electron Microscope was used to examine all samples with photographs taken of each. The samples were mounted on stubs using araldite and coated with a gold/paladium mixture. The operating conditions used were 20 kv with a spot size of 20 or 50, depending on the required enlargement, which ranged from tens to thousands of times magnification. Photography parameters used were contrast -1 and brightness +5. A Tracer-Northern (TN5500) EDS system acquired a ray spectrum between 0-20 kv for 30 seconds.

3.6 X-RAY DIFFRACTION (XRD)

Rock samples were crushed using a tungsten carbide mill and set into a powder press as a bulk sample. A Phillips 1050 X-Ray Diffractometer with a cobalt tube was then used to scan the samples between 3 to 75 degrees, two theta using a one degree divergence slit and a half degree receiving slit. The results were recorded onto computer using the SIE 112 program and then interpreted using a JCPDS program supplied by the CSIRO, (X-Plot).

XRD is used to determine the mineralogy of a rock sample and is particularly useful for determination of clay mineralogy and the presence and type of carbonate. A ratio of illite to kaolin was determined by measuring the peak heights of illite and kaolin on the XRD graphs and then using the formula 2I/K=ratio. This ratio has been crossplotted with various parameters such as grain size, percentage mineral, and porosity to find trends.

3.7 WIRELINE LOGS

Gamma Ray and Sonic logs were used to correlate between wells and for determination of facies relationships.

A sandstone cutoff value on the gamma ray log of 100 API was generally used as this, in most cases, coincided with the mid-point between high and low gamma readings. Coals were distinguished on the basis of a velocity peak on the sonic log relative to that produced by sandstones and shales. A velocity cutoff of one hundred microseconds per foot was commonly employed.

Additional information was gained from the caliper log, which was used to check for cavities. The resistivity logs were used to determine hydrocarbon bearing zones and water saturations.

3.8 DATA HANDLING

The data used for this thesis were entered into a data base, Dbase 3 Plus, on an IBM compatible computer, using files constructed by B.Farrow (NCPGG). The files containing available data are: a well data file, a core analysis file, an XRD file, an SEM file, a thin section file, and a geological log file. These files were constructed for samples on a well by well basis.

Graphs were made using a "Lotus 123" spreadsheet program and diagrams were drawn using "Microsoft Paintbrush". The thesis was typed using "Microsoft Word".

CHAPTER 4 ENVIRONMENTAL ANALYSIS

4.1 FACIES ANALYSIS

A facies is described by Reading (1978) as "a body of rock with specified characteristics defined on the basis of colour, bedding, composition, texture, fossils and sedimentary structures". A facies should also be a distinctive body of rock that forms under certain conditions of sedimentation, reflecting a particular process or environment. Lithofacies codes, as used by Miall (1978) were applied to the core descriptions. Details of each code are described below.

Gravels

Gravel facies comprise intraformational or channel lag deposits formed by traction load in upper flow regimes. Facies **Gms (matrix supported gravel)** and **Gm (massive or crudely bedded gravel)** are patchy and generally less than 10 cm thick. Some imbrication of the gravel size particles is observed in Gm type gravels indicating crude bedding whereas Gms gravel deposits sometimes have intraformational, framework size clasts of silt typical of bank collapse material that indicates lateral and basal stream reworking. Most gravel intervals that were logged are Gms.

Sandstones

The most common sand lithofacies are **Sx (crossbedded sandstone)** and Sr **(ripple laminated sandstone)** and are commonly identified together.

Sp-Planar cross bedding

Fine to coarse-grained sandstone with planar cross beds are indicative of linguoid bars, transverse bars and sand waves of the lower flow regime (Williams et al, 1984). Pebbles occasionally occur in this facies and sorting ranges from poor to moderate. Crossbeds have a slope of less than 10 degrees and may contain some grain imbrication. These fine to coarse-grained sands were deposited in a fluvial channel as the channel migrated laterally.

St-Trough cross bedding

Trough crossbeds are the result of migrating dunes under lower flow regime conditions in a fluvial channel (ibid). These crossbeds result from the deposition of fine to coarse-grained sediments in a laterally migrating fluvial channel. A Low length/height ratio of laminae (Walker 1984) characterises trough crossbeds, as well as curved discontinuous surfaces between beds which can occasionally be seen in core.

Sx-Crossbedding (type unknown)

Because of the limited field view in core, and the large scale of these features, a distinction cannot always be made between planar and trough types, as described above. Crossbeds are a common feature in the cores, most of which have straight slopes that continue up the sand units at a uniform angle. The consistency of angle and the planar nature of the beds suggest planar crossbedding. However, the slope angles are often about 15-20 degrees which indicate trough crossbedding. The angle in some cases may apparently reverse in direction. It can be assessed that these features came from a gently meandering fluvial channel of moderately high energy. The bases are sometimes scoured and have a pebbly channel lag. The crossbeds are preserved during the migration of the point bar.

Sm-Massive sandstone

Owing to either fluid escape or bioturbation (ibid), these sandstones lack internal sedimentary features. The lack of internal structure may occur in fine to coarse-grained sediments but is most common in the medium grain size clastics.

Sr-Ripple cross laminations

Ripple cross lamination is the most common lithofacies and is the product of a lower energy regime in the upper portions of a point bar or a crevasse splay deposit (Williams 1984). These sands are generally very fine to fine grained, and often contain carbonaceous specks, mud clasts, and flaser bedding. Sorting is generally moderate to good; bedding is sometimes disturbed because of burrowing organisms and therefore can be associated with facies Sb.

Sb-Bioturbated sands

Bioturbation by burrowing organisms is relatively common in very fine to fine-grained sands and tends to disrupt bedding laminae. Rootlets have also been seen but these are rare. Both types of bioturbation are often associated with coaly organic clasts. This facies occurs in crevasse splay deposits and proximal overbank deposits where burrowing organisms can rework the sands during periods of non-deposition (Williams 1984).

Sd-Soft sediment deformation

Soft sediment deformation occurs in fine to very fine-grained sands as disrupted bedding and microfaults. This deformation may be the result of slumping, mass movement of sediments, subsidence due to compaction and/or fluid escape from the sediments. Deformation mostly occurs in flood basin to lacustrine deposits and/or is associated with compactional subsidence in prodelta muds (Walker 1984). These sediments have been destratified and are usually well to moderately sorted.

Sw/Fw-Interlaminated sands & muds (rippled)

Interlamination of wave rippled sands and silts with abundant flaser bedding is common in very fine grained sediments. The sediments may have been deposited during periods of overbank flooding with the silts being deposited during the final stages of the flood (Williams 1984). This facies often occurs between rippled sands and muddy facies.

<u>Mudstones</u>

Fl-Flat, finely laminated mudstone

Flat, finely laminated mudstone is common and consists of sands, silts and muds deposited as overbank deposits during the waning stages of a flood (ibid). The sediments contain very small ripples and may be associated with facies Fb. The Fl facies generally occurs with the Sw/Fw facies which contains a higher proportion of sand and the Fsc facies.

Fsc-Laminated to massive mudstone.

These laminated to massive silts and clays were deposited on a flood plain during the waning stages of floods and are often thick (ibid). Such sediments contain a much higher proportion of clays and silts than the Sw/Fw and Fl facies and do not contain any crossbedding. They generally overlie facies Fl and may be overlain by facies C.

Fb (bioturbated mudstone) and **Fd (soft sediment deformed mudstone)** are the fine grained lithofacies equivalents of Sb and Sd.

C-Coal

Coal consists of plant remains and carbonaceous material which have undergone coalification. The deposits are representative of flood basin swamps and oxbow lakes where the preservation of organic matter occurs (Walker 1984). In reflected light the coals can be seen to be composed mostly of inertinite with varying amounts of liptinite.

4.2 GENETIC INCREMENTS OF STRATA

A Genetic Increment of Strata (GIS) is useful for correlating discontinuous strata and has been defined by Busch (1974) as "an interval of strata representing one cycle of sedimentation in which each lithologic component is related genetically to all others; the upper boundary must be a lithologic time marker and the lower boundary may be either a lithologic time marker or an unconformity". One or several GIS units bounded by these lithologic time markers represent an association (Faridi and Hunt 1987).

Good lithologic time markers are laterally consistent coal seams or discontinuous facies change sequences. These represent the stagnant stage of overbank and flood basin sedimentation which is relatively continuous across the basin and can often be traced from well to well using wireline log signatures.

The Patchawarra Formation has been divided into five associations (ibid) which are numbered in increasing order from the base of the Patchawarra. In this report the Patchawarra Associations are referred to here as P1-P5 (Figure 4.1). Of the five associations present in the Toolachee Field area, only the top four are hydrocarbon bearing. Three vertical facies profiles were recognized by Faridi and Hunt (1987):

1)aggradational fining upward

2)progradational coarsening upward

3)thick coarsening-upward sequences combined with discontinuous fining-upward units, or uniform units consisting of carbonaceous shale and siltstone with pulses of sandstone.

Three main depositional environments were interpreted by Faridi and Hunt (1987):

1)fluvial channel sandstones, overlain by overbank or swamp deposits (fining-upward sequences)

2)prograding crevasse splay, shoreline and deltaic sandstones adjacent to channel systems (coarsening- upwards sequences)

3)flood basin/lacustrine sediments (combined coarsening-upward and minor fining upward units).

Smith (1987) has distinguished four genetic sequences in the Epsilon Formation using coal and lake marker beds that are labelled E1 to E4, with E1, the thickest unit at the base. The fluvio-deltaic nature of the Epsilon Formation has led to the distinction of four depositional environments:

1)distributary channels (fining upward)

2)distributary mouth bars reworked by wave action (fining upward)

3)shoreline sands (coarsening upward)

4)prodelta deposits with lacustrine muds (coarsening upward).

This report divides the Toolachee Formation into seven associations (T1-T7) numbered from the oldest at the bottom to the youngest at the top. The formation was divided into associations using laterally continuous coal and lake marker beds, with the five bottom units (T1-T5) corresponding to unit C, and T6-T7 corresponding to unit B of Stuart (1976) (Figure 4.2). Three main environments of deposition were identified using gamma ray and sonic logs:

1)fluvial channel sequences overlain by overbank and coal deposits (upwards fining);

2)flood plain and lacustrine (combined coarsening-upward and minor fining upwards units);

3)prograding shales and siltstones capped by shoreline or deltaic sandstones (coarsening upwards).

Maps of total sand isopach, facies, percentage channel deposits, percentage shoreline deposits, percentage deltaic deposits and paleogeography were produced.

Note: Brumby and Munkarie not mentioned due to lack of data from Smith (1987).

4.3 PALAEOGEOGRAPHY

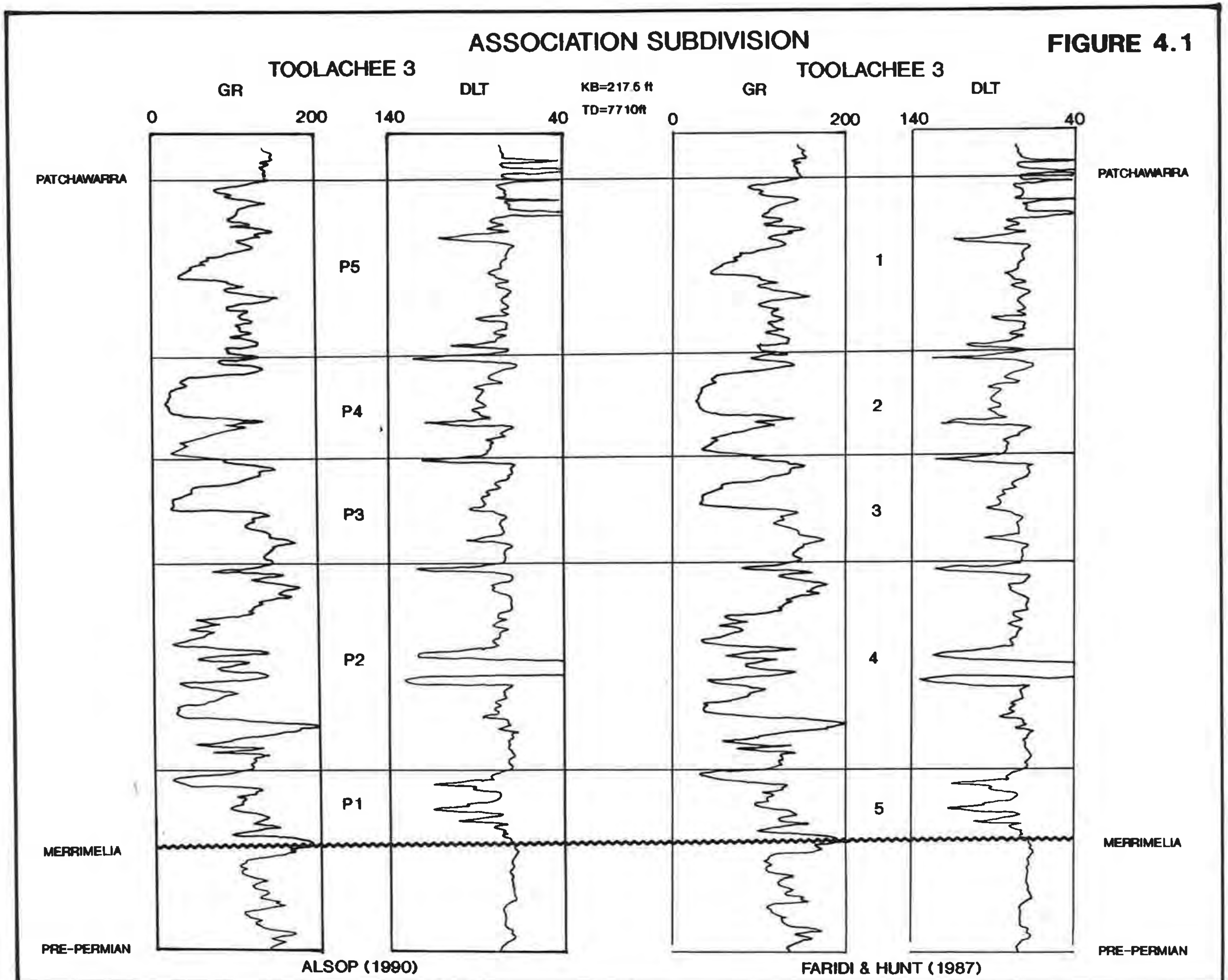
Reconstruction of paleogeography is achieved using GIS units. These paleogeography maps show the types of depositional environments acting in an area during a specific time interval that is bounded by time marker horizons. The GIS units used are those discussed in the previous section and are similar to those generated by Faridi and Hunt (1987) (Figure 4.1).

Association P1

Paleogeography description of the Patchawarra Formation starts with Association P1 which marks the onset of fluvial channel sedimentation (Faridi and Hunt 1987) in the eastern, southern and south-western sectors of the Toolachee field. At this time, a central paleohigh extended from north of the field to as far south as Toolachee 18 (Figures 4.3 & 4.4). This paleohigh was then surrounded by coal swamps which merged further out into flood basin and channel deposits. A paleohigh also existed in the Munkarie 2 region. A river flowed from south to north between the Toolachee and Munkarie paleohighs which later switched to the western side of the field during the upper part of the association. Sedimentation was controlled by the reactivation of major faults such as the Munkarie-Narcoonowie and Kidman Faults (Faridi and Hunt 1987). The paleohigh was reduced in height due to subsidence, erosion and onlap during Association P1. Channel deposits were best preserved in the east of Munkarie Field.

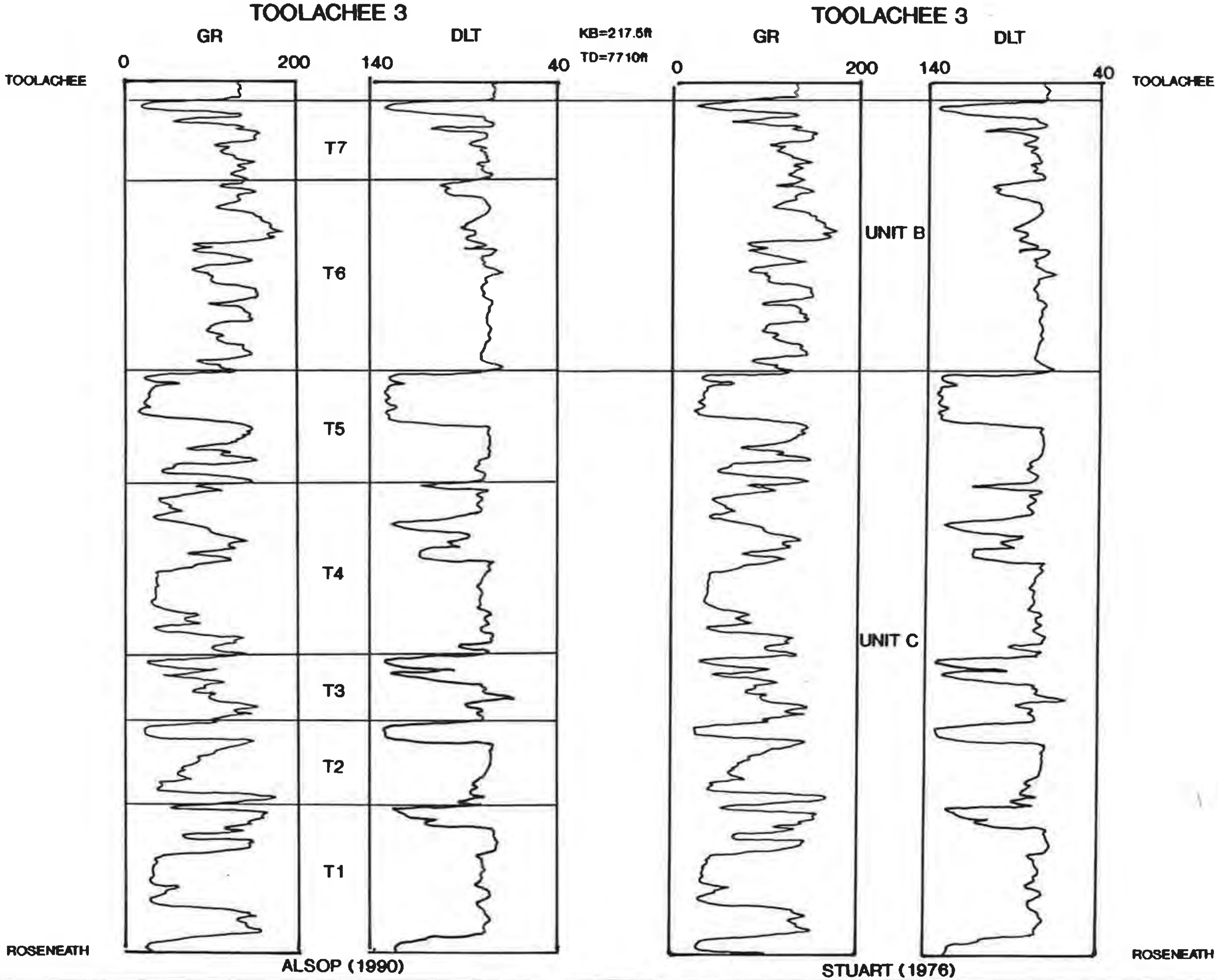
Association P2

In Association P2 (Figures 4.5 & 4.6), the exposed area of the Toolachee paleohigh has been further reduced during the deposition of fluvial sediments. The Toolachee-Kidman Channel meander belt extended from the central eastern part of the Toolachee Field to east of Brumby Field. On the western side of the Toolachee Field, there was a fluvial channel that swung around from the north to north-west and has been named the Kapinka Channel (Faridi and Hunt 1987). The central western portion of the Toolachee Field is a narrow paleohigh surrounded by overbank deposits.


ASSOCIATION SUBDIVISION
FIGURE 4.1
TOOLACHEE 3
GR
DLT
KB=217.5 ft
TD=7710ft
0
200
140
40
PATCHAWARRA
P5
P4
P3
P2
P1
MERRIMELIA
PRE-PERMIAN
ALSOP (1990)
TOOLACHEE 3
GR
DLT
1
2
3
4
5
FARIDI & HUNT (1987)

ASSOCIATION SUBDIVISION

FIGURE 4.2



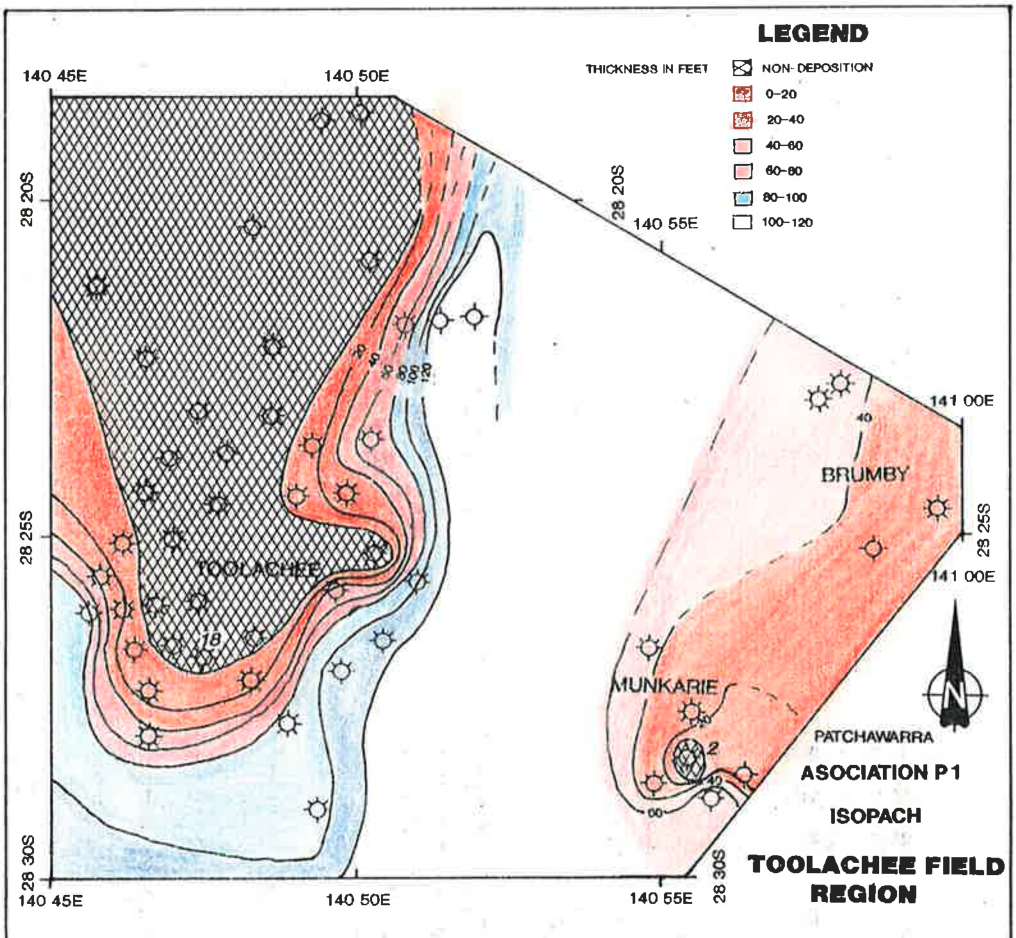


FIGURE 4.3

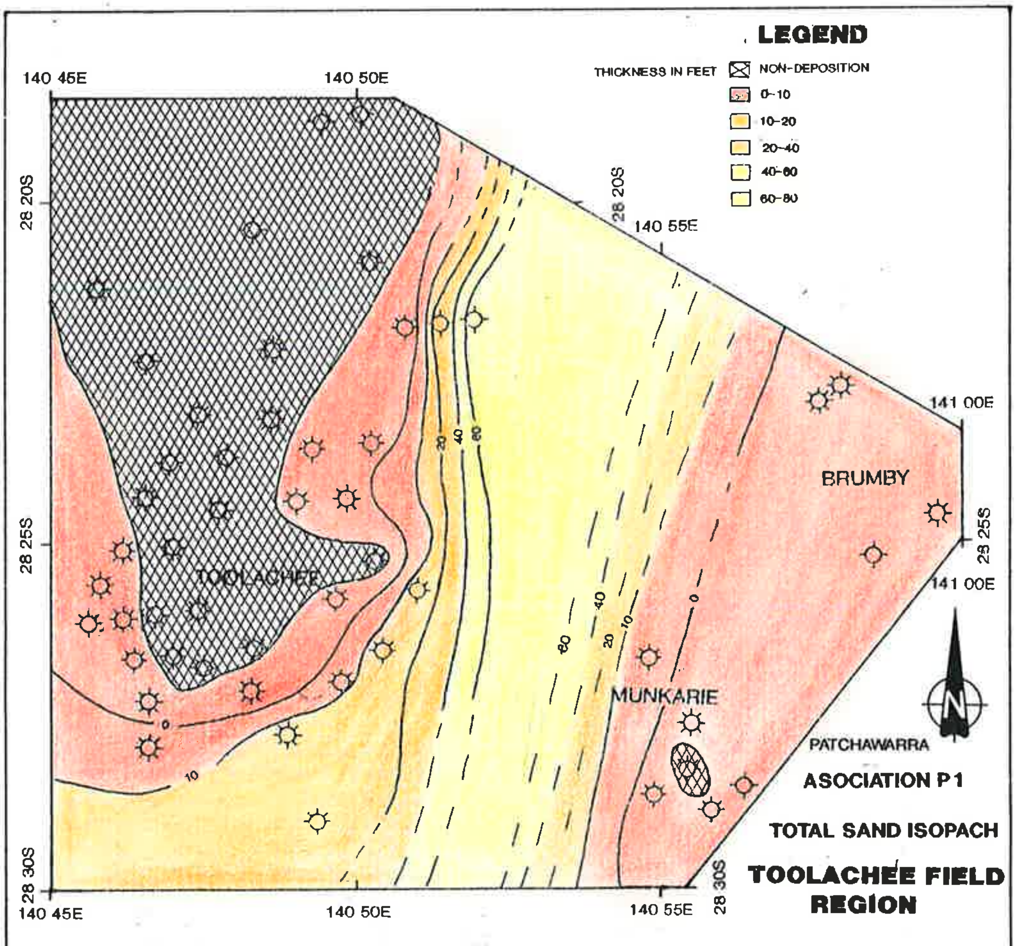


FIGURE 4.4

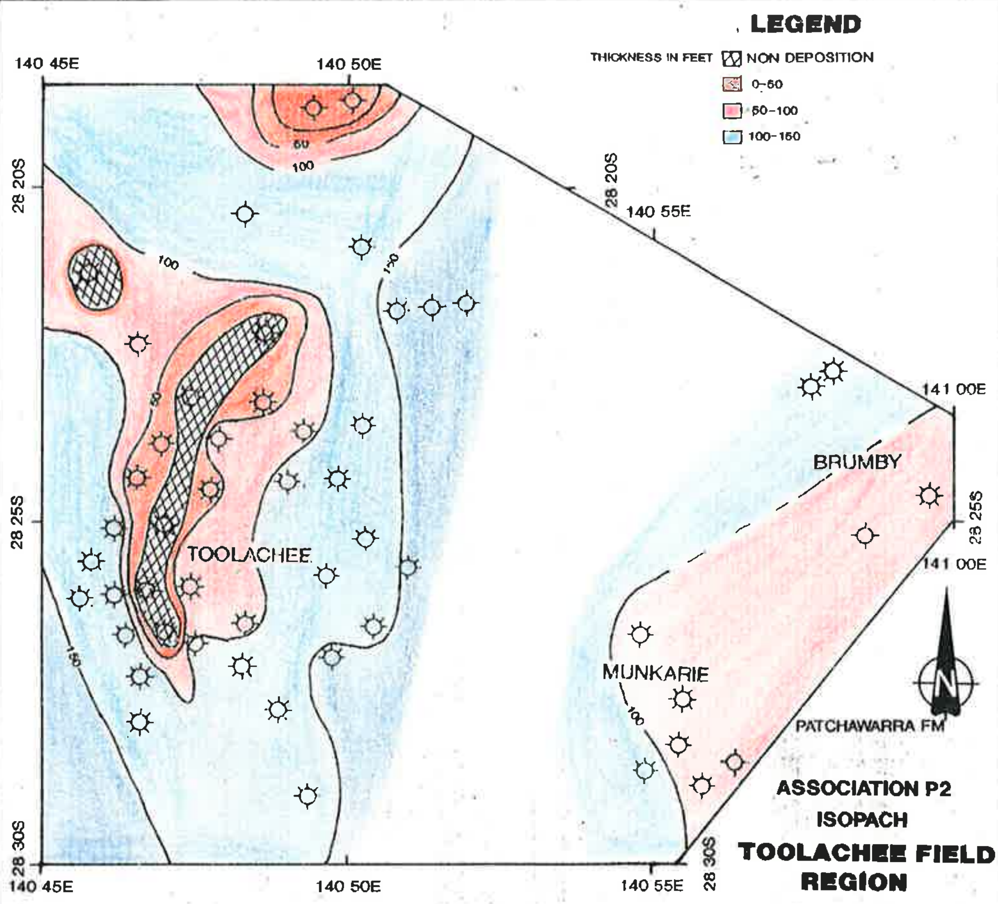


FIGURE 4.5

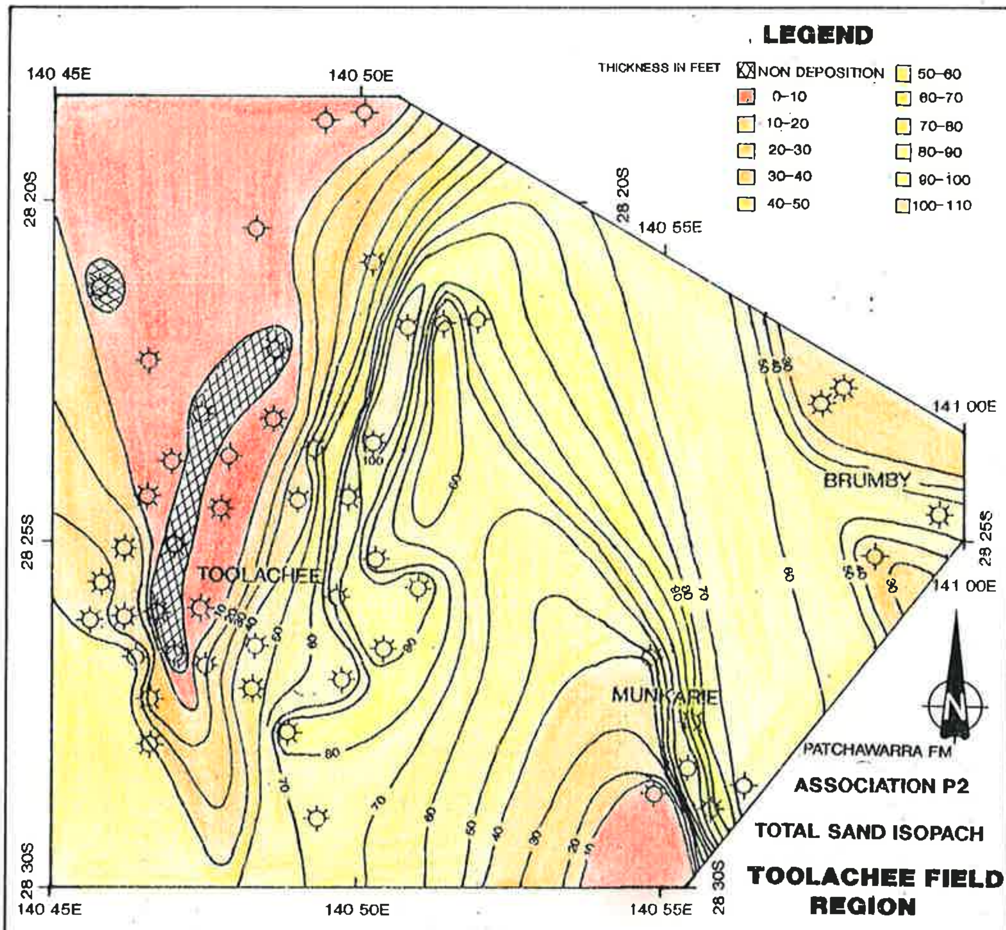


FIGURE 4.6

Association P3

Association P3 (Figures 4.7 & 4.8) shows the disappearance of the paleohigh, to be replaced by overbank sediments and a widening of the channel regions. During this period, overbank sediments were deposited over the old channel area in the eastern side of the field. The central region of the Toolachee Field contained a north-south orientated channel complex which increased in width and thickness to the north. At this time channel sands were deposited in both Brumby and Munkarie Field areas.

Association P4

In Association P4, (Figures 4.9 & 4.10), the central to south-eastern part of the Toolachee Field contained overbank deposits while a river flowed in a northerly direction through the western area of the field. Fluvial channels are also preserved in a wide belt between Brumby and Munkarie Fields.

Association P5

During Association P5, (Figures 4.11 & 4.12) a large reduction in channel deposition occurred in this area with most channels associated with a deltaic system. Fluvial channels trend between Toolachee and Munkarie, and between Munkarie and Brumby. Deltaic deposits occur in the central eastern region sourced by distributary channels from the south. Shoreline deposition occurred in the west and north of the Toolachee Field as well as in Brumby and Munkarie Fields. Lacustrine sediments comprise the rest of the deposits.

The overall sequence of the Patchawarra Formation implies an environment which had a moderately high energy river flowing through the area. Subsequent lowering of depositional gradients was due to concurrent erosion, subsidence and sediment accumulation. Interaction of these factors probably accounts for the reduced height of upland. As a result, sediments comprising the upper portion of the Patchawarra Formation are considered to be deltaic in origin with distributaries having lower depositional gradients. The delta was later inundated by the advance of the Murteree lake, with the accumulation of finer-grained sediments.

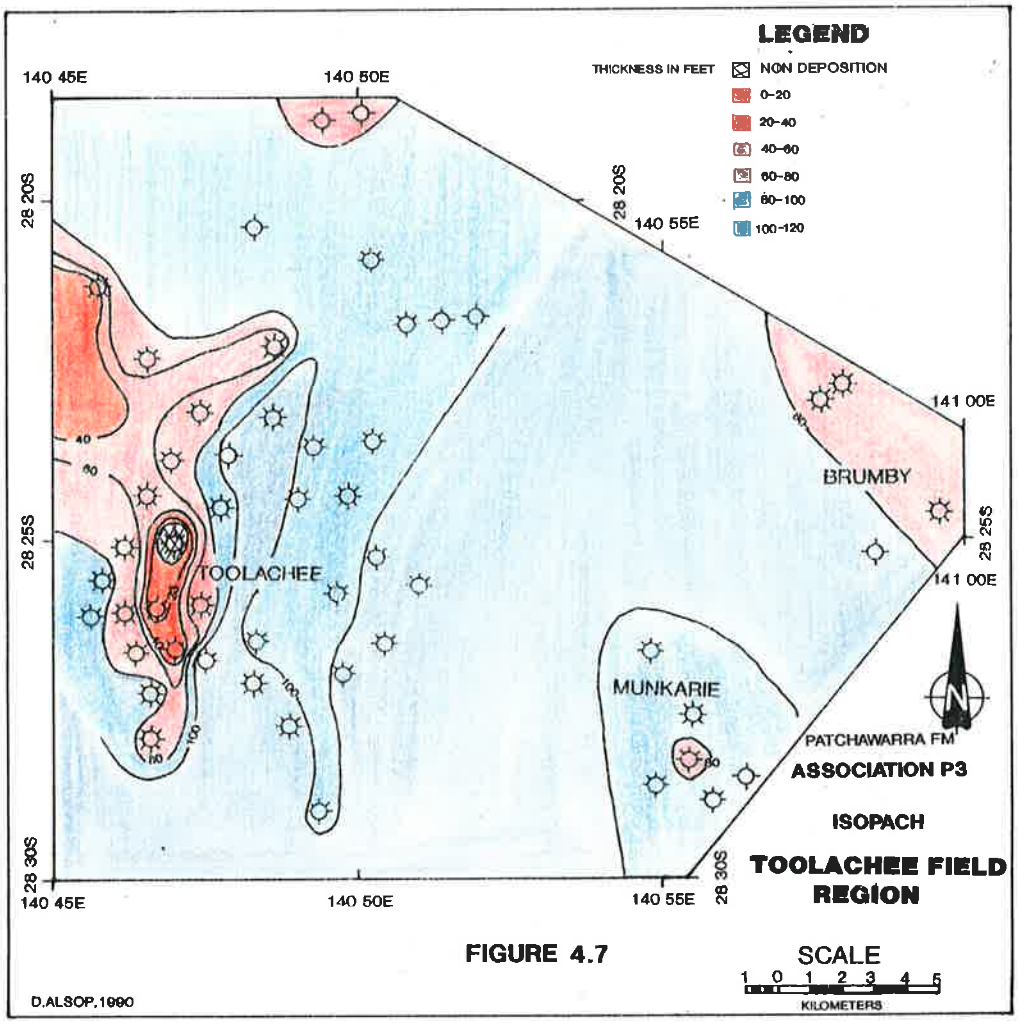


FIGURE 4.7

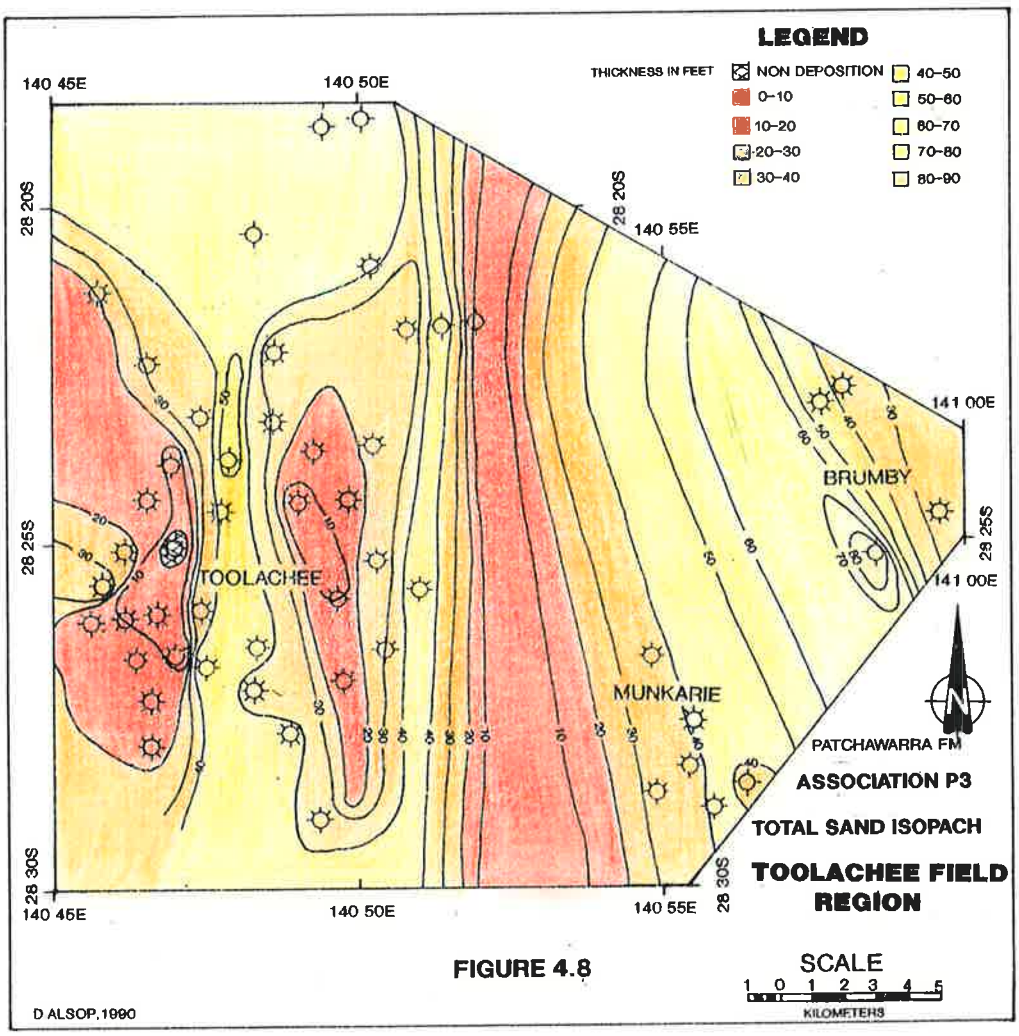


FIGURE 4.8

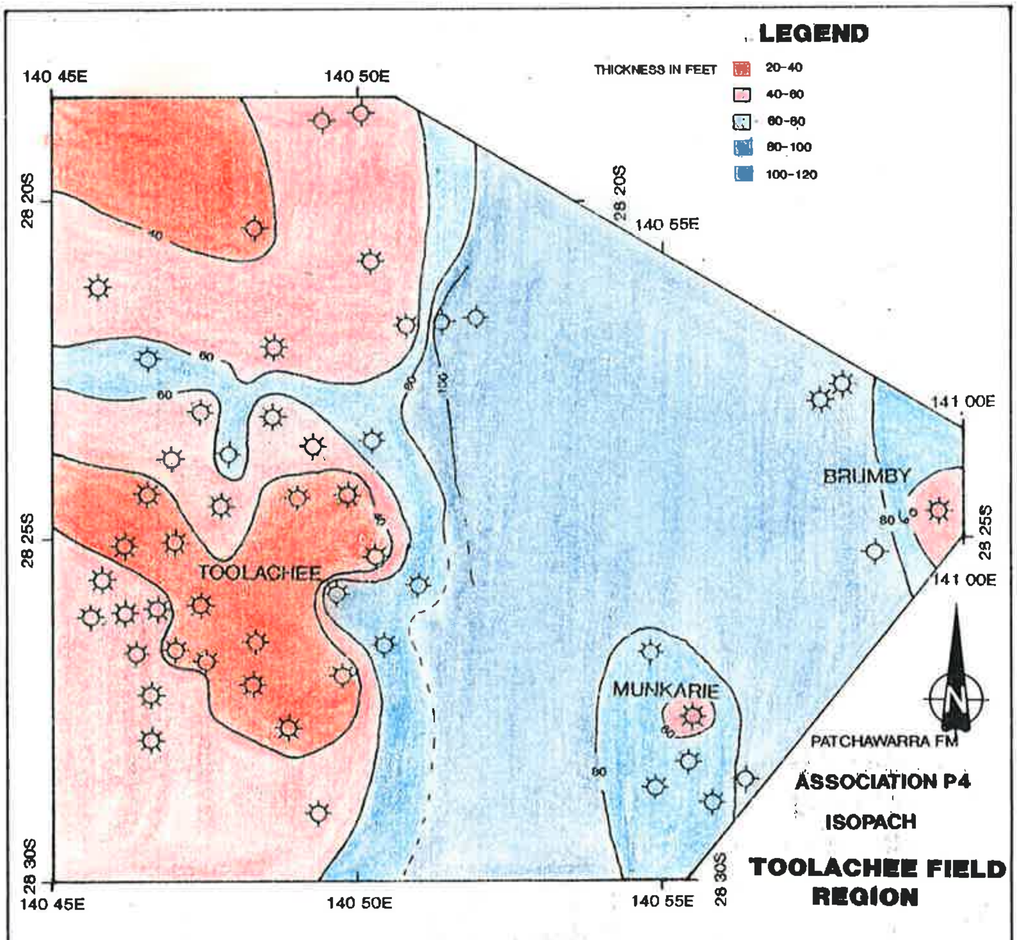


FIGURE 4.9

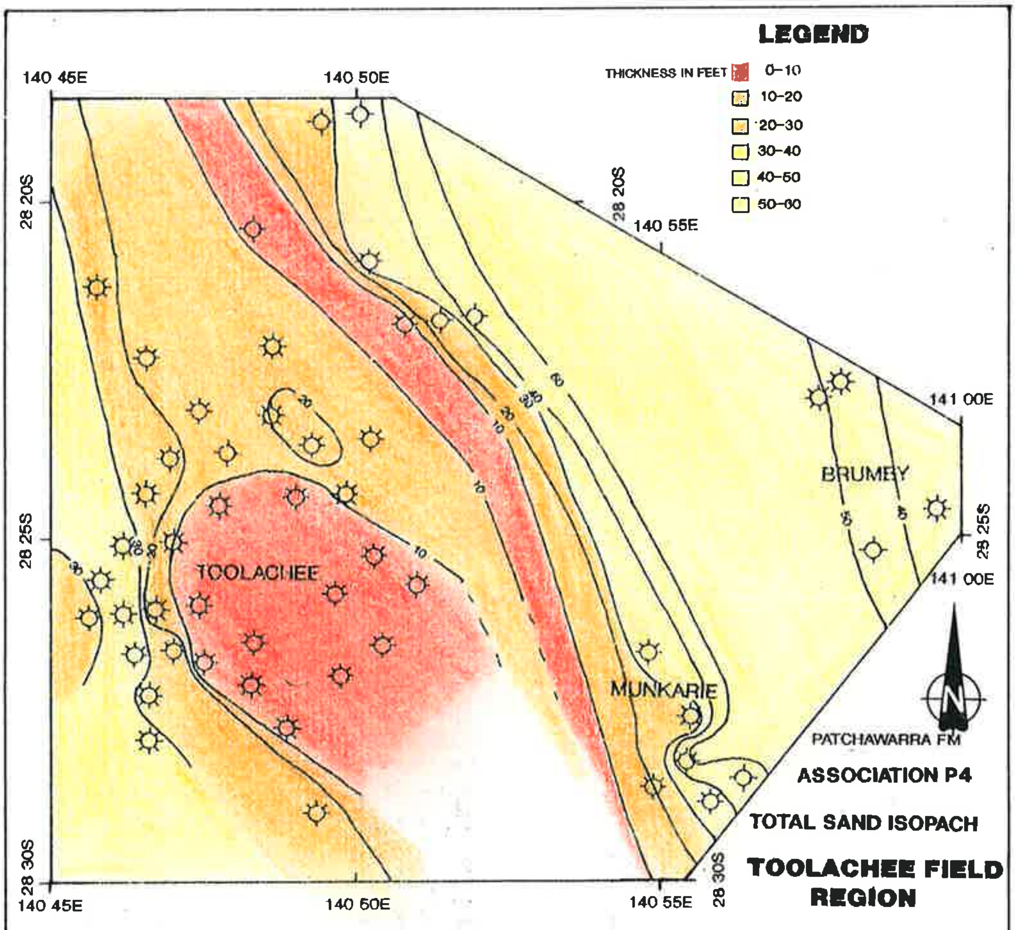


FIGURE 4.10

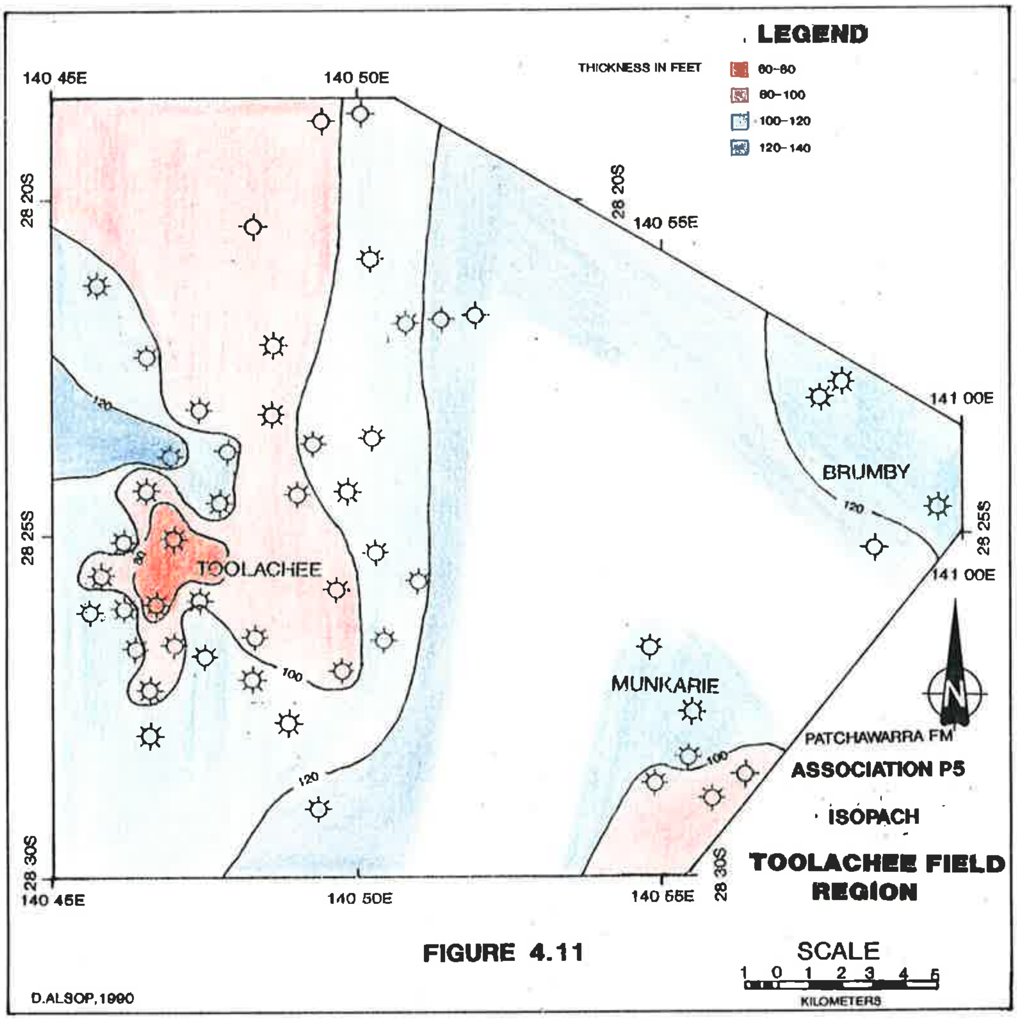


FIGURE 4.11

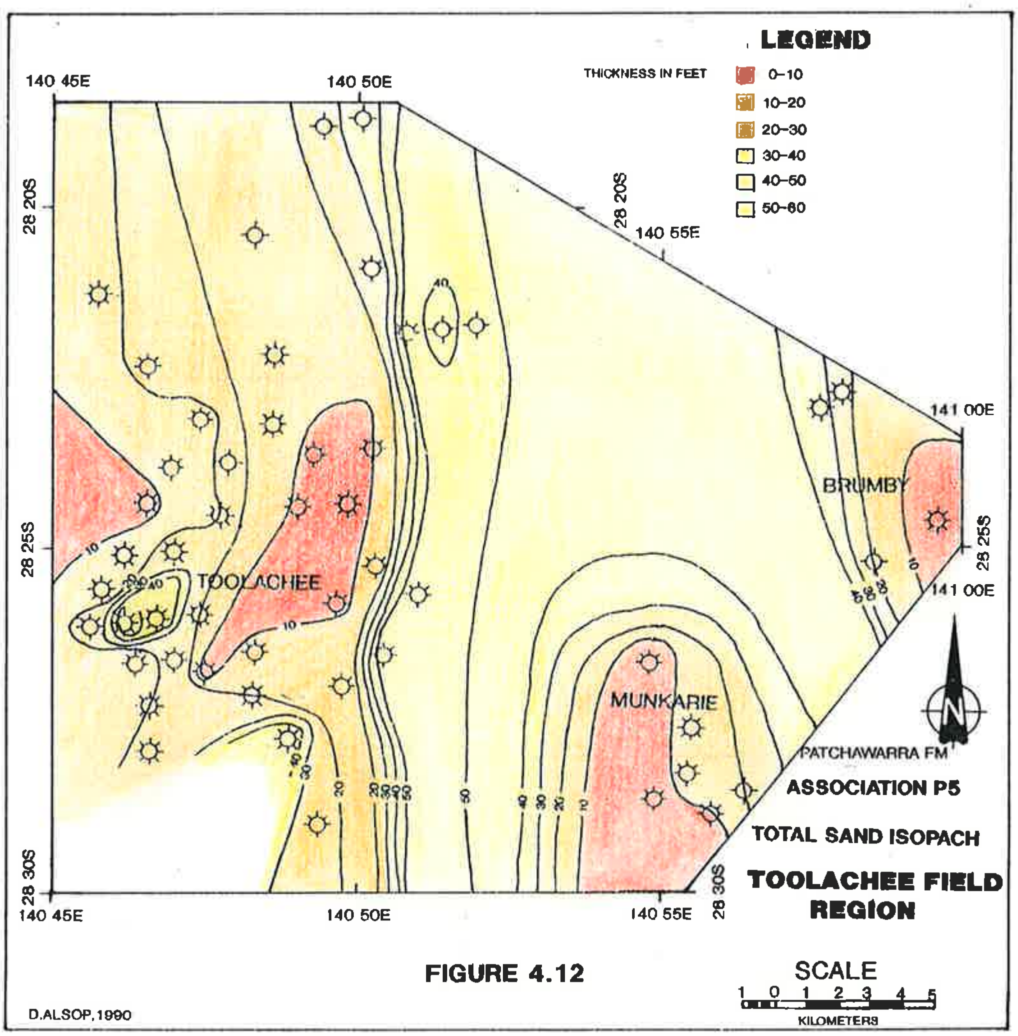


FIGURE 4.12

Association E1

The Epsilon Formation conformably overlies the Murteree Shale. Deposition of the Epsilon Formation commenced during Association E1 (Smith 1987) with a west-northwest to east-southeast orientated distributary mouth bar environment occurring through the central part of the Toolachee region (Figure 4.13). This deltaic area was surrounded by lacustrine sediments with probable wave action redistribution. There was a coal swamp in the north east, around Toolachee 9 and Toolachee East 2, which was probably a slightly elevated area in comparison with the lake.

Association E2

Association E2 (ibid) shows a region of fluvial to deltaic deposition in the south of the Toolachee Field around Toolachee 31 and 7 (Figure 4.14). The sands in this east-west depositional system appear to trend from a more distributary channel nature in the west to a wider, more shoreline to deltaic nature in the east. To the north of the deltaic area, also orientated in an east-west direction, was an area of thin coal deposition. This marsh to shallow lacustine area surrounded a lake to the north in which lacustrine shales and siltstones were deposited, with shoreline deposits laid down during regressions of the lake (Smith 1987).

Association E3

The E3 Association (ibid) contains distributary sands from the north-west to the south-east of the Toolachee Field area, with deltaic and shoreline deposits encroaching on the southern region where a lake was situated (Figure 4.15). The river system flowed towards the north-east to the lake, with deltas and shoreline facies deposited during times of regression of the lake.

Association E4

During Association E4 (ibid) the lake was situated to the north-east and north-west, on either side of a north-south orientated river system (Figure 4.16). The southern region was dominated by distributary and deltaic deposits which trend down the central part of the Toolachee Field.

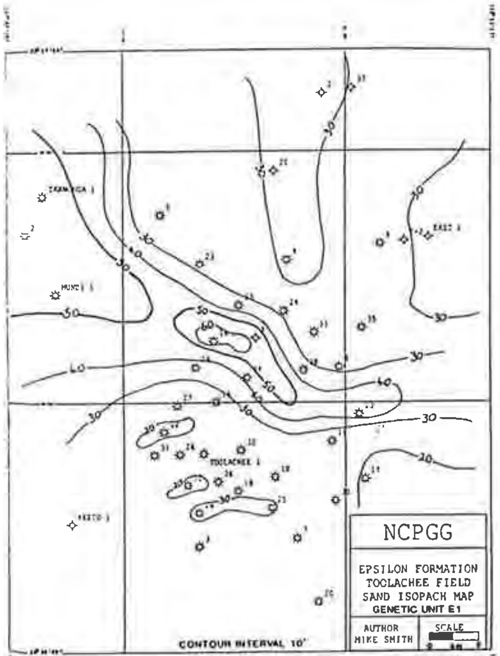


FIGURE 4.13

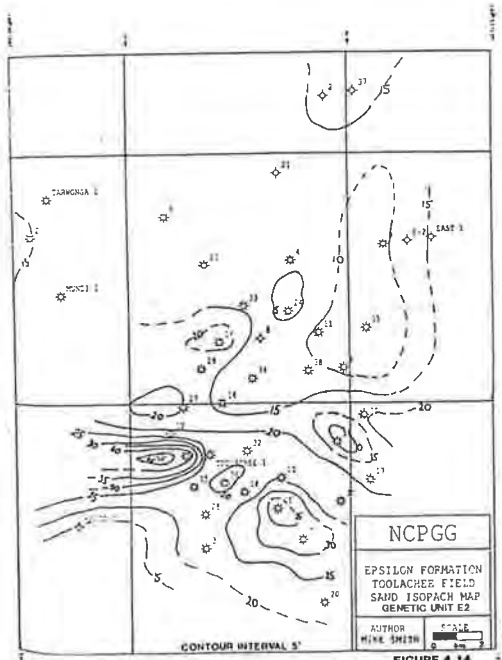


FIGURE 4.14

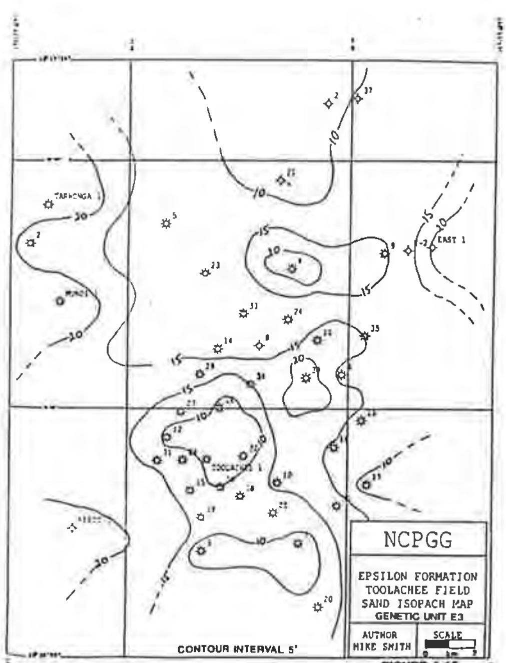


FIGURE 4.15

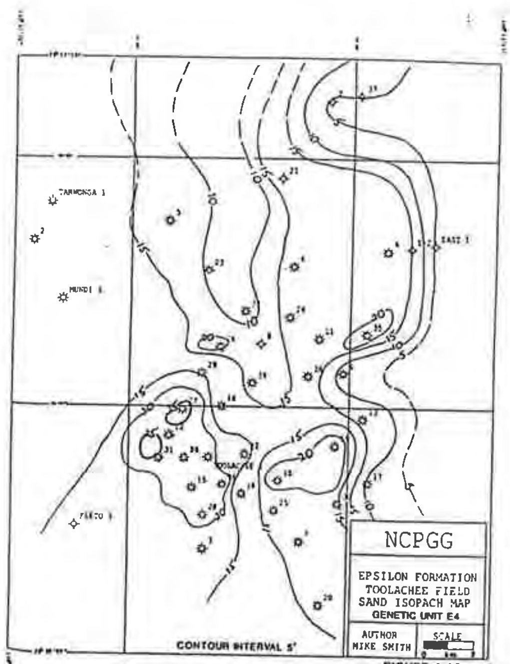


FIGURE 4.16

The environment of deposition during the Epsilon Formation is interpreted as a distributary channel to deltaic, shoreline and lacustrine regime.

Association T1

The Toolachee Formation unconformably overlies either the Roseneath Shale or the Daralingie Formation. During Association T1 (Figures 4.17 & 4.18), the base of the Toolachee Formation, a north-south channel system was present in the western part of the Toolachee Field. Its limits are to the east of Toolachee 1 and Toolachee 5 and, at times, as far as Toolachee 34. The eastern part of the field at this time was a marsh environment with coals and some flood basin deposits. Further to the north-east, around the Toolachee East area, a fluvial channel deposited sandstones mixed with overbank deposits.

Association T2

The onset of Association T2 (Figures 4.19 & 4.20), saw a swing in the north-south fluvial system to the central and eastern area of the Toolachee Field. The thickness of channel deposits increases down the eastern flank. The fluvial meander belt during T2 was wide and interrupted only at Toolachee 4, where overbank clastics and coal were deposited. The meander belt contains channel deposits and point bar sequences. To the south-west, overbank and flood plain sediments were deposited with some coal.

Association T3

Association T3 (Figures 4.21 & 4.22) saw a narrowing of the fluvial channel system with likely trends to the north between the Toolachee and Brumby Fields and then north-west across the northern part of the Toolachee Field. Later, it was located further west of the Toolachee Field. Both the south-west and south-east areas again contained flood basin and overbank deposits. Brumby and Munkarie Fields showed some channelization, but flood basin deposits dominated during this association.

Association T4

In Association T4 (Figures 4.23 & 4.24) there is a shift of the channel system, with a meander belt now trending northwards through the east-central area of the Toolachee Field. A channel system was dominant in the Brumby and Munkarie Fields.

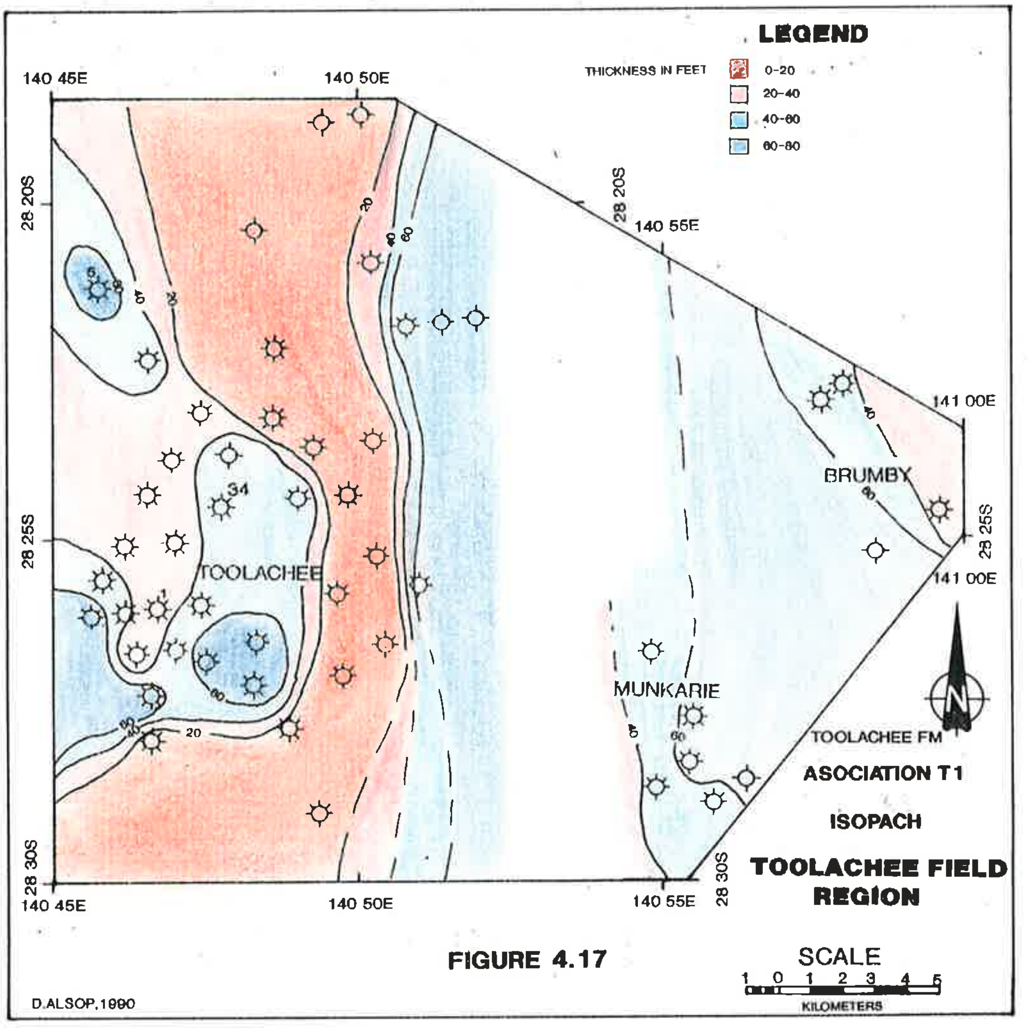


FIGURE 4.17

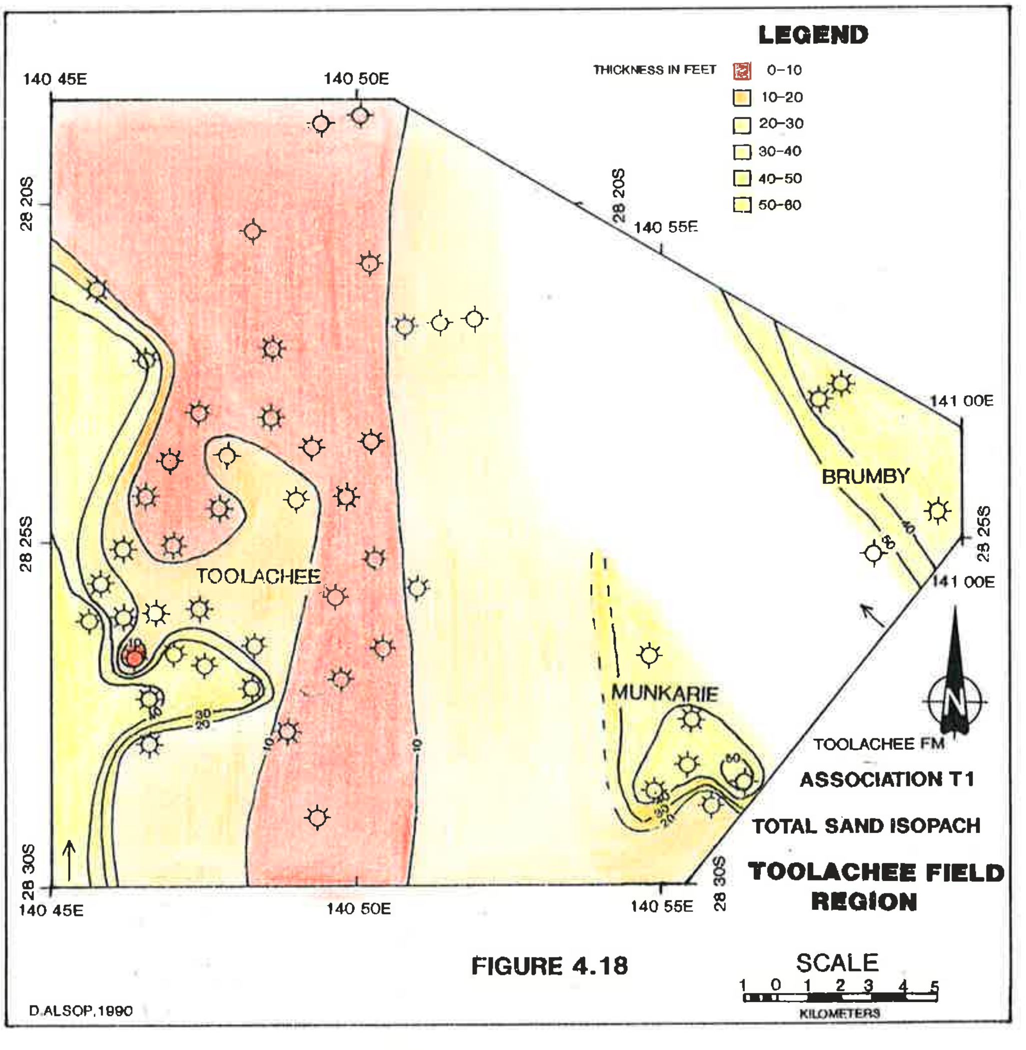


FIGURE 4.18

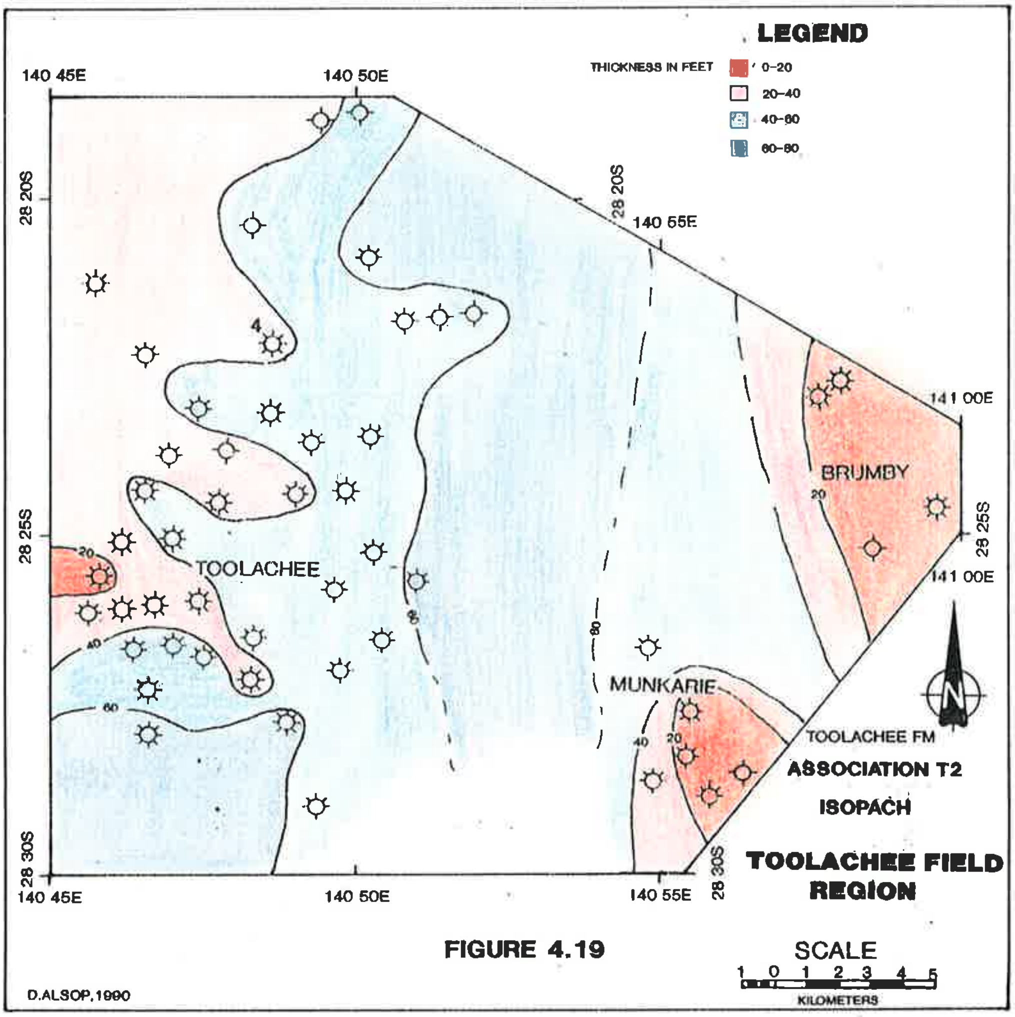


FIGURE 4.19

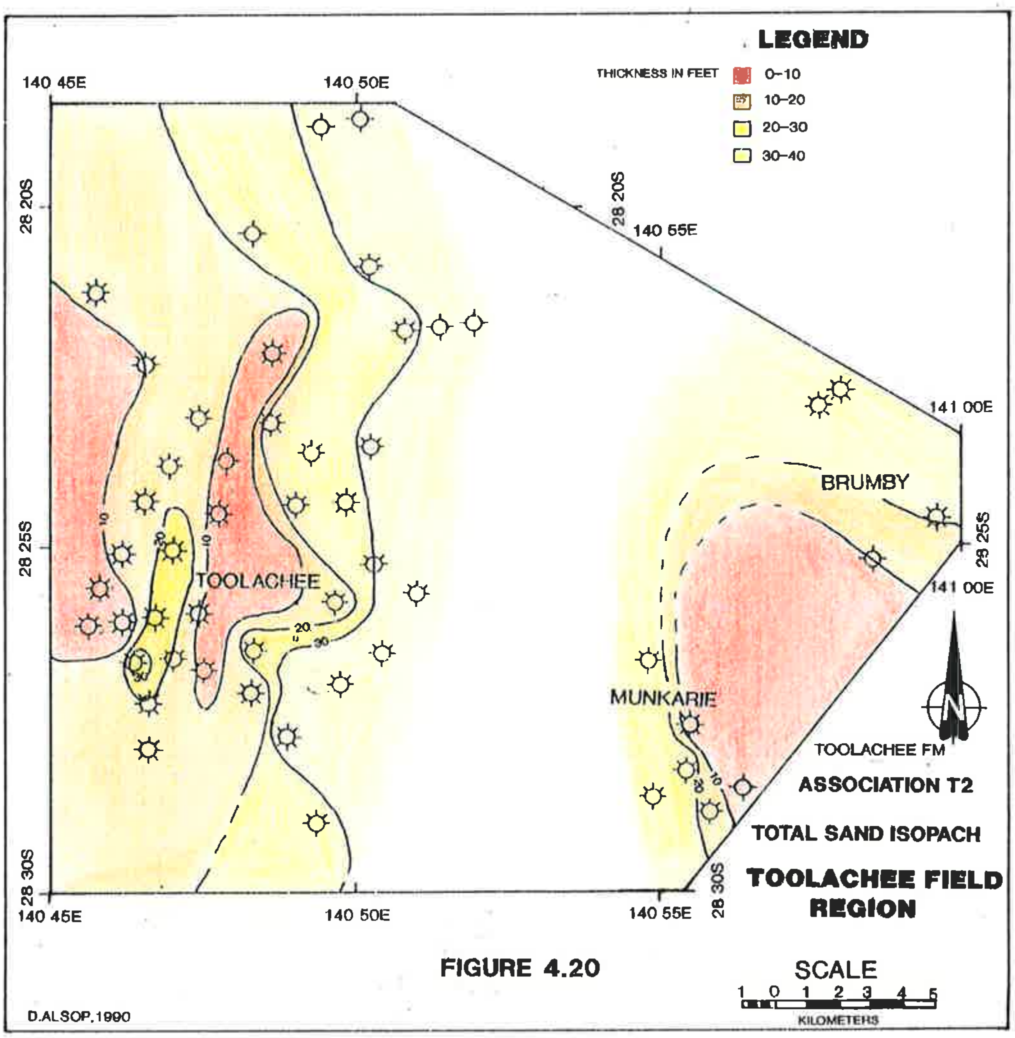


FIGURE 4.20

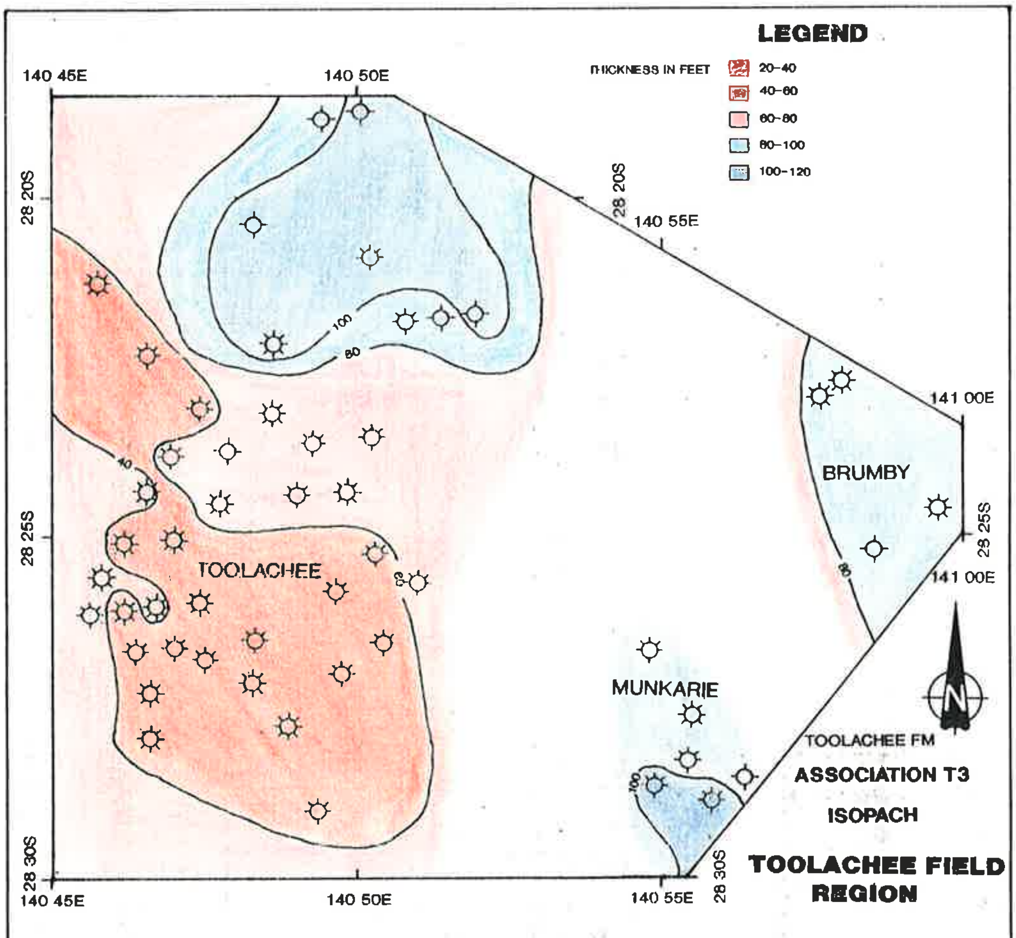


FIGURE 4.21

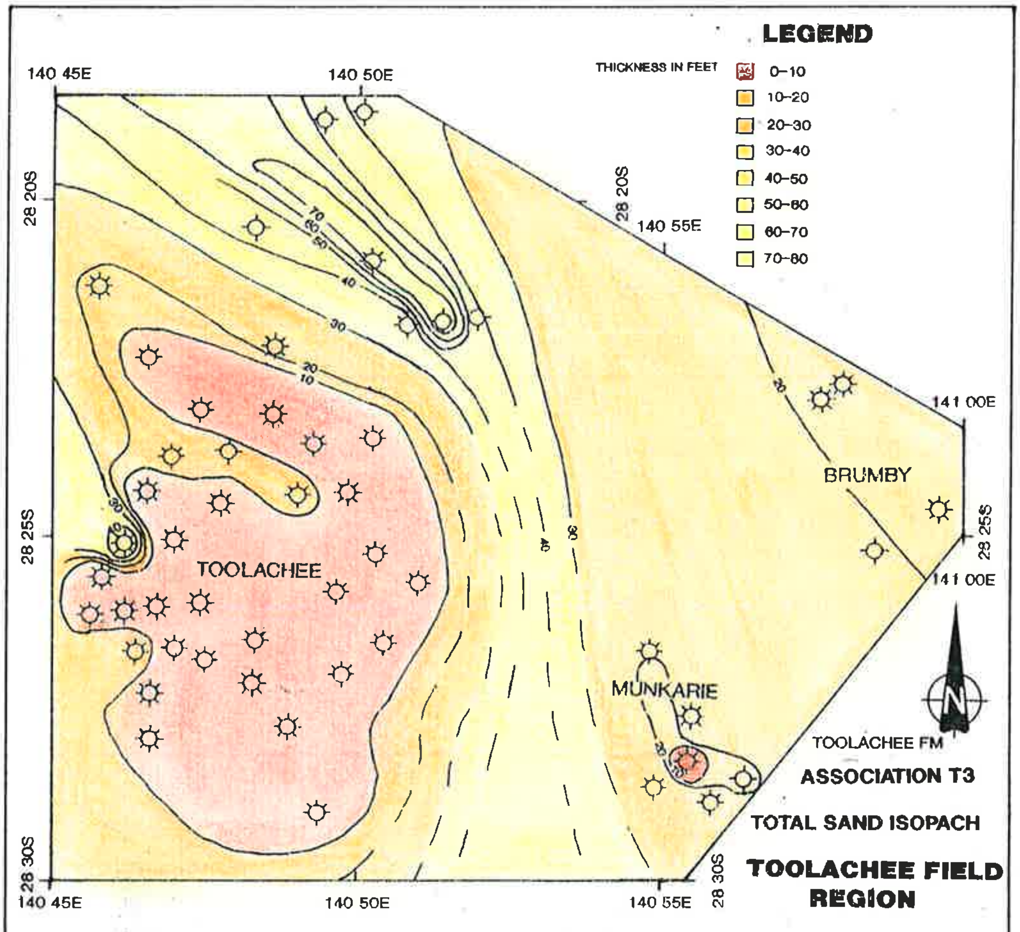


FIGURE 4.22

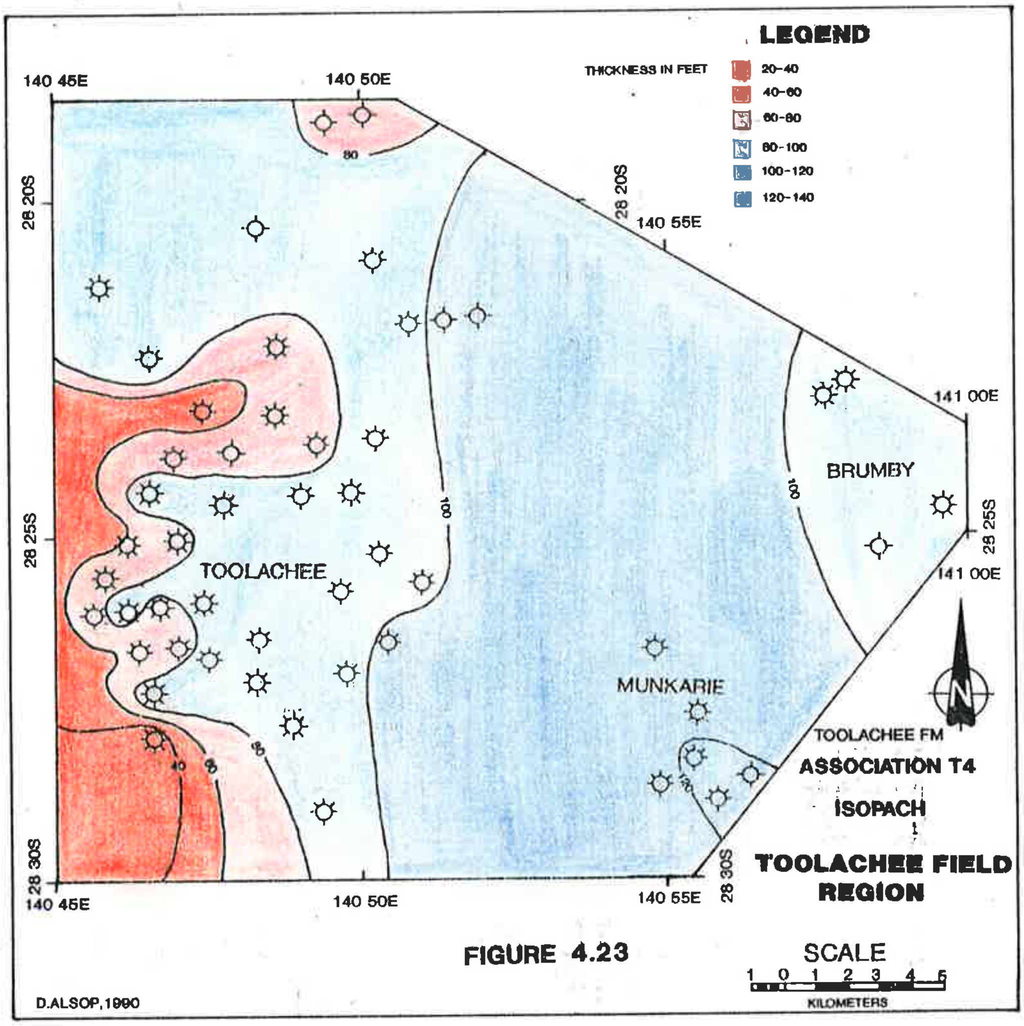


FIGURE 4.23

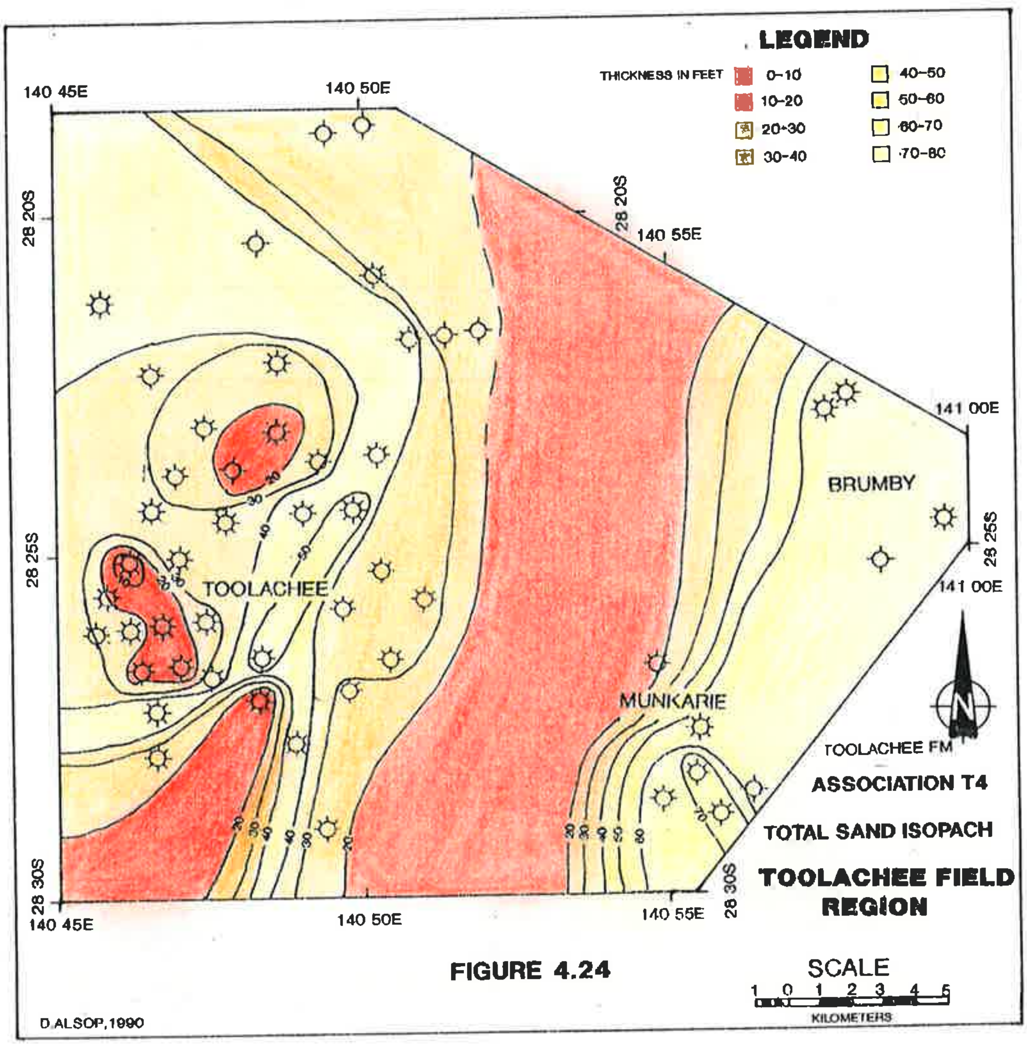


FIGURE 4.24

Association T5

An east-west fluvial channel belt of stacked channels occurs in the southern part of the Toolachee Field during Association T5 (Figures 4.25 & 4.26) progressing into a distributary mouth bar to the east. To the north of the channel belt is an area of overbank and minor channel deposition. Further north, flood basin deposits and coals are found.

Association T6

In Association T6, there is a reduction in the width of the channel belt and a shift back to a north-south orientation in the south-central region which bends around to an east-west orientation in the north. Three areas of deposition of silts and muds in a lacustrine environment can be seen in the north-west, the central-west, and to the east of the channellised belt. Deltaic, shoreline and offshore bar sequences occur between the channel zone and the area of lacustrine deposition and probably represent shoreline deposits grading laterally into the offshore bars and lacustrine sediments.

Association T7

There is a transgression of the lake possibly from the west during Association T7, during which time there were some minor channels to the north-west, with the rest of the field subject to lacustrine conditions with some coal swamps.

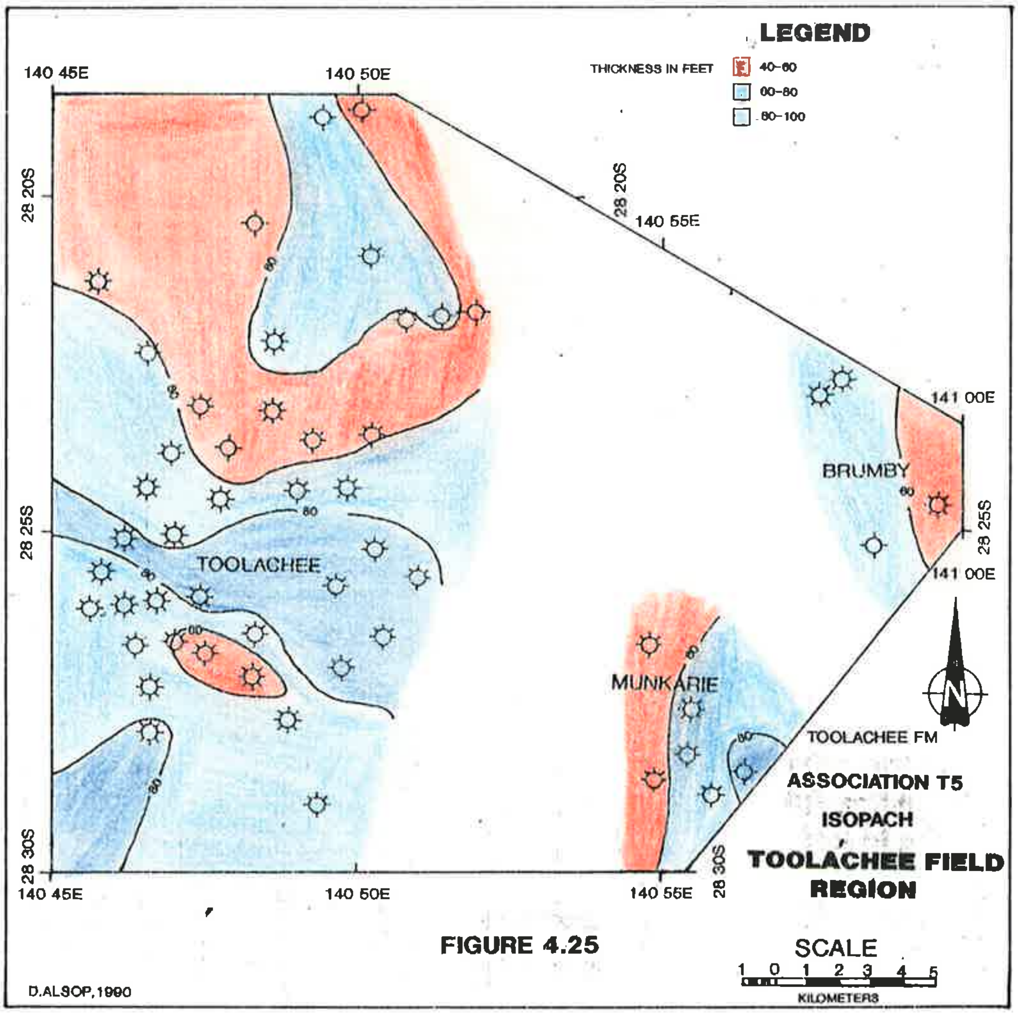


FIGURE 4.25

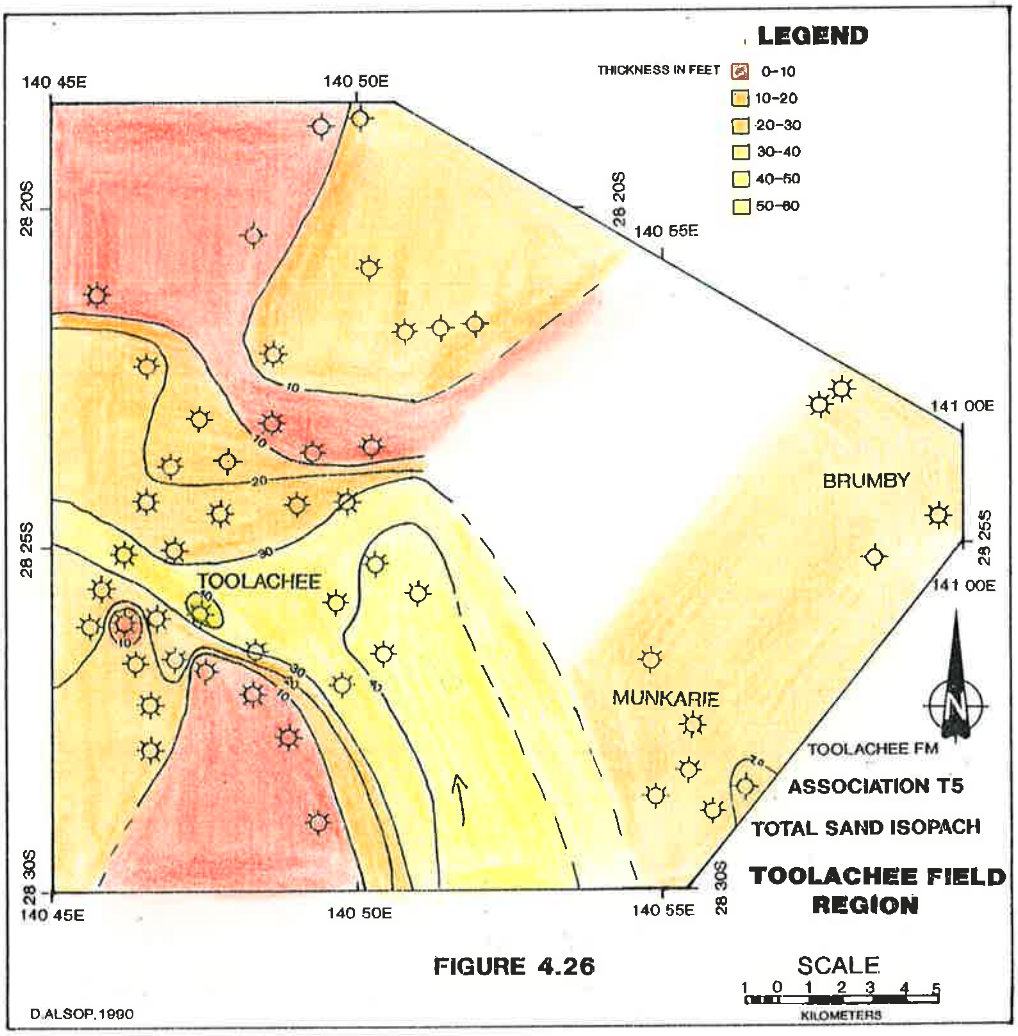


FIGURE 4.26

CHAPTER 5 DIAGENESIS

5.1 CLASTIC DIAGENESIS

5.11 INTRODUCTION

The sandstones in the study area are dominantly sublitharenites. Diagenetic influences affecting clastic sandstones in the Toolachee Field include compaction, cementation of quartz grains by silica, alteration and precipitation of authigenic clays, alteration of micas, feldspars and rock fragments, and precipitation of sparry and micritic siderite cement.

Compaction reduces the thickness of a sedimentary layer by reorganisation of its constituent grains to form a tighter packing, thereby reducing porosity. The degree of compaction generally depends partly on the ratio of fine to coarse material and on the character of the sediment framework (Wolf & Chilingarian 1976). Muller (1967) has stated that the initial water content of an argillaceous mud is approximately 50-80%, which corresponds to a porosity of 70-90%, whereas the water content for sands is 20-30% which corresponds to 30 to 50% porosity. Therefore the expulsion of water from muds plays a much greater role in compaction than in sands.

Detrital quartz grains dominate the mineralogy of most rocks in the area and are the main framework grains. The precipitation of silica as quartz overgrowths has been observed to play a significant role in cementing the framework of the sublitharenites found in the study area. The quartz overgrowths show both destructive and constructive influences on the reservoir quality of the sandstones present. The main destructive influence is its ability to reduce porosity by partially filling in the pores, while the main constructive influence is to support the framework of the rock, to minimise later compaction and thereby preserve porosity.

The authigenic clays present in the study area are kaolin, illite and very minor chlorite. Schultz-Rojan and Phillips (1989) noted a similar suite of authigenic kaolin, illite, chlorite and pyrophyllite from the Nappamerri Trough. Two varieties of kaolin are present, kaolinite and dickite. Kaolinite is generally less than ten microns in diameter while dickite is normally between ten to sixty microns. These clays have formed either by precipitation into pore spaces or by alteration of mineral grains. Authigenic illite occurs only in small amounts (less than one percent) and is probably formed by the alteration of feldspars and micas. Very minor chlorite is present in one specimen, and its origin is uncertain.

Muscovite is the dominant form of mica present with only minor biotite being identified. The muscovite is often deformed due to compaction and it occasionally shows signs of alteration; the biotite, is usually altered.

Feldspar is present in minor quantities, around three percent, and is mostly potassium-rich feldspar with some plagioclase. Both types of feldspar show the effects of alteration to clays and original feldspar content would have been higher prior to complete dissolution or alteration of feldspars to form oversized secondary pores or authigenic clays.

Rock fragments are mostly metamorphic in origin, consisting of metamorphosed sandstones, siltstones and shales. The main minerals present are polycrystalline quartz with some mica.

The two varieties of carbonate present are siderite and minor calcite, both of which occur as porosity occluding cements. Siderite is present as both fine-grained micrite and coarsely crystalline sparite. Calcite has been identified only as sparite cement.

5.12 COMPACTION

Compaction has been observed in thin section as grain rotation, grain slippage, deformation of ductile grains, alignment of clay plates and pressure solution at grain contacts.

Grain rotation and grain slippage have played a relatively minor role due to the early precipitation of quartz cement which has preserved a loosely packed framework of original detrital grains (Plates 1a and b) in the fine to coarse-grained sandstones. The litharenites, containing higher percentages of polycrystalline quartz grains, appear to have been most affected by rotation and slippage. The polycrystalline quartz grains generally tend to lack overgrowth rims (Plates 1b and c) and hence may become rotated more easily during compaction until cemented into place by overgrowth rims extending from surrounding quartz grains.

Deformation of ductile grains mostly affects those sandstones that contain mica, labile rock fragments, coaly stringers and mud rip up clasts. Muscovite flakes are easily deformed and are often squeezed between detrital grains to take the shape of the pore space (Plate 1d). The muscovite is generally in contact with detrital grain surfaces and may occasionally be partially enclosed in quartz overgrowths. Deformation may sometimes be halted by cementation of the rock framework before the mica is totally deformed (Plate 1e). However, in these cases, the mica is often altered to illite and kaolin clays. Most of the labile rock fragments, consisting of metamorphosed siltstones and shales, have been altered to micas, kaolinite and illite. These fragments can still be seen to have suffered deformation to fit the shape of the pore. Coaly stringers (Plate 2b) and mud rip up clasts (Plate 2c) show similar effects of compaction on their grain shapes.

The pressure of the overlying rock has possibly been sufficient to cause horizontal alignment of the detrital clay platelets in most of the finer grained sandstones and siltstones (Blatt 1979). This arrangement may also be inherent from the hydraulic regime in which the clays were deposited.

Pressure solution causes a reduction in the thickness of sediment by dissolution and removal of quartz (Blatt 1979). In cross section, stylolites appear as ragged lines cutting across the fabric of the rock and are generally dark because of an accumulation of insoluble minerals along their boundaries (Plate 2d). Portions of the rock where pressure dissolution occurred generally contain fewer overgrowth rims on quartz (Plate 2f and 3a) along with tighter grain packing.

Grain size and sorting also play an important role in the size and shape of pores. The coarser well-sorted sediments generally contain larger primary pore spaces (Plate 3b) while those finer or more poorly sorted sediments often have smaller pore spaces or have their pores filled with clays (Plate 3c and d). The proportion of unstable minerals included in the sediment also influence porosity. Unstable minerals are often more easily crushed or altered than the more stable minerals such as quartz. These grains, such as rock fragments of shale or siltstone, often take the shape of the pore surrounding them (Plate 3f and 4a) and hence reduce the porosity of the rock. Mica is also affected this way and will often undergo expansion of its crystal lattice due to alteration (Plate 5b). Unstable minerals such as feldspar may dissolve to leave secondary pore spaces (Plate 5c).

5.13 SILICA CEMENTATION

Quartz overgrowths cause the most significant reduction in porosity of the sublitharenites found in the Toolachee Field. Euhedral, rhombohedral overgrowths develop as syntaxial rim on nucleii of monocrystalline detrital quartz (Plate 5d). Euhedral crystal faces are better developed in fine to coarse-grained samples with low clay content and open pore spaces. The euhedral crystals grow into pores and either cleanly line pores with straight edges, interlock with other quartz overgrowths, or intergrow with kaolin booklets to give serrated boundaries (Plate 5e). The clean euhedral crystals that line pore spaces often result in the preservation of primary porosity by providing a loose but solid framework (Plate 4b and c) which minimises later compactional effects and helps maintain good permeability throughout the sandstone. Fully interlocking overgrowths, which comprise a small percentage of most samples, totally occlude porosity where they occur and hence are destructive with respect to porosity and permeability. The majority of interlocking overgrowths, surround triangular primary pore spaces. This tends to give a high degree of interconnectability of pore spaces and hence a higher permeability.

Intergrowth of quartz and kaolin (Plate 5e) results from the precipitation of kaolin during overgrowth formation. This intergrowth often occurs in secondary pore spaces where minerals such as feldspar or rock fragments have been dissolved. Cathodoluminescence shows that those spaces containing kaolin involve much less quartz overgrowth development than pores comprising no kaolin (Plate 4e and f). The precipitation of authigenic dickite appears to disrupt the formation of quartz overgrowths. The amount of overgrowth rim tends to be reduced or absent when next to dickite. It is generally intergrown with the first or second generation of overgrowth and, occasionally, the third. This implies that the initial stages of dissolution of mineral grains, such as feldspars, may have occurred soon after initial cementation of the quartz framework grains with the first generation of quartz. This was followed soon after by precipitation of dickite.

Silica precipitated as overgrowths in optical continuity with the detrital nucleii can be seen in sample 0167 from Toolachee 3 (Plate 6a and b). Thermodynamic considerations favour extension of an existing crystal structure rather than a new nucleation in a void space

(Blatt 1979). The rhombohedral crystal faces seen in sample 0167 form because they grow faster than prism faces on quartz. Blatt (1979) has suggested that the initial faces are sometimes lost as they come into contact with overgrowths from adjacent detrital grains to form crystalographically irrational boundary surfaces (Plate 6a). Overgrowths in the form of quartz druse are most likely to form on the surfaces of quartz grains during the initial stages of silica cementation (Plate 5f). Polycrystalline quartz grains generally lack overgrowth rims (Plates 4c and d).

Detrital quartz grains are well supported by a framework of overgrowths in contact with each other. There is loose packing of the original detrital grains (Plate 1b). This may suggest early precipitation of quartz cement occurred in the area of meteoric water flow (Bjorlykke 1987), before large scale compaction could occur. There may also have been an internal source of silica from the dissolution and alteration of unstable mineral grains. Fluvial surface waters have an average of 13 ppm of dissolved silica which Blatt (1979) has suggested is adequate to initiate precipitation of quartz in pore spaces, but in minute amounts only. Many times the pore volume of water are needed to flow through the reservoir to account for the amount of silica cementation that has taken place and the main region with sufficient flow is in the meteoric water zone which may exist from the surface down to hundreds of meters. This early cementation has then contributed to minimising the effects of compaction on the grains present by providing strength to the rock framework. Bjorlykke (1987) has suggested the formation of early cement may inhibit later cementation and reduce pressure solution by distributing the grain to grain stress over larger areas on the grain framework, thereby relieving points of concentrated stress.

Cathodoluminescence has demonstrated that there are at least three phases of silica cementation. Three distinct generations of quartz cement (Plate 4c) can be seen in many samples and are here labelled G1, G2 and G3. The oldest generation is next to the original grain boundary, with the subsequent overgrowths becoming younger towards the pore space. The oldest generation of quartz overgrowth cement, G1 (Plate 4c), luminesces a medium orange brown and surrounds the original quartz grain. This creates a grain with straight euhedral boundaries, although some minor subhedral edges can occasionally be seen. This first phase of overgrowth (G1) is often irregular in thickness and infills fractures within the quartz grains (Plate 6b). The boundaries of the G1 generation are sometimes irregular because of the formation of authigenic dickite which interfingers with the quartz, giving it a ragged edge. Contact between overgrowths from adjacent grains provide initial strength to the grain framework. The overgrowths form mostly on monocrystalline quartz and are generally absent from polycrystalline quartz. The second generation of quartz overgrowth, G2 (Plate 4c), luminesces a greenish to bluish colour and may exhibit either a patchy or homogenous appearance. This phase may be further subdivided to give a fourth generation by distinguishing between the green and blue phase. However, as they rarely occur together around the same grain, they have not been separated here. This second generation is the most variable in distribution and can either produce thick rims on the quartz or be entirely absent. Dickite clay sometimes interfingers with this phase of overgrowth formation, producing ragged boundaries. The G2 generation leaves a euhedral crystalline boundary for the base of the third generation. The youngest generation of quartz overgrowth, G3 (Plate 4c), is light brown and is more continuous and uniform in nature than either G1 or G2. This third phase is variable in thickness and may occur over either the G1 or G2 rims. It occurs only occasionally next to dickite and is usually disrupted by interference with surrounding grains.

The solubility of silica increases with rising temperature and pH (Blatt 1979). Chemical etching of quartz overgrowths occurs in many samples and appears to occur mainly on one crystal face of the rhombohedron producing deep V-shaped pits (Plate 5g). Dissolution of quartz occurred after the final phase of silica cementation, but simultaneously with the precipitation of sparry siderite. The chemical conditions needed for formation of sparry siderite include a higher pH than that for silica precipitation. Hence it can be deduced that the dissolution of quartz probably occurred at greater depths, where the temperature and pressure were sufficient to increase its solubility or where the pH changed.

Dust lines occur in most samples along the interface between the original quartz grain and the quartz overgrowth. In thin section, these lines highlight the old grain boundaries and overgrowths. Dust lines are formed when minerals, organic matter or fluids are trapped along the detrital grain margin as the overgrowth begins its precipitation at various points in contact with the original grain and then merges to form the final euhedral overgrowth (McBride 1989). Coatings on grains by kaolin or other clays can prevent the formation of quartz overgrowths (Plate 4f).

Sources of Silica

Evidence to support shallow quartz cementation can be seen using cathodoluminescence which shows few grain to grain contacts of detrital grains but many "floating grains" (Plate 1f). This implies early precipitation before compaction. Depending on their source and composition, moving pore waters can redistribute silica throughout the sandstone as ions in solution. Due to the large volumes of water required to produce sufficient overgrowths, it has been suggested by Blatt (1979) and Bjorlykke (1988) that the high flow rates in the meteoric water zone are the most probable transportation zone. The detrital grains themselves may serve as a partial source of silica for precipitation in an adjacent part of the rock unit. Further evidence comes from observations by Blatt (1979) who has shown that it is uncommon to find an appreciable amount of secondary quartz in mineralogically less mature sandstones such as arkoses and lith-arenites. The detrital quartz grains therefore act as a source of dissolved silica and as a nucleation site for the precipitated silica. Fluvial surface waters contain adequate silica to initiate precipitation of quartz in pore spaces but only in very small amounts. Blatt (1979) has suggested that the bulk of cementation occurs by vertically circulating meteoric pore waters at shallow depths because flow rates at depths of greater than several hundred meters are too slow for the volumes of pore waters needed. The meteoric water will initially be undersaturated with respects to minerals such as carbonate and feldspar and supersaturated with respects to silica. However, McBride (1989) has indicated from fluid inclusion studies, that the temperatures at which quartz formed, places it at a depth of between one to two kilometres. This zone is well below the region of meteoric water flow and he suggests rising thermal waters, enriched in silica, will precipitate large volumes of silica as it cools. No fluid inclusion or isotope studies have been done as yet in the study area. It is possible that both of these sources of silica have influenced precipitation of different stages of quartz.

Water enriched in silica may also be produced by the dehydration of minerals, such as clays, adding further quantities of silica to the system (ibid).

Another possible source of silica could be from organic chelates present in the ground water and thus huge volumes of water are not required (Gostin, pers. comm.). Evidence for this possible source are silicified, undecomposed flowers, found in Eromanga sediments (ibid).

Euhedral quartz overgrowths are prominent in primary pores, oversized pores and, to a lesser extent, those which contain kaolin (Plate 4c). Little feldspar is seen in the Permian sediments. However, the few feldspar crystals that are present are often partially dissolved or altered (Plate 3a). Near the surface meteoric pore waters are generally undersaturated with respect to feldspar and hence feldspar may either dissolve out completely or be altered to kaolin. The kaolinization of feldspars produces a volume of silica equivalent to forty percent of the altered feldspar adding to that which may precipitate as quartz (Hayes 1979).

Pressure solution is evident in about fifteen percent of samples. Evidence of this comes from the presence of stylolites which have concentrations of carbonaceous material and clay along their boundaries (Plate 2d). The stylolites consist of a jagged, sutured, interlocking penetration of both sides that embays grains. They commonly parallel the bedding and may be up to 2cm in amplitude. Microstylolites have a relief along the seam of less than one millimetre, indicating differential solution between two mineral grains (Plate 2f).

The largest stylolites occur in the coarse-grained sandstones and the microstylolites may be present between individual quartz grains, at which stage they may also be called sutured contacts. There appears to be no difference in stylolite amplitudes or morphology with depth over the interval studied. In sandstones composed mostly of well-sorted quartz grains, the grain to grain contacts may initially be very small with high effective stress. The stress at the grain to grain contacts deforms the crystal lattice and increases the solubility of the quartz. At these contact points dissolution may occur (Bjorlykke 1987). The adjacent area will then be supersaturated with respect to silica and, through diffusion of ions in solution, the silica may be precipitated as quartz overgrowths on other nearby grains. Grain to grain pressure solution results in very tight packing of the grains and reduced porosity within the affected area (Plate 3a). Impurities such as clay or carbonaceous material occur as laminae, particles or coatings on the surface of quartz grains. The accumulation of these impurities favours pressure solution rather than the precipitation of overgrowths (Pittman 1972) (Plate 6d). Stylolites may also contain bitumen staining which can be seen along the stylolites such as in sample 0535 from Toolachee 6. The bitumen is likely to be an accumulation of relict material.

Pore waters enriched in silica and forced upward by the compaction of shales also add to the amount of dissolved silica. However, the flow is limited by the amount of water contained in the underlying shale sequence (Hayes 1979) which is likely to be vast. In the Patchawarra Formation, sands are interbedded with shale sequences which could add some silica-enriched pore waters. The Toolachee and Epsilon Formations are both underlain by thick lacustrine shale beds which could have supplied appreciable quantities of silica-rich pore waters. If this hypothesis is correct then increased amounts of quartz overgrowths should occur next to shale boundaries. This increase in the amount of precipitated quartz has been observed in the study area. The medium to coarse sands at the base of sand units sometimes appear cemented tighter within two to three feet of an underlying shale. This area may have been preferentially cemented by silica-rich waters flowing through the sands during the dewatering of the shales. There is a lack of core, however, across major shale sandstone boundaries. More core data are needed to test the hypothesis. The conversion of smectite to illite may play a minor role as a source of silica, with only small amounts in the order of less than one percent authigenic illite being seen in the Toolachee Field. Munkarie Field possibly contains up to three percent authigenic illite; hence this process is probably more important here. Towe (1962) suggested that the structural state of the smectite is conserved and that smectite layers are converted to illitic layers. This is achieved by substitution of magnesium and iron for aluminium in the octahedral layers with the subsequent release of 2.2 grams of silica per 100 grams of clay transformed. Finer-grained sandstones which contain clays appear to be highly compacted.

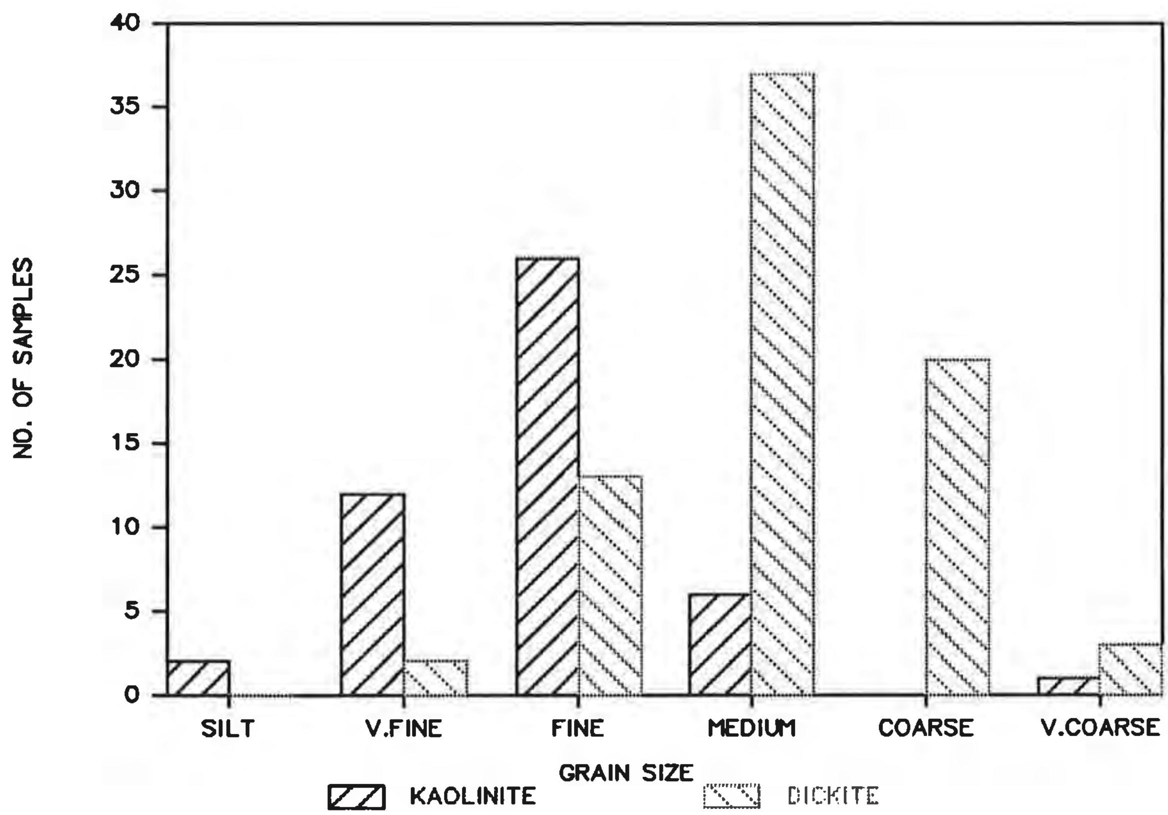
5.14 CLAYS

Kaolin

Two varieties of kaolin clay present in the study area, identified using XRD, are kaolinite 1T and dickite. Kaolinite is the dominant form in the finer grained rocks (Figure 5.1) which also contain a higher illite content. The kaolinite is mostly less than 10 microns in size and it ranges from euhedral books to anhedral plates mixed with detrital illite. The detrital form of kaolinite was identified as anhedral plates with a broken appearance (Plate 5h). This was degraded as it passed through the cycle of weathering, erosion and transportation to be mixed with other minerals. These processes have resulted in the separation of the plates from their books and the destruction of their euhedral crystal edges, forming irregular boundaries. The kaolinite plates can be observed to be dispersed as matrix. It may also be concentrated as aggregates, as in mud rip up clasts, on laminae or reworked by organisms (Plate 6f).

Figure 5.1

TOOLACHEE FIELD:KAOLINITE AND DICKITE VS GRAIN SIZE



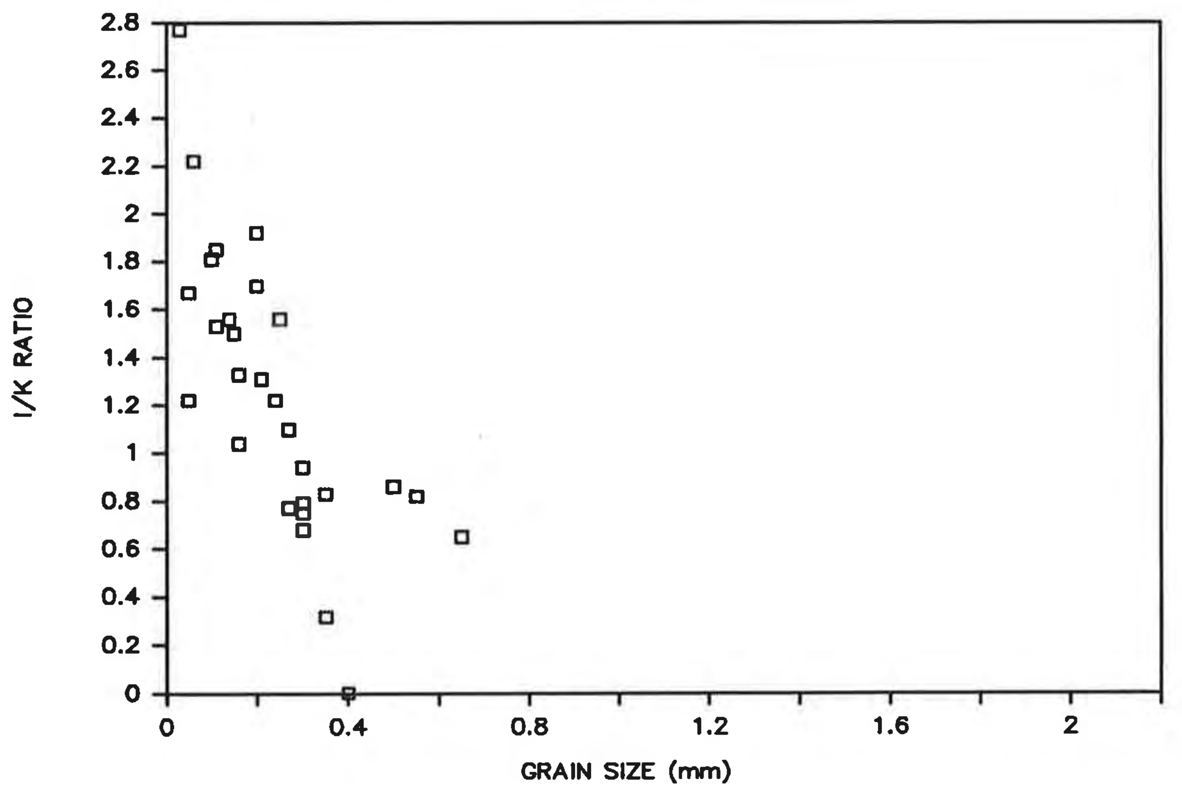
Detrital clays are often deformed by compaction (Plate 4a) while the authigenic kaolinite and dickite show no deformation (Plate 7a). Deformation includes bent plates and sometimes a preferred orientation of the clay platelets. Authigenic kaolinite appears as vermiform less than 10 microns in size.

Dickite is present as euhedral pseudohexagonal stacked plates, sometimes vermiform, that range in size from 10 microns to 50 microns in diameter, as can be seen in samples from Toolachee 6 and Brumby 1 (Plate 7b and 7c). Booklets and vermicular forms of dickite occur as pore fillings between quartz grains, as clays replacing feldspars in secondary oversized pores and intergrown with quartz overgrowths. Dickite forms rare pseudomorphs after some detrital grains, such as feldspar or rock fragments, which have been completely replaced or dissolved and later infilled by dickite (Wilson & Pittman 1977). Dickite booklets embedded in quartz overgrowths are always unaltered, while the quartz overgrowths occasionally show signs of chemical etching (Plate 5g). Dickite is considered authigenic in origin since the euhedral crystal faces could not have survived transportation and deposition without being modified (Ross and Kerr 1930). Dickite is rarely mixed with other clay minerals. Wilson and Pittman (1977) have attributed this to the growth of clay under a limited range of subsurface physical and chemical conditions. Detrital clays such as kaolinite and illite, however, are generally mixed together because of the diverse rock types and soils from which they are derived. The dickite has precipitated out of solution, replaced a parent material (feldspar) or has recrystallized from detrital kaolin clays (Shelton 1964). It is most probably formed in large, oversized pores by precipitation from solutions saturated with respect to quartz and aluminium. Alteration of existing grains to dickite during the various stages of quartz overgrowth formation also probably occurs in the oversized pores. However, this source is considered to be less important than precipitation because of the volume of quartz and dickite present. It has intergrown with the margins of the euhedral overgrowths (Plate 5e).

The dickite can be seen to have precipitated at different times by observing the way it penetrates various generations of overgrowths (Plate 4c). Dickite often fills the secondary pores while primary pores usually remain free of the authigenic clay. Some oversized pores only contain euhedral quartz overgrowths around their edges. When dickite fills primary pore spaces it either occurs next to the original grain with no overgrowth rim, or it is intergrown with the first generation of quartz cement and rarely can be seen to intergrow with latter generations. This may indicate that dickite may have started forming contemporaneously or slightly before quartz cementation within the primary pore spaces. Most of the dickite, however, is found in secondary pores, where it sometimes occurs next to quartz grains with no overgrowth formation. Dickite has precipitated from solution and it is probable that some recrystallization of feldspar has occurred where it appears in patches within other clay material or quartz (Shelton 1964). These patches of dickite have been observed in most samples in the study area on a minor scale using SEM.

Figure 5.2

TOOLACHEE FIELD: ILLITE TO KAOLIN RATIO VS GRAIN SIZE



It has been assumed that pores are filled from the grain surface inwards because the cementing grains require a supporting substrate and cannot precipitate in pore spaces (Wilson

& Pittman 1977). Therefore, cements and kaolin in the centre of the pores are younger than those at the grain surface.

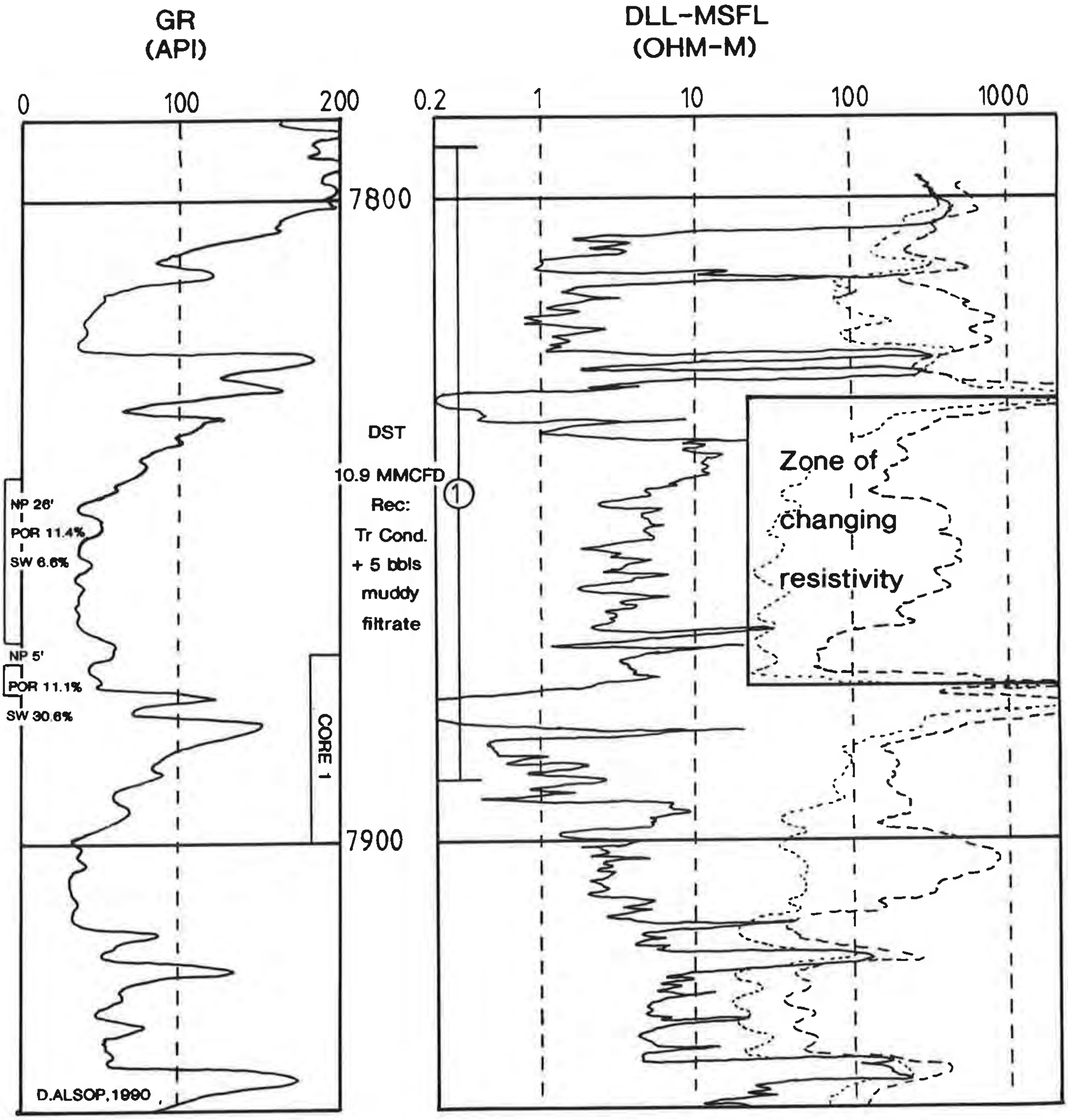
Dickite occurs most abundantly in higher energy facies of medium to coarse grained sublitharenites which contained good primary porosity and permeability allowing free flow of pore waters.

Glass (1958) and Weaver (1959) have noted that there might be an initial preference for dickite formation within continental sequences that contain fresh pore waters. Dickite occurs most abundantly in moderate to well-sorted sublitharenites with an illite to kaolin ratio of less than 1.00. Figure 5.2 shows illite to kaolin ratio versus grain size. The illite to kaolin ratio here was determined by XRD peak ratios and the grain size by thin section analysis. This can be used in conjunction with XRD data to separate kaolinite and dickite. Above this value both dickite and kaolinite tend to exist until the value reaches 1.80, at which point the kaolin clays are almost entirely kaolinite.

Dickite causes a significant reduction in porosity in many coarser-grained samples although it does contain micropores in the order of 3-20 microns (Plate 7a). This microporosity may prove significant in gas fields, such as the Toolachee Field, where gas may be produced from these small pore spaces. In Marsilea 1, located in the north of the Brumby Field, a zone has been identified in a channel sandstone (Figure 5.3) where the resistivity curve changes from high to low resistivity. The high resistivity zone shows values in the order of 500 ohm-m while, in the low resistivity zone, values drop to around 60 ohm-m. There is good separation of the three resistivity curves in each zone and a slight increase in the gamma ray curve from 36 API to 40 API. This zone has been traced through to Mettika 1, Toolachee 8 and Toolachee 21 (Butler, Pers. Com.). The zone was thought to be an gas/water contact but a drill stem test was carried out and produced gas with no water (Butler, Pers. Com.). Thin section analysis by AMDEL across this zone found the high resistivity zone contained 1 to 3 percent authigenic kaolin, while the low resistivity zone contained 12 to 15 percent authigenic kaolin and a water saturation of up to 46 percent. The change in resistivity across the boundary from high to low may be due to an increased presence of water as irreducible water saturation due to the larger surface area in the

MARSILEA 1

FIGURE 5.3



authigenic kaolin. This may also account for the increased water saturation observed 16.6% in the high resistivity zone and 30.6% in the low resistivity zone. A DST over this zone in Marsilea 1 was 10.9 MMCFD while the low resistivity zone in Mettika 1 recorded only 2.1 MMCFD. This drop in flow rate suggests that the microporosity in the authigenic kaolin may still be large enough to allow gas to flow past the irreducible water film in the micropores, although at a reduced rate. Microporosity may therefore prove significant in gas exploration and needs further examination within this field.

Illite

Most illite that occurs in the study area is detrital in the form of platelets that have irregular edges under SEM and show some deformation due to compaction (Plate 7d). The illite is generally concentrated in shaly or silty laminae in fine-grained sandstones to shales and sometimes can be found in burrows (Plate 6f) because of reworking of the original sediment soon after deposition. The laminations of clay are composed of individual clay particles that have a strong preferred orientation imposed by the platy nature of the particles. The illite is generally randomly mixed with kaolin. XRD identified the illite as the 2M1 form.

Some authigenic illite has been observed in the medium to coarse-grained sediments as delicate curved lettuce-like plates (Plate 7e) lining pores and also as plates in between kaolin from the alteration of mica (Plate 7f). The authigenic illite may have come from the alteration of plagioclase feldspar (Wilson and Pittman 1977). Rare grains of corroded and altering plagioclase feldspar have been observed in thin section in the study area and are thought to be the most probable origin of the authigenic lettuce-like illite seen in the study area. Illite may also form when there is an excess of potassium in the pore water after alteration of potassium-rich feldspar to kaolin. The conversion of smectite to illite is another possible origin (Wilson and Pittman 1977). However, no smectite has been found to support this mode of genesis in the area. Authigenic illite is of minor significance but, where it does occur, it reduces porosity and inhibits permeability.

Chlorite

Chlorite has been seen in only one sample where it was identified by morphology using SEM. It forms euhedral radiating plates that line an oversized pore in a coarse-grained sublitharenite (Plate 7g). These observations suggest that the chlorite is authigenic. No chlorite was found using XRD and no EDS spectra were possible to confirm this finding. The crystals have lobate edges with individual plates ranging from 20 to 40 microns in diameter and usually attached to a detrital grain. Pore lining chlorite grows normal to detrital grains and may block pore throats to reduce permeability. It is however, present in only very minor quantities.

5.15 CARBONATE

SIDERITE

Siderite occurs as micrite and spar throughout the field. The micrite and spar formed at different times and have different origins as suggested by their diverse modes of occurrence. The micrite is characteristic of carbonate cements formed in the vadose zone, while the sparry siderite is usually associated with deeper burial in the phreatic zone (James and Choquette, 1984).

The micritic variety occurs in finer grained rocks where there is an abundance of carbonaceous material with which it is in contact. Micritic siderite may be massive or emanate as a radial growth away from a coaly substrate (Plate 8a). Radial growth may be due to some recrystallization of the micrite. Micrite may also occur as isolated blotches (Plate 8b) or dispersed throughout the rock. Dapples (1979) noted that a necessary condition for micrite to develop appears to be that enough carbonaceous matter was incorporated in the sediment to maintain a higher concentration of ferrous, than ferric, iron, i.e. maintain reducing conditions. Bands of micritic siderite in bioturbated sediments show a disruption in the siderite band when cutting across burrows filled with clean sand, indicating very early emplacement. Schulz-Rojahn and Phillips (1989) suggest that either the siderite accumulated in a zone subject to bioturbation or the burrow had a different diagenetic history to the siderite bands.

Sparry siderite occurs as coarsely crystalline euhedral crystals that intergrow with other spar crystals, quartz and dickite (Plate 7h). Siderite spar is almost always attached to quartz overgrowths, detrital quartz grains or embayed into detrital grains. The spar appears to have partially replaced the quartz. Rare kaolin books intergrow with the spar (Plate 9a) which suggests that their formation may overlap in regions of high pH.

CALCITE

Calcite has been found in several samples from Toolachee 1 and 3 (Plate 8c and d) and Toolachee East 1, identified using XRD. The calcite is important in the upper formations such as the Nappameri, Toolachee and Epsilon Formations, especially in the north-east of the Toolachee Field. It has been found in only minor quantities in the Patchawarra Formation, some in core, but mostly in the cuttings samples from Toolachee East 1. Calcite was probably formed very early because it acts as framework support in a looser manner than is shown by the quartz-cemented sections (Plate 8e). Calcite generally surrounds quartz with no overgrowth rim between the sparry calcite and the quartz grain. It may also partially replace quartz (Plate 8f and 10a). Calcite may therefore have been precipitated before the quartz overgrowths. Feldspar grains appear relatively unaltered when surrounded by calcite (Plate 8e).

5.16 MICA

Muscovite

Muscovite is present in most samples as tabular crystals (Plate 9b). Particle size depends on the average grain size of the sample and mica usually comprises one to three percent of the rock. Crystals of muscovite are mechanically unstable and are often deformed and broken into the shape of the pore space and hence form a close packing in this area during compaction (Plate 10b). Micas inhibit quartz overgrowth formation at grain contacts. The sheetlike form may act as a localized permeability barrier in some cases where the muscovite is concentrated along a particular layer such as a stylolite. The crystals are mostly unaltered but some alteration occurs in places where the mica has been broken.

Biotite

Biotite is possibly present in small quantities in the sublitharenites and has only been identified in its altered form through SEM observations. It has been altered to alternating plates of kaolin and illite and can be seen to have swelled and been deformed in some cases (Plate 9f).

5.17 ROCK FRAGMENTS

Lithic rock fragments occurring in the study area are composed of polycrystalline quartz, mica and secondary clay minerals. They range between one to 35 percent of the rock composition with an average value of seven percent in the medium grained sublitharenites.

Polycrystalline quartz is the dominant form of lithic fragment in most fine to very coarse grained sediments (Plate 4d). It contains stressed quartz grains that have been fused together, often along ragged boundaries suggesting formation in a metamorphic regime. The grains exhibit undulose extinction and may show some schistose fabric. These clasts are usually rounded and range in size from fine to coarse. It is possible that they have been derived from erosion of fine to coarse grained quartzites of the underlying Warburton Basin. Overgrowths do not generally form on the polycrystalline quartz grains (Plate 4c) and hence they are more subject to compactional effects than monocrystalline quartz grains.

Orientated muscovite often occurs within polycrystalline quartz clasts. Some clasts are almost entirely composed of mica with a high degree of schistosity. This mica generally appears unaltered by diagenesis.

Up to 30 percent of the rock fragments have been altered to clays and micas so that their origin cannot be assessed. These grains appear to have been deformed due to compaction and the clays have taken on a preferred orientation. Minor coarse volcanic rock fragments have been observed in some very coarse grained samples.

5.18 FELDSPARS

Plagioclase and orthoclase feldspars are present in very minor quantities. Both have been identified in thin section (Plate 9e and 10 c) and using cathodoluminescence (Plate 3a) but none was observed in SEM. Plagioclase is distinctive because of its twinning and is generally found partially dissolved.

True estimates of the amount of feldspar present in the original sediment are extremely difficult because most of the feldspar has probably been either dissolved out to form oversized pores or has altered to kaolin leaving no trace of the original grain or structure. Some of the rock fragments that show alteration to orientated clays may, in fact, be altered feldspar grains. The feldspars may best be identified using cathodoluminescence as the feldspars appear red (Plate 3b). Some rocks contain as much as 10% feldspar; however, 3% is about average. Feldspars are best preserved when encased in carbonate cement or enclosed in quartz grains (Plate 9e and 10c).

5.19 ORGANIC MATERIAL

Bituminous coal is relatively common in the Toolachee Field and is indicative of the fluvial to lacustrine origin of the sediments. Coal generally occurs in seams up to several metres thick and varies in composition with different amounts of vitrinite, liptinite and inertinite. Those coals which contain as much as 20% liptinite show beading of water suggesting the presence of liquid hydrocarbons. Beading shows up in the sands directly above some of the coals. The liptinite macerals present include liptodetrinite, sporinite and minor resinite (B.Michaelsen-pers.comm.). Telovitrinite is the main vitrinite maceral in the coal. This vitrinite is an ideal source for gas. Inertinite is relatively minor and is composed primarily of fusinite (B.Michaelsen-pers.comm.).

Coaly stringers are common in the siltstones and some sands, and have been deformed between grains during compaction. Thin stringers sometimes occur along the site where pressure solution has formed large stylolites (Plate 2b). The stringers also appear necessary for the formation of micritic siderite which always occurs in immediate contact with the coal.

Bitumen staining occurs in some samples and occupies either whole pores or rims the pore. Bitumen coats the final stage of quartz overgrowths and also appears as a honey colour stain in the dickite. This indicates that hydrocarbons have passed through these reservoir rocks after the final stage of quartz overgrowth formation and were able to penetrate the microporosity in the authigenic kaolin. They have also been observed along stylolites which may be as relict material.

DISCUSSION

The effects of diagenesis on reservoirs in the study area have been profound and have resulted in the preservation of up to 22% porosity. The first stage of diagenesis recognized is early stage compaction in which there was deformation and dewatering of clay laminae as well as deformation of micas. Initial silica cement was precipitated as quartz overgrowths in the meteoric water zone and associated flushing probably caused the dissolution or alteration of feldspars and the more labile rock fragments. The introduction of quartz cement at this early stage bound the framework of loosely packed sands which minimised the effects of further compaction on the quartz grains and newly-formed dissolution pores. Three generations of quartz overgrowth rims were precipitated, with authigenic kaolin precipitating and intergrowing with the quartz cement, primarily during the first and second generations, with some also intergrowing with the third generation of overgrowth. The precipitation of dickite continued after overgrowth formation, growing further into the pores, until a time when oil migrated through some of the reservoir sands. Spar siderite then started replacing quartz at the very end of dickite precipitation and partially filled pores. The precipitation of sparry siderite was possibly brought about by a continued trend of the pore waters towards higher pH values. Modern day pore waters in the study area range from pH values of 6.0 to 8.6, consistent with this trend. This would have then also been responsible for chemical etching the faces of some quartz overgrowths.

5.2 DISTRIBUTION OF DIAGENESIS

The distribution of facies and paleoenvironment appear to be the primary controls on diagenesis in the Toolachee Field with depth only playing a relatively minor role within the interval studied.

5.21 FACIES

Both detrital and authigenic mineralogy appear to depend on grain size. Variations in quartz, dickite, kaolinite, illite, siderite and lithic fragments tend to reflect the changes observed in grain size.

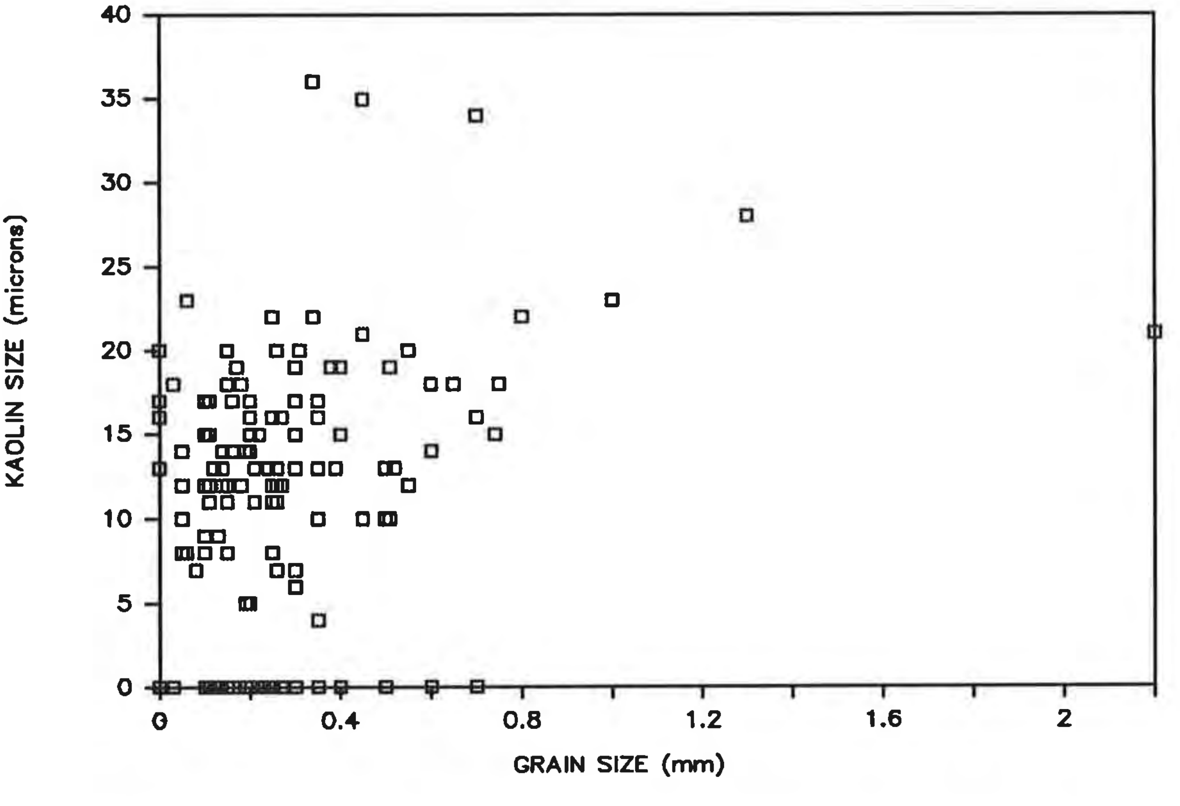
Quartz overgrowths are thin to thick and vary with grain size. The fine-grained rocks, generally, are well cemented in places by overgrowth rims on quartz, while other areas with higher clay contents have undergone more compaction and have little or no overgrowth formation (Plate 3d). The medium-grained sublitharenites tend to contain medium to thick quartz overgrowth rims which are relatively uniformly spread throughout the rock (Plate 1b), with only those areas of quartz in contact with kaolin having thin to absent overgrowth rims.

The coarser-grained sublitharenites to litharenites generally have thinner overgrowth rims around the quartz (Plate 10d and e) and the quartz cement is sporadically dispersed, tending to form in clusters. The thinner rims on coarser grains may indicate a limited supply of silica for overgrowth formation; hence the cement is spread more thinly around the larger grains. Some larger grains have thicker rims which may be disrupted by the presence of authigenic dickite in adjacent pore spaces.

The illite to kaolin (I/K) ratio tends to decrease with an increase in grain size (Figure 5.2), because of the increased presence of authigenic dickite in the coarser-grained rocks. In the finer-grained rocks, detrital illite and kaolinite are dominant, with the ratio being higher. There is an increase in illite and kaolinite with a decrease in grain size with a subsequent decrease in dickite. Both kaolinite and dickite may be present in the same sample.

FIGURE 5.4

TOOLACHEE FIELD: KAOLIN VS GRAIN SIZE

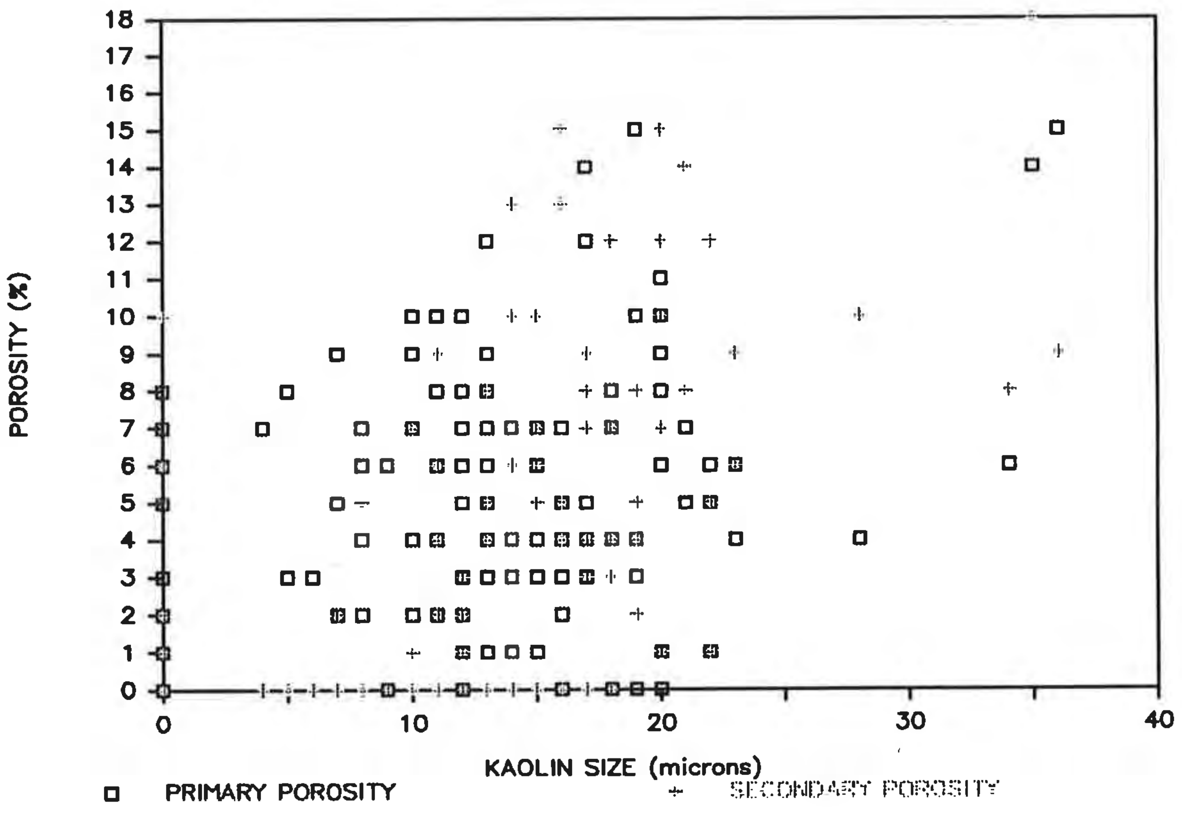


Kaolin size (from SEM) may be up to 60 microns (Plate 9b) and enlarges with increasing grain size (from thin section analysis) of the rock (Figure 5.4), both primary and secondary pore size (Figure 5.5), and a decrease of I/K ratio (Figure 5.6). The increase in crystal size is probably due to an increase in the flow of pore waters through the coarser grained sediments and more room for growth of the clay crystals. The result of the increased crystal size of kaolin is an increase in microporosity which may be up to 15 microns in diameter.

There is a decrease in illite (Figure 5.7) and a slight decrease in kaolin (Figure 5.8) with an increase in quartz content. This trend possibly indicates that the cleaner sands contain a higher quartz content.

FIGURE 5.5

TOOLACHEE FIELD: POROSITY VS KAOLIN SIZE



Micritic siderite also appears to show a dependence on grain size and mineralogy, with an increase in micritic siderite observed in thin section from increases in I/K ratio (from XRD) and the amount of carbonaceous material (Figure 5.9), and decreases in grain size (from thin section) (Figure 5.10) and quartz (from thin section) (Figure 5.11). The micritic siderite, therefore, tends to occur in fine to very fine-grained sublitharenites which contain carbonaceous material and detrital clays. Sparry siderite usually occurs in the coarser-grained rocks associated with quartz and lower I/K ratios and is not found in conjunction with carbonaceous material.

Figure 5.6

TOOLACHEE FIELD: KAOLIN VS ILLITE TO KAOLIN RATIO

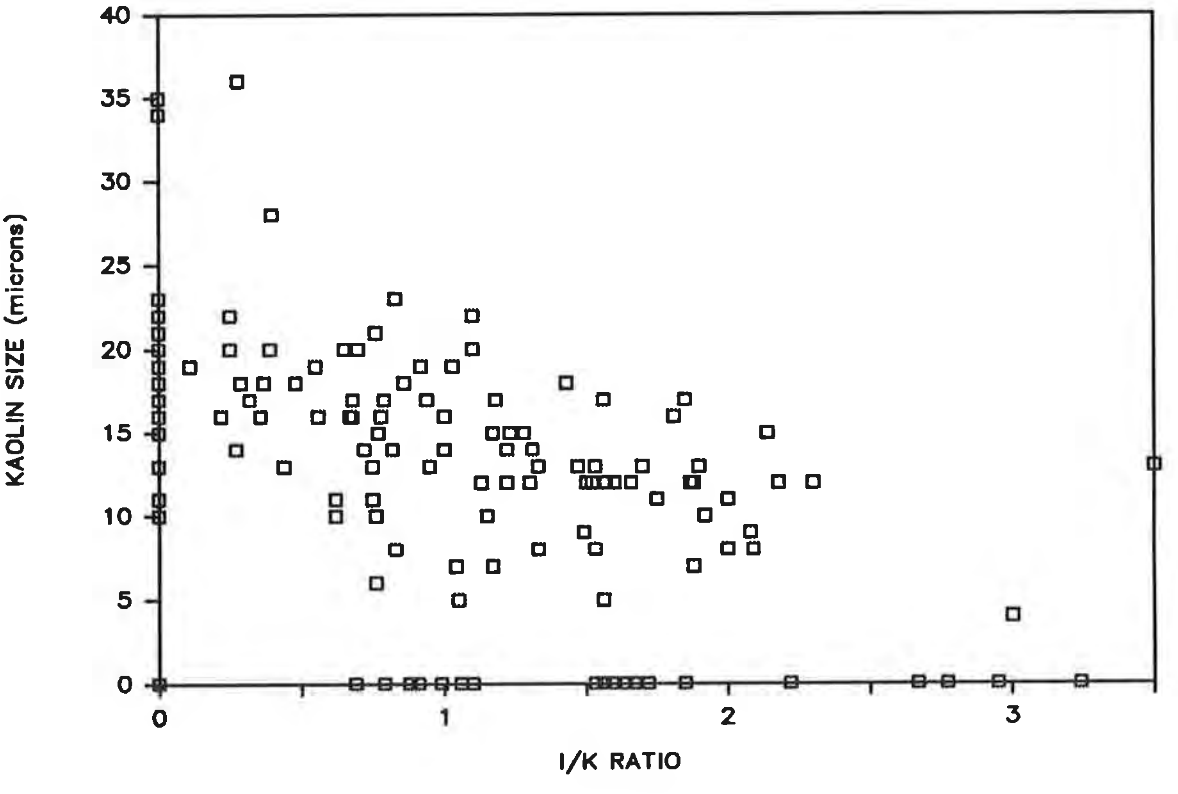


Figure 5.7

TOOLACHEE FIELD: ILLITE VS QUARTZ

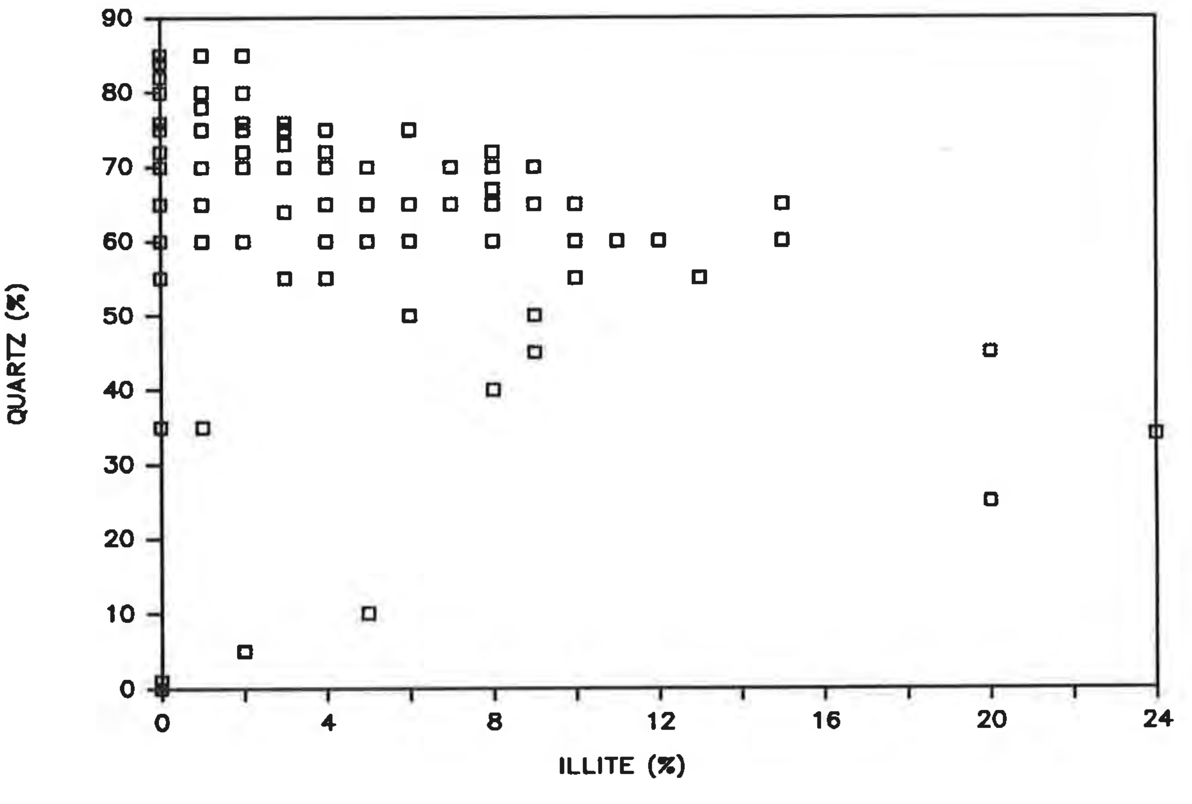


Figure 5.8

TOOLACHEE FIELD: KAOLIN VS QUARTZ

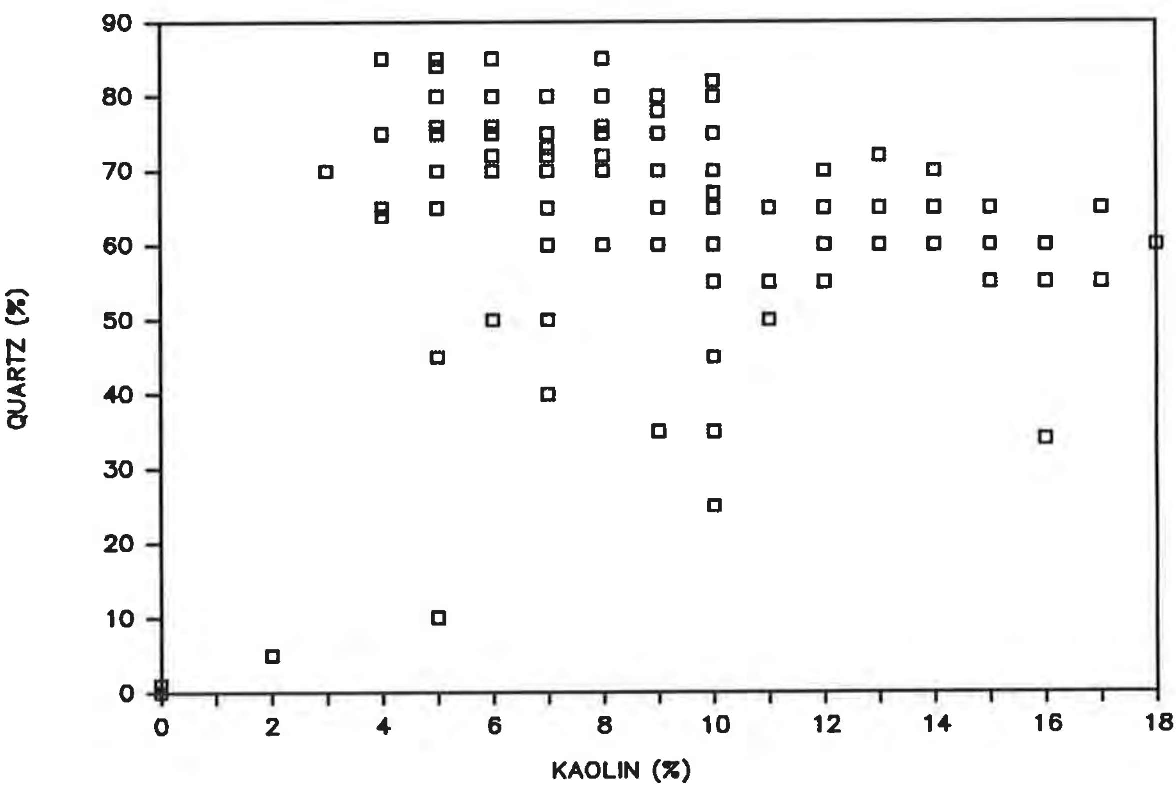


FIGURE 5.9

TOOLACHEE: MICRITIC SIDERITE VS CARBONACEOUS MATERIAL

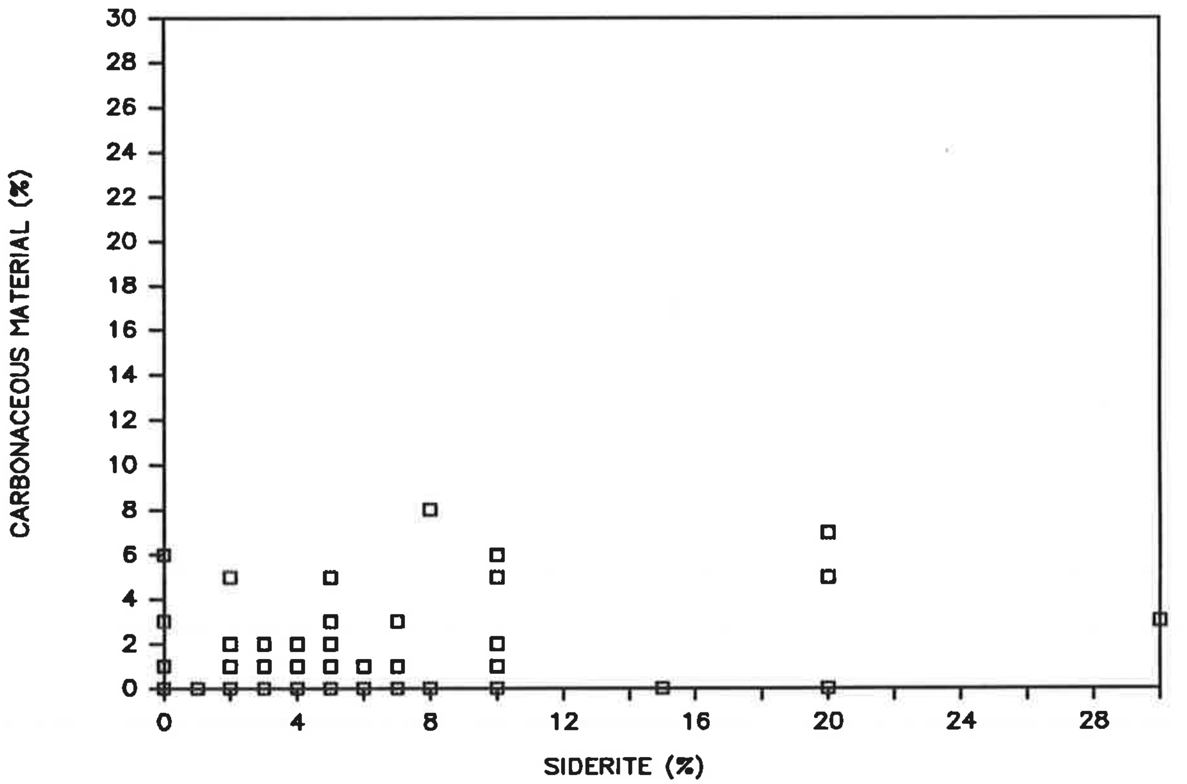


FIGURE 5.10

TOOLACHEE: MICRITIC SIDERITE VS GRAIN SIZE

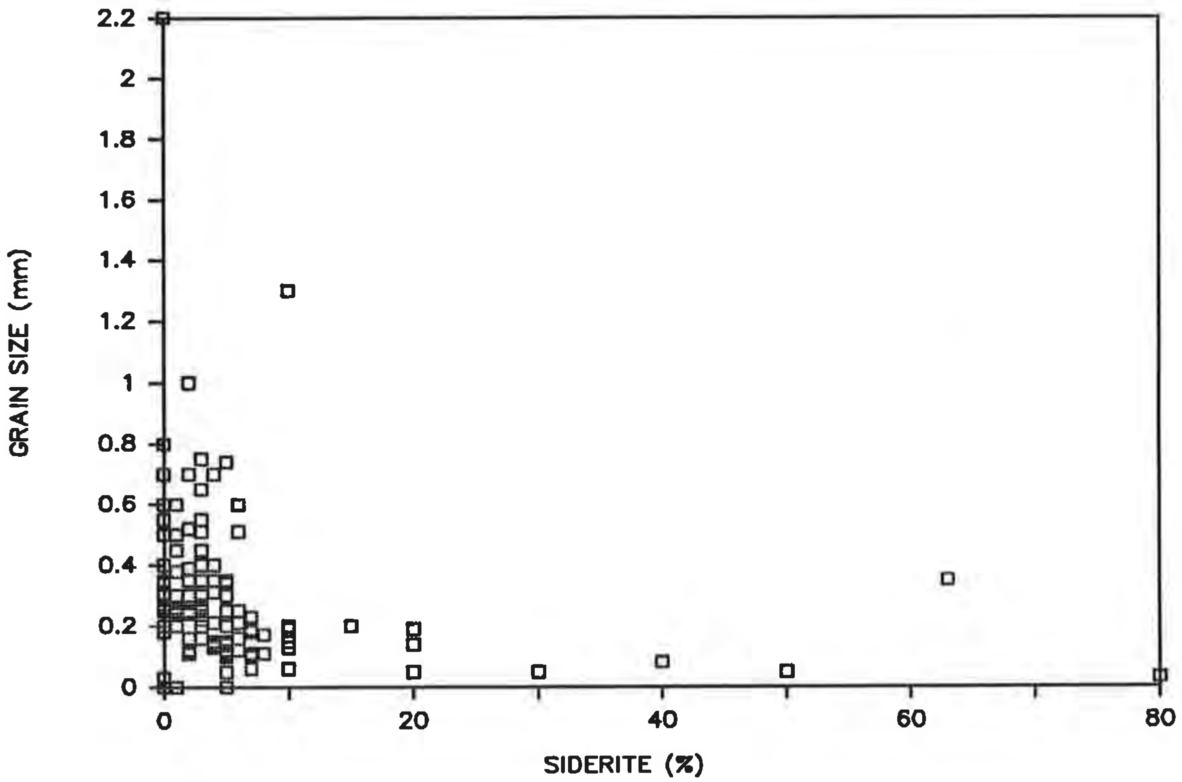
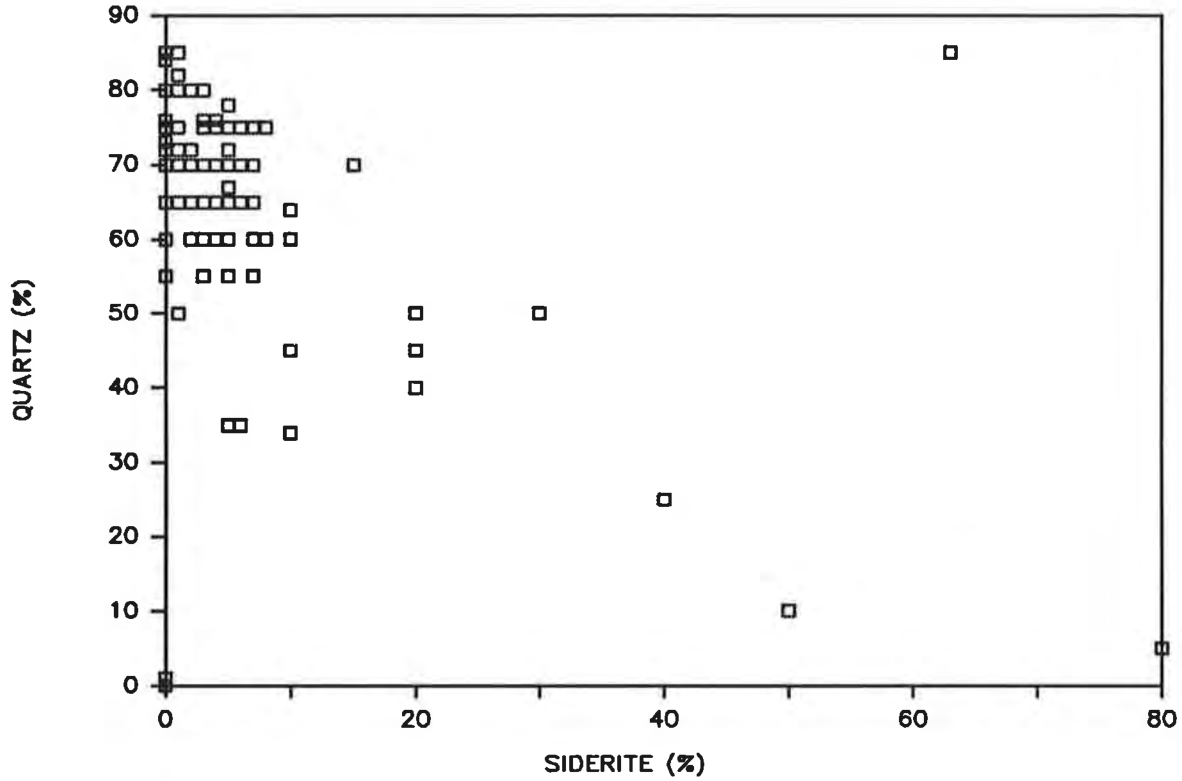


FIGURE 5.11

TOOLACHEE: TOTAL SIDERITE VS QUARTZ



5.22 DEPTH

Variations in diagenetic trends with depth have been discussed by formation intervals, using information gained from cuttings samples and core.

The sand near the base of the Nappamerri Formation tends to contain some quartz overgrowths and is generally well cemented by carbonate. Carbonate, both siderite and calcite, has been observed in thin sections of cuttings samples to occlude porosity but keeping a very loose framework of detrital grains. Quartz overgrowths do not normally appear next to the carbonate but occur between some detrital quartz grains. Where carbonate is minor, quartz overgrowths are more prevalent and primary porosity is greater. Toolachee 3 and Toolachee East 1 contain high amounts of carbonate, up to 60%, which fills most of the porosity. Toolachee 1 contains less carbonate and shows good primary porosity of up to 12% with some secondary porosity.

The Toolachee Formation contains a zone of carbonate cementation through the upper sands. This zone was identified from cuttings samples in Toolachee 1 and 3 as well as Toolachee East 1. The sparry carbonate provides a very loose grain framework for the rock with the quartz grains loosely encased in siderite or calcite. XRD results show the carbonate is primarily siderite in Toolachee 1 and 3, with calcite prominent at Toolachee East 1. Carbonate reduces porosity to a level below 6% and minimises quartz overgrowth formation. Authigenic kaolin is slightly more prominent in the upper sands than in the lower sands, which contain much less carbonate and thicker quartz overgrowth rims. The euhedral quartz overgrowths provide a rigid, loose framework which has helped preserve very good primary porosity with some secondary porosity. This preservation can be seen in core from Toolachee 1 in which 22% porosity and 236 millidarcies permeability has been recorded from core plug analyses (Appendix 2). Cuttings with good porosity were found in Toolachee 1 and 3 while those from Toolachee East 1 were tight, because of more intense silicification. The cuttings samples from Toolachee East 1 showed thick interlocking quartz overgrowth rims which occluded most of the porosity. Carbonate cementation of the grains was also common with alteration of feldspar to carbonate observed in samples 0648 and 0650.

The cuttings samples examined from the Daralingie Formation of Toolachee 1 and Toolachee East 1 showed euhedral quartz overgrowths cementing a loose framework of mostly monocrystalline quartz grains. Good primary porosity and some secondary porosity have been preserved at these locations. Porosity was obstructed in Toolachee East 1 where carbonate cementation was present. The Daralingie Formation is absent at Toolachee 3 where the Toolachee Formation directly overlies the Roseneath Shale.

The Epsilon Formation has siderite as a major porosity reducing mineral. Siderite occurs throughout the Epsilon Formation as both spar and micrite. Siderite often fills most of the pores when it is present (Plate 10f) and is only reduced in abundance at Toolachee 34 and Munkarie 2. In these wells, good porosity and bitumen staining are both observed in core samples. Calcite, as well as siderite, is observed to occlude porosity in Toolachee East 1. Authigenic kaolin, as well as quartz overgrowths, is a major porosity reducing mineral in the

Toolachee region. Authigenic illite was observed using SEM to be more abundant in Munkarie 2.

The Patchawarra Formation, described in more detail below, contains euhedral quartz overgrowths which cement the grains into a loose framework. Porosity tends to be relatively good, and is mostly primary, but there is an increase in secondary oversized pores compared to the above formations. Toolachee East 1 contains an increase in silicification with interlocking quartz overgrowths occluding most porosity. There appears to be an increase in authigenic illite in Munkarie 2 where lettuce-like illite was observed using SEM.

There is also a slight overall increase in quartz, kaolin and siderite with depth in the southern part of the Toolachee Field. These trends, at least in the case of quartz, can be attributed to the general increase in grain size through the Patchawarra Formation in this region.

5.23 PALEOGEOGRAPHIC LOCATION

PATCHAWARRA FORMATION

Association P1

No thin sections from core were studied from Association P1.

Association P2

Overgrowth rims on quartz grains tend to be moderate to thick with those rims on coarse grains being the thinnest and most variable. The packing of the grains is generally loose, but some tight packing occurs in stylolitised regions. Stylolites and chemical etching of quartz are widespread in the medium to coarse-grained sediments of the eastern and south-western Toolachee Field. Minor healed fractures in quartz were observed in Toolachee 19. The siderite present is almost all sparry siderite with only minor amounts of micrite existent in the fine-grained sublitharenites. Alteration of feldspars appear more prevalent in the medium to coarse-grained sediments and bitumen staining has been observed in the east of the Toolachee Field at Toolachee 6 and Toolachee 19.

Note: No detailed diagenetic discussion of Epsilon and Toolachee Associations due to lack of suitable data from these formations.

ASSOCIATION P3

Moderate to thick overgrowth rims were observed on quartz in Association P3 with the coarser-grained sediments generally containing a thinner rim than the medium to fine-grained sediments. Many of the quartz overgrowth rims are zoned, indicating one to two generations of quartz cement have been precipitated. The presence of dickite in pore spaces appears to inhibit the precipitation of overgrowth rims on quartz with the dickite often intergrowing with the first generation cement. Dickite is abundant in the fine to coarse-grained rocks and often contains microporosity. Chemical etching of quartz is widespread in the Toolachee Field but was unobserved in Brumby Field. Stylolites are also common in the Toolachee and Brumby Fields; they are, however, absent in the point-bar sequence at Toolachee 6 in the eastern part of the field. There is a higher feldspar content in Association 3 than in either Association P4 or P5. The grain sizes have generally increased from Association P4 and the rocks are sometimes litharenites.

ASSOCIATION P4

Thick quartz overgrowth rims have been observed surrounding quartz grains in medium-grained rocks in the Toolachee Field while rims are thin to absent in coarse-grained rocks of the south-western Toolachee and Brumby Fields. Quartz overgrowth rims are also thin to absent in areas next to stylolites. Stylolites and microstylolites are present in the medium to coarse-grained sublitharenites and generally absent from the finer-grained rocks of the central to south-eastern Toolachee Field. Three generations of quartz overgrowth formation have been noted. Bitumen staining is present in Toolachee 1, Brumby 1, and Munkarie 2, suggesting that migration of liquid hydrocarbons occurred at the end of the third stage. The presence of authigenic dickite appears to retard overgrowth formation on quartz. Those pores partially filled with dickite generally contain thin to absent overgrowths when in contact with the dickite. Dickite is absent from some of the finer-grained rocks of the south western Toolachee and is generally in greater proportions in the medium to coarser-grained rocks of the western and north eastern Toolachee Field, the Brumby and Munkarie Fields. Authigenic illite appears to be more abundant in Brumby and Munkarie Fields while there is very little in the Toolachee Field. This increase in authigenic illite may be due to higher geothermal gradients in these fields. Sparry and micritic siderite are abundant in all three fields with micrite mostly in the finer-grained rocks while sparite is present in fine to coarse-grained sublitharenites. Minor fracture healing has been observed in Brumby 1.

ASSOCIATION P5

In Patchawarra Association P5, relatively thick overgrowth rims occur on quartz in the medium to fine-grained rocks. The quartz overgrowth rims exist uniformly throughout the rock except where authigenic kaolin has formed. In pore spaces containing kaolin, quartz overgrowths are generally greatly reduced in thickness, or lacking altogether. The overgrowth rims are often zoned under luminescent light and consist of one to three generations of overgrowth development. Some kaolin appears to have formed during the first generation of overgrowth formation while more kaolin has formed during the second generation. Relatively thin overgrowth rims occur in coarser-grained sublitharenites with most quartz cement forming in sporadic patches, leaving just enough overgrowth rims on other grains to give a straight euhedral boundary. The medium to coarse-grained sediments are located in the eastern and south-central region of the Toolachee Field while the finer-grained sediments are located in the central to western sector.

Chemical etching of quartz in association 5 is widespread throughout Toolachee, Brumby, and Munkarie Fields with etching only unobserved in the far north of the Toolachee Field at Toolachee 21. The chemical etching appears to occur regardless of grain size.

Stylolites are widespread throughout the study area in Association 5 and occur in fine to coarse-grained sublitharenites, being more prevalent in the coarser-grained samples.

Dickite appears to be more abundant in the coarser-grained samples taken from channel deposits from the eastern and south-central regions of the Toolachee Field and western Brumby Field. Channel deposits are the coarsest sediments deposited by the river and comprise the basal section of the point bar sequence and may be tens of metres thick. Quartz and lithics are also more abundant in these coarser-grained rocks at the expense of clays and micrite. Micritic siderite is more abundant in the finer-grained rocks throughout the study area while sparry siderite is more prevalent in the fine to medium-grained sublitharenites.

CHAPTER 6 RESERVOIR QUALITY AND DISTRIBUTION

6.1 INTRODUCTION

Reservoir quality of a sediment is an assessment of the amount of fluid contained within the sediment and the potential for recovery. The storage capacity of the reservoir is determined by the porosity of the rock. Pores will contain irreducible water directly adjacent to the grains with the hydrocarbons in the remainder of the pore.

Gas is dominant in the study area, with the western lobe containing wet gas and the eastern lobe containing dry gas. However, at one stage, oil passed through some parts of the reservoir leaving bitumen staining in the pores. The pore fluids were initially water, oil and then gas, indicated by relict amounts of early phases in some pores.

Three main types of porosity are found: primary, secondary and microporosity. Primary porosity is pore space resulting from the original rock texture. Secondary porosity is pore space formed during diagenesis such as dissolution of sedimentary grains or authigenic cement, or fracturing of the rock. Microporosity is the pore space which ranges in size from two to fifteen microns that occurs generally in association with authigenic kaolin.

The recoverability of hydrocarbons from the reservoir depends on permeability. This is the amount of interconnection of pore throats between sedimentary grains. Recovery rates also depend on irreducible water saturation. If the pore throats are too small and the water barrier across the throat is joined, then hydrocarbons will not be able to squeeze through the throat.

The interconnection of pore throats and irreducible water saturation are extremely important in determining the economic viability of a reservoir.

6.2 POROSITY

6.21 PRIMARY POROSITY

Primary porosity is often best preserved in medium to coarse grained sublitharenites which contain minor amounts of detrital clay. Common triangular pores are the remnants of primary pores and occur between interlocking euhedral quartz overgrowths (Plate 3b). Pore size ranges from fifteen to two hundred microns depending on the grain size of the rock. They are often bound on all sides by straight edges which show either no or only minor signs of intergrowth with kaolin or siderite (Plate 9c). The presence of primary porosity is important for permeability because primary intergranular pores are generally interconnected, whereas secondary pores may be isolated.

6.22 SECONDARY POROSITY

The main classes of secondary porosity occurring in the study area are primarily due to dissolution of sedimentary grains, with minor dissolution of pore filling cement and fracturing. The major textual groups of these secondary pores are oversized pores with minor intra-constituent pores and open fractures (Schmidt and McDonald, 1979).

Porosity created by the dissolution of sedimentary material is the most important class of secondary pore observed in the Toolachee Field. The main texture exhibited is oversized pores (Plate 5c) that can be observed through inhomogeneity of packing, elongation of pores, large euhedral quartz overgrowths and some corroded grains. The oversized pores range in size from eighty to one thousand microns depending on grain size of the rock. Schmidt and McDonald (1979) suggest that oversized pores exceed the diameter of adjacent grains by a factor of at least 1.2. Oversized pores tend to be unevenly scattered throughout the rock and may vary greatly in size within the same specimen. These pores may be elongate (Plate 5c) and generally conform with the fabric of the rock such as surfaces of grain imbrication. The oversized pores generally are surrounded by excellent rhombohedral quartz overgrowths or may be filled in by authigenic dickite and euhedral siderite (Plate 9d). Oversized pores have probably formed by the dissolution of feldspars and/or rock fragments. However, because the dissolution process has been so complete, there is little evidence to predict accurately the nature of the original grains. Corroded grains of feldspar are rare but can be seen in some samples in thin section and alteration to clays may be distinguished using cathodoluminescence (Plate 6b). The oversized pores are extremely important in medium to very coarse-grained litharenite because they make up most of the pore spaces in the rock.

Intra-constituent pores are rare but do occur in some of the partially dissolved feldspar grains. These grains are primarily plagioclase and would play a very minor part in overall porosity.

Dissolution of pore-filling cement is very minor with its only effect appearing to be the chemical etching of quartz overgrowth. Although this partial dissolution of quartz cement is widespread, the etching is so minor that it would only add a fraction towards porosity.

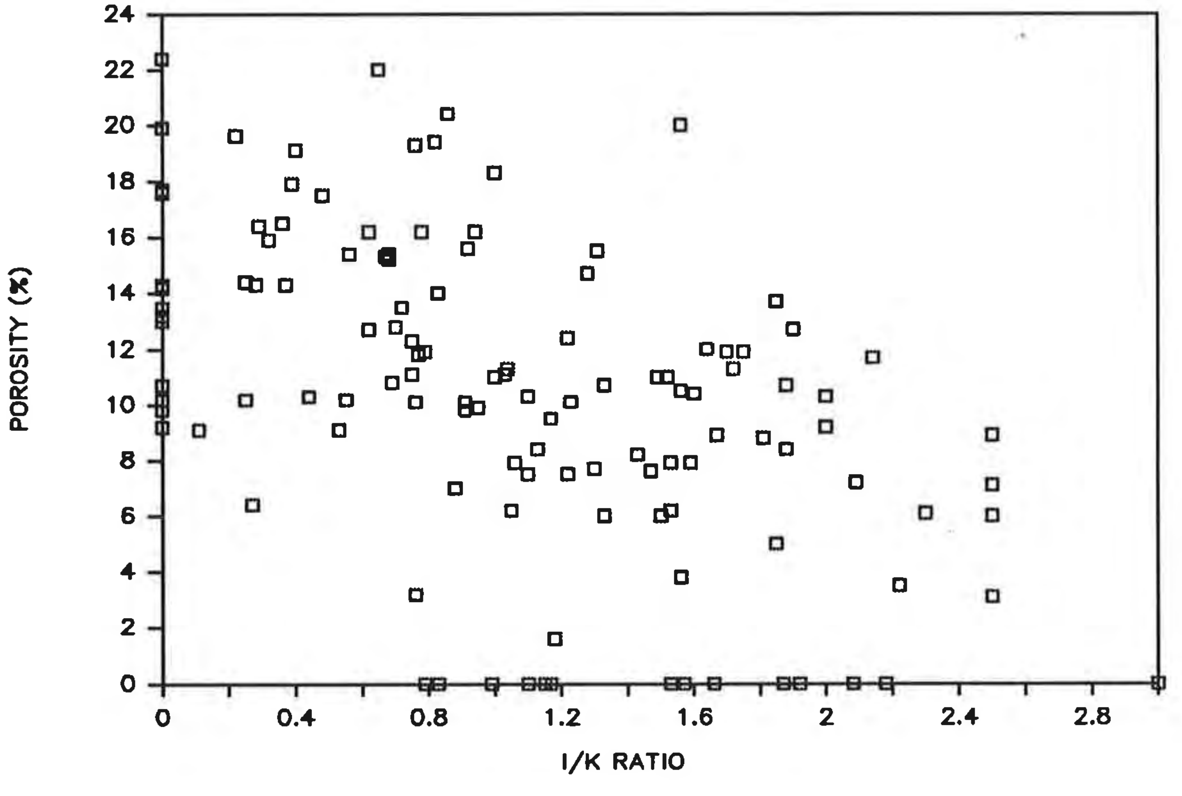
Porosity created by fracturing of the rock occurs on a minor scale with some vertical and horizontal fractures being observed. Most fractures have an indeterminate origin and may have been formed during drilling. Some vertical fractures, however, are open and contain bitumen staining. Other fractures have been filled by authigenic dickite. Fractured grains have been observed using cathodoluminescence and have usually been filled in by the first, and sometimes second, generation of quartz overgrowth cement. It can therefore be determined that some fracturing of the rock was present in the reservoir at the time of hydrocarbon migration in those fractures left open after precipitation of diagenetic minerals. This small addition to total porosity is significant because it also may have acted as a migration pathway for petroleum liquids and gas.

6.23 MICROPOROSITY

Microporosity associated with euhedral kaolin plays an important part in overall porosity because these clays are abundant in oversized pore spaces (Plate 9d), intergranular spaces and sometimes block pore throats in the medium to coarse-grained rocks. The micropores range from two to fifteen microns in diameter and hence may be able to hold and produce gas, providing the irreducible water film on the clays does not block the pore throats. The increase in water associated with irreducible water saturation in dickite may also cause an increase in water saturation of the rock and also a possible decrease in resistivity on the resistivity log. The illite to kaolin ratio decreases with an increase in porosity (Figure 6.1). The decrease in the ratio is significant in that the lower the ratio, the more likely the authigenic origin of the kaolin and hence the greater proportion of microporosity. This trend is best displayed in the crossbedded (Sx) and massive (Sm) sandstone facies.

FIGURE 6.1

TOOLACHEE FIELD: I/K RATIO VS POROSITY



6.3 PERMEABILITY

Permeability denotes the ability of a rock to allow a liquid or gas to flow through it. The porosity of a sandstone is ineffective if there is no interconnection of pores. Clean well-sorted sandstones with good primary porosity appear to contain the best permeabilities, with silty rocks the worst. In clean sands composed primarily of quartz and dickite, the amount of dickite in the pore throats is probably the major limiting factor with the degree of quartz cementation also being important. Dickite nucleates on the surface of quartz grains and grows into the pore space. During this period of precipitation, dickite may not only fill the pore but extend into the pore throats and hence block off interconnection of adjacent primary and secondary pores. Dickite contains microporosity which may allow some gas flow, but at reduced rates, between the pores. The presence of illite also appears to be significant with lower permeabilities occurring where illite is abundant. This may be due to the detrital nature of illite and hence a more active pore blocking role through being squeezed into pore throats during compaction. Fully interlocking quartz overgrowths which totally occlude porosity and block pore throats, are present in most samples but only in minor quantities.

Siderite is another cement that can adversely effect permeability of the reservoir. Sparry siderite tends to precipitate as crystals within oversized pores. Siderite crystals also form in clean primary pore spaces and in pore throats (Plate 9e) and may substantially reduce interconnection of pores in some cases. Crystals of siderite form best in clean sands which often would have good porosity, diminishing the quality of the best reservoirs.

Ductile grains and detrital clays are detrimental to permeability because they are generally squeezed into the pore shape and into the surrounding pore throat. These grains are the primary cause for loss of permeability in the finer-grained rocks where there is an abundance of detrital clays, micas and altered lithic rock fragments. Ductile-altered lithic rock fragments will also play an important roll in reducing permeability in medium to coarse-grained litharenites.

It is important to note the lack of chlorite and illite/smectite clays because these may have a very detrimental effect on permeability. These fine crystals tend to line pores and pore throats, extending out from the grain at right angles. The thickness of the irreducible water layer is extended and can often block pore throats. Early authigenic illite can be significant in reducing the amount of quartz/carbonate cementation and therefore preserving some primary porosity. Authigenic chlorite may also reduce the amount of quartz and carbonate cementation, if formed early.

6.4 VARIATIONS IN RESERVOIR QUALITY

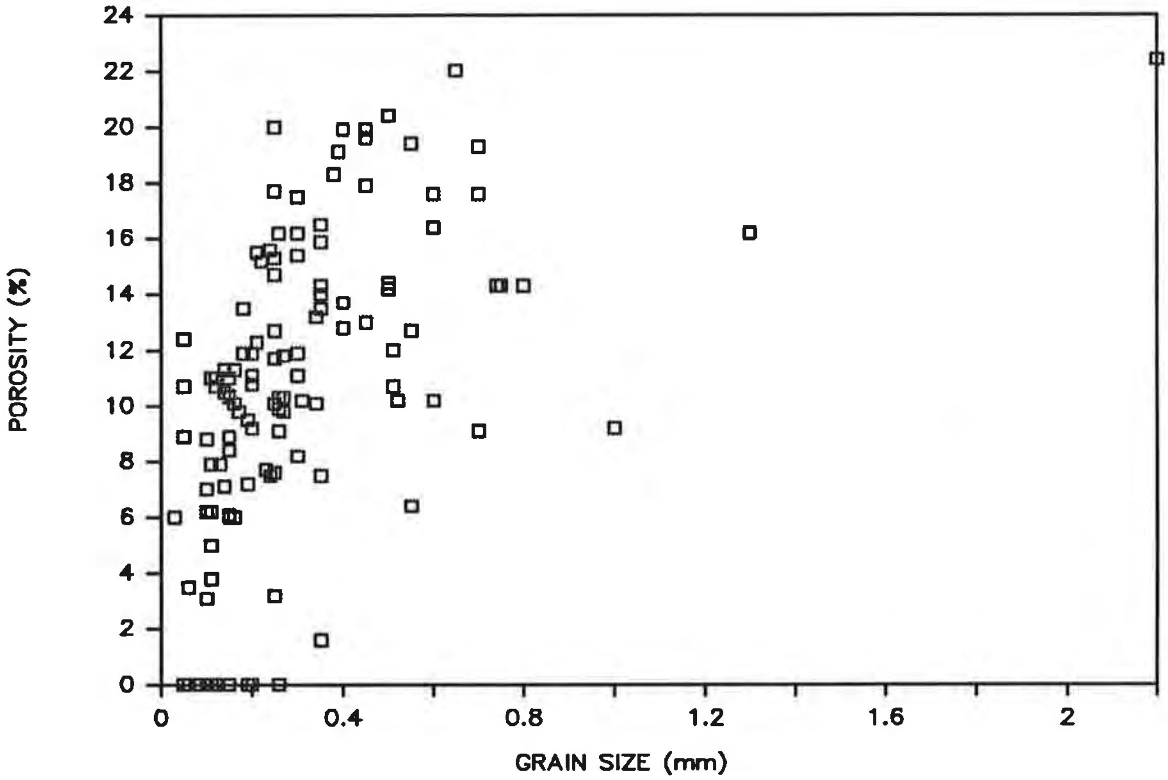
6.41 FACIES

Massive sublitharenites (Sm facies) tend to have porosities ranging between 6-20% with an average value of 12% and permeabilities up to 130md. Porosity does not appear to be affected by depth but rather by the distribution of facies with depth. The major trend observed is a correlation between porosity, permeability and grain size with respect to depth

(Figures 6.2 and 6.3) (porosity and permeability from core plug analysis, grain size from thin section analysis).

FIGURE 6.2

TOOLACHEE FIELD: POROSITY VS GRAIN SIZE



When one parameter increases, they all increase with the best zone occurring in the Patchawarra Formation at depths of 7200-7400 feet. Grain sizes range between 0.1-1mm with an average of 0.35mm. This facies is important in a hydrocarbon reservoir because it contains significant porosities and permeabilities which are only surpassed by crossbedded facies.

Crossbedded sublitharenites (Sx,St,Sp) have porosities which range from 9-22% with permeabilities from 0-750md (Patchawarra), 0-70md (Epsilon) and 230-300md (Toolachee). Porosity appears to decrease overall with depth. However, within each formation, there are both increases and decreases with depth, probably due to changes in grain size across point bar deposits. Permeability appears to depend not on depth but more on grain size, with the larger grain sizes in the Patchawarra Formation giving the best permeabilities. Porosity also follows the trends in grain size but is probably more affected by diagenetic alteration. The crossbedded facies contains the best porosities and permeabilities and shares the coarsest grain sizes with Sm facies. It is the most important facies because it contains consistently high porosities and permeabilities from which hydrocarbons can be, and are being, produced.

The rippled sandstone facies (Sr) has porosities ranging from 0-13% with an average of 8% and permeabilities of 0-1.8md. Porosity shows an overall decrease with respect to depth from the Toolachee to the Patchawarra Formations while, within the Patchawarra Formation, it displays an increase with depth. The permeability of the sandstones reflects the same trends that occur in the grain size distribution with depth, while the porosity graph shows different trends. This facies, while containing reasonable porosities, generally contains poor permeabilities and hence is marginal when considering the economic viability of a reservoir.

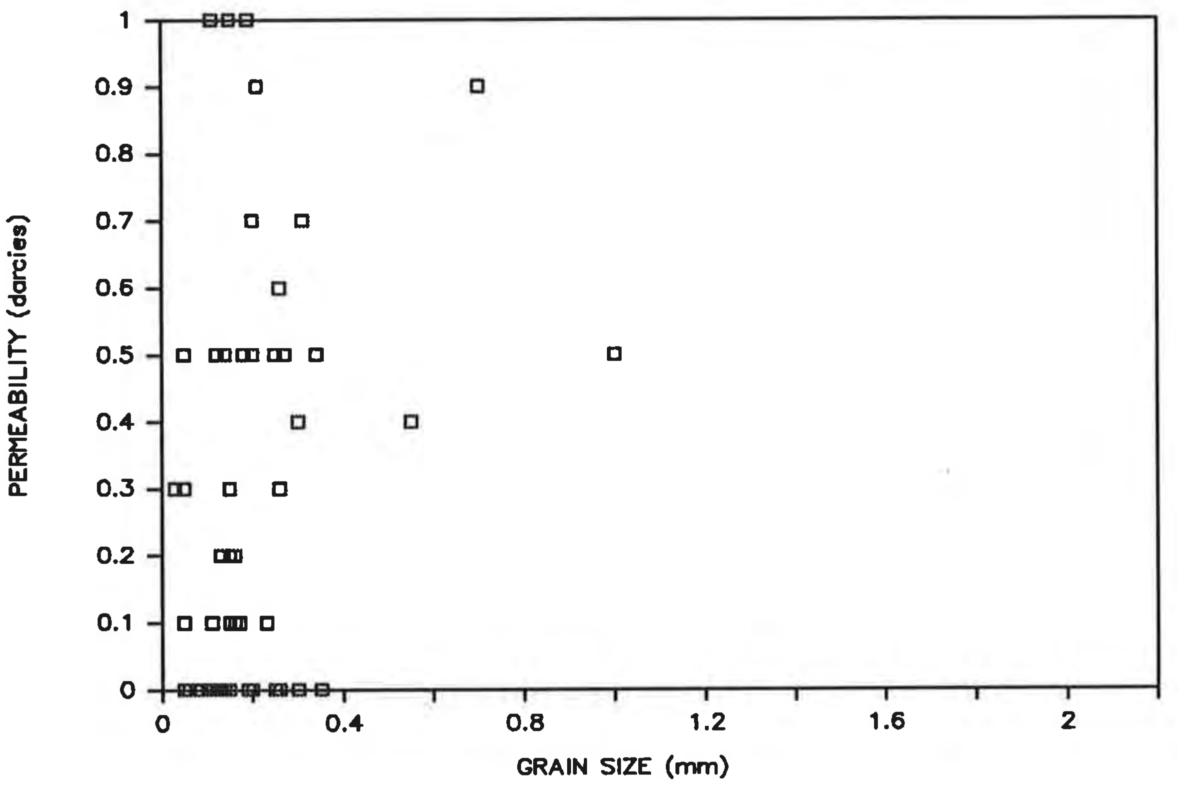
The shaly sandstone facies containing ripples and flaser bedding (Sw/Fw) has porosities in the order of 0-11.5%, general permeabilities of 0-2md and grain sizes of 0.04-0.3mm. Unlike the porosity-permeability graphs, porosity graphs are different and do not indicate the presence of any trends with depth. This facies contains marginal porosities and generally uneconomic permeabilities for hydrocarbon production.

The sandy mudstone facies (Fl) has porosities of 0-10% and permeability values of 0-0.3md with the majority being zero. No significant trends can be seen here probably through lack of data as all samples with any significant porosity came from the Patchawarra Formation. This facies is not considered a viable prospect for oil or gas production because of its poor porosities and permeabilities.

Overall porosity appears to be best and most consistent in the medium grain-size range. This may suggest that the coarser-grained rocks, which are less texturally mature and more poorly sorted, are more variable in nature. Permeability, however, generally increases with increases in grain size (Figure 6.3).

FIGURE 6.3

TOOLACHEE FIELD:PERMEABILITY VS GRAIN SIZE



Porosity also tends to increase with a decrease in the I/K ratio (Figure 6.1) while there has been no relationship observed between I/K ratio and permeability. Porosity appears to depend more on diagenetic effects such as early silica cementation, production of authigenic clays, and production of secondary porosity. Permeability seems to depend more on environmental control such as grain size, sorting and depositional facies.

6.42 DEPTH

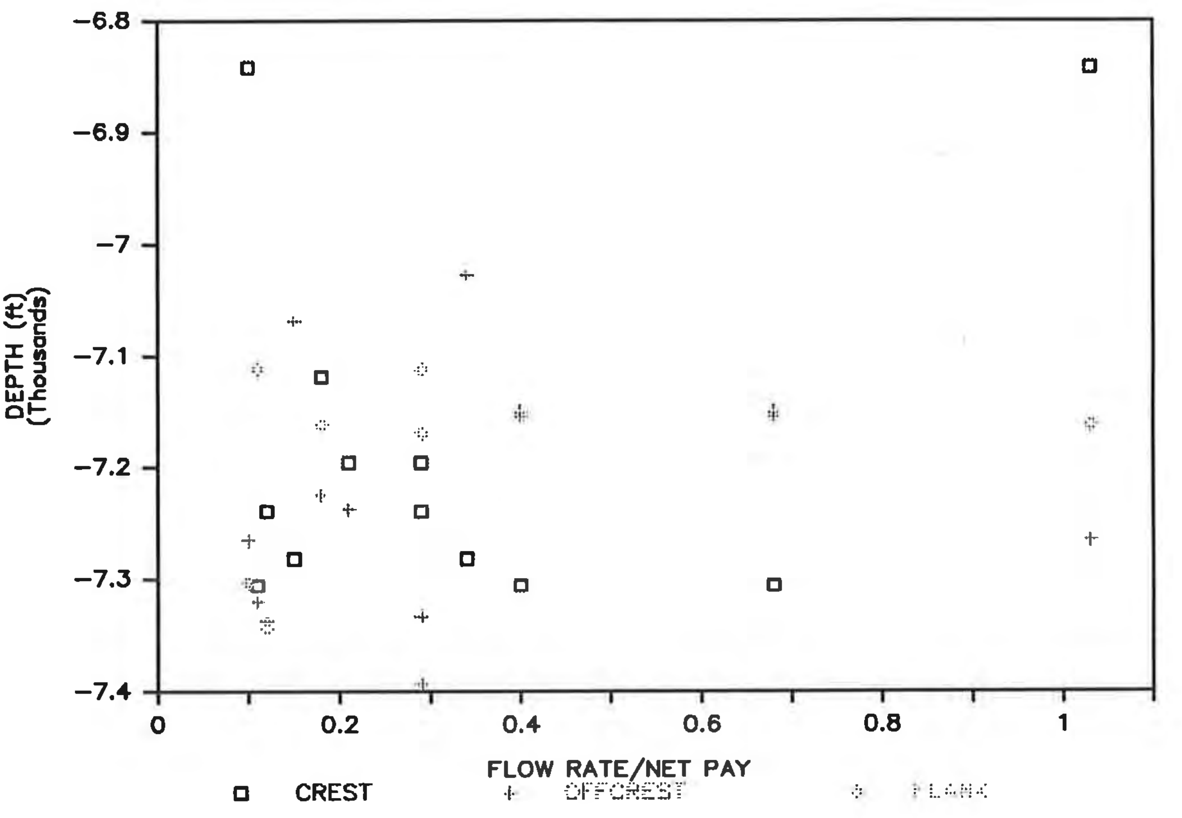
Porosity and permeability over the interval studied do not show any significant trends with depth apart from those associated with depositional environment. There are porosity and permeability peaks at 6900ft to 7000ft and 7200ft to 7500ft which correspond to peaks in grain size at these depths, i.e. a sample anomaly arising from the weight of samples from one field.

Reservoir quality, using flow rate divided by net pay and plotted against depth (Figure 6.4), shows that those wells situated in crestal positions, or positions just off the crest, give better quality reservoir characteristics than those wells situated on the flanks.

It was also found by this method that those wells in the southern part of the western gas lobe (Figure 6.5) also showed better reservoir characteristics than those to the north and east.

FIGURE 6.4

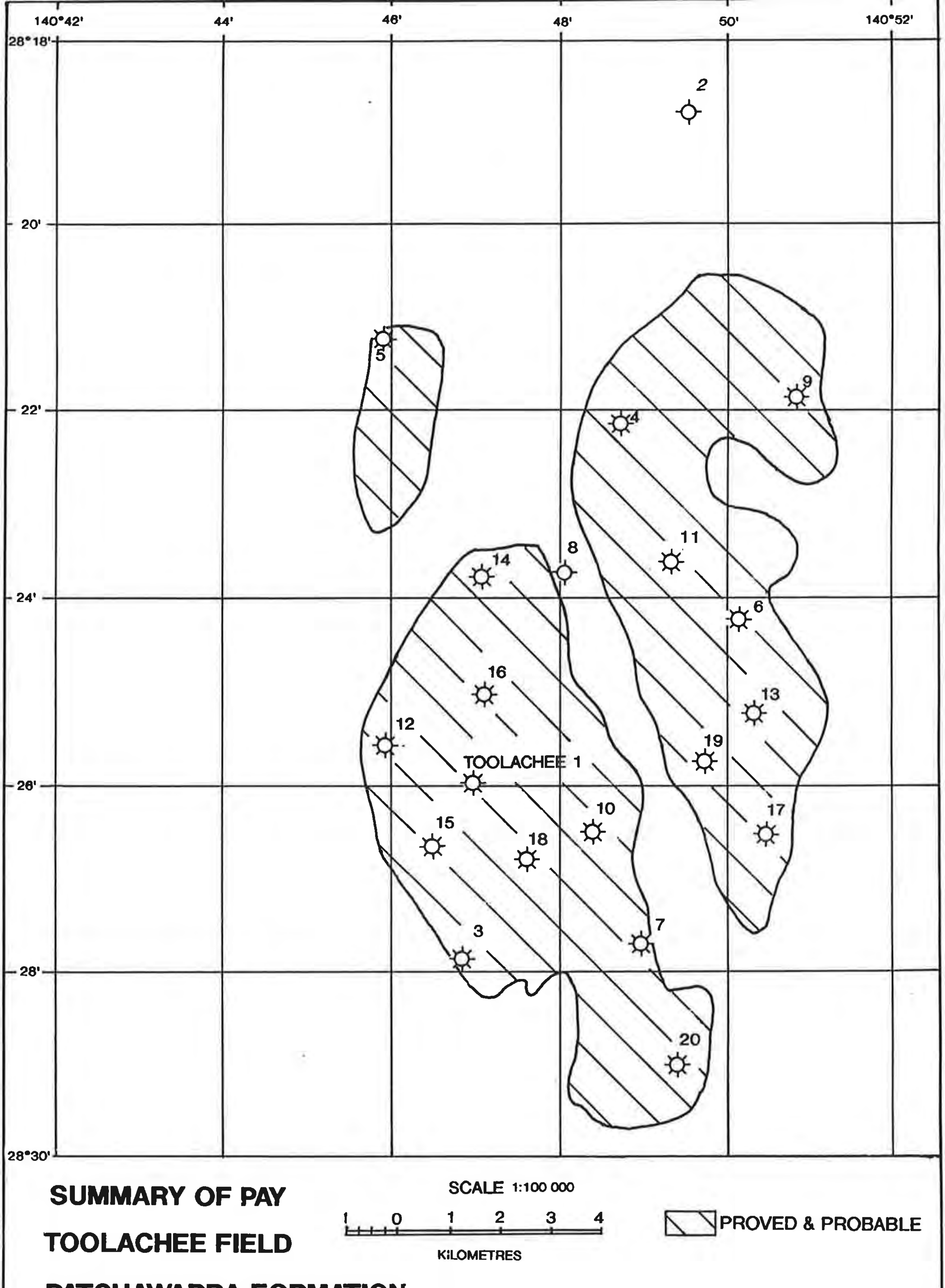
TOOLACHEE FIELD: FLOW RATE/NET PAY VS DEPTH



6.43 PALEOGEOGRAPHIC LOCATION

Association P2

Porosity is generally good in the fine to coarse grained stacked channel sediments with average porosities from 10.4 to 14.6% and permeabilities up to 262md. Secondary porosity is generally greater than primary porosity in the coarser-grained rocks observed in the eastern and south western Toolachee Field.



SUMMARY OF PAY

TOOLACHEE FIELD

PATCHAWARRA FORMATION

FIGURE 6.5

ASSOCIATION P3

Secondary porosity is generally more abundant than in associations P4 or P5 and is higher in medium to coarse-grained rocks. Porosity is best developed in the sand-bar which overlies prograding sequences, as in Toolachee 6 where porosity is up to 19.3% with permeabilities of 69.8md. Permeabilities are generally best in the channel sands where they reach 565md with average porosities of around 14%. Primary porosity still plays an important role in this association, especially in the medium to fine-grained sediments.

ASSOCIATION P4

Primary porosity is generally greater in association P4 than in P5 with both primary and secondary porosity increasing with grain size. Secondary porosity is often very low to absent in finer grained rocks. Average porosity ranges from 10.7 to 17.7% in stacked channel sequences with permeabilities of 23.2 to 720md and gas pay of 5.7 to 8.0 MMCFD. Overbank deposits with thin channel sands have average porosities ranging from 7.9 to 11.7% with permeabilities of 0 to 6.6md and gas pay of 4.1 MMCFD to tight. Anomalously low porosity values were found at Toolachee 31 where stacked channels sands were tight owing to higher than normal amounts of clay blocking pore spaces. Toolachee 31 was drilled next to a possible sealing fault (B. Jensen-Schmidt, pers.comm). Chemical etching is widespread and is absent only in fine-grained sediments with abundant clay.

ASSOCIATION P5

Primary porosity in association P5 appears to be relatively greater than secondary and microporosity in the finer-grained rocks, while secondary porosity is relatively more abundant in the coarser-grained rocks of the eastern Toolachee Field, the south-central area around Toolachee 1, and the western region of Brumby Field. Reservoir quality is best in the south-central and eastern region of the Toolachee Field, and the western area of Brumby Field. The distribution of porosity is environmentally controlled with stacked channels containing average porosities of 10-14%, permeabilities of 63-189md and pay of 2.9-8.4 MMCFD. Those areas containing progrades with channels contain sandy crossbedded facies and massive sandstone facies within the channel. The sandy facies in this area have average porosities of 9-12% with permeabilities of 2-80md and pay of 2.9-5.0 MMCFD. The prograding lacustrine sequences are generally composed of muddy and fine-grained sandy facies such as Fl and Sw/Fw. These facies often are tight, having porosities less than 10% and less than 3md permeability.

Note-No detailed reservoir quality discussion of Epsilon and Toolachee Associations due to lack of suitable data from these formations.

CHAPTER 7 DISCUSSION AND CONCLUSIONS

The main influences affecting reservoir quality within the study area are combination of environmental and diagenetic controls. The main environmental controls on reservoir quality are grain size, sorting, and mineralogy of the detrital grains and clays. The grain size of the initial sediment is an important factor with the medium to coarse-grained rocks of the Patchawarra Formation exhibiting the best porosity and permeabilities throughout the Toolachee, Brumby and Munkarie Fields. Sorting also plays a role in reservoir quality with well-sorted sandstones (sublitharenites) in the medium grain size range often having better porosity than the more poorly sorted sandstones in this range. The mineralogy exhibits an important influence with monocrystalline quartz grains showing development of euhedral quartz overgrowth rims. These rims have either completely silicified the sublitharenite or, more often, partly silicified the grains prior to compaction leaving a loose but rigid framework which helps to preserve primary porosity. Where polycrystalline quartz grains are present, no quartz overgrowths exist and the grains are more subject to compactional effects such as grain fracturing and pressure solution. Other rock fragments also tend to show more compactional effects and alteration. Feldspar also shows alteration to clay replacement by carbonate when present. Detrital clays can fill pores in the sedimentary regime and are therefore also destructive with respect to porosity. When carbonaceous materials are present they provide a base for the precipitation of micritic siderite.

The main diagenetic controls found to influence the reservoir quality in the Toolachee region are the precipitation of quartz cement, carbonate cement, and authigenic clays, the alteration and dissolution of minerals, compaction and pressure solution. Quartz cement has precipitated as overgrowths on quartz grains and has cemented grains together to form a rigid framework. This cement formed relatively early in the diagenetic history because it has generally left an open framework, indicating minimal compactional effects. This open framework has provided a good base for the preservation of primary porosity in the fine to coarse-grained sublitharenites. Occasionally quartz cement occludes all porosity as in the Patchawarra Formation in the north east of the Toolachee Field. Carbonate cement is also important with respect to porosity reduction. The main carbonate is siderite which occurs as sparite in the coarser-grained samples and micrite in the finer-grained samples containing carbonaceous material. Siderite has been found in all formations throughout the field; its percentage is lowest in the Lower Toolachee Formation and the Patchawarra Formation. Calcite is also present, its major influence being in the north-east of the Toolachee Field at Toolachee East 1. Where calcite is present it generally cements the quartz grains as an open framework but occludes all porosity. Authigenic clays such as dickite and illite are present with dickite being the most abundant and important. Dickite contains microporosity which may allow gas to flow through it, although at reduced rates. It has been found mostly in over-sized secondary pores as well as in some primary pores and, hence, may occupy a large amount of pore space and help determine the permeability of the rock. Dissolution of feldspars and rock fragments may also play an important part in the diagenetic history with the formation of the oversized pores. Grains such as micas and rock fragments have been affected by compaction, by deformation of grains and compaction of the grain framework by pressure solution.

The best quality reservoirs in the Toolachee Field appear to be towards the south-west, in the Patchawarra Formation, in coarser-grained channel deposits with good preservation of primary porosity. The Patchawarra Formation is the main gas-producing interval within the area studied. The remaining southern to central area also contains relatively good reservoirs while those areas to the north are often poorer quality. The poorer quality in the north is due to finer grain sizes giving lower porosities and permeabilities together with reduced thickness of pay intervals. These deposits are often thin channels or crevasse splay sands. The Toolachee East region has the poorest quality with a higher degree of silicification and more calcification than anywhere within the main field. The central north-south region also is of poor quality due to less sand deposition. This area had a higher degree overbank deposition throughout most of the Patchawarra Formation. Wells drilled on crestal positions or near crestal positions appear to contain better preserved reservoir characteristics than wells drilled on the flanks of the structural highs.

The Epsilon Formation also contains producing gas reservoirs, although reservoir quality is much poorer than in the Patchawarra Formation. The Epsilon Formation generally tends to be fine-grained and well sorted because of the deltaic and shoreline depositional nature of the sands. Siderite precipitation and the fine-grained character of the sublitharenites appear to be the main controls on reservoir quality. The best porosity and permeabilities are found around Toolachee 34 and Munkarie 2 where the grain size ranges up to medium.

While the Toolachee Formation contains good quality reservoirs, it is water wet. The lack of gas charge into this formation is possibly due to the absence of a seal at time of migration or the lack of faults which may act in the Patchawarra and Epsilon Formations as migration pathways for the hydrocarbons.

The Patchawarra Formation channel sands, therefore, contain the best quality gas charged reservoirs in the Toolachee, Brumby and Munkarie Fields, with the Epsilon shoreline sands being potential secondary targets.

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PLATE 1

A) White light: Toolachee 3, 7284' 4", sample 0322,(4* lens, 10* zoom). Medium grained sublitharenite with porosity appearing as black. Primary porosity with some oversized pores. Quartz grains (Q), rock fragments (RF), overgrowths (OG).

B) Cathodoluminesence photomicrograph of above sample. Loosely packed detrital quartz grains (Q) surrounded by quartz overgrowths (OG). No overgrowths on rock fragments (RF). Porosity (P) is black and is mostly primary with some secondary Up to three generations of quartz overgrowth. Quartz appears in a variety of colours from brown to pink to blue.

C) Crossed polars of above sample. Shows monocrystalline and polycrystalline quartz (Q) with drusy overgrowth on polycrystalline grain.

D) Crossed polars: Toolachee 3, 7220'3",sample 0316. (250 micron scale bar). Deformation and possible alteration of mica (M) between quartz grains (Q) and rock fragments.

E) White light: Toolachee 3,7340', sample 0328. (2.5* lens). Medium grained sublitharenite with porosity appearing as green. Compaction of mica (M) and many pores filled with dickite (D). Floating quartz grains (Q) amoungst clay suggesting clay is matrix, not cement in some areas.

F) Cathodoluminesence photomicrograph of above sample. (4* lens with 10* zoom). Loosely packed detrital quartz grains (Q) surrounded by quartz overgrowths. Authigenic kaolin (dickite) (D) is bright blue with possible carbonate (C) bright red. Alteration of red feldspar. Porosity is dark brown.

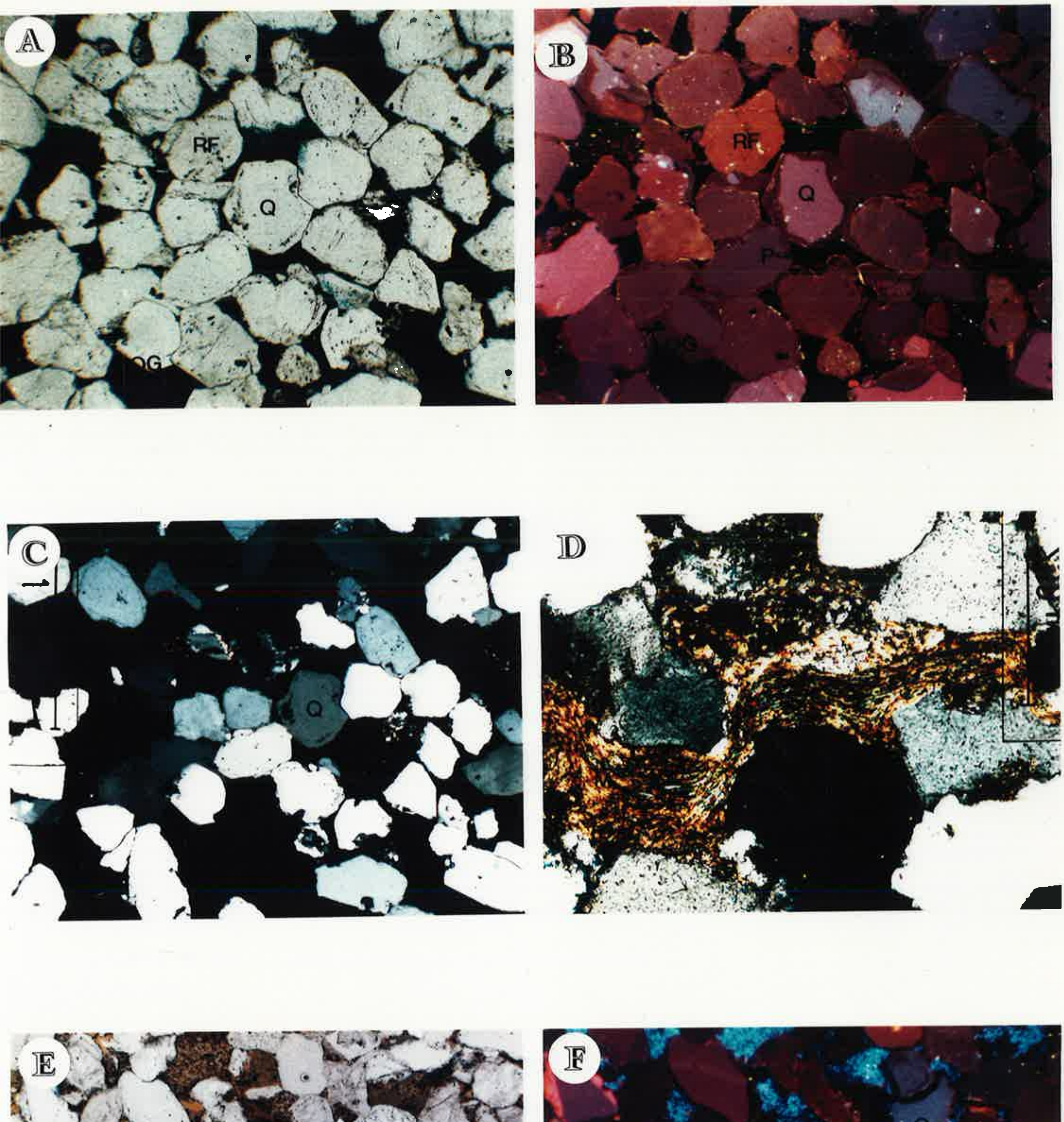

A
RF
Q
OG
B
RF
Q
P
C
Q
D
E
Q
D
M
F
Q
D
C

PLATE 2

A) Crossed polars of Plate 1e: Toolachee 3,7340', sample 0328. Quartz (Q).

B) White light: Toolachee 3, 7211', sample 0315. (1 mm scale bar). Fine grained sublitharenite with minor porosity (Blue-green). Carbonaceous band above a stylolite.

C) White light: Toolachee 1, 6911', sample 0345. Rip up clasts (RUC) in fine grained sublitharenite.

D) White light: Toolachee 15, 7377', Sample 0354. Stylolite (STY) with insoluble mineral and possible bitumen residue along ragged boundary. Mica (m) accumulation. Quartz (Q), porosity (P).

E) Crossed polars of above sample. Mica (M).

F) White light: Toolachee 6, 7638', Sample 0535. (4* lens with 8* zoom). Medium to coarse grained, pressure dissolution seams, through quartz (Q) and polycrystalline quartz grains (RF).

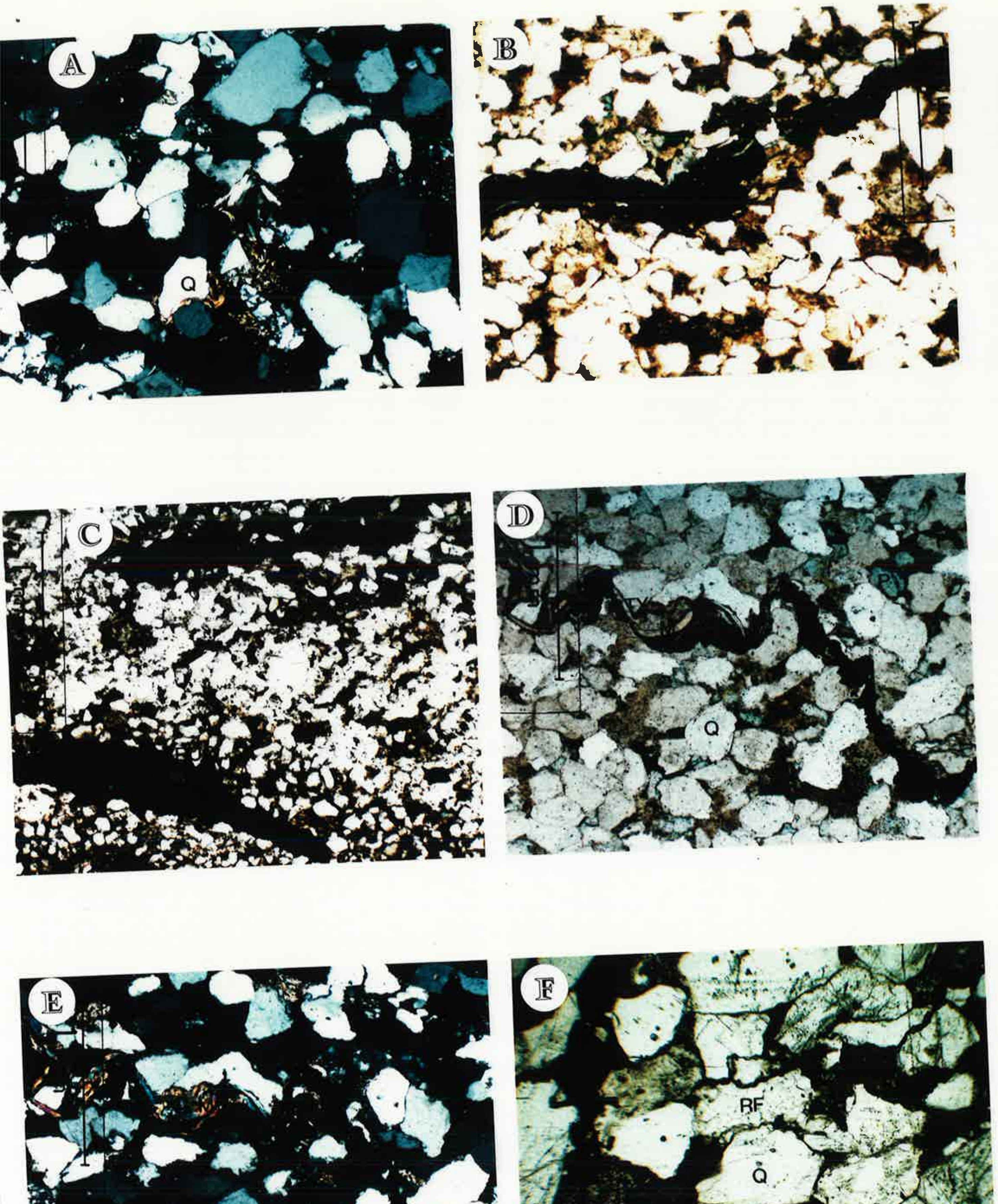

A
Q
B
C
D
P
Q
E
F
RF
Q

PLATE 3

A) Cathodoluminesence: Same sample as 2f. Toolachee 6, 7638', Sample 0535. (4* lens with 8* zoom). Lack of overgrowths on polycrystalline quartz grains (RF) and in pressure dissolution area. Pressure solution (PS), quartz (Q), dickite (D), feldspar (FDS).

B) White light: Toolachee 1, 6063', Sample 0552, (2.5* lens). Good primary porosity (P) (blue-green) in medium grained sublitharenite. Quartz (Q),

C) White light: Toolachee 34, 6893'3", Sample 0557, (4 lens with 10* zoom). Fine grained sublitharenite with fracture and well cemented.

D) Cathodoluminesence: Same sample as above. Quartz grains (Q) with quartz overgrowths and kaolin (D). Minor porosity. Yellow spots are diamond dust from thin section preparation.

E) Crossed polars of above sample.

F) White light: Toolachee 1, 6051', Sample 0550, (2.5* lens). Crushed rock fragments and clays, pressure solution. Quartz (Q).

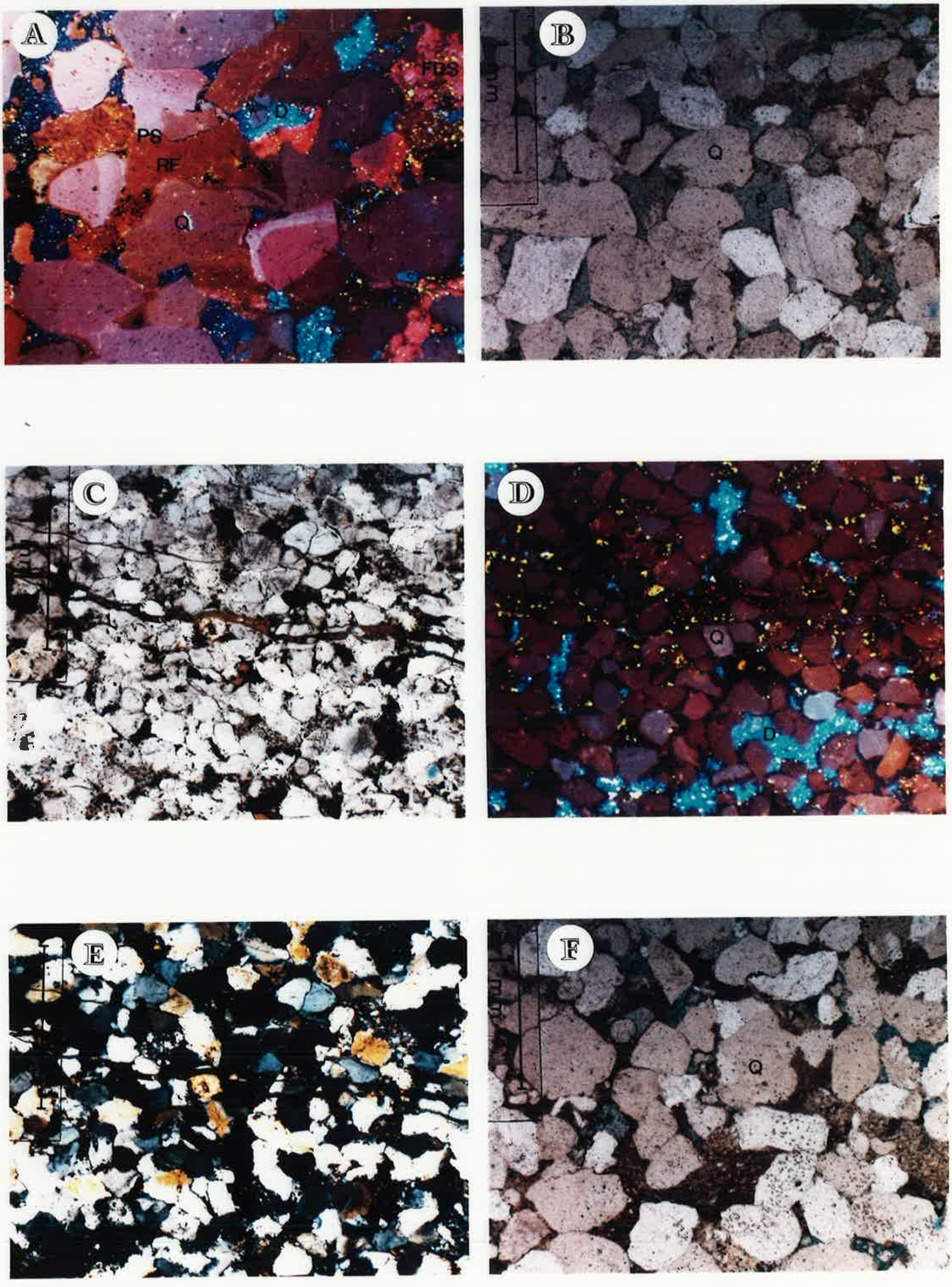

A
PS
RF
Q
D
FDS
B
Q
P
C
D
Q
D
E
F
Q

Plate 4

A) Crossed polars: same as sample 3F. Toolachee 1, 6051', Sample 0550, (2.5* lens). Quartz (Q).

B) White light: Toolachee 1, 6891', Sample 0342, (4* lens with 8* zoom). Good porosity, dust bands in quartz overgrowths (OG). Quartz (Q), rock fragment (RF).

C) Cathodoluminesence: Same sample as above. Loose grain packing, three generations of quartz overgrowths (OG). Quartz (Q), dickite (D), porosity (P), rock fragment (RF).

D) Crossed polars of above sample. Quartz (Q), rock fragment (RF).

E) Whie light: Toolachee 9, 7319', sample 0440, (4* lens, 10* zoom). Tightly cemented sublitharenite. Quartz (Q).

F) Cathodoluminescence: same sample as above. Early silica phase heals cracks. Quartz (Q), dickite (D), overgrowths (OG).

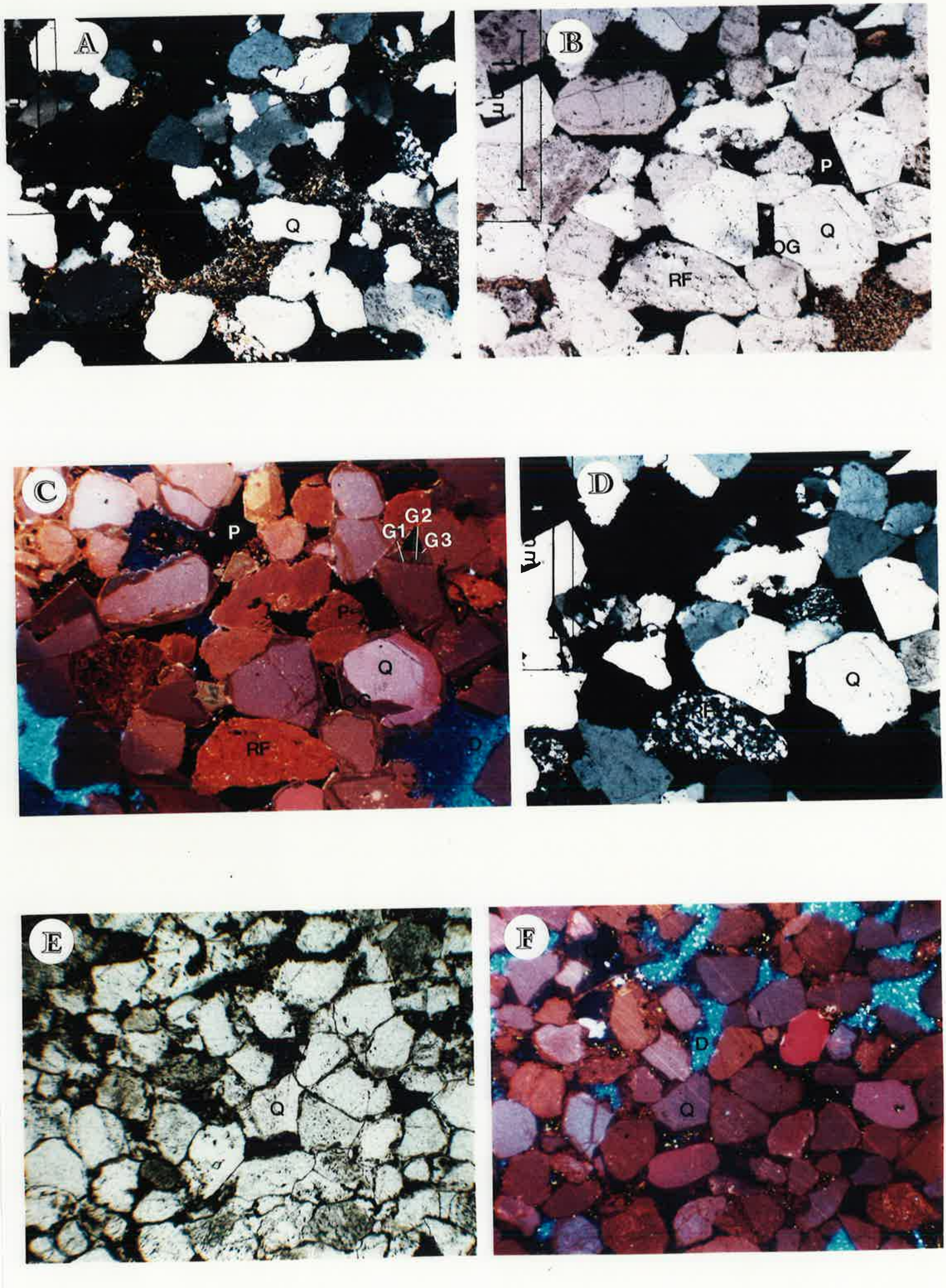

A
Q
B
P
Q
QG
RF
C
P
G1
G2
G3
Q
QG
RF
D
Q
E
Q
F
D
Q

Plate 5

A) SEM: Toolachee 3, 7281', Sample 0321. Mica grain (M) deformed and crushed between quartz grains.

B) SEM: Toolachee 1, 6063', Sample 0552. Alteration of mica to alternating illite (thin) and kaolin (K) (thick) plates.

C) SEM: Toolachee 15, 7382'3", Sample 0355. Secondary oversized dissolution pores (OS), quartz overgrowths (Q), authigenic kaolin.

D) SEM: Toolachee 18, 7327'3", Sample 0425. Euhedral quartz overgrowths (Q).

E) SEM: Toolachee 5, 7393'9", Sample 0389. Intergrowths of authigenic dickite (D) and quartz overgrowths (Q).

F) SEM: Toolachee 3, 7428', Sample 0167. Druse quartz (DR).

G) SEM: Toolachee 15, 7370'2", Sample 0353. Chemical etching of quartz (CE), quartz (Q).

H) SEM: Toolachee 3, 7334'6", Sample 0327. Detrital kaolin (K).


A
M
10µm200kV 262E3 0006/17 @TOOL03
B
10µm200kV 402E3 0001/55 TOOL 1
C
1mm200kV 264E1 0005/31 TOOL@15
D
01mm200kV 170E2 0001/23 @TOOL18
E
10µm200kV 115E3 0009/36 TOOL 5
F
DR
10µm200kV 169E3 0001/16 @TOOL03
G
Q
10µm201kV 230E3 0002/33 TOOL@15
H
10µm200kV 131E3 0004/11 @@TOOL3

Plate 6

A) White light: Toolachee 3, 7428', Sample 0167, (4* lens with 10* zoom). Coarse grained sublitharenite, good porosity (P), quartz (Q), rock fragments (RF).

B) Cathodoluminesence: Same sample as Plate 3F. Grain fracture filled by two generations of quartz overgrowth (OG). quartz (Q), dickite (D), rock fragment (RF).

C) Crossed polars of above sample. Quartz (Q), rock fragment (RF).

D) White light: Toolachee 3, 7284'4", Sample 0322. Stylolite (STY) through sublitharenite. Quartz (Q), porosity (P).

E) Crossed polars of above sample. Quartz (Q).

F) White light: Toolachee 8, 7381'9", Sample 0433. Bioturbation reworked sediment in burrow (BU).

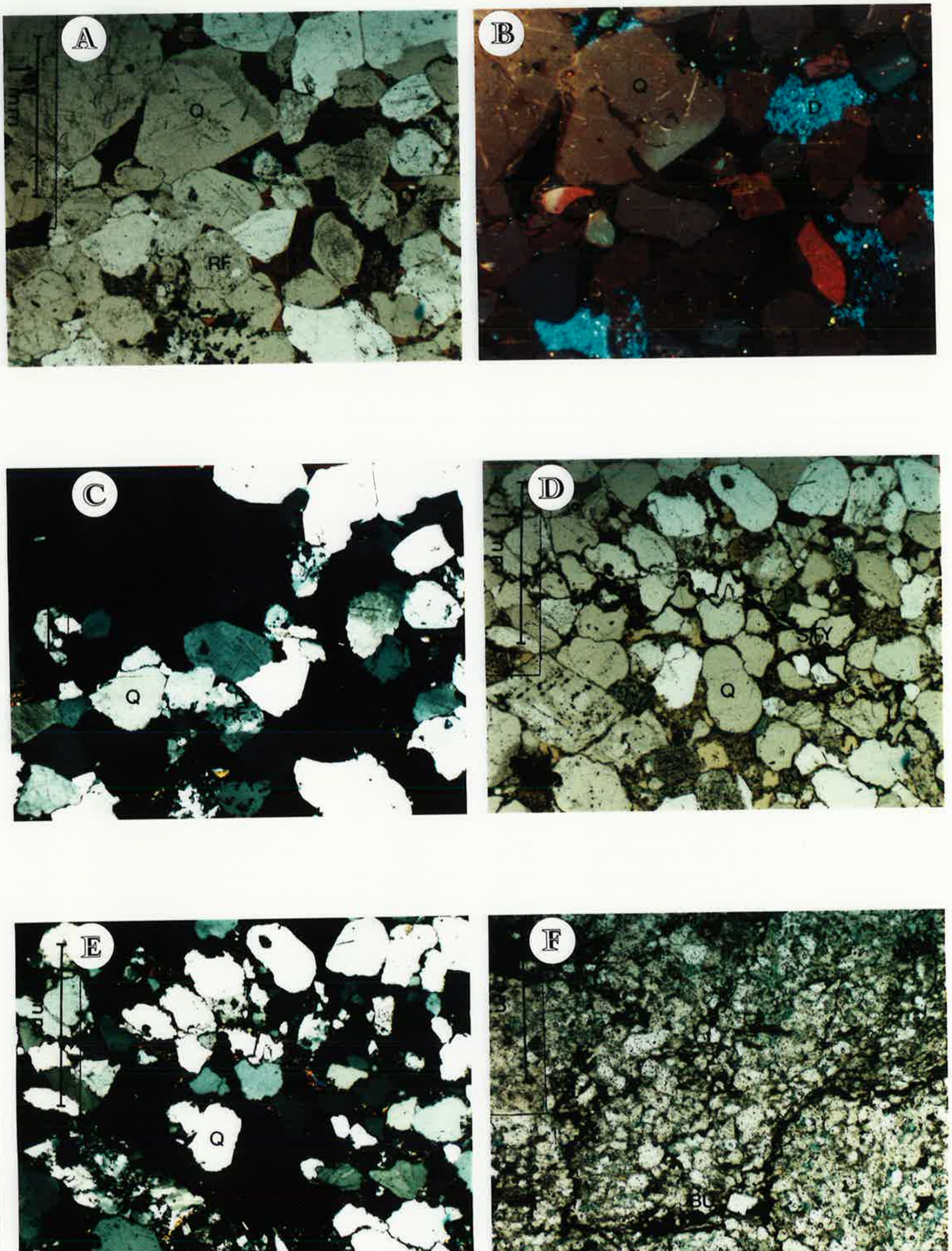

A
Q
RF
B
Q
D
C
Q
RF
D
Q
E
Q
F

Plate 7

A) SEM: Toolachee 6, 7473'4", sample 0531. Authigenic dickite (D) with microporosity inbetween dickite booklets.

B) SEM: Toolachee 6, 7589', sample 0533. Large authigenic dickite (D) stack.

C) SEM: Toolachee 1, 6063', sample 0552. Vermiform dickite (D) growing into pore and intergrowing with quartz (Q).

D) SEM: Toolachee 3, sample 7457'3", sample 0172. Anhedral detrital illite plates (I).

E) SEM: Toolachee 1, 6056', sample 0551. Authigenic lettuce-like illite (I).

F) SEM: Toolachee 3, 7271, sample 0321. Alteration of biotite to kaolin (K) and illite (I) with expansion of crystal lattice.

G) SEM: Toolachee 12, 7290, sample 0323. Authigenic chlorite (CH) in pore space.

H) SEM: Toolachee 3, 7428', sample 0167. Oversized pore with dickite (D), siderite (S) and quartz overgrowths (Q).


A
10µm201kV 115E3 0007/49 TOOL 6


B
10µm201kV 101E3 0009/50 TOOL 6


C
0.1mm200kV 885E2 0003/55 TOOL 1


D
10µm200kV 250E3 0001/02 @@TOOL3


E
10µm200kV 131E3 0007/52 TOOL 1


F
10µm199kV 262E3 0003/17 @TOOL03


G
CH
10µm200kV 105E3 0009/12 @@TOOL3


H
S
Q
0.1mm200kV 241E2 0001/15 @TOOL03

Plate 8

A) Crossed polars: Toolachee 3, 7438'3", Sample 0169. Radial form of micritic siderite (S) with coal laminations (CM).

B) Crossed polars: Toolachee 3, 7438'3", Sample 0169. . Patchy micritic siderite (S) with coaly laminations.

C) White light: Toolachee 1, 5990, Sample 0635, (4* lens with 10* zoom). Cuttings sample of calcite (C) cementing loose framework of quartz (Q) grains.

D) Cathodoluminesence: Same sample as above. Calcite (C) (yellow), quartz (Q) (blue to brown).

E) Crossed polars: Toolachee East 1, 6440', Sample 0648. Calcite (C) supporting loose framework of quartz (Q) and feldspar grains plus etching.

F) White light: Toolachee East 1, 6440', Sample 0648. Calcite (C) replacing quartz (Q).

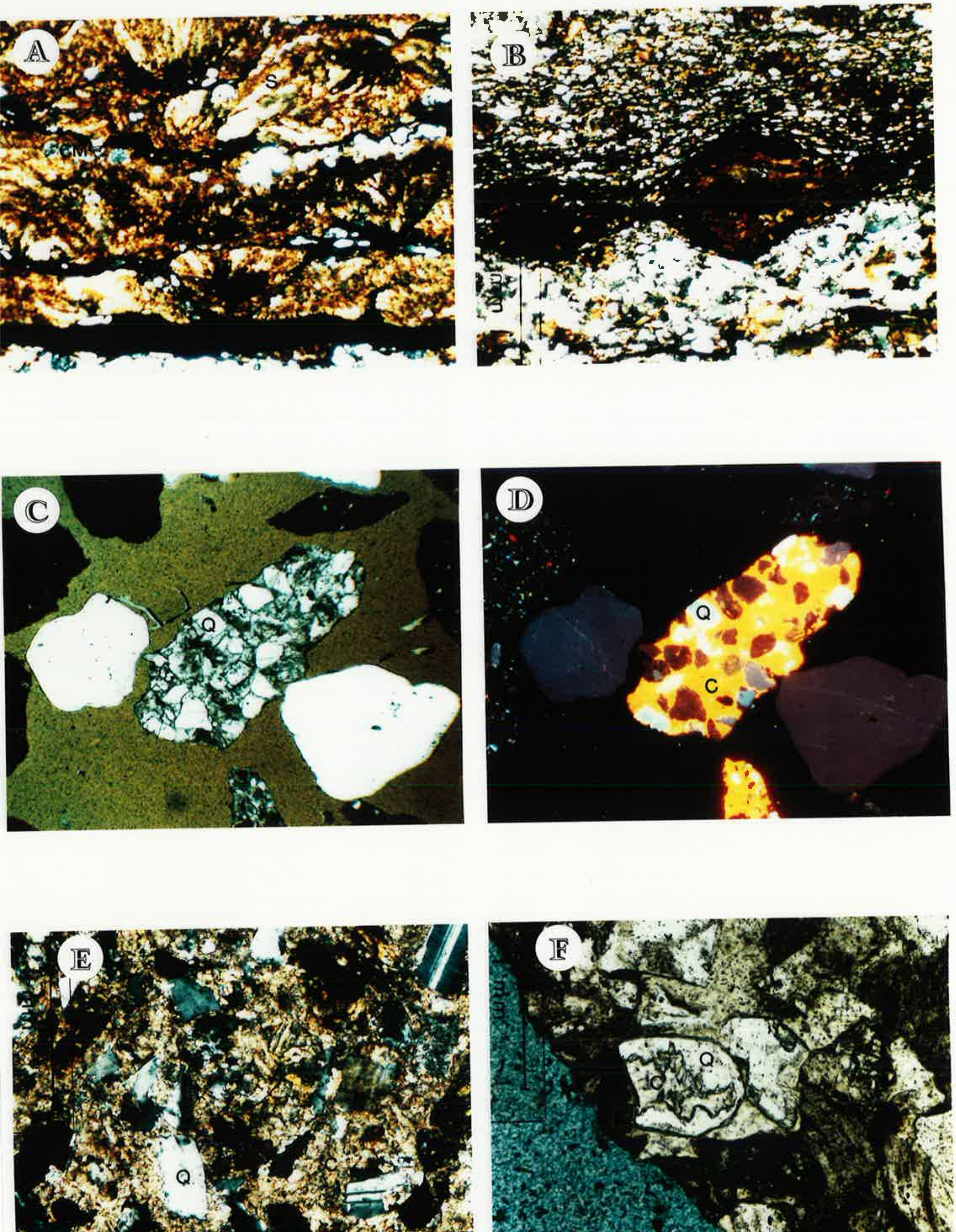

A
S
CM
B
C
Q
D
Q
C
E
Q
F
Q
C

Plate 9

A) SEM: Toolachee 3, 7428', Sample 0167. Authigenic siderite (S) replacing quartz.

B) SEM: Toolachee 3, 7445'6", Sample 0171. Detrital tabular mica (M) flake.

C) SEM: Toolachee 3, 7340', Sample 0328. Primary porosity between quartz (Q) grains with overgrowths.

D) SEM: Toolachee 3, 7290', Sample 0323. Euhedral dickite (D) filling oversized pore. Microporosity in between dickite platelets.

E) SEM: Brumby 1, 7404'3", Sample 0574. Euhedral siderite (S) filling pore throat between quartz overgrowths (Q).

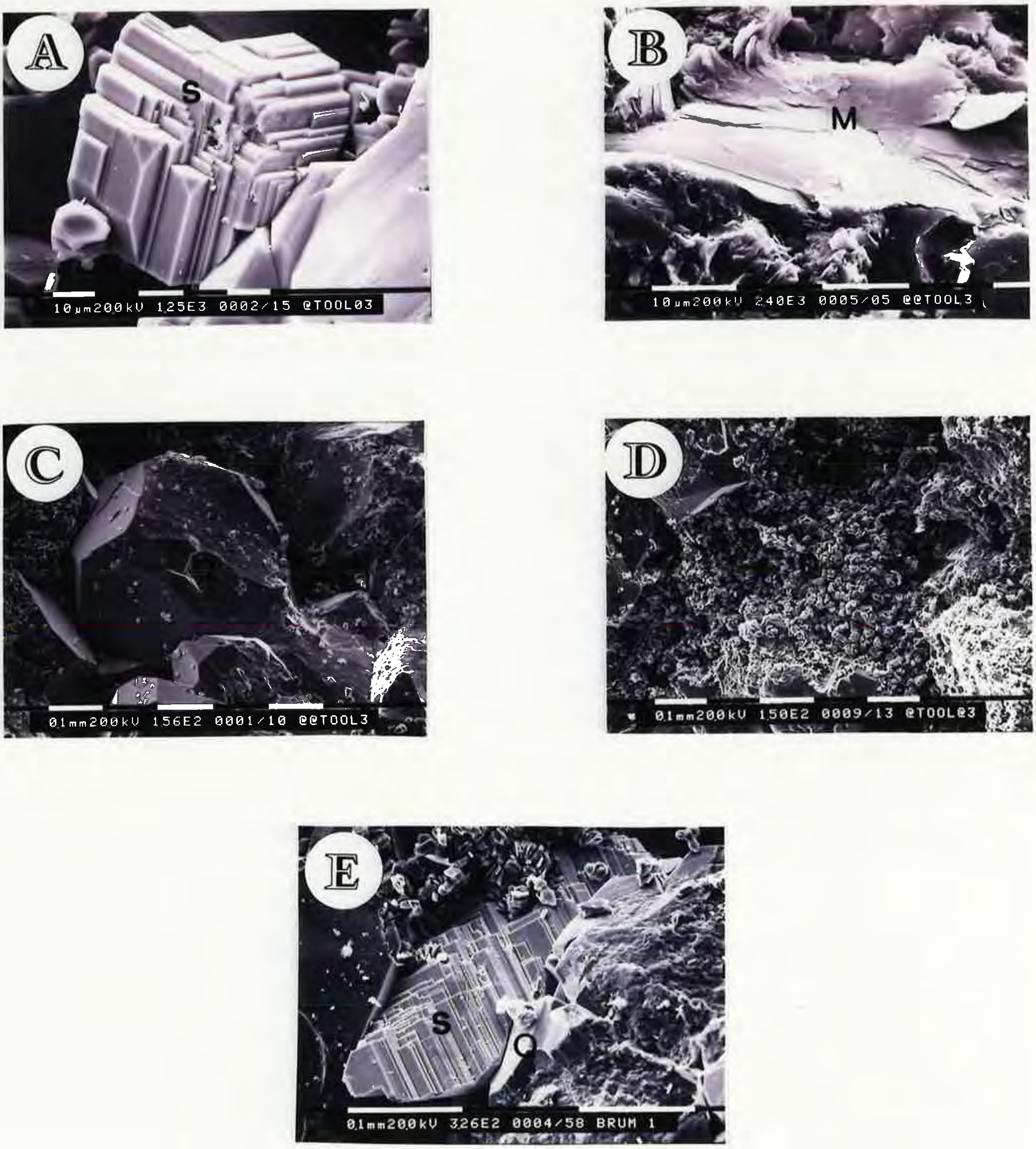

A
S
10μm200kV 125E3 0002/15 @TOOL03
B
M
10μm200kV 240E3 0005/05 @@TOOL3
C
01mm200kV 156E2 0001/10 @@TOOL3
D
01mm200kV 150E2 0009/13 @TOOL@3
E
S
Q
0.1mm200kV 326E2 0004/58 BRUM 1

Plate 10

A) Crossed polars: Same sample as in 8f. Toolachee East 1, 6440', Sample 0648. Replacement of quartz (Q) by calcite (C).

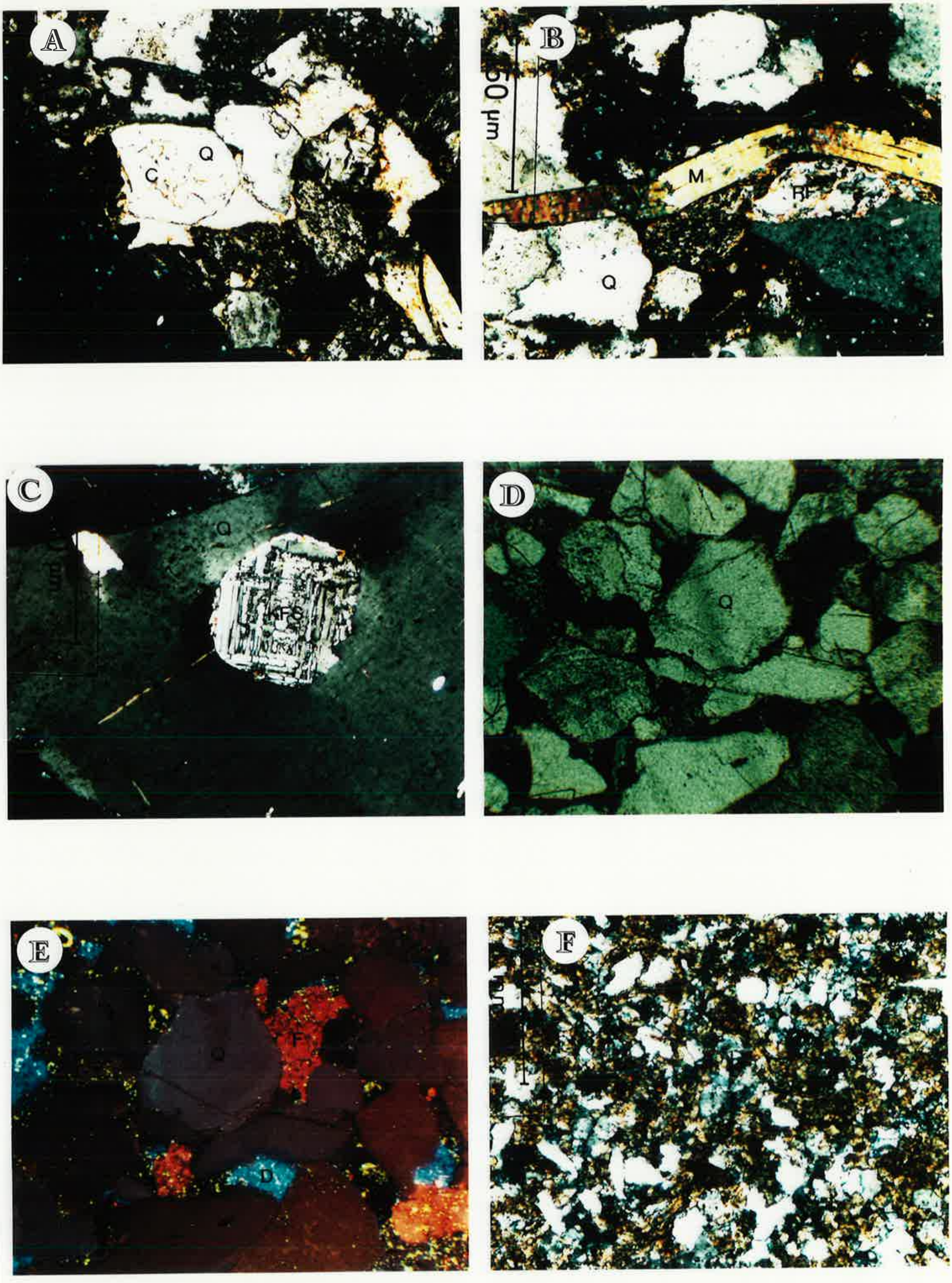
B) Crossed polars: Toolachee 15, 7377', sample 0354. Bent mica flake (M) with alteration at fractures in grain. Quartz (Q), rock fragment (RF).

C) Crossed polars: Toolachee 3, 6320', sample 0642. Feldspar (KFS) (microcline) grain encased in quartz (Q).

D) White light: Toolachee 19, 7639.5', Sample 0446, (4* lens with 12.5* zoom). Coarse grained sublitharenite with pressure solution seams. Quartz (Q).

E) Cathodoluminesence: Same sample as above. Alteration of feldspar (F), dickite (D), quartz (Q). No overgrowths along pressure solution seam.

F) Crossed polars: Toolachee 1, 6484'1", Sample 0554. Siderite filling pores in fine grained sublitharenite from Epsilon Formation.


A
Q
C
B
50 µm
M
RF
Q
C
Q
KFS
D
Q
E
Q
F
D
F

APPENDIX 1
Core Logging Description

APPENDIX 1: Core logging description

Section: **Contents:**

1 Introduction

This appendix contains the details of the logging of 1296 feet of core in 14 drill holes within the study area, as listed in Table 1.

WELL	INTERVAL	FT	FMN
Toolachee 1	6049'-6073'	24	Toolachee
	Subtotal:	24	
Toolachee 1	not logged	0	Epsilon
Toolachee 32	not logged	0	Epsilon
Toolachee 34	not logged	0	Epsilon
Toolachee 1	7191'-7444'	68	Patchawarra
Toolachee 3	7191'-7444'	253	Patchawarra
Toolachee 5	7226'-7410'	27	Patchawarra
Toolachee 6	7339'-7646'	307	Patchawarra
Toolachee 8	7330'-7390'	60	Patchawarra
Toolachee 9	7282'-7334'	52	Patchawarra
Toolachee 12	7183'-7213'	30	Patchawarra
Toolachee 15	7363'-7390'	27	Patchawarra
Toolachee 18	7309'-7337'	28	Patchawarra
Toolachee 21	7347'-7377'	30	Patchawarra
Brumby 1	7363'-7515'	48	Patchawarra
Munkarie 2	7238'-7286'	152	Patchawarra
	Subtotal:	1267'	

Total 1296'

Table 1. Study area drillhole core logged and presented in this Appendix.

The condition of the core is generally sound. All core is cut longitudinally into two slabs. Minor thin brown clay coating of the outside of all core is commonly dessicated and probably originates from drilling operations. Core recovery is good.

All core has been stored for several years within wooden core boxes at room temperature with little or no exposure to extremes of temperature or humidity.

2 Physical measurements

Characterisation of the core follows the format of Swanson 1981 (commonly referred to as the Shell sample examination manual).

2.1 Depth

All core logging is recorded relative to driller's depth marked on the core, at a scale of 1cm representing 1 foot of core. By comparing geophysical well logging traces (gamma, sonic) with core logging results a driller's depth to core depth conversion was determined. Conversions to obtain core depth from driller's depths of each examined well are included in Table 3.

Well	Core	Correction
TOOLACHEE 1	1 (6059-6084)	(+10)
	2 (6489-6503)	(+7)
	3 (6898-6915)	(+8)
	4 (6915-6966)	(+8)
TOOLACHEE 3	1 (7200-7260)	(+9)
	2 (7260-7320)	(+9)
	3 (7320-7378)	(+9)
	4 (7378-7436)	(+7)
	5 (7436-7474)	(+7)
TOOLACHEE 5	1 (7226-7286)	(+7)
	2 (7286-7346)	(+7)
	3 (7346-7406)	(+7)
	4 (7406-7424)	(+7)
TOOLACHEE 6	1,2,3 (7339-7519)	(+10)
	4,5,6 (7526-7646)	(+9)
TOOLACHEE 8	1 (7330-7390)	(-3)
TOOLACHEE 9	1 (7286-7345)	(+10)
	2 (7806-7810)	(+10)
TOOLACHEE 12	1 (7191-7222)	(+9)

		(3)
TOOLACHEE 15	1 (7373-7403)	(+12)
TOOLACHEE 18	1 (7315-7345)	(+6)
TOOLACHEE 19	1 (7620-7650)	(+7)
TOOLACHEE 21	1 (7359-7389)	(+12)

Table 2. Driller's depth to logger's depth conversion. All depths are in feet.

2.2 Others

Grain size was defined using the Wentworth scale distribution of average grain diameter and was obtained by comparison with a visual estimation chart.

Rock type identification uses the classification by Folk (1974). Most sands are sublithic quartz arenites (SLA) and lithic arenites (LA) because of their high quartz content, variable rock fragment content and low feldspar content.

Sorting as defined by Folk (1974) decreases from well sorted material with S.D.= 0.2 at the left of the sorting column to poorly sorted material with S.D.=1.2 at the right of the sorting column.

Roundness as defined by Swanson (1981) varies from angular (0.1) to well rounded (0.9) from left to right of the roundness column.

Sphericity as defined in Swanson (1981) varies from low (0.3) to high (0.9) from left to right of the sphericity column.

Visible porosity is recorded as trace = -, T = poor, P = fair = F, good = G and excellent = E.

Sorting, roundness, sphericity and porosity are all visually estimated.

Sedimentary structures are recorded to the right of the mud column as shown on the reference sheet.

3 Sedimentary facies determination.

Sedimentary rock type descriptions uses lithofacies codes as outlined by Miall (1978). Their definition and inferred environment of deposition are listed in chapter 4. It is important to note that more than one sedimentary environment can form deposits with similar combinations of lithic types, sedimentary structures, thicknesses and adjacent related lithic assemblages.

4 Reference sheet (see over)

5 Logging forms (see over)

6 References

Miall A.D. 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. *In* Miall A.D. (Ed.) *Fluvial Sedimentology*, Canadian Society of Petroleum Geology, Memoir 5, 597-604

Miall A.D. 1988. Reservoir heterogeneities in fluvial sandstones: lessons from outcrop studies. *American Association of Petroleum Geologists Bulletin* **72**, 682-697.

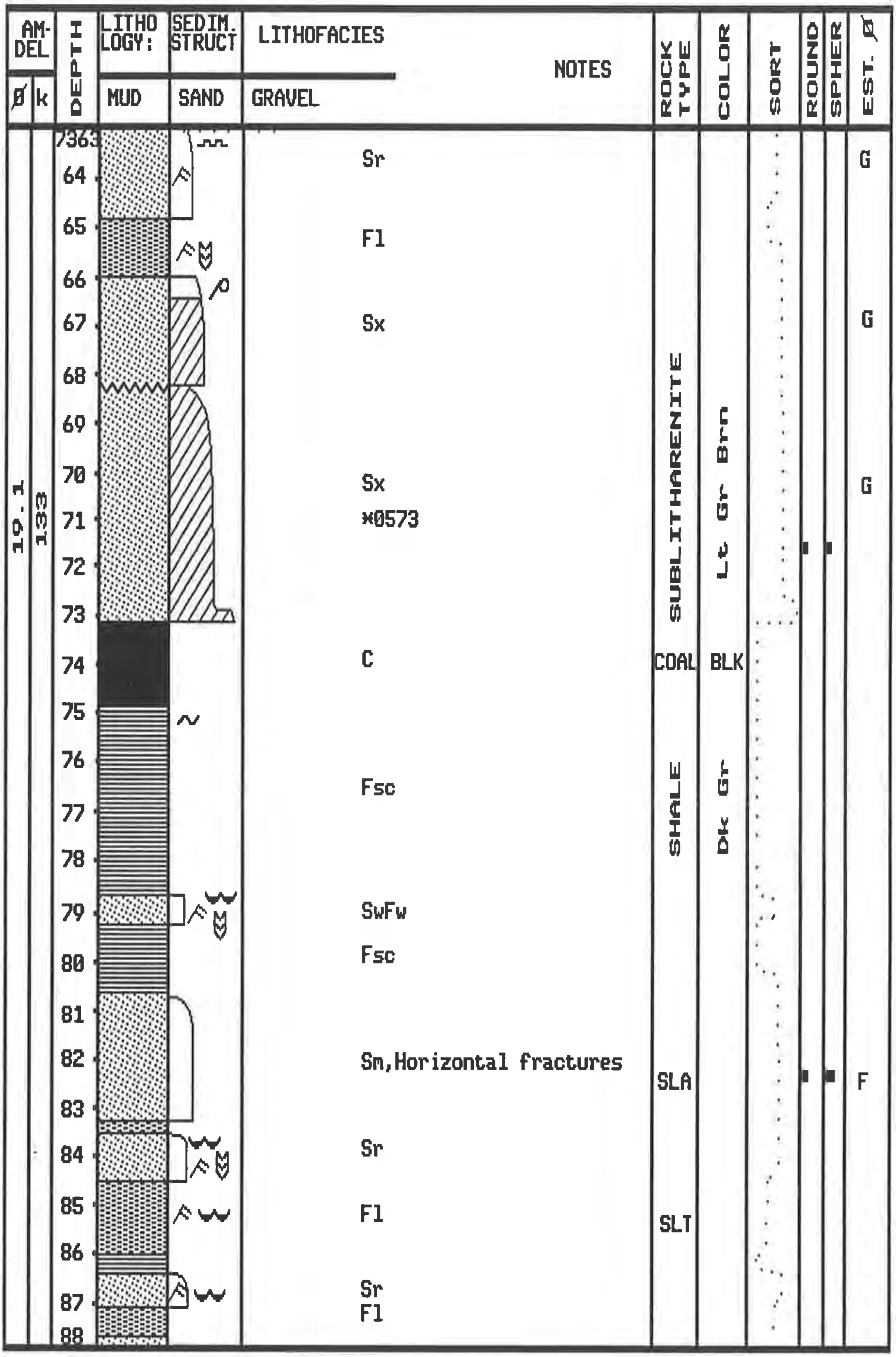
Swanson R.G. 1981. Sample examination manual. *American Association of Petroleum Geologists*, Tulsa.

Williams B.P.J. 1982. Facies analysis of Gidgealpa Group reservoir rocks, southern Cooper Basin, South Australia. A preliminary report. Unpublished Report to South Australian Oil & Gas Pty. Ltd.

KEY

- SHALE
- SILTSTONE
- INTERBEDDED SANDSTONE/SILTSTONE
- COAL
- SANDSTONE
- CONGLOMERATE
- CROSS BEDDING
- SCOUR BASE
- BIOTURBATION
- COALY STRINGERS
- DEWATERING STRUCTURES
- FLASER BEDDING
- HORIZONTAL LAMINATIONS
- MICROFAULTING
- RIPPLES
- ROOTLETS
- SLUMPING
- STYLOLITES

BRUMBY 1/ PATCHAWARRA/ CORE 1/ 7363-7388'/PAGE 1



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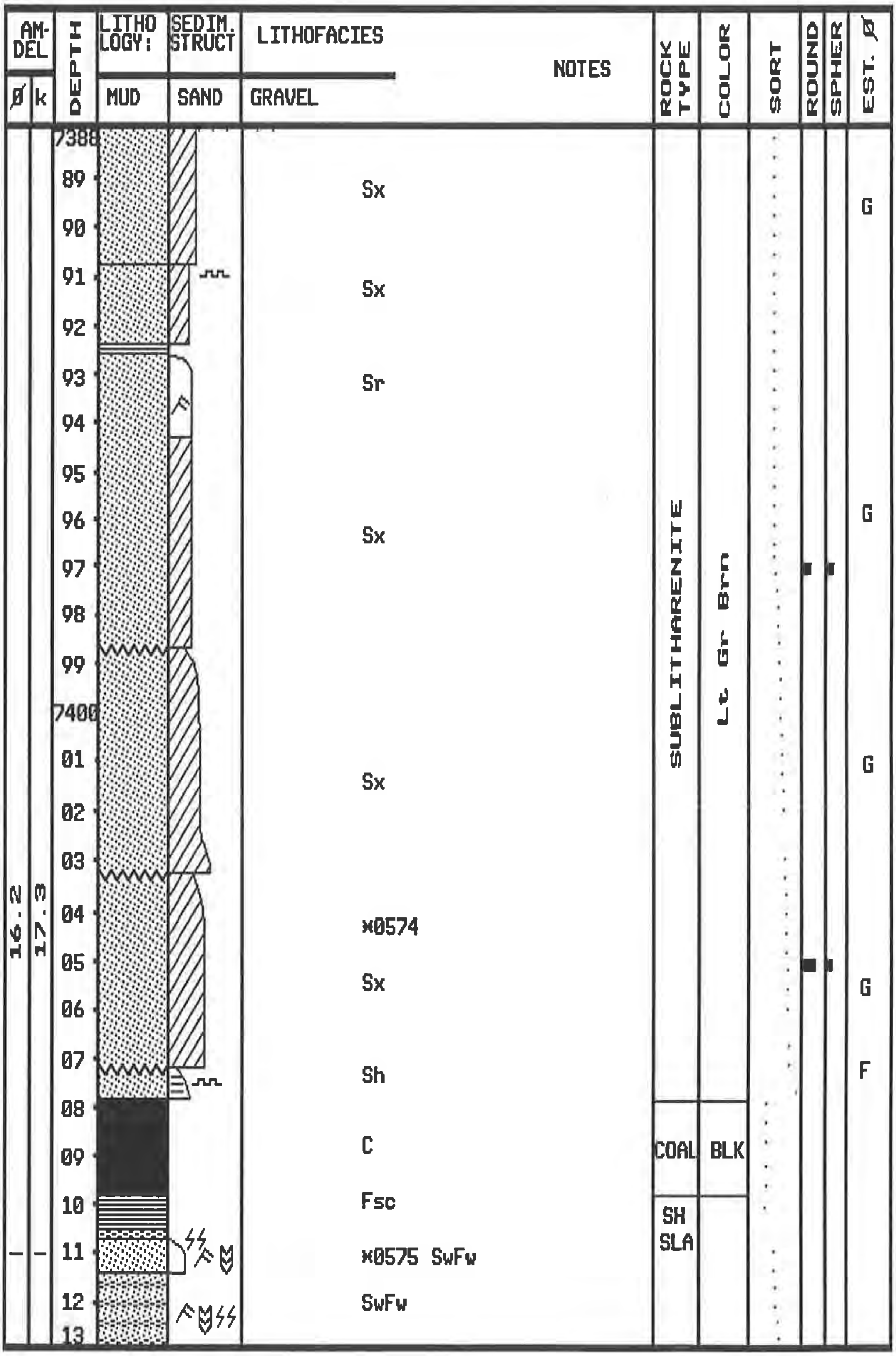

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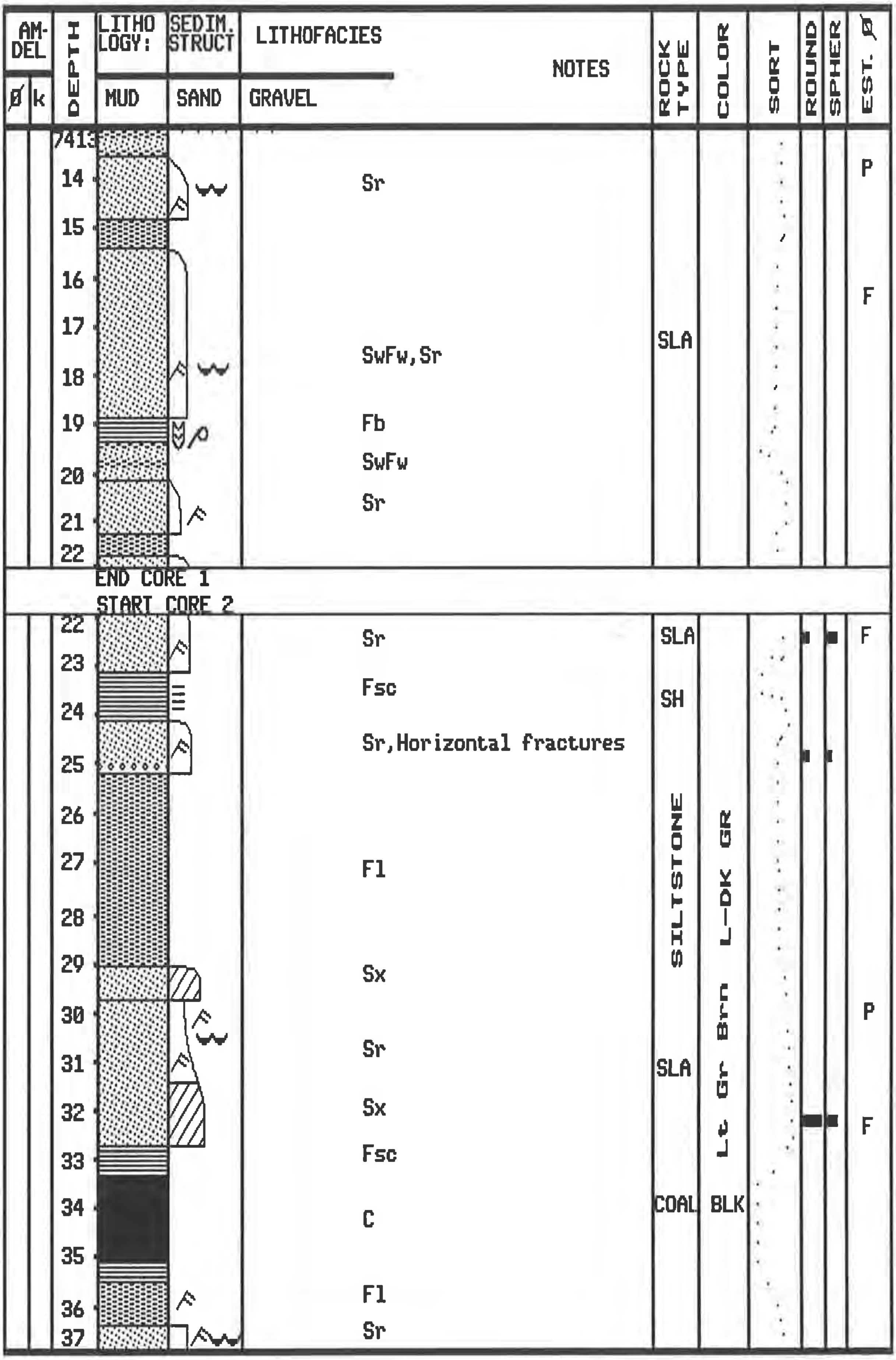

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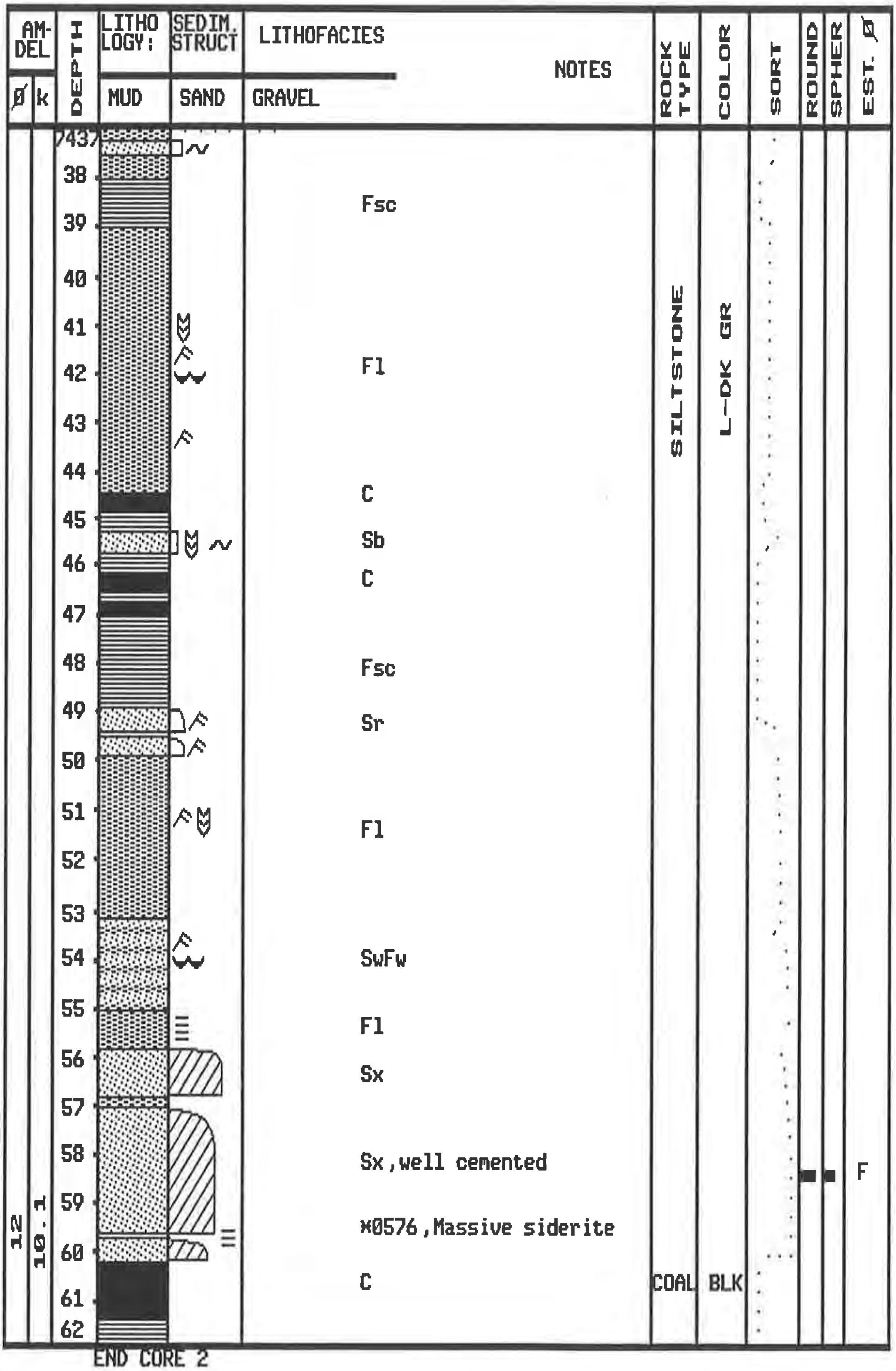

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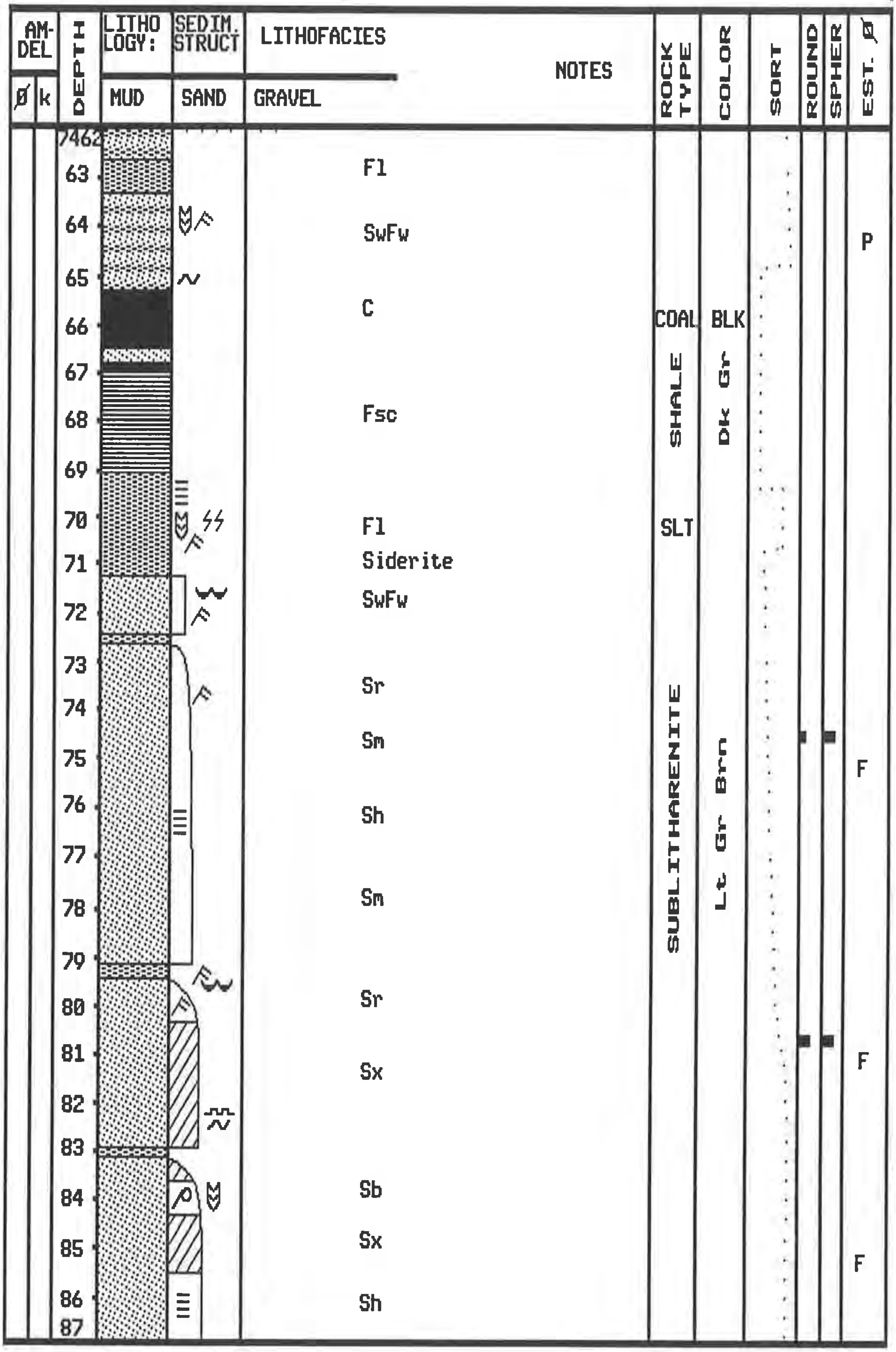

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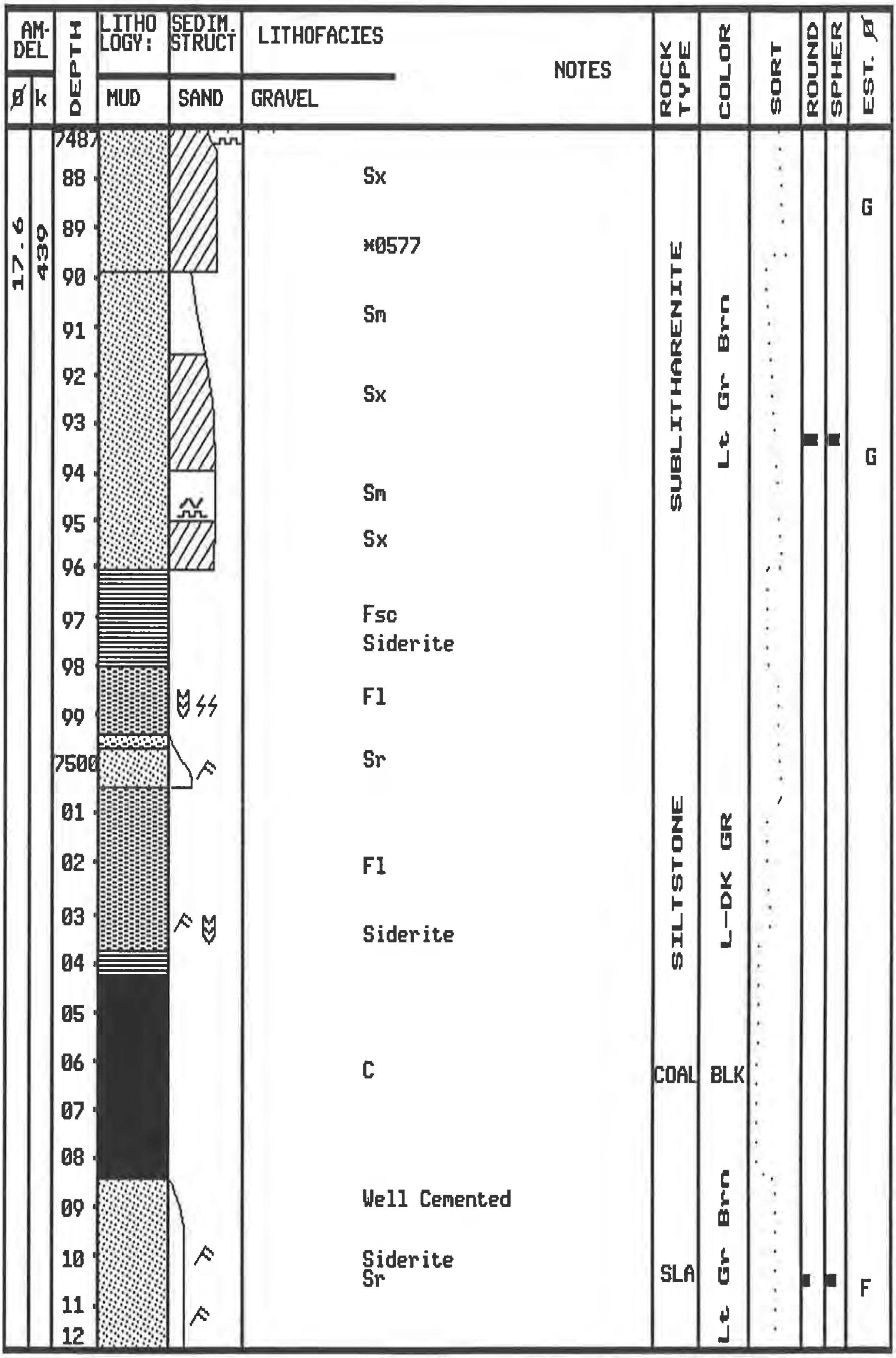
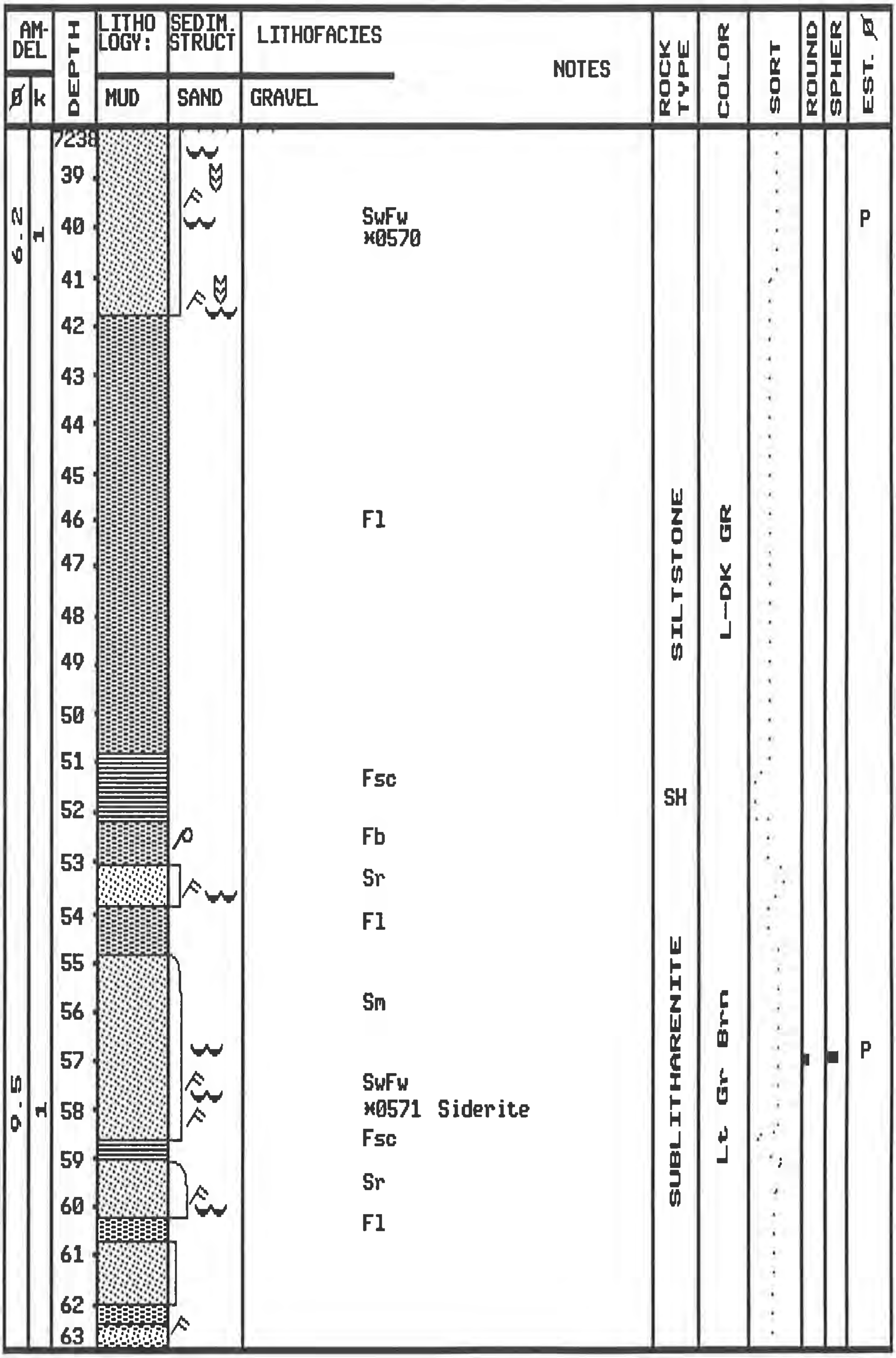


BRUMBY 1/ PATCHAWARRA/ CORE 3/ 7512-7515'/ PAGE 7

AMDEL Ø	AMDEL k	DEPTH	LITHOLOGY: MUD	SEDIM. STRUCT: SAND	LITHOFACIES: GRAVEL	NOTES	ROCK TYPE	COLOR	SORT	ROUND	SPHER	EST. Ø
		7512			Sr							
		13					SLA					F
		14			Sx							
		15										

MUNKARIE 2/ PATCHAWARRA/ CORE 1/ 7238-7263'/ PAGE 1



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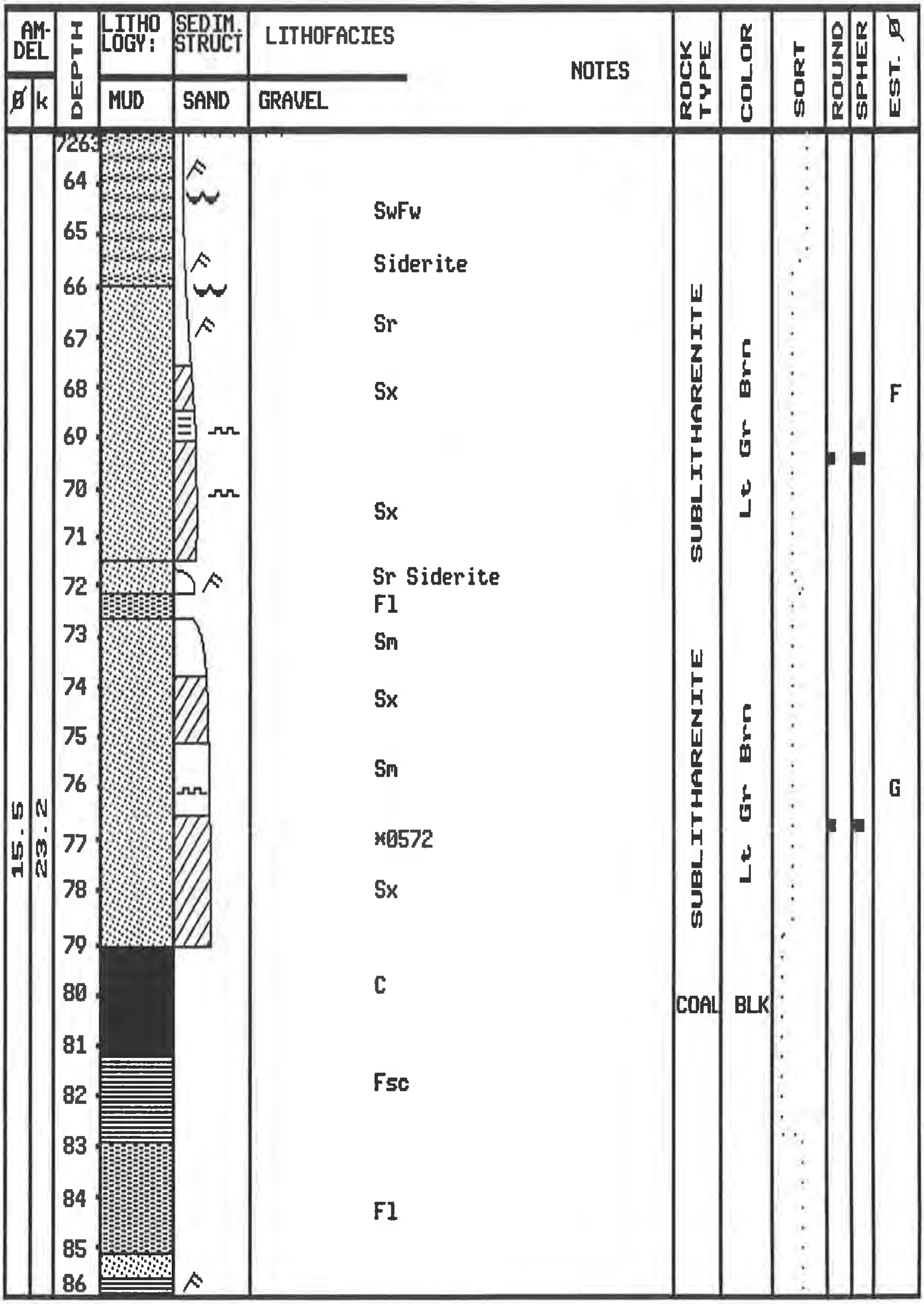

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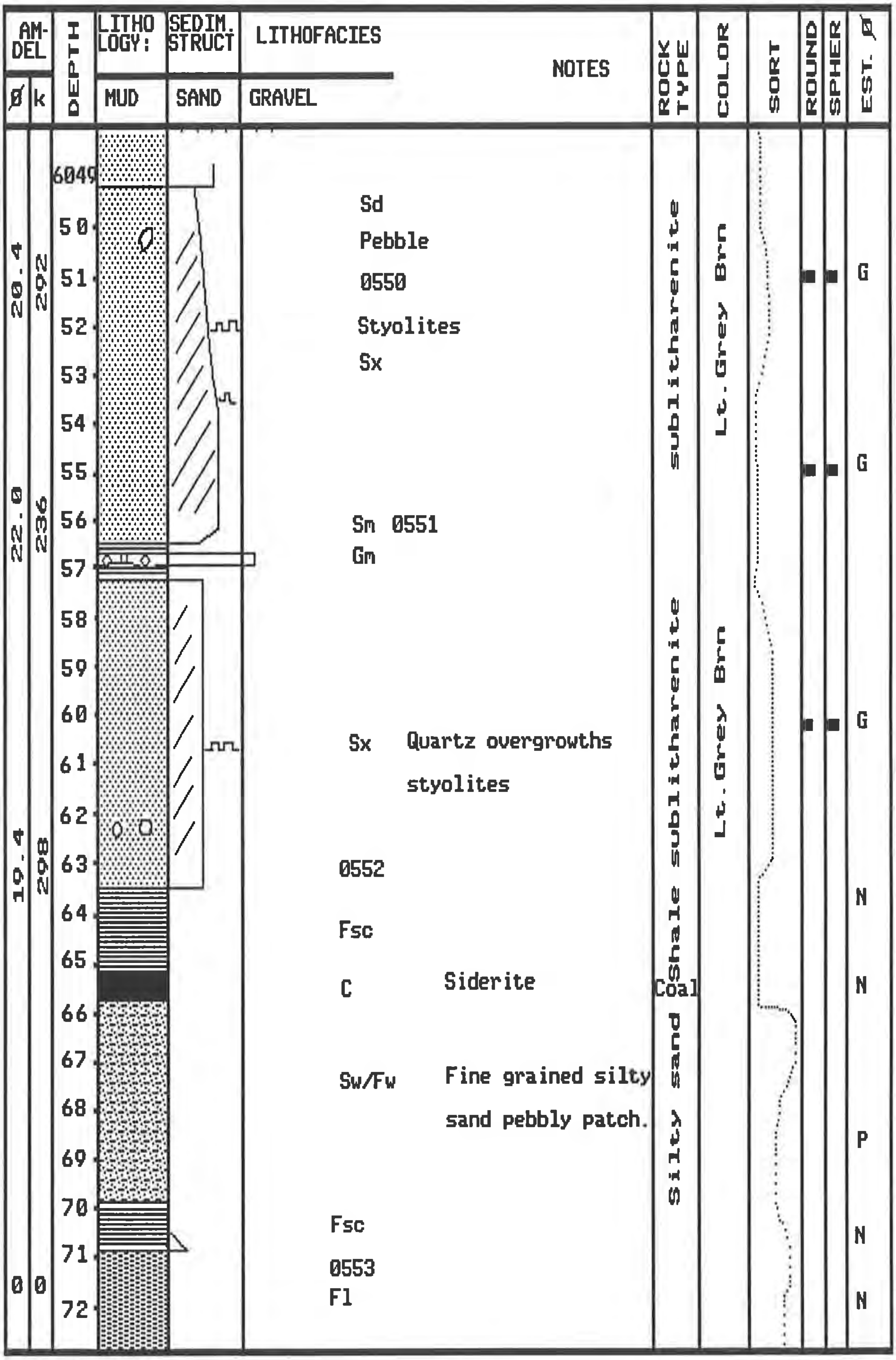

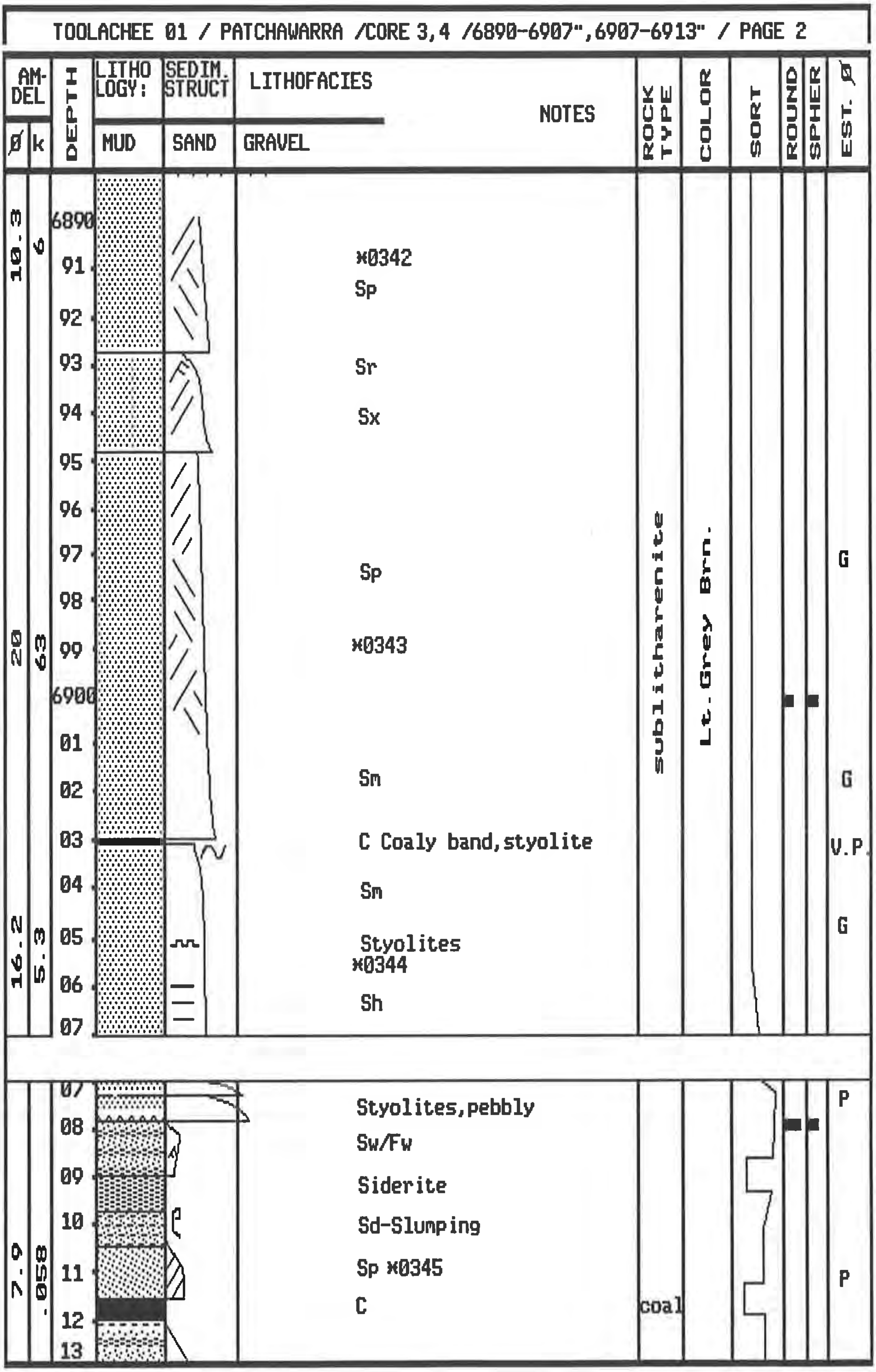
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13
*0342
Sp
Sr
Sx
Sp
*0343
Sm
C Coaly band,styolite
Sm
Styolites
*0344
Sh
Styolites,pebbly
Sw/Fw
Siderite
Sd-Slumping
Sp *0345
C
sublitharenite
coal
Lt.Grey Brn.
G
G
V.P.
G
P
P

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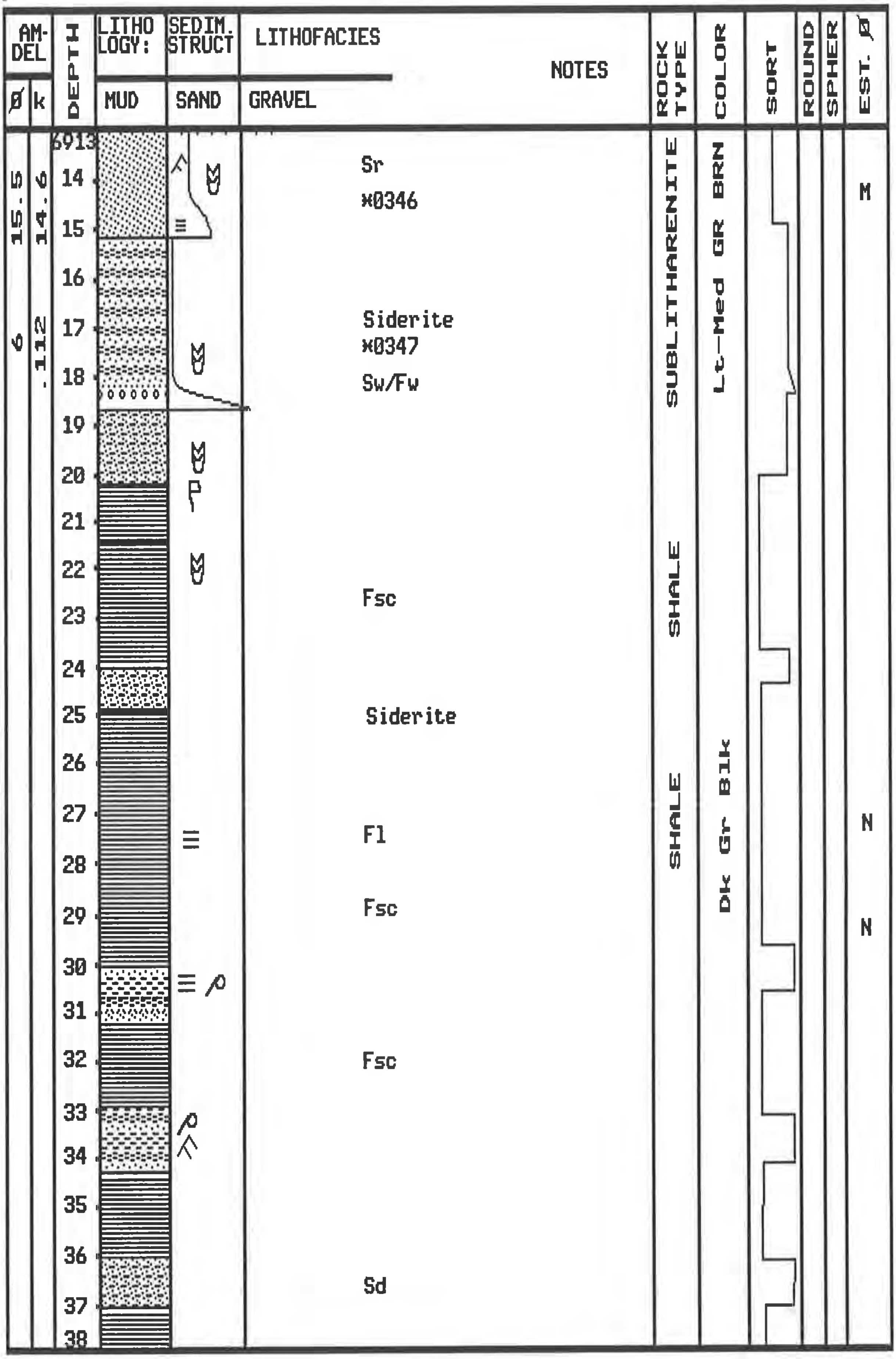

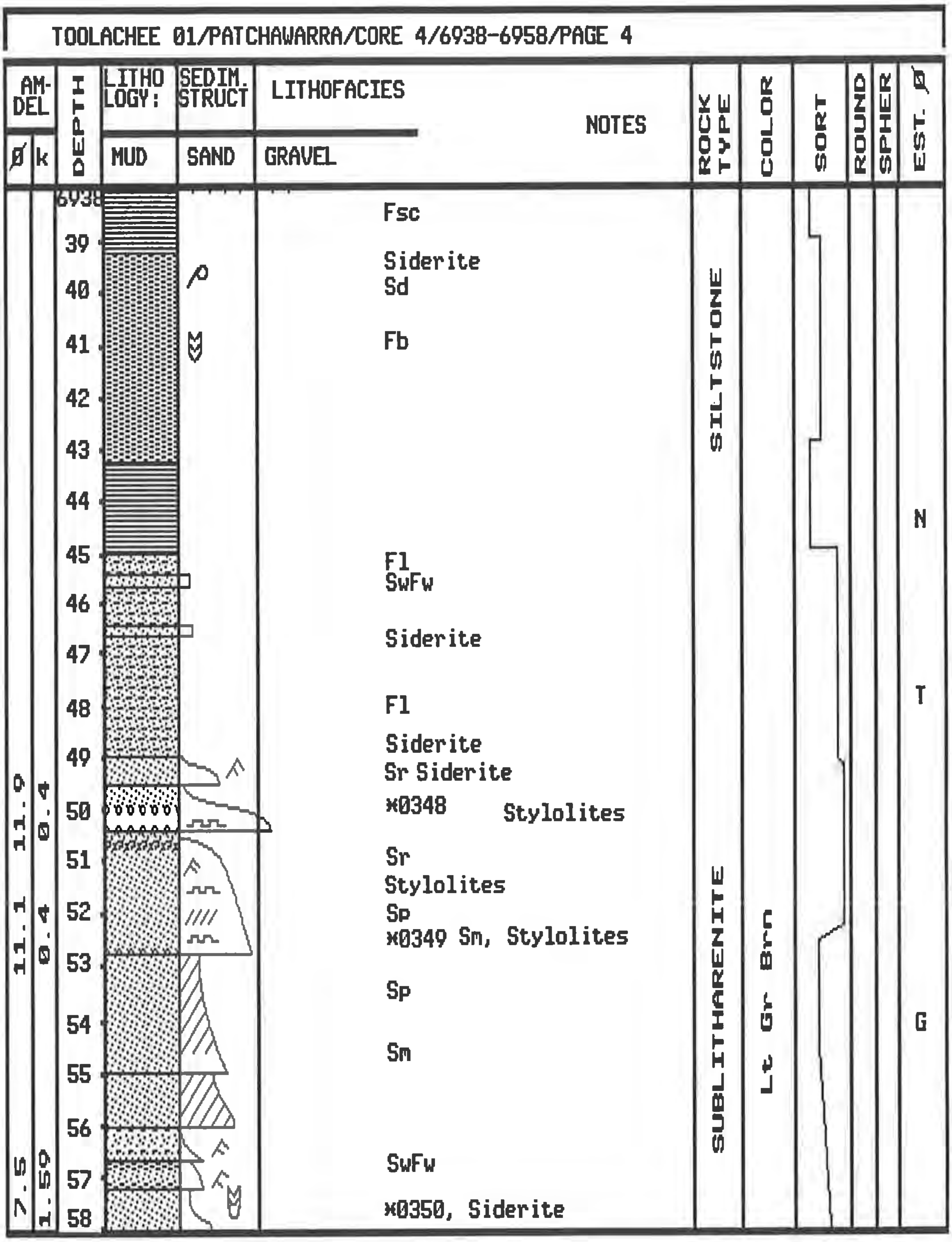
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Fsc
Siderite
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Fl
SwFw
Siderite
Fl
Siderite
Sr Siderite
*0348
Stylolites
Sr
Stylolites
Sp
*0349 Sm, Stylolites
Sp
Sm
SwFw
*0350, Siderite
11.9
0.4
11.1
0.4
7.5
1.59
SILTSTONE
SUBLITHARENITE
Lt Gr Brn
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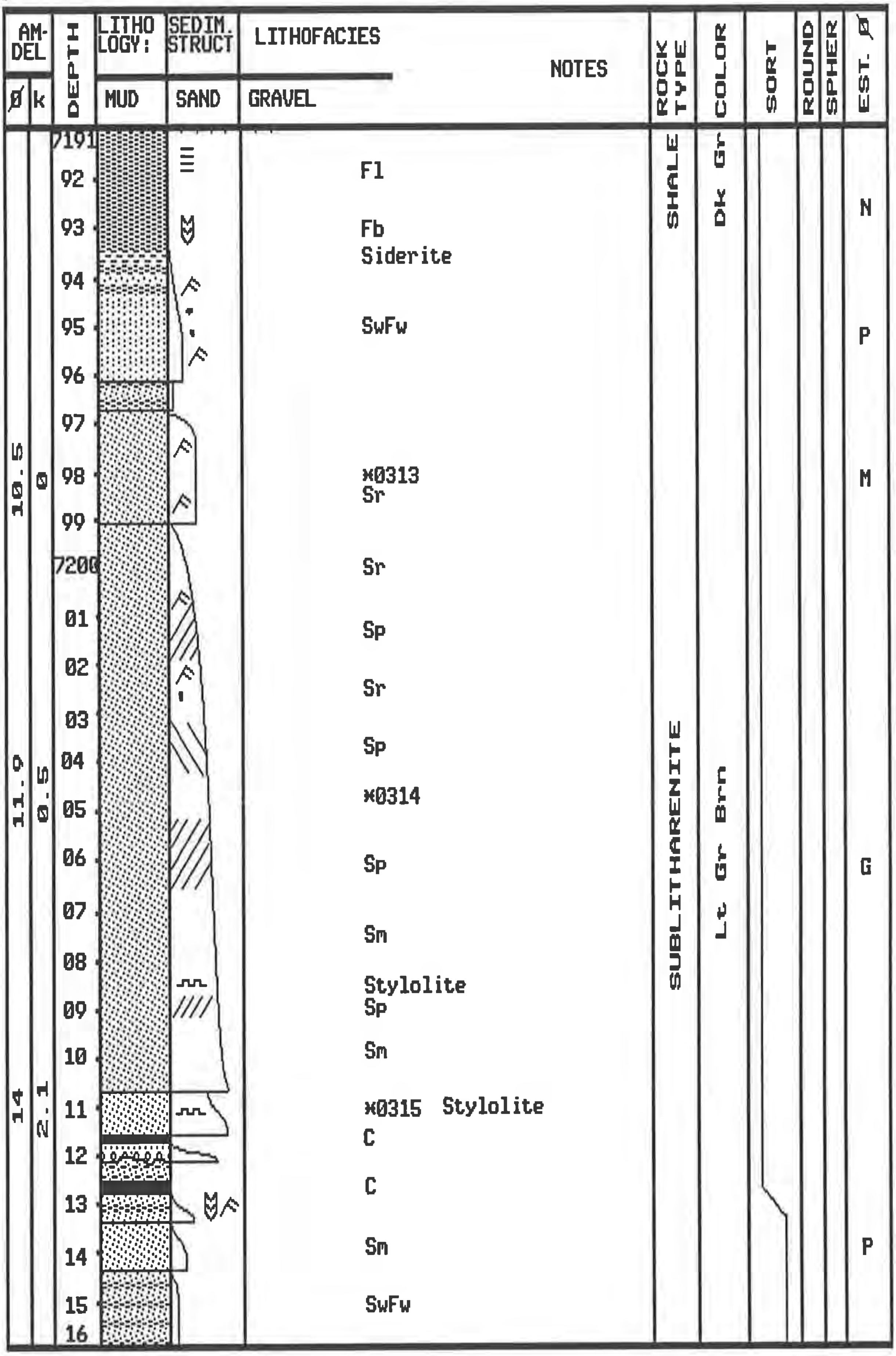

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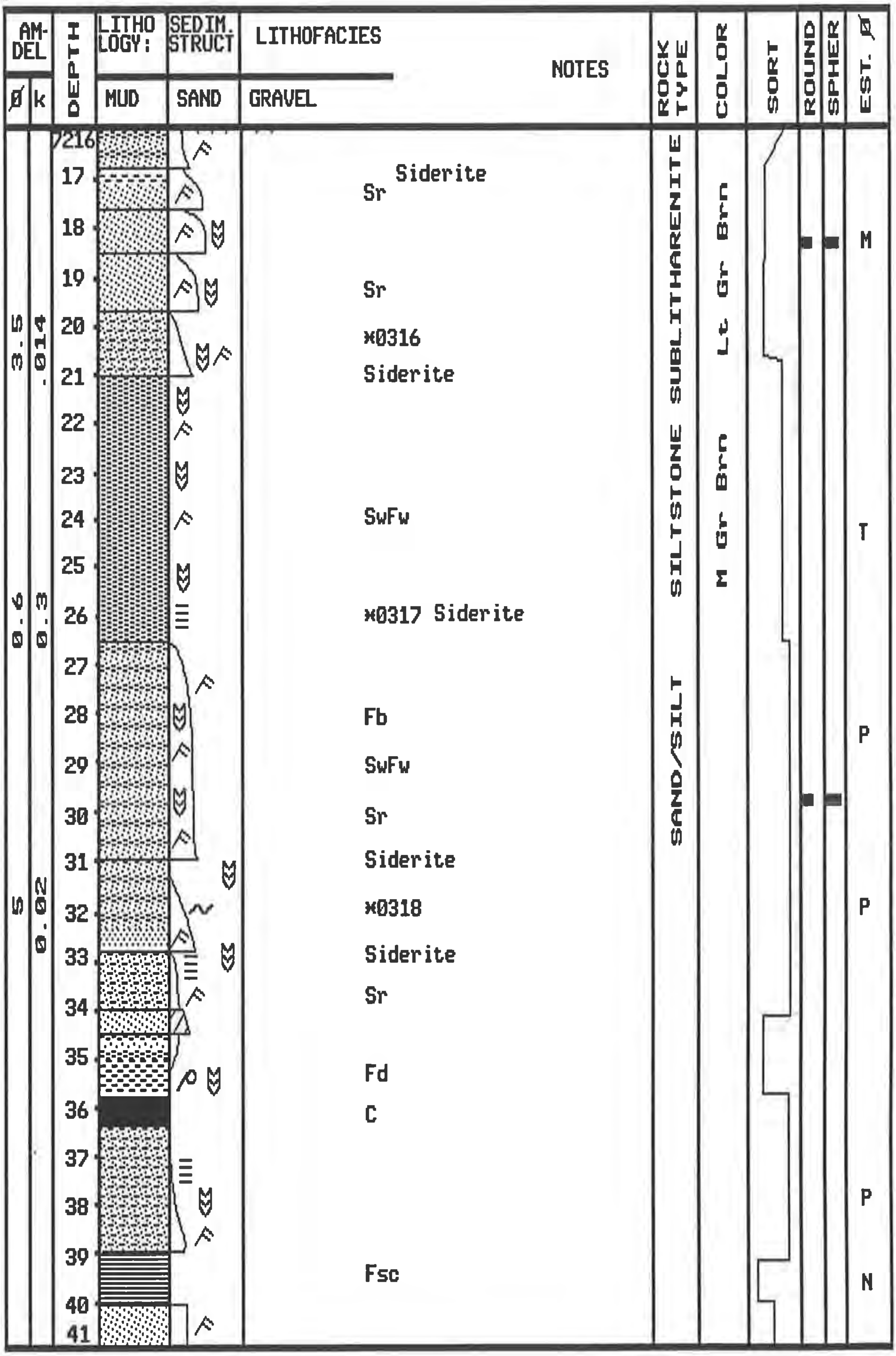

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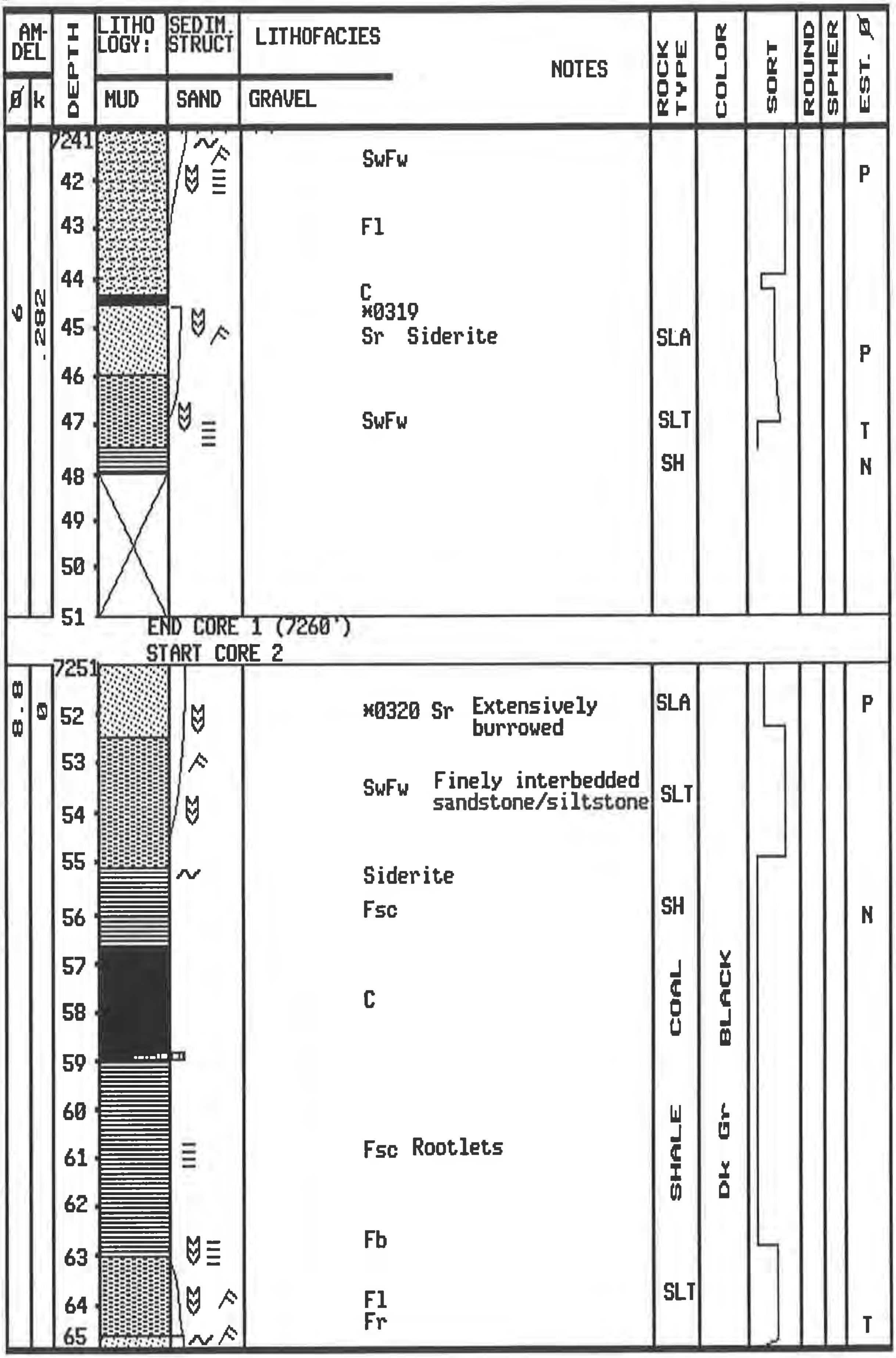

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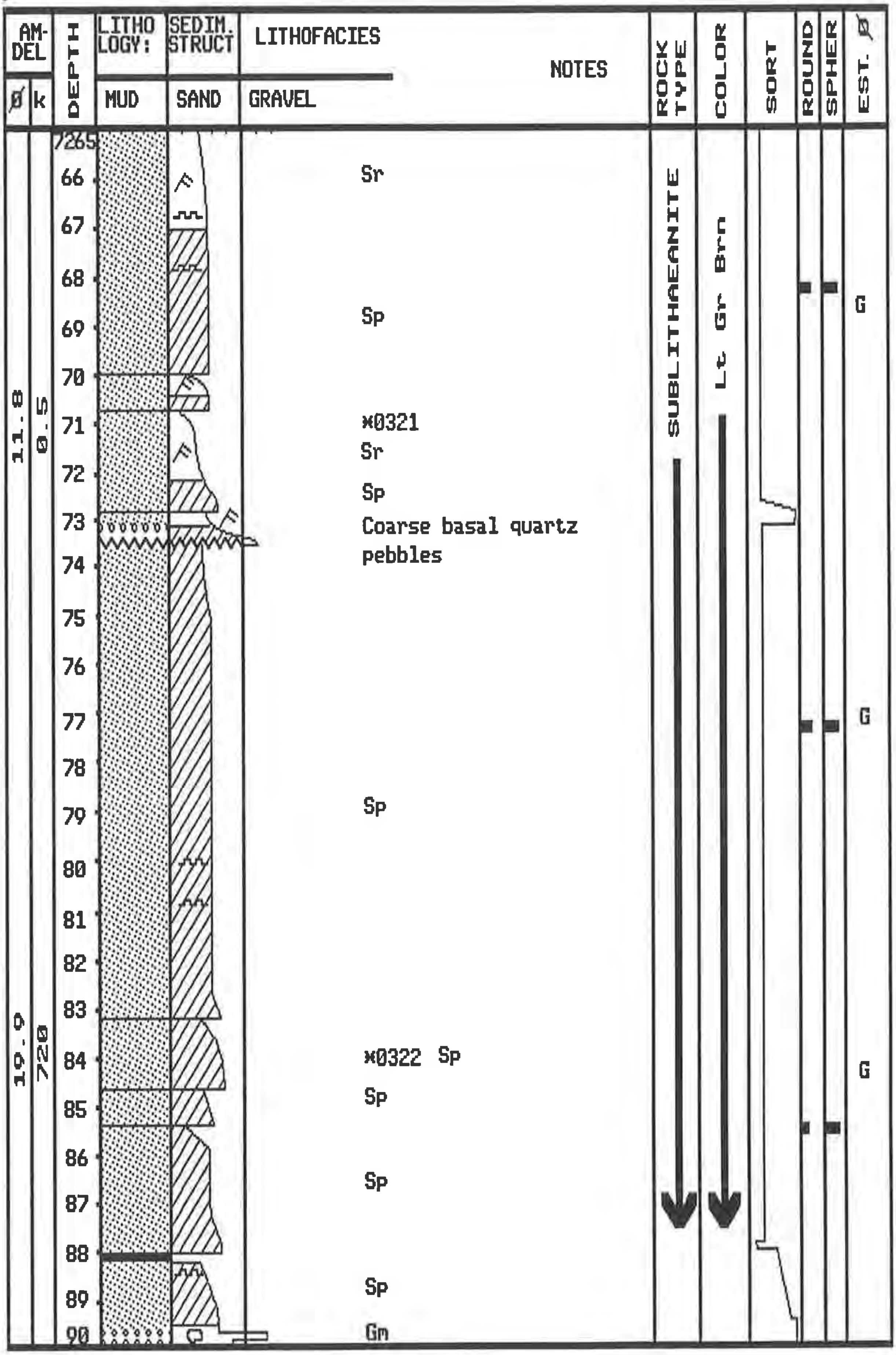

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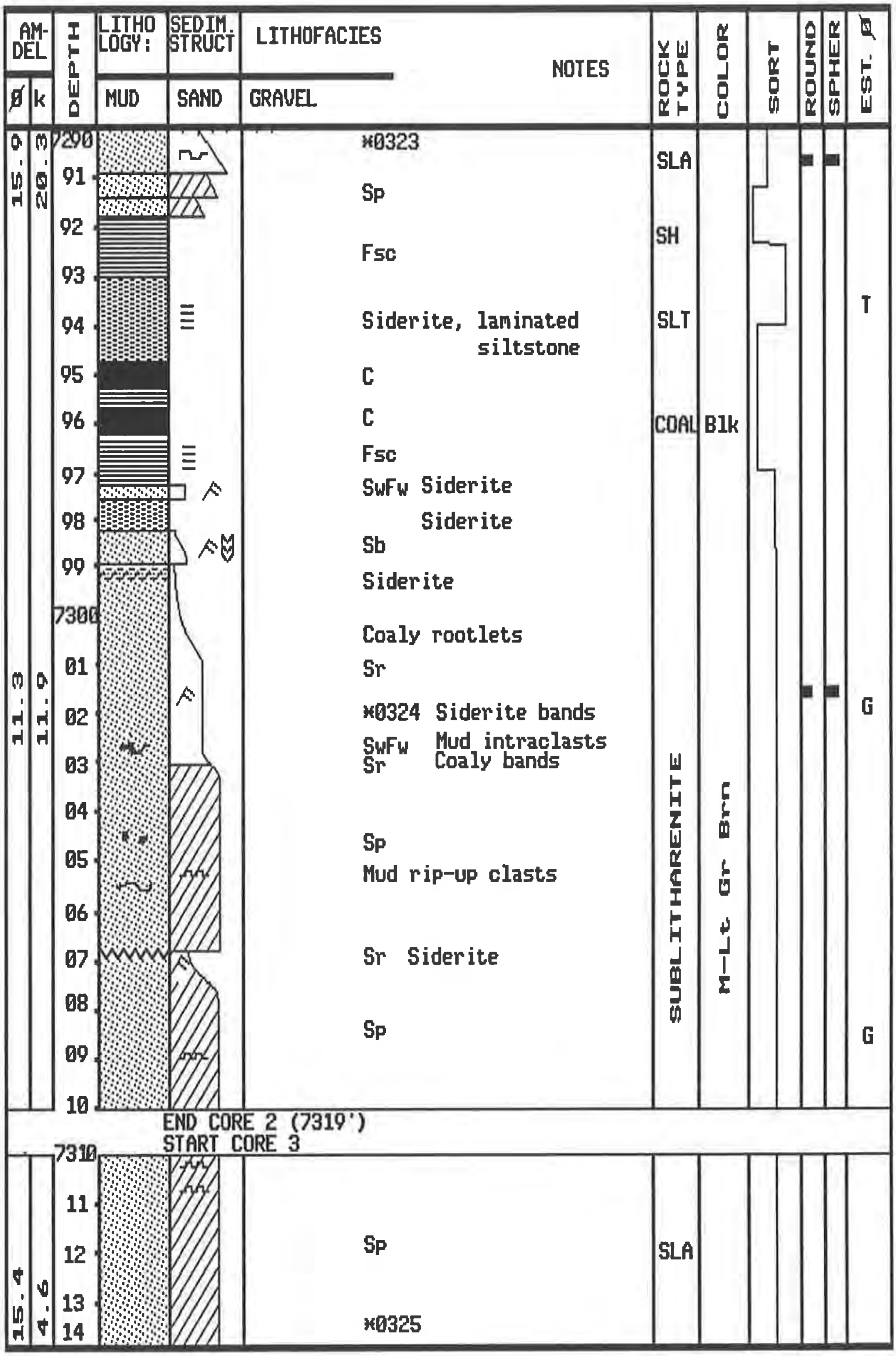

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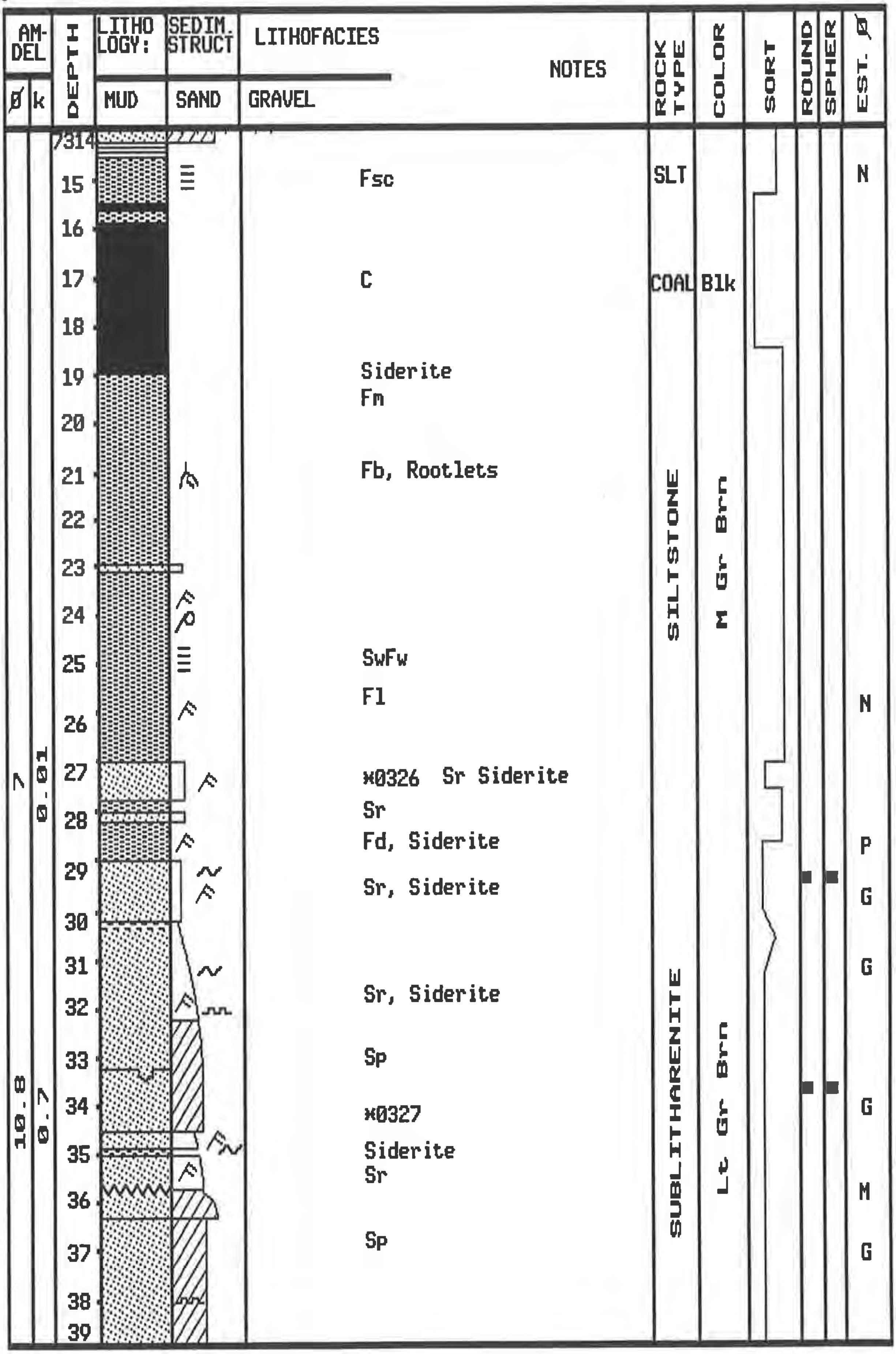

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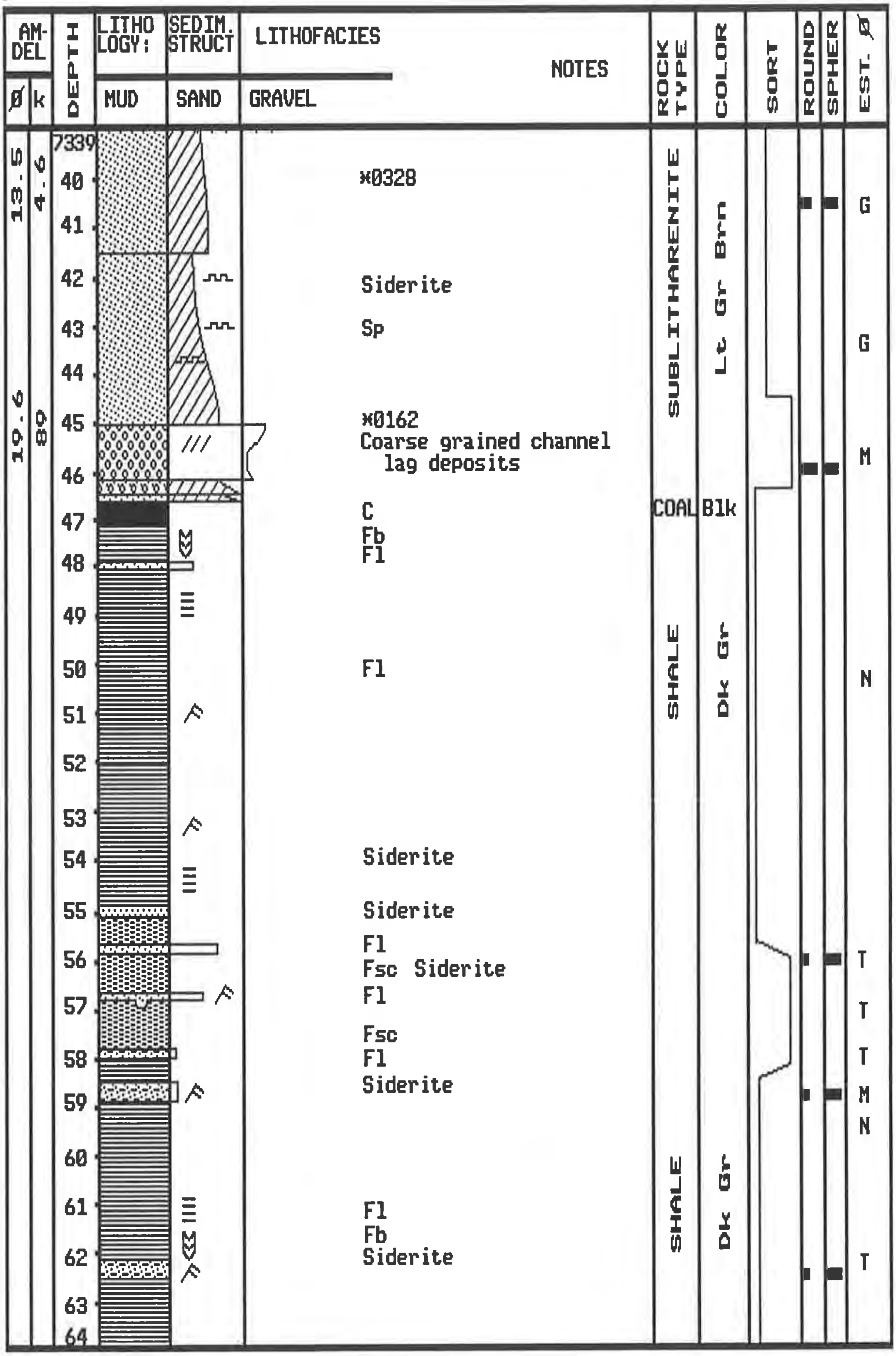

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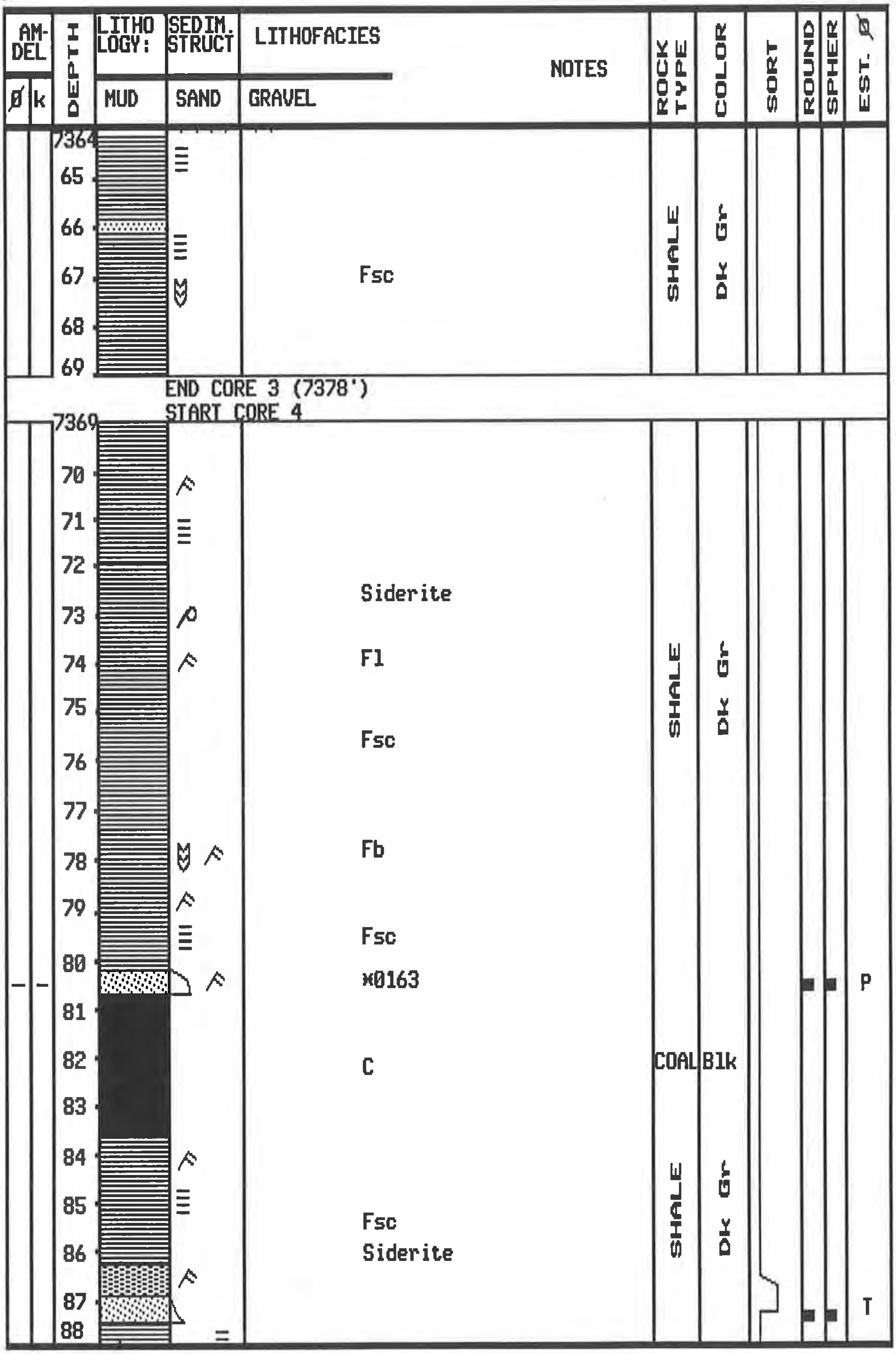

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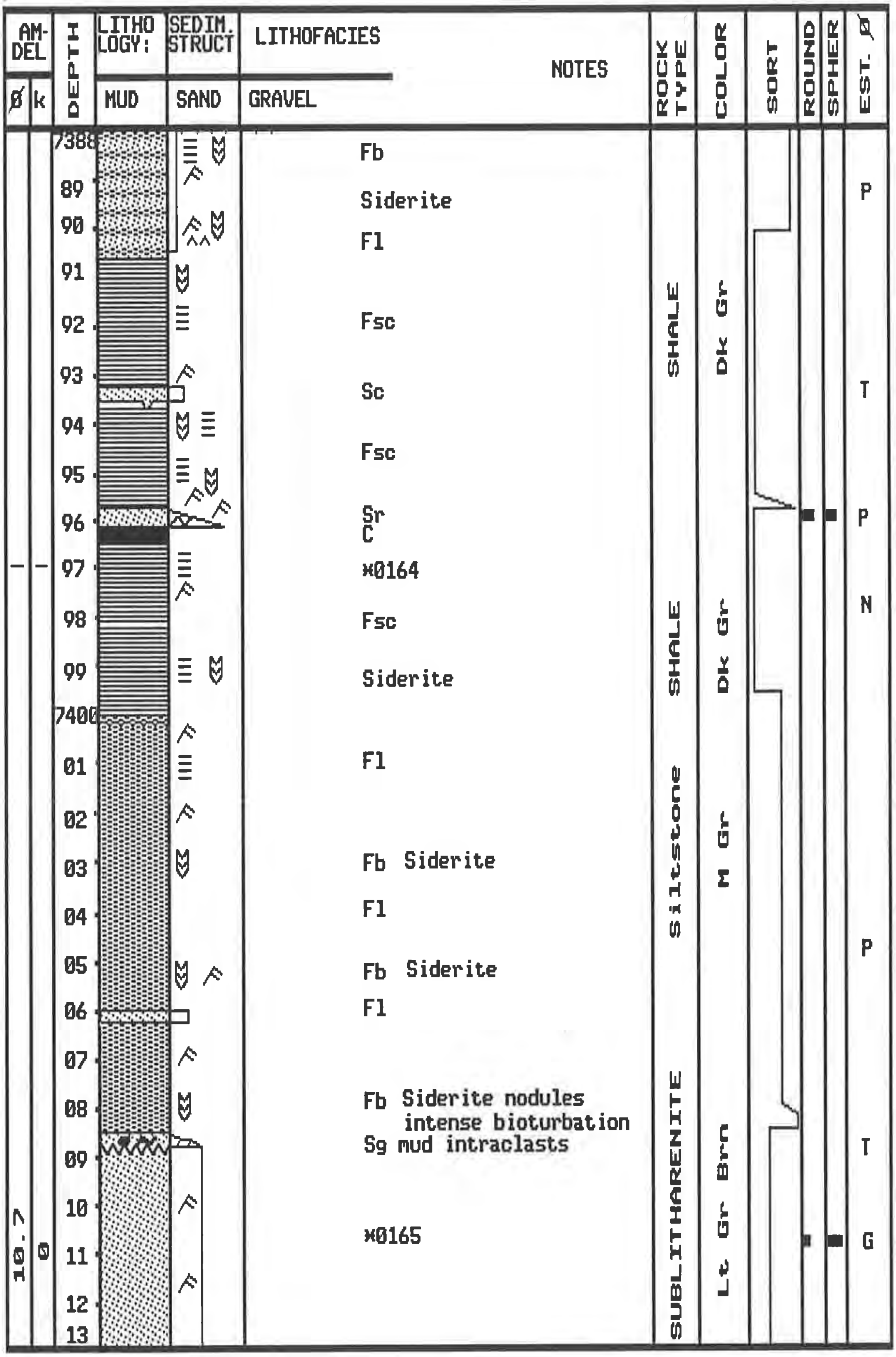

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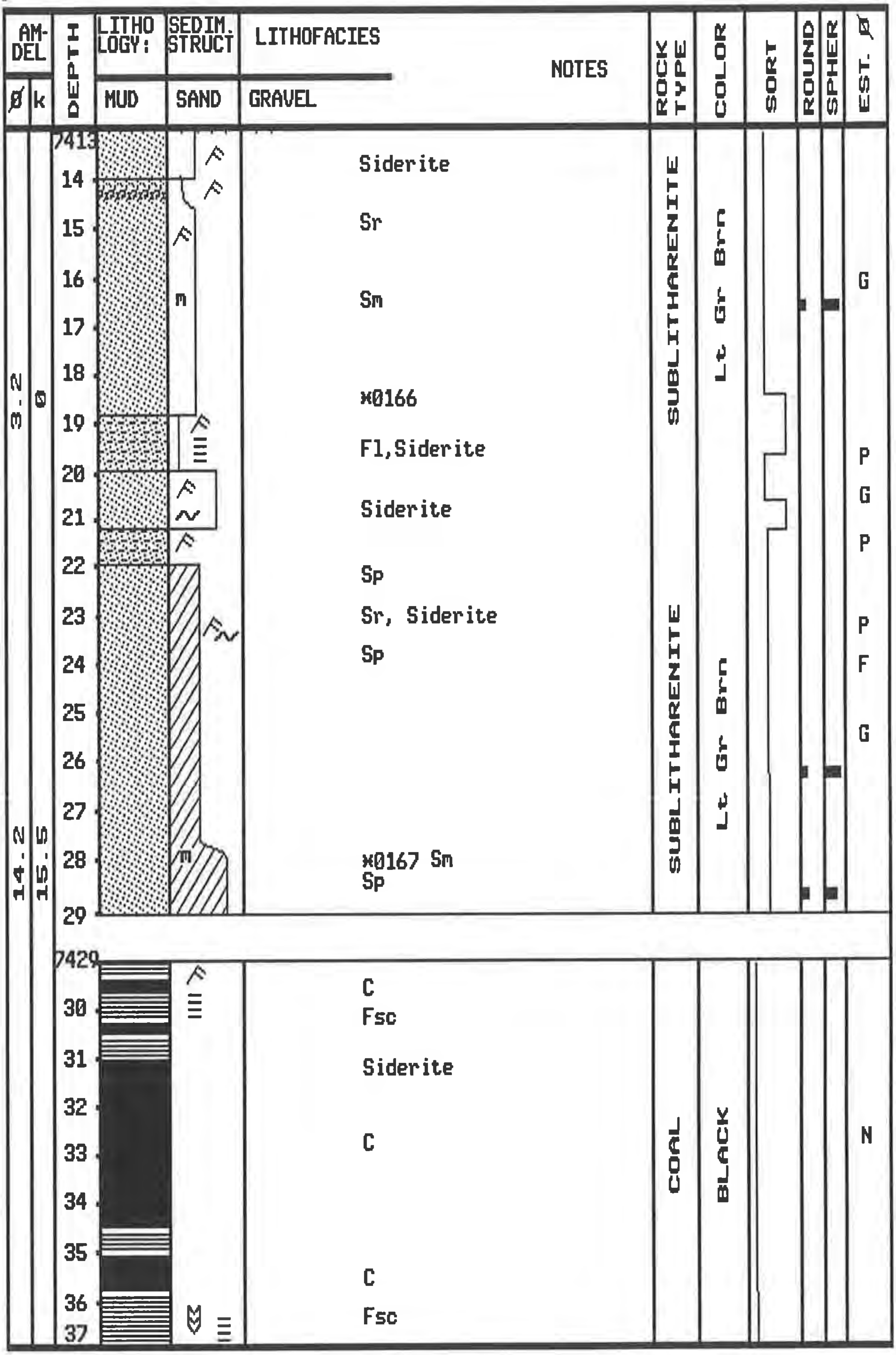

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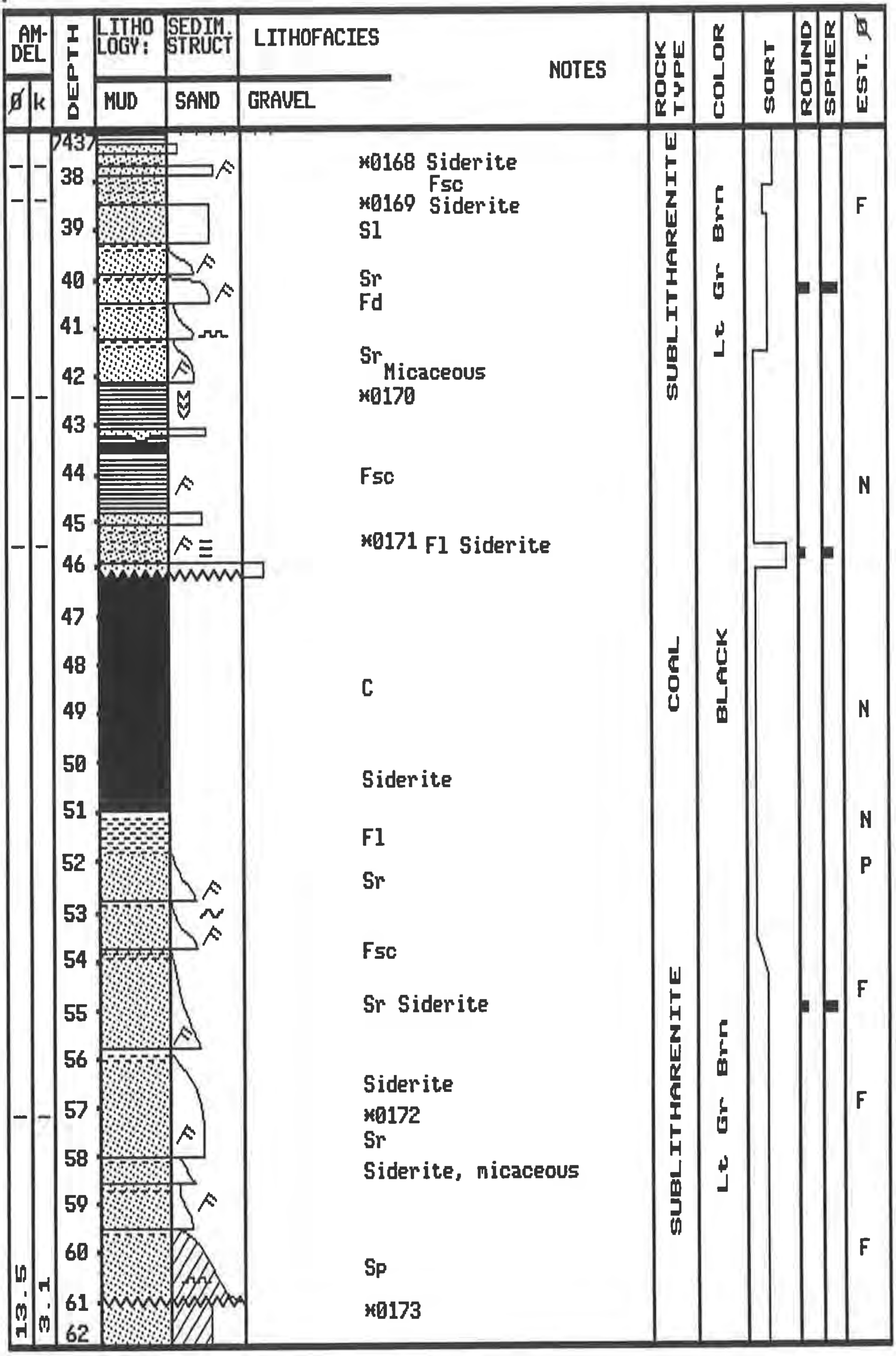

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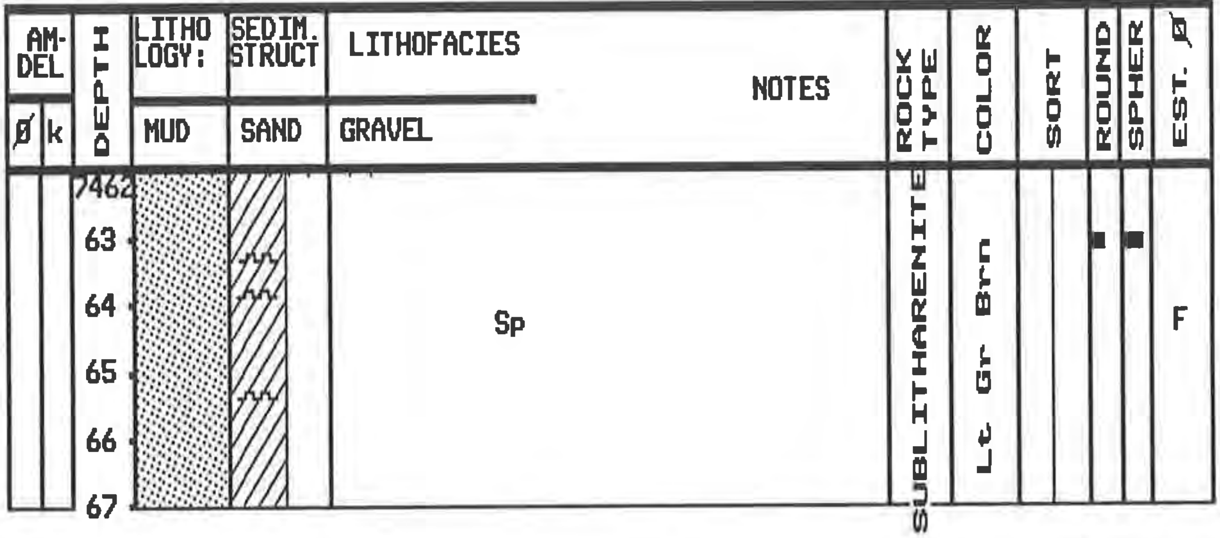

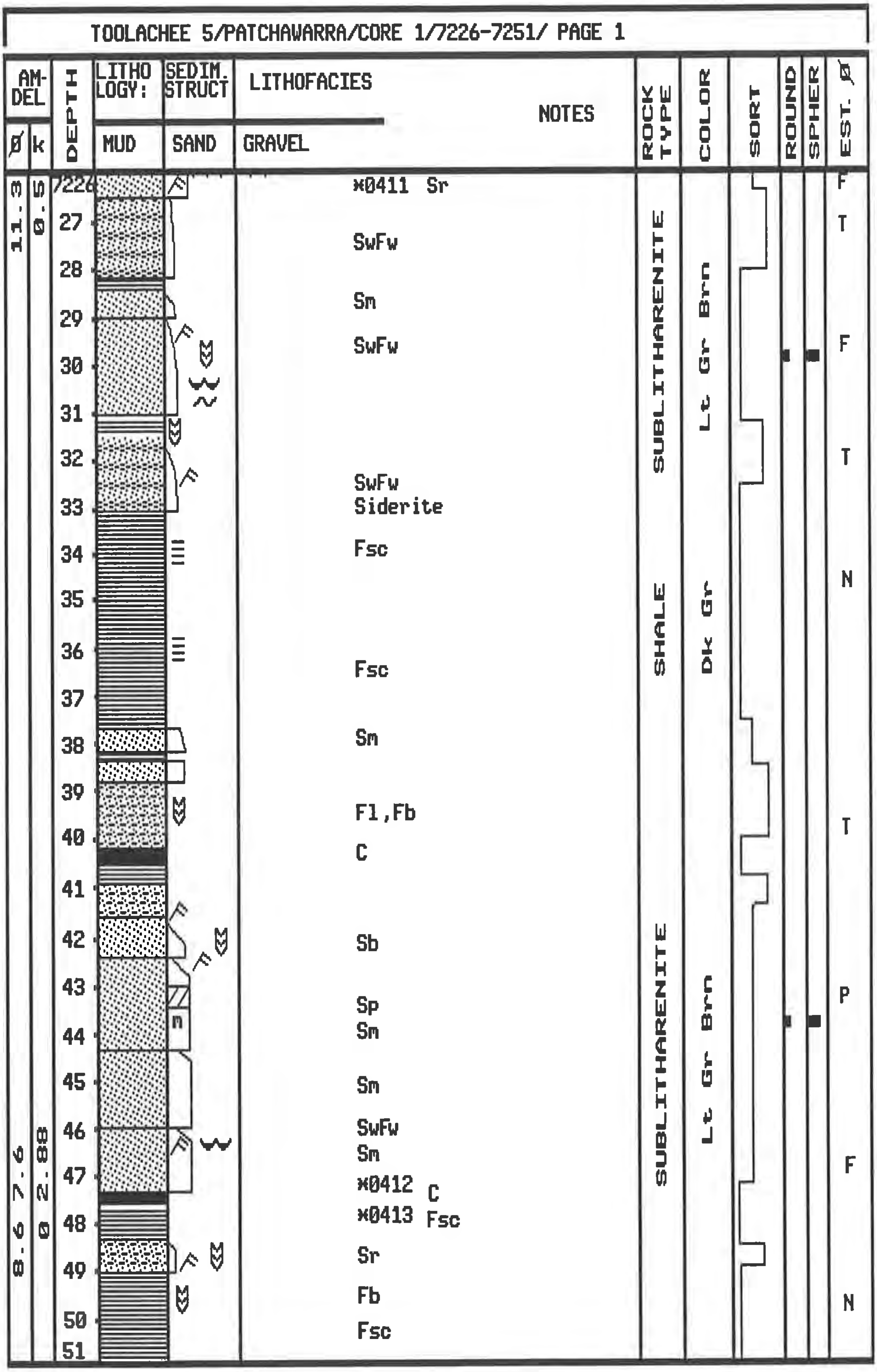
TOOLACHEE 5/PATCHAWARRA/CORE 1/7226-7251/ PAGE 1
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8.6 7.6
0 2.88
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×0411 Sr
SwFw
Sm
SwFw
SwFw
Siderite
Fsc
Fsc
Sm
Fl,Fb
C
Sb
Sp
Sm
Sm
SwFw
Sm
×0412 C
×0413 Fsc
Sr
Fb
Fsc
SUBLITHARENITE
SHALE
SUBLITHARENITE
Lt Gr Brn
Dk Gr
Lt Gr Brn
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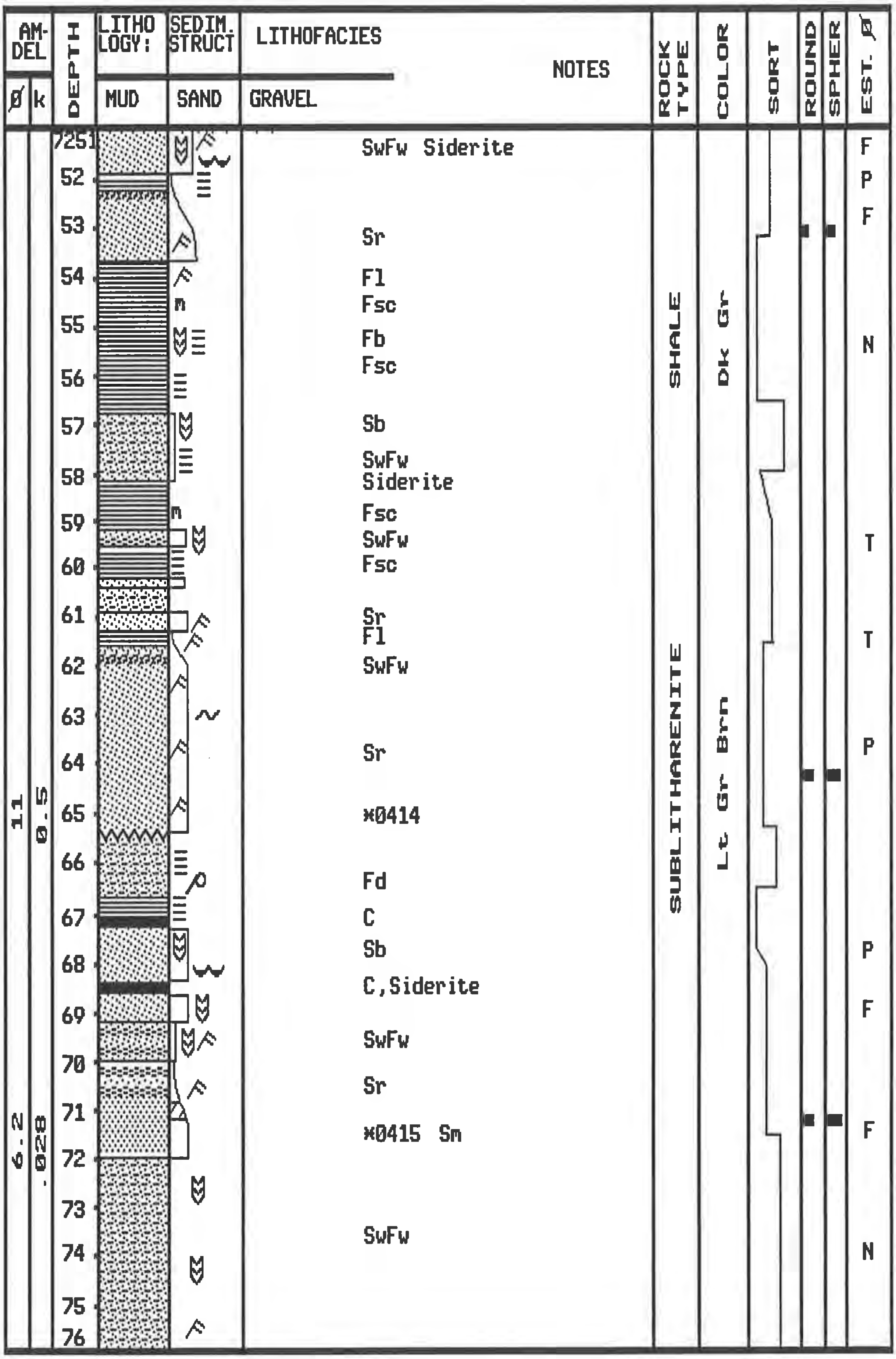
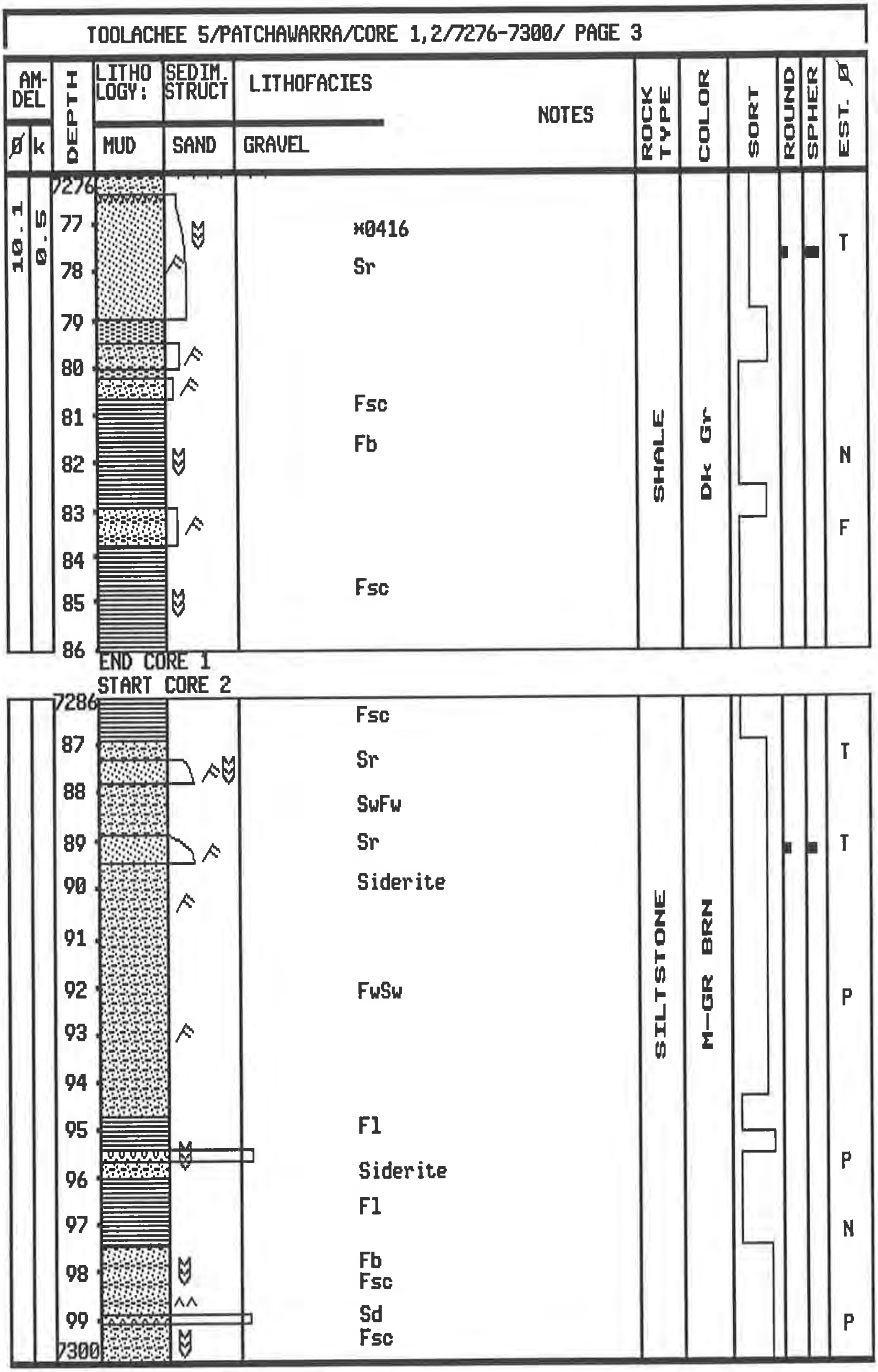
TOOLACHEE 5/PATCHAWARRA/CORE 1/ 7251-7276/ PAGE 2

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AM-DEL
Ø k
DEPTH
LITHOLOGY:
SEDIM. STRUCT
LITHOFACIES
NOTES
MUD
SAND
GRAVEL
ROCK TYPE
COLOR
SORT
ROUND
SPHER
EST. Ø
10.1
0.5
7276
77
78
79
80
81
82
83
84
85
86
×0416
Sr
Fsc
Fb
Fsc
SHALE
Dk Gr
T
N
F
END CORE 1
START CORE 2
7286
87
88
89
90
91
92
93
94
95
96
97
98
99
7300
Fsc
Sr
SwFw
Sr
Siderite
FwSw
Fl
Siderite
Fl
Fb
Fsc
Sd
Fsc
SILTSTONE
M-GR BRN
T
T
P
P
N
P

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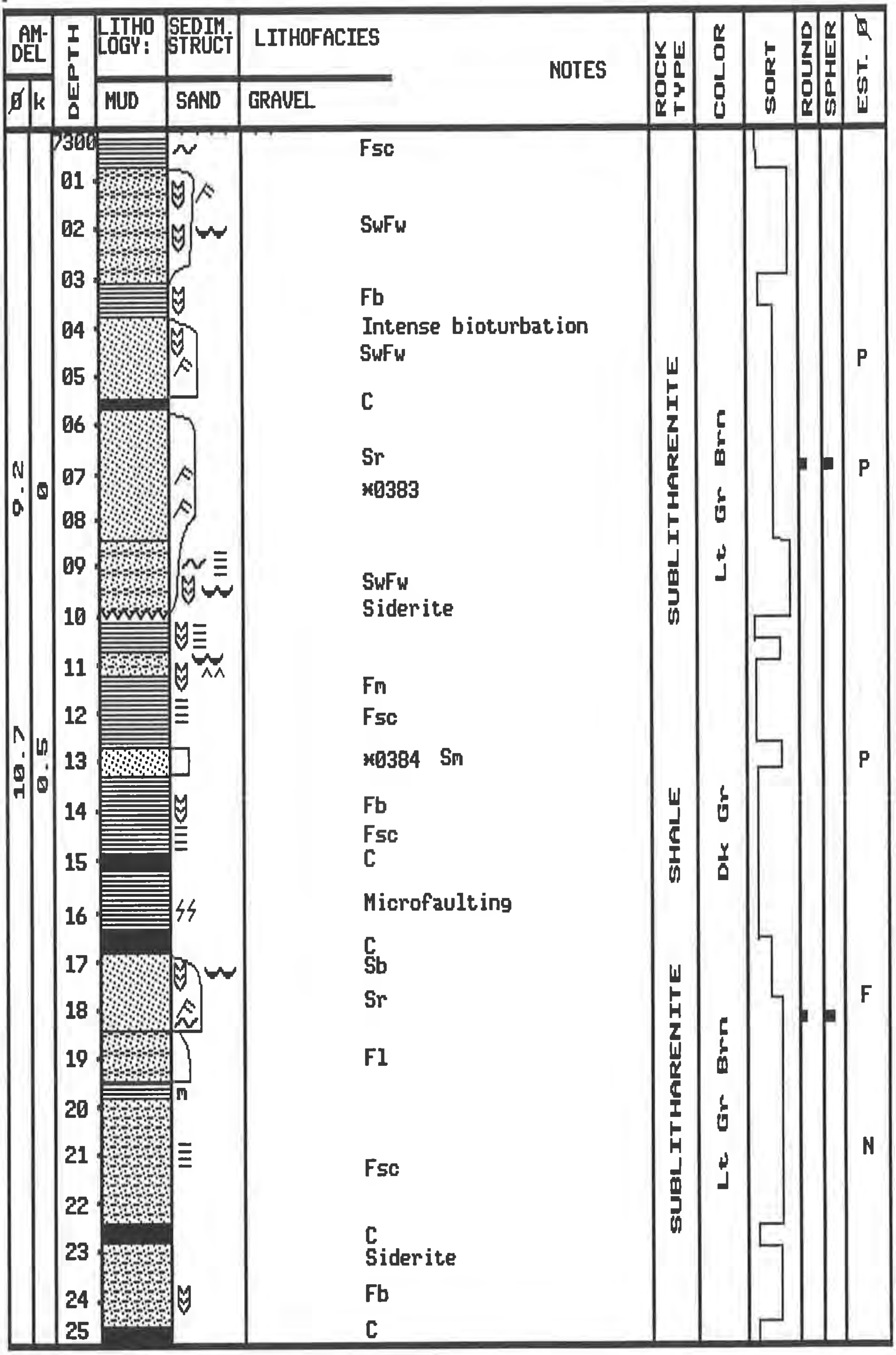

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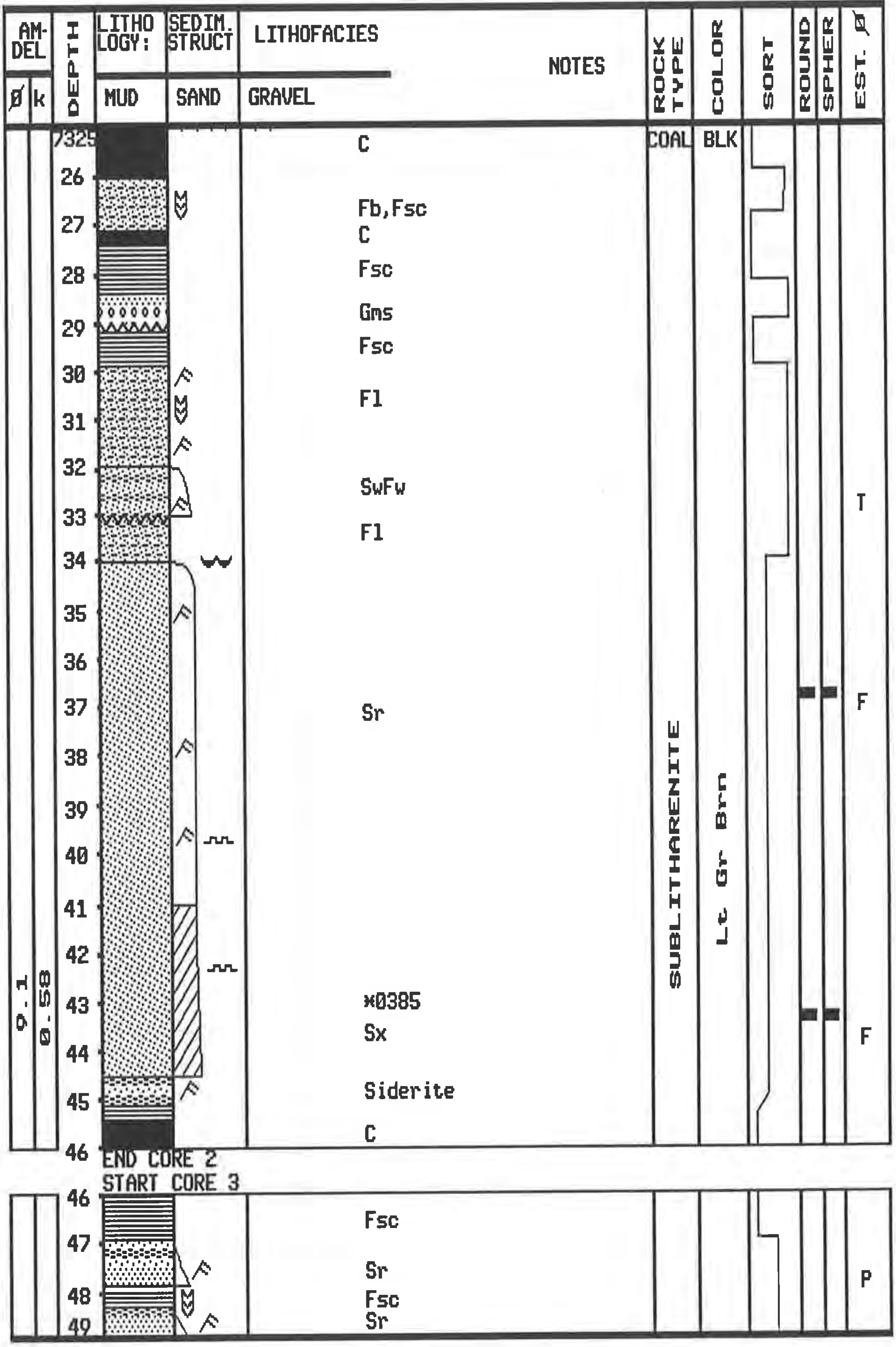

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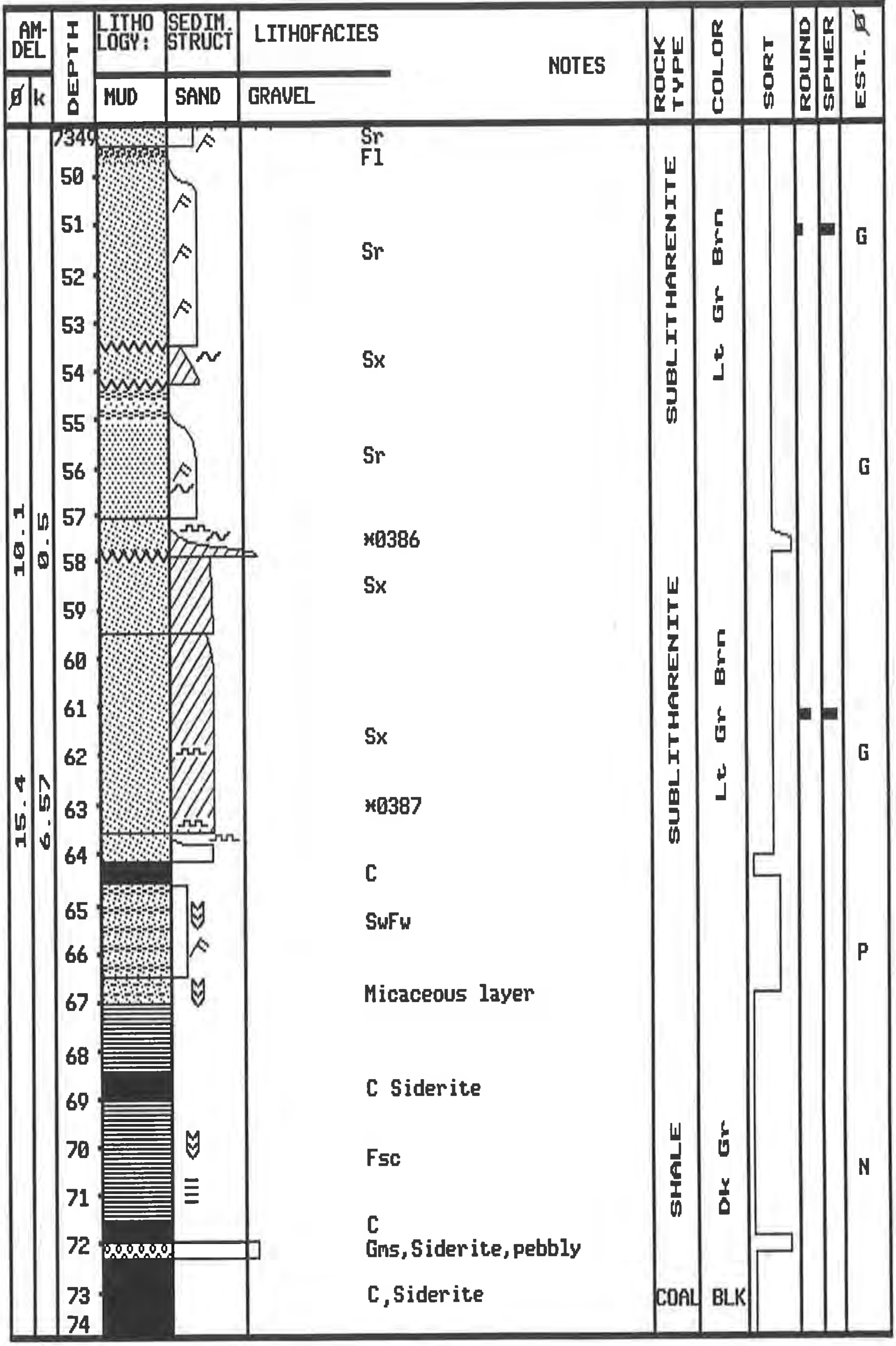

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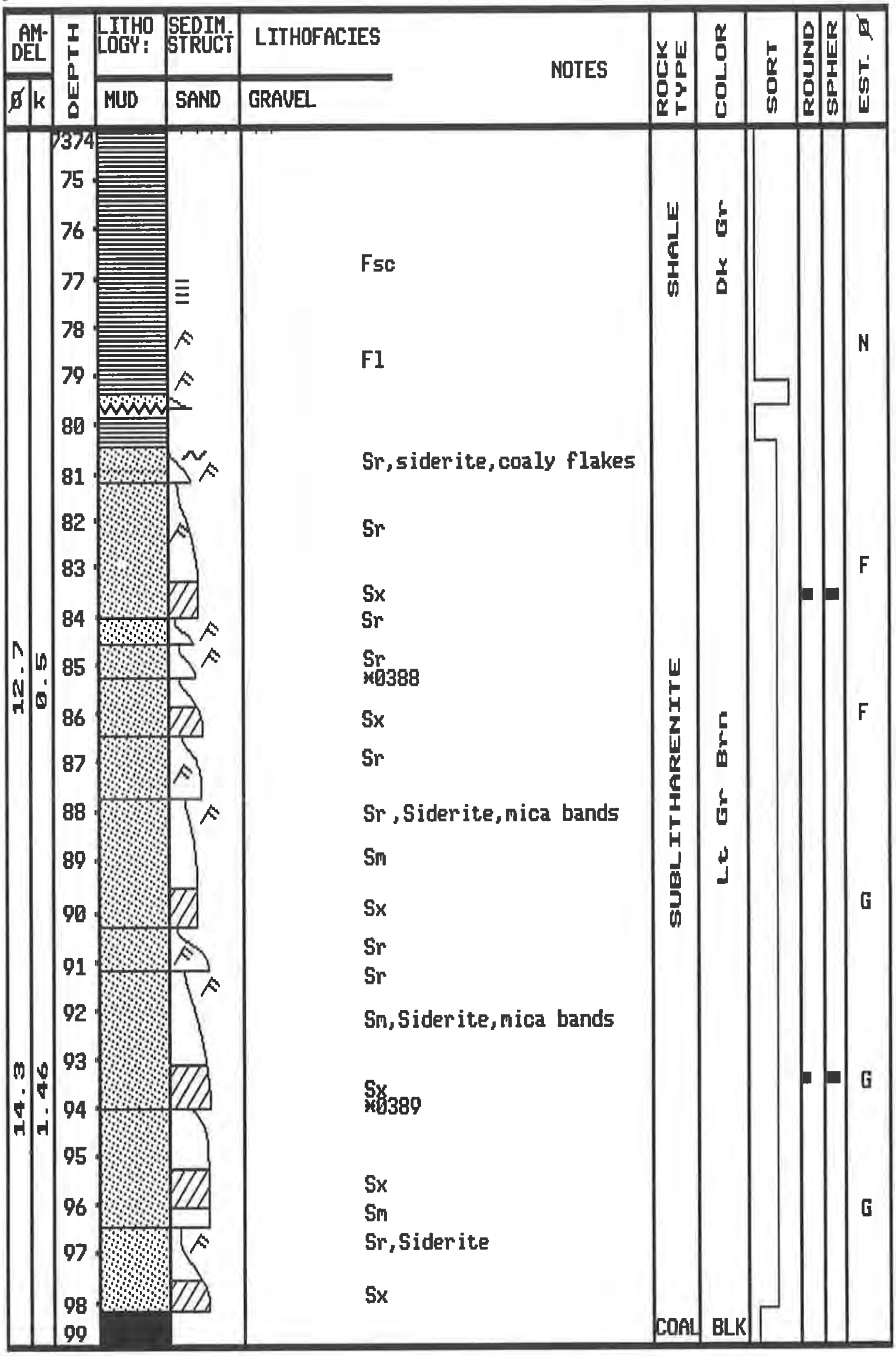
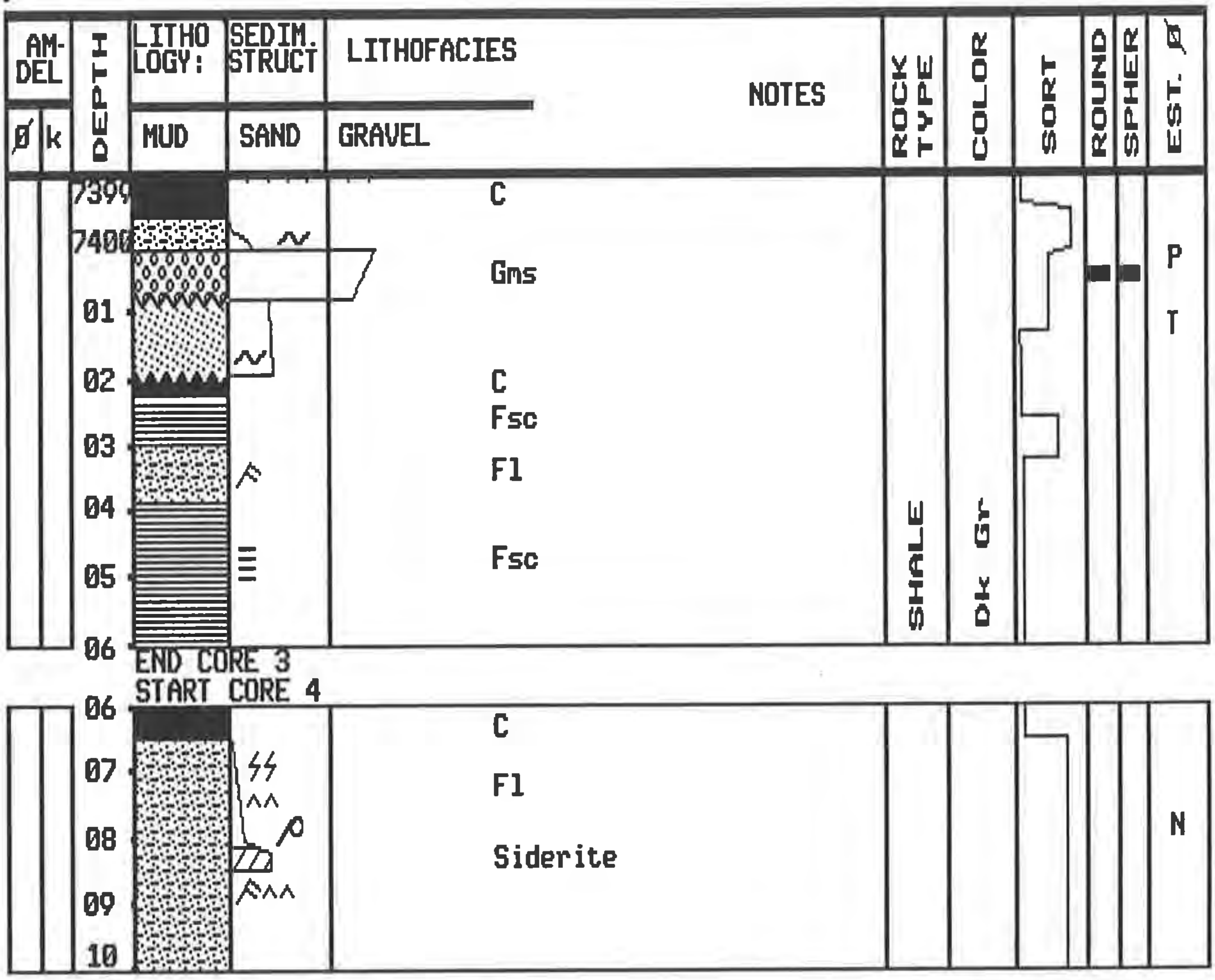
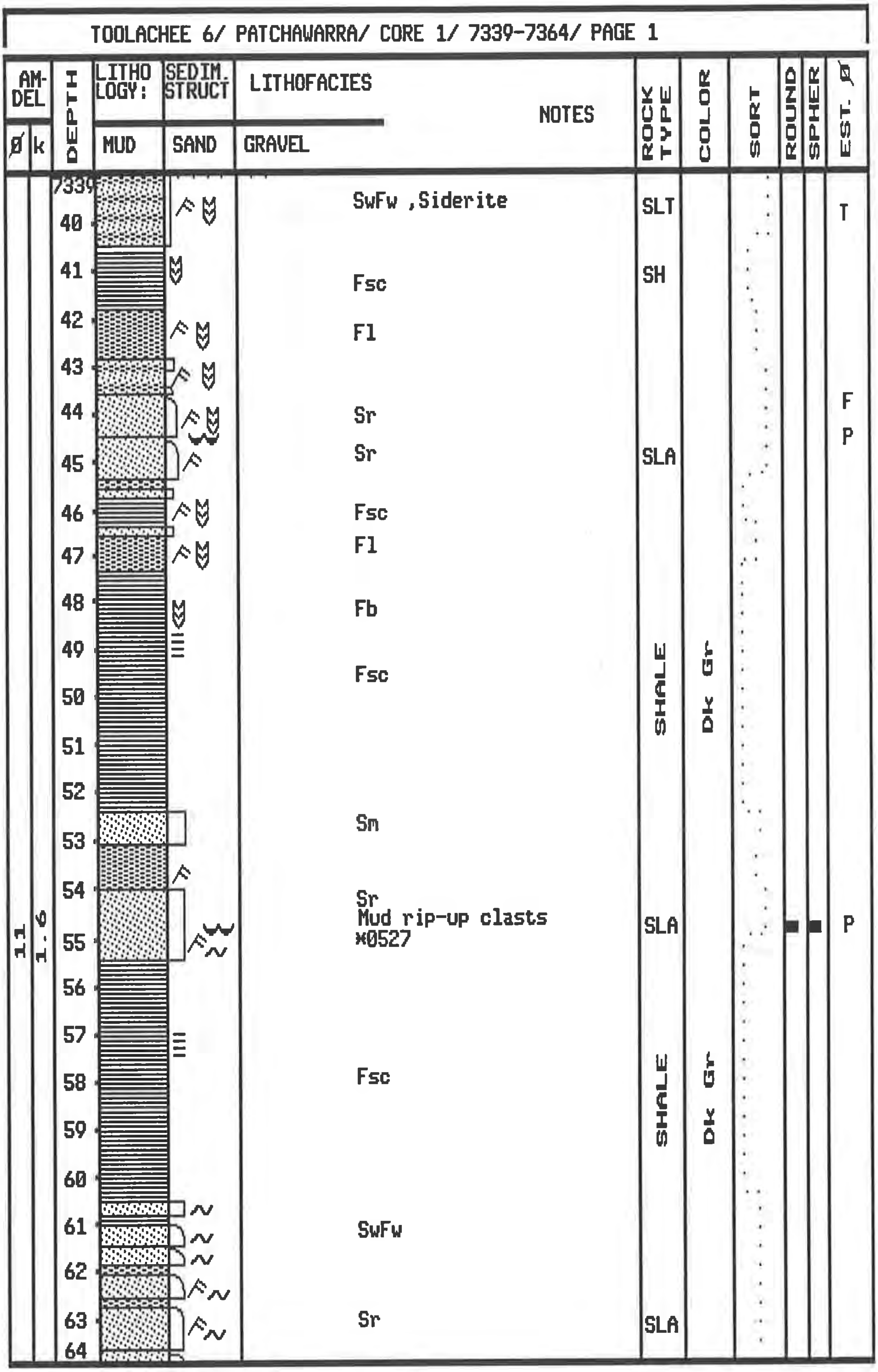


TOOLACHEE 5/PATCHAWARRA/CORE 3,4/7399-7410/ PAGE 8





TOOLACHEE 6/ PATCHAWARRA/ CORE 1/ 7339-7364/ PAGE 1
AM-DEL
Ø
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DEPTH
LITHOLOGY:
SEDIM. STRUCT
LITHOFACIES
MUD
SAND
GRAVEL
NOTES
ROCK TYPE
COLOR
SORT
ROUND
SPHER
EST. Ø
7339
40
41
42
43
44
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46
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61
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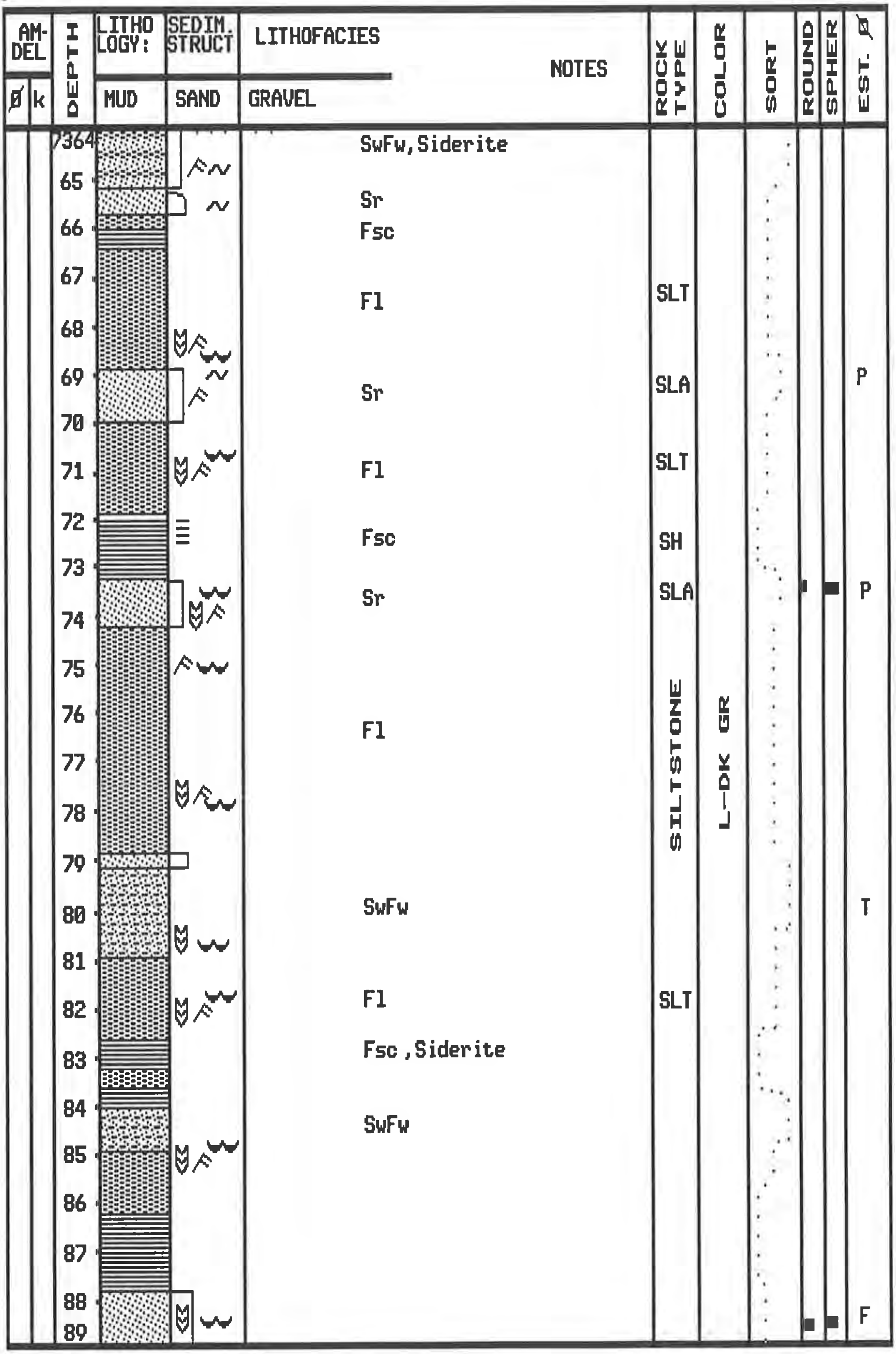
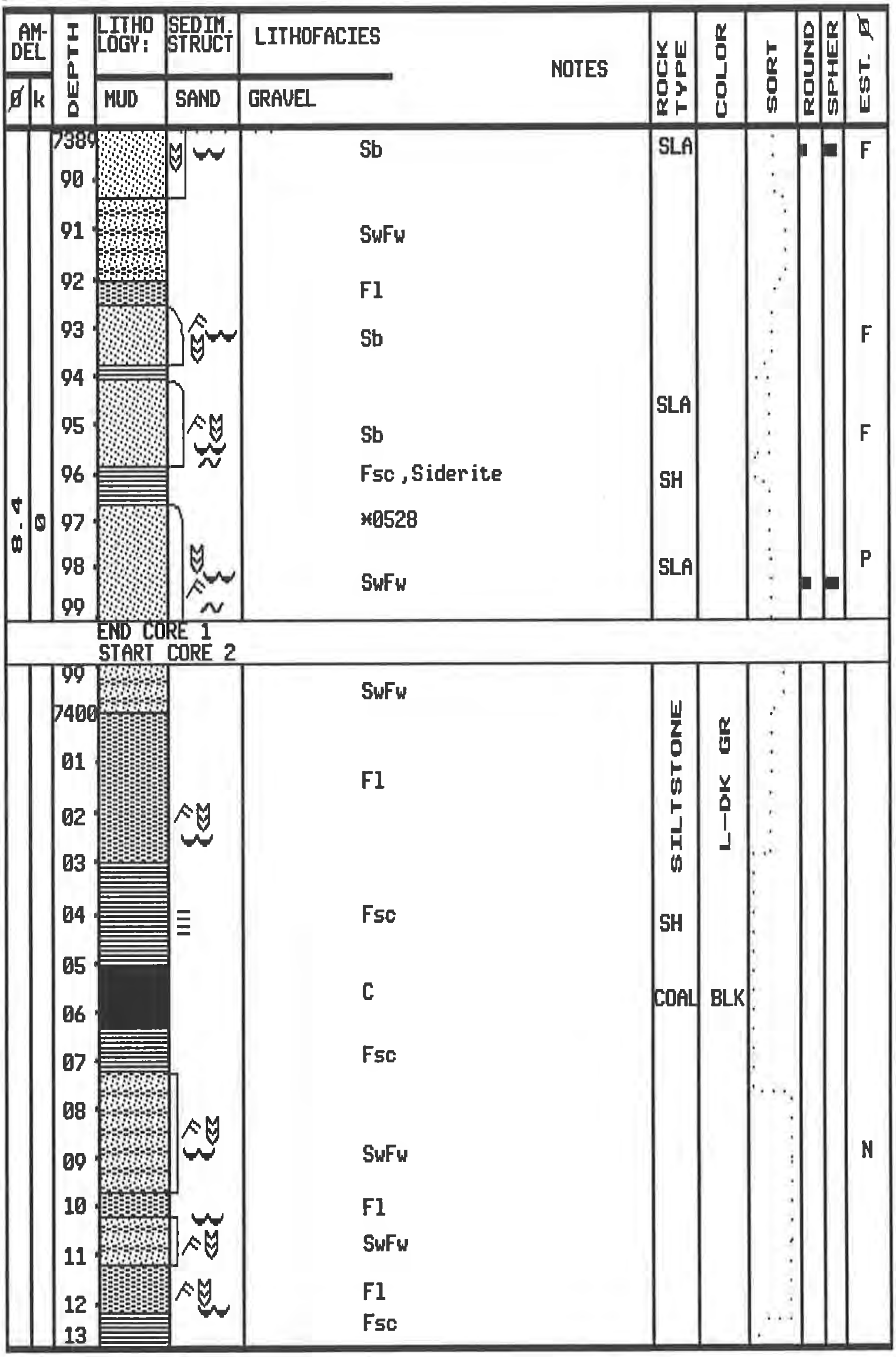
63
64
SwFw ,Siderite
SLT
T
Fsc
SH
Fl
Sr
F
Sr
P
SLA
Fsc
Fl
Fb
Fsc
SHALE
Dk Gr
Sm
Sr
Mud rip-up clasts
*0527
SLA
P
11
1.6
Fsc
SHALE
Dk Gr
SwFw
Sr
SLA

TOOLACHEE 6/ PATCHAWARRA/ CORE 1/ 7364-7389'/ PAGE 2



TOOLACHEE 6/ PATCHAWARRA/ CORE 1,2/ 7389-7413/ PAGE 3



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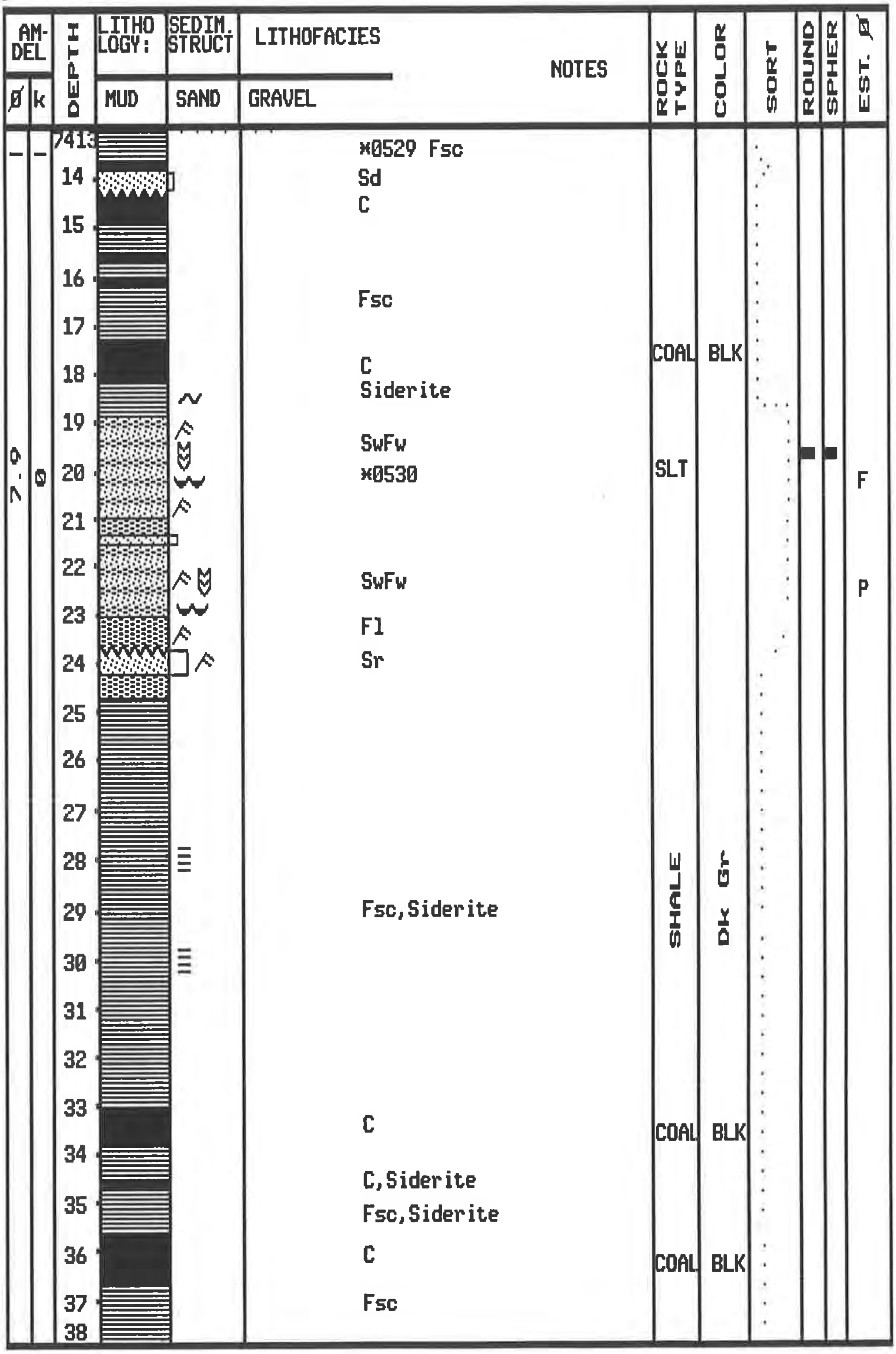

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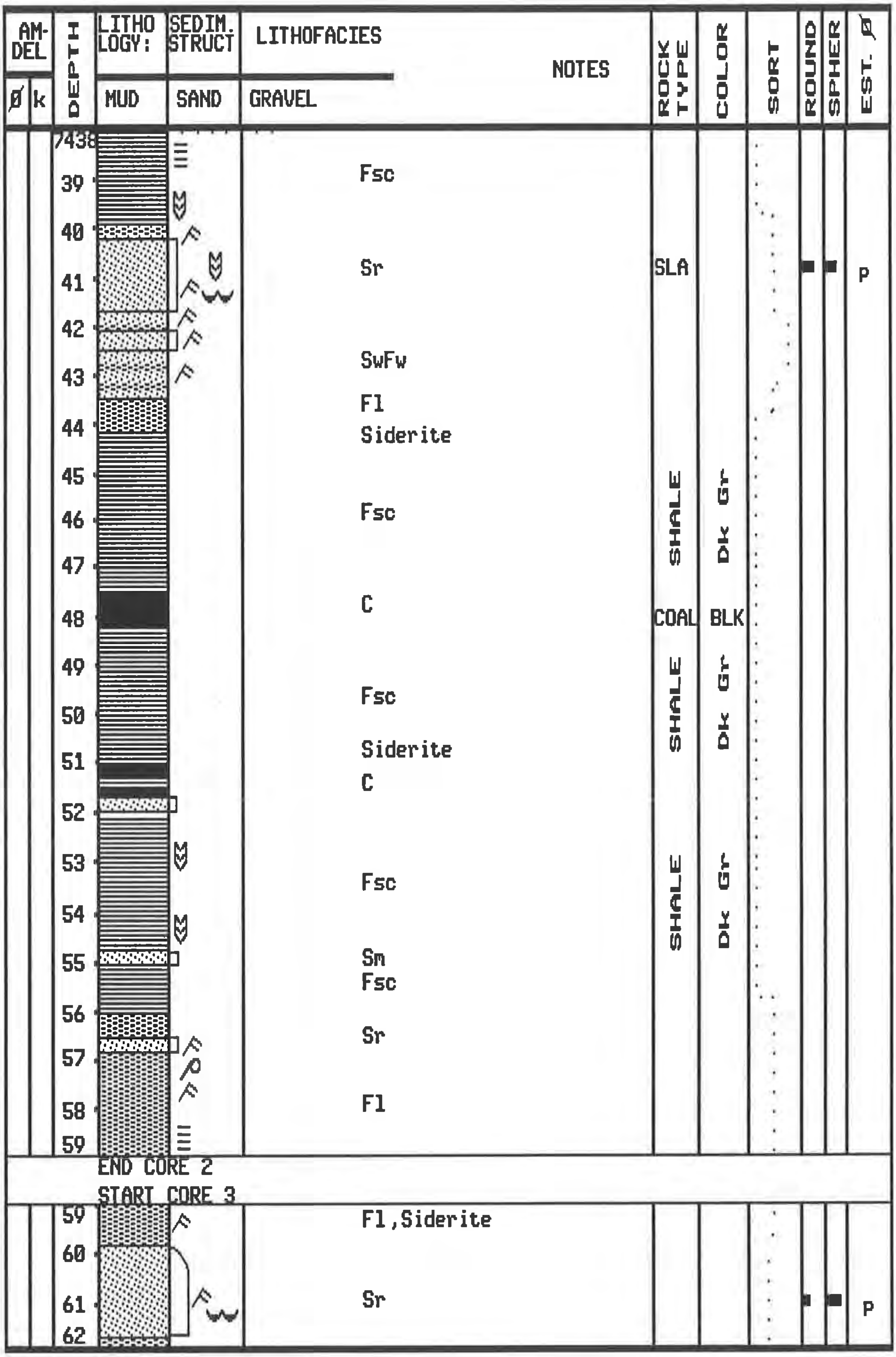

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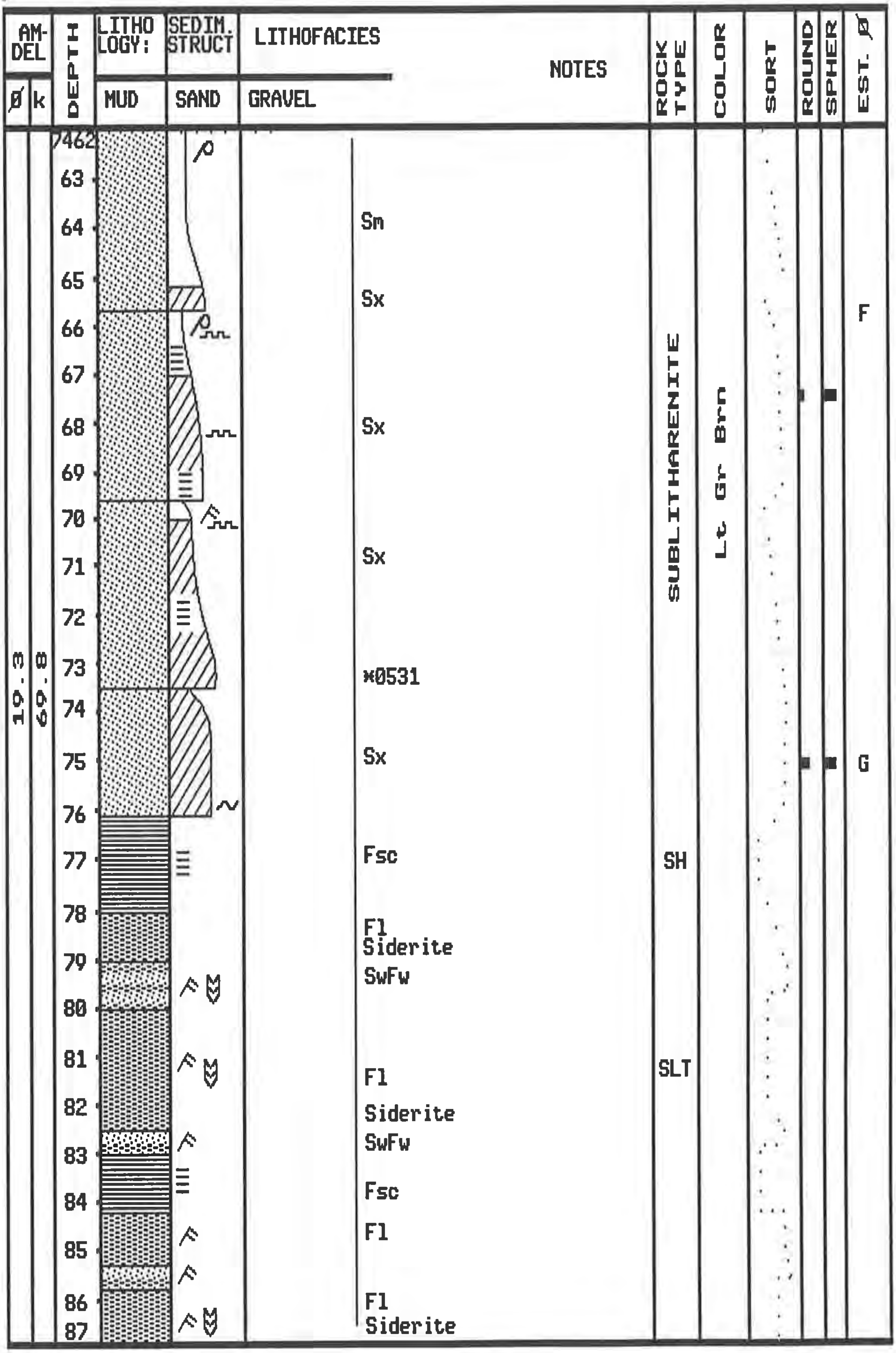
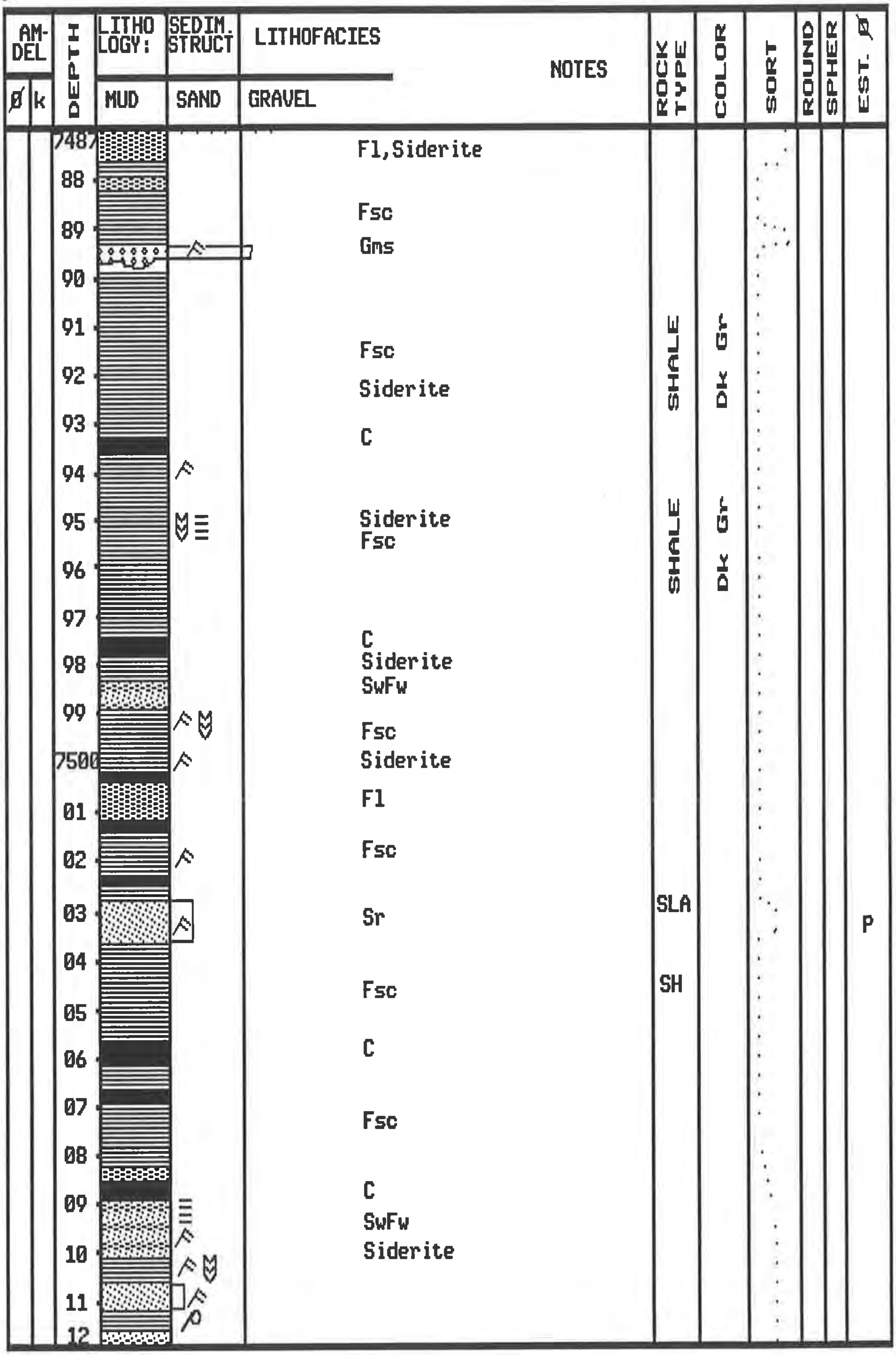
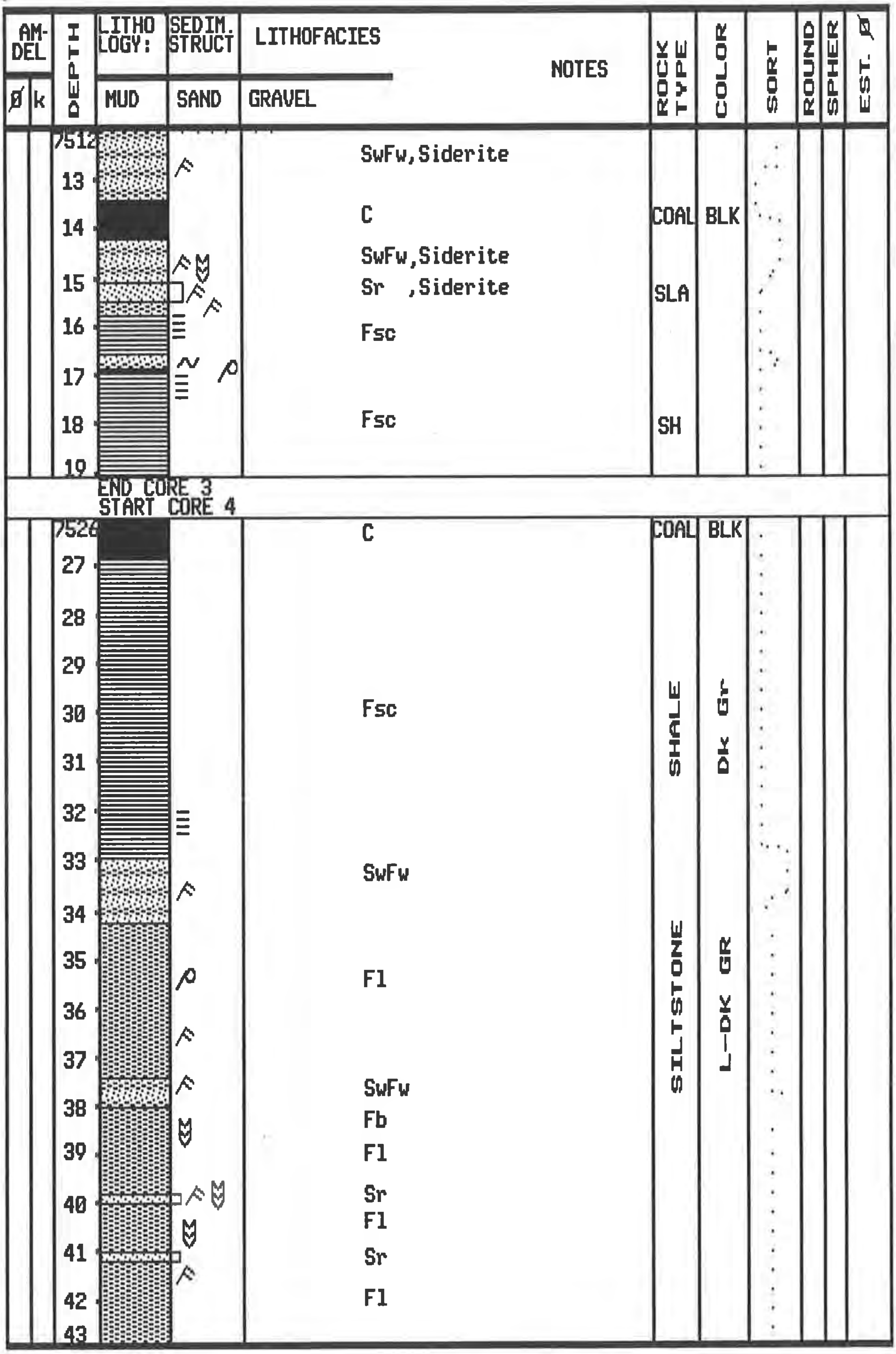


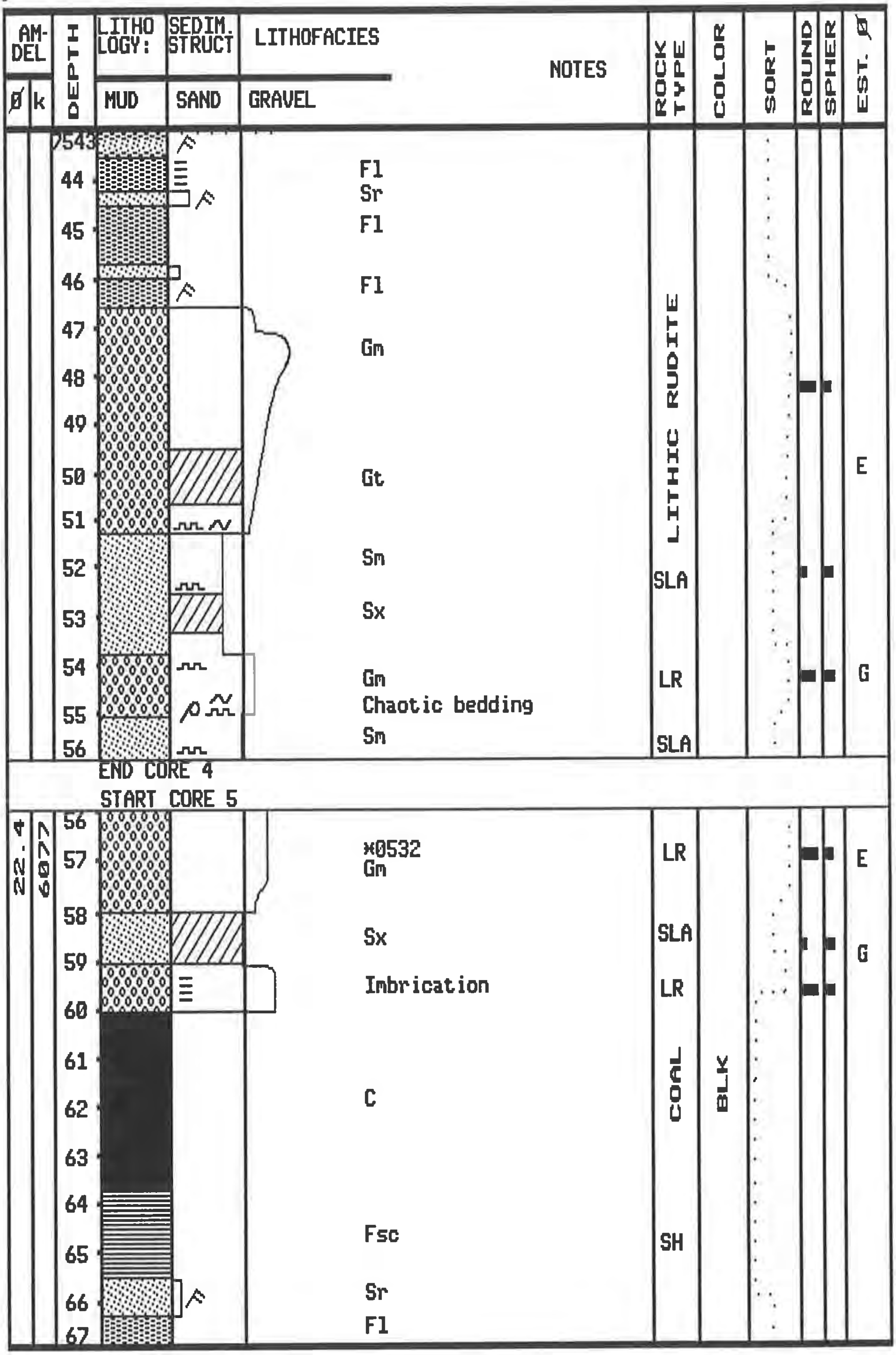
TOOLACHEE 6/ PATCHAWARRA/ CORE 3/ 7487-7512'/PAGE 7



TOOLACHEE 6/ PATCHAWARRA/ CORE 3,4/ 7512-7543'/ PAGE 8



TOOLACHEE 6/ PATCHAWARRA/ CORE 4,5/ 7543-7567'/ PAGE 9



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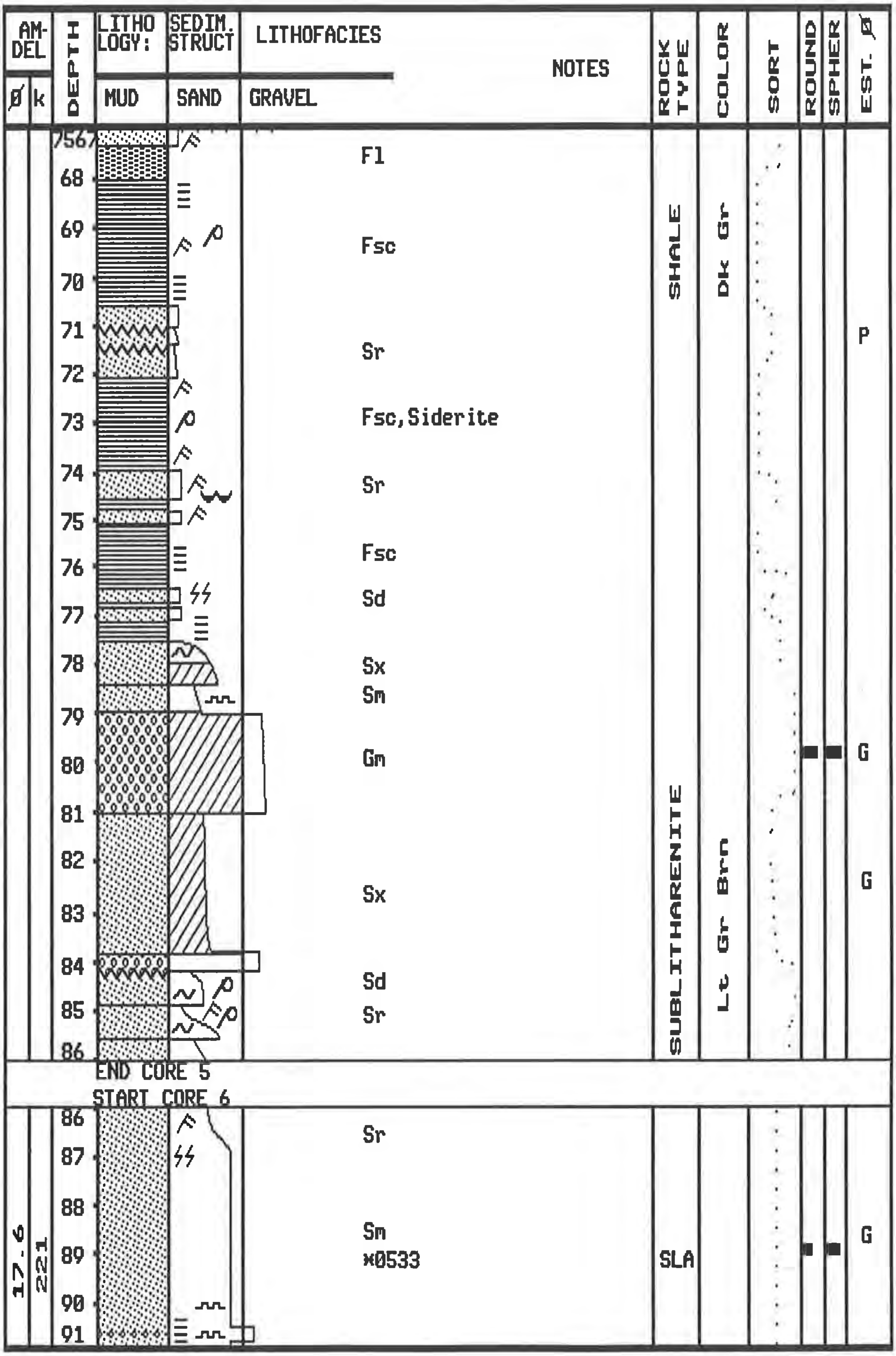
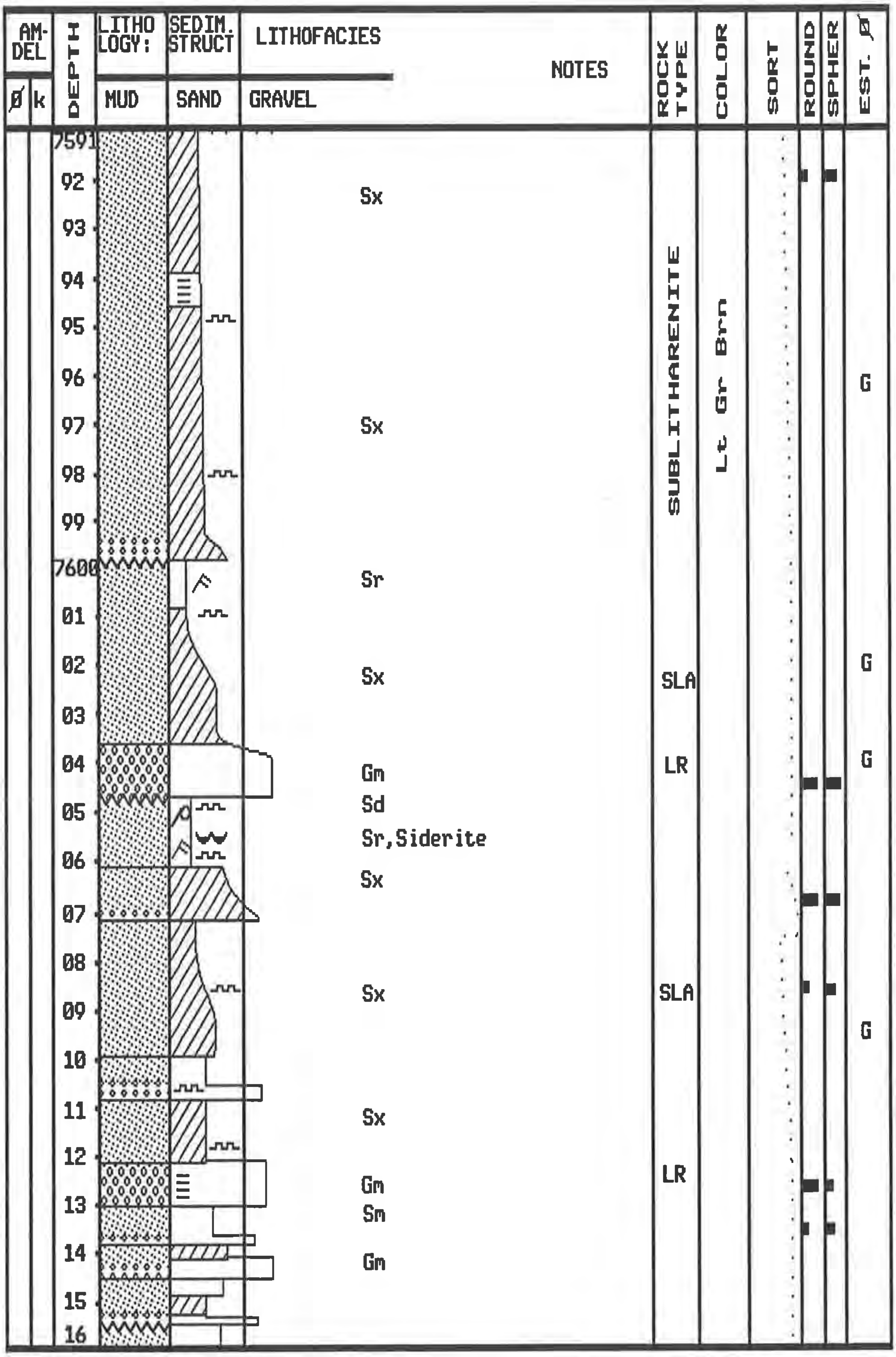
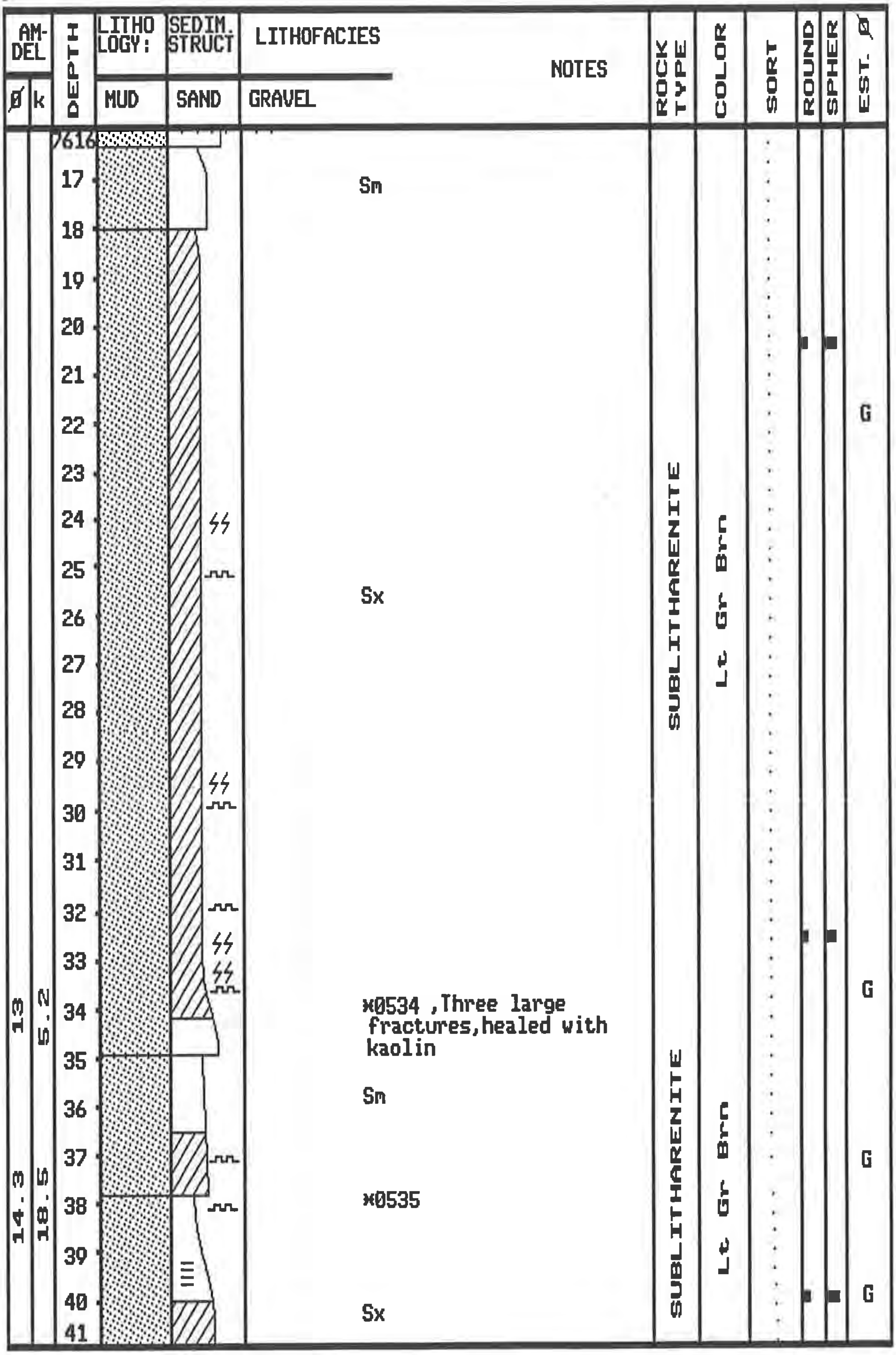


TOOLACHEE 6/ PATCHAWARRA/ CORE 6/ 7591-7616'/ PAGE 11



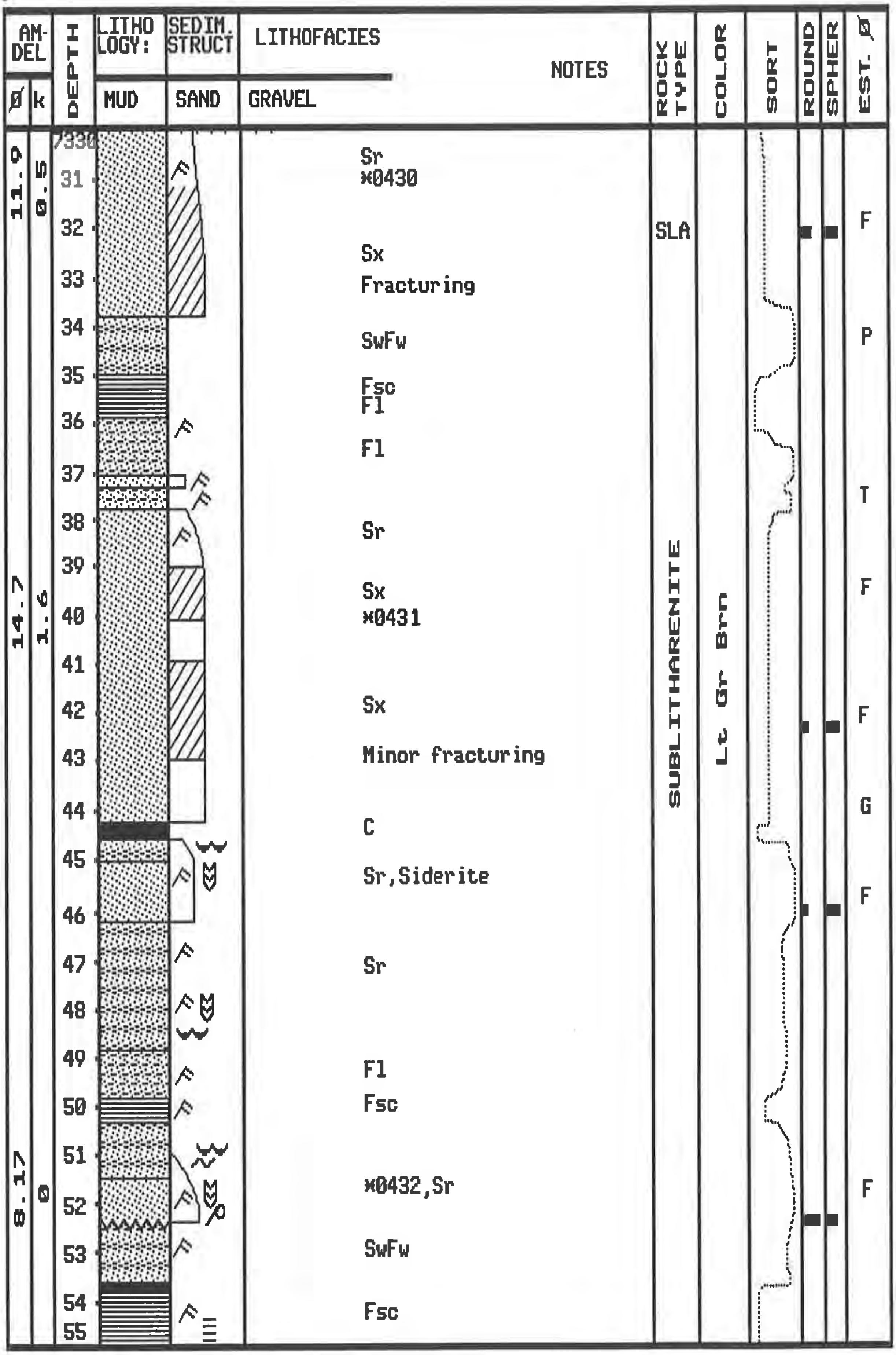
TOOLACHEE 6/ PATCHAWARRA/ CORE 6/ 7616-7641'/ PAGE 12



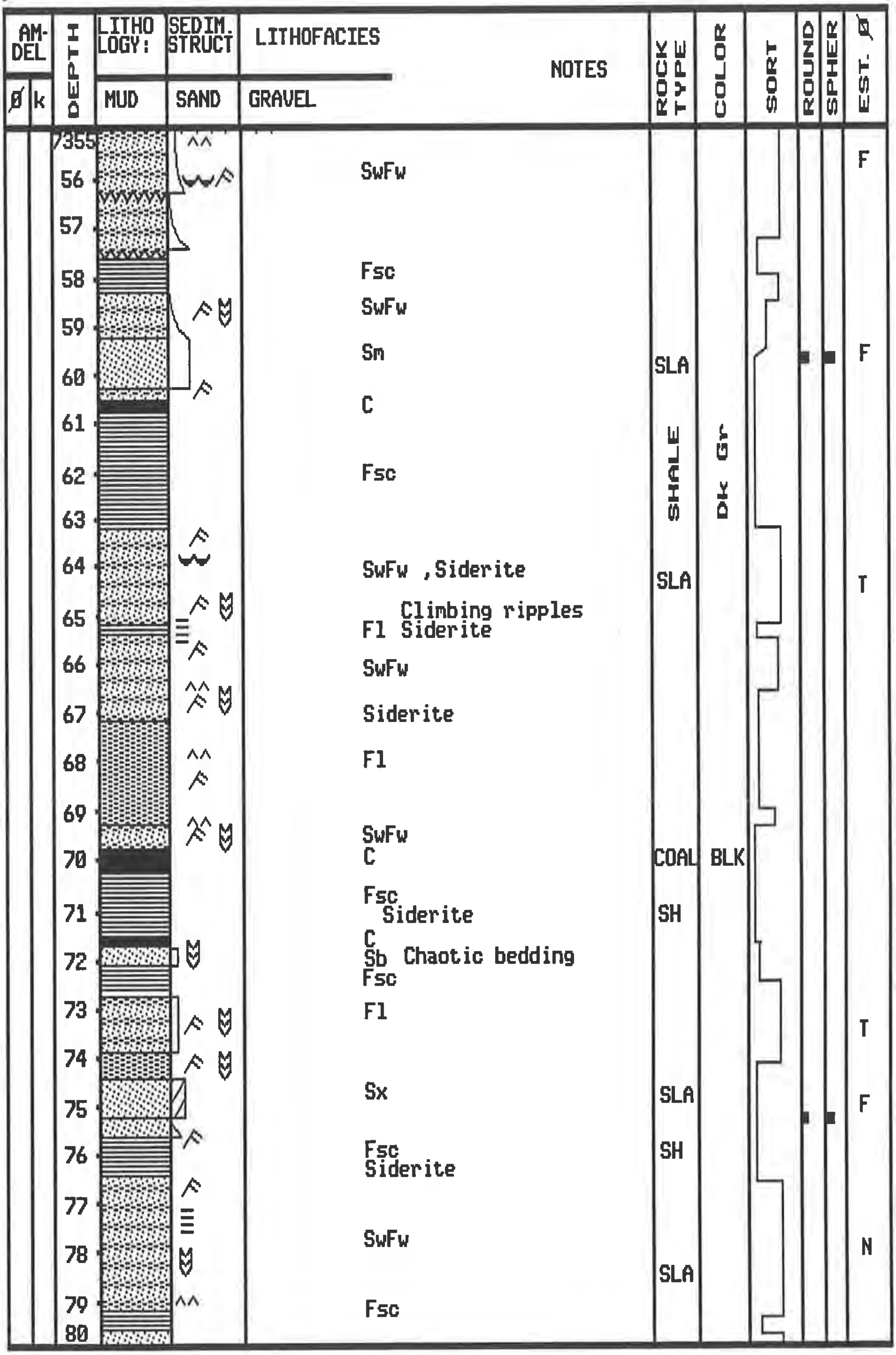
TOOLACHEE 6/ PATCHAWARRA/ CORE 6/ 7641-7646'/ PAGE 13

AMDEL Ø	AMDEL k	DEPTH	LITHOLOGY: MUD	SEDIM. STRUCT: SAND	LITHOFACIES: GRAVEL	NOTES	ROCK TYPE	COLOR	SORT	ROUND	SPHER	EST. Ø
16.4	103	7641			×0536							
		42			Sx		SLA					G
		43										
		44			Fd		SHALE	Dk Gr				
		45			Fsc							N
		46										

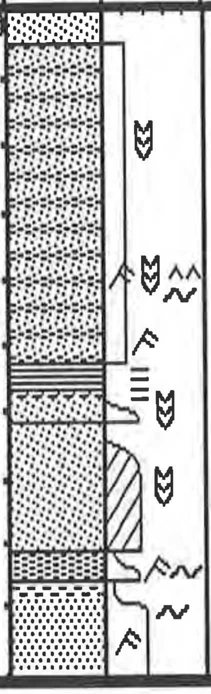
TOOLACHEE 8/PATCHAWARRA/CORE 1/7330-7355/PAGE 1



TOOLACHEE 8/PATCHAWARRA/CORE 1/7355-7380/ PAGE 2

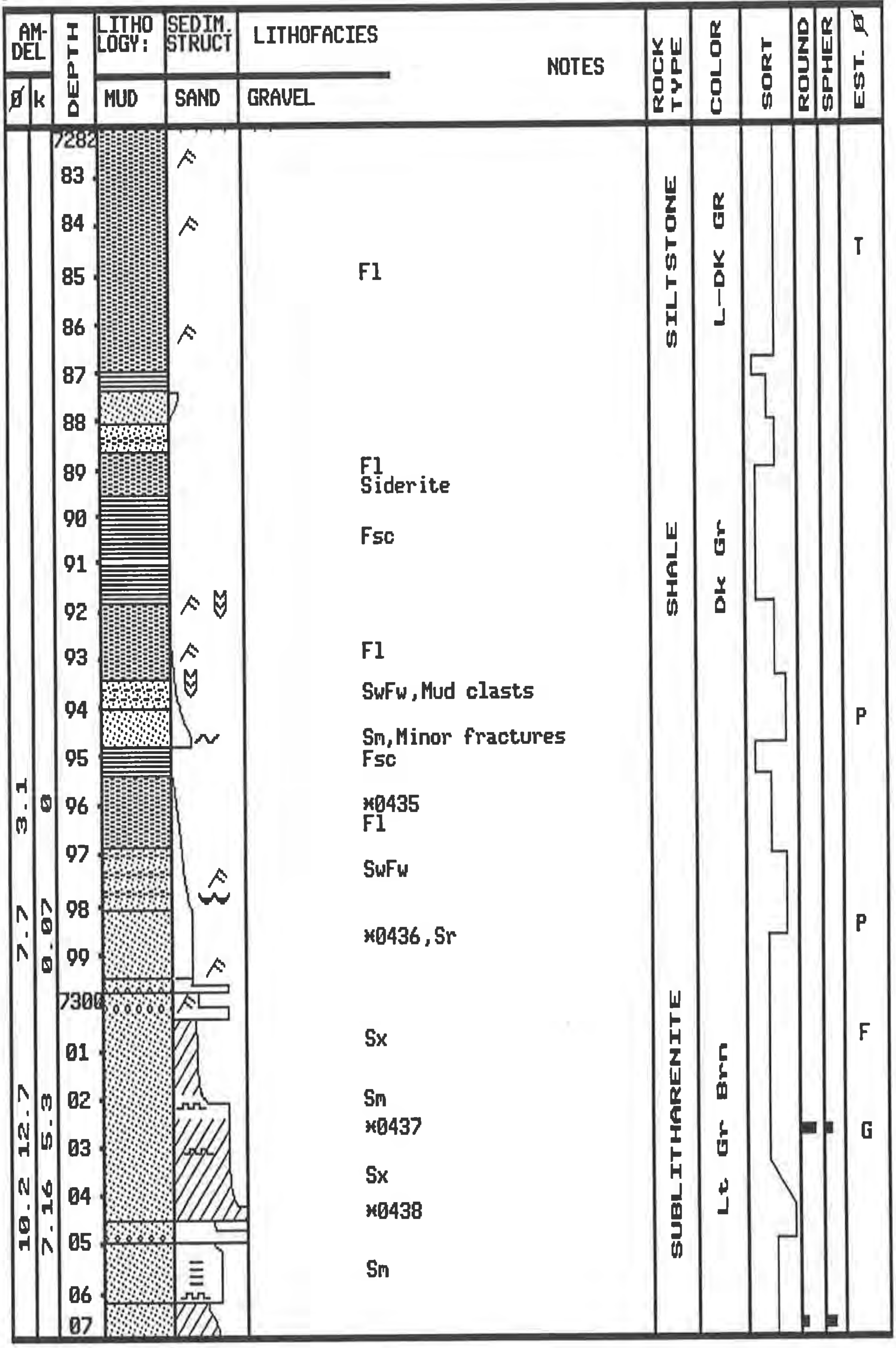


TOOLACHEE 8/PATCHAWARRA/CORE 1/ 7380-7390/ PAGE 3

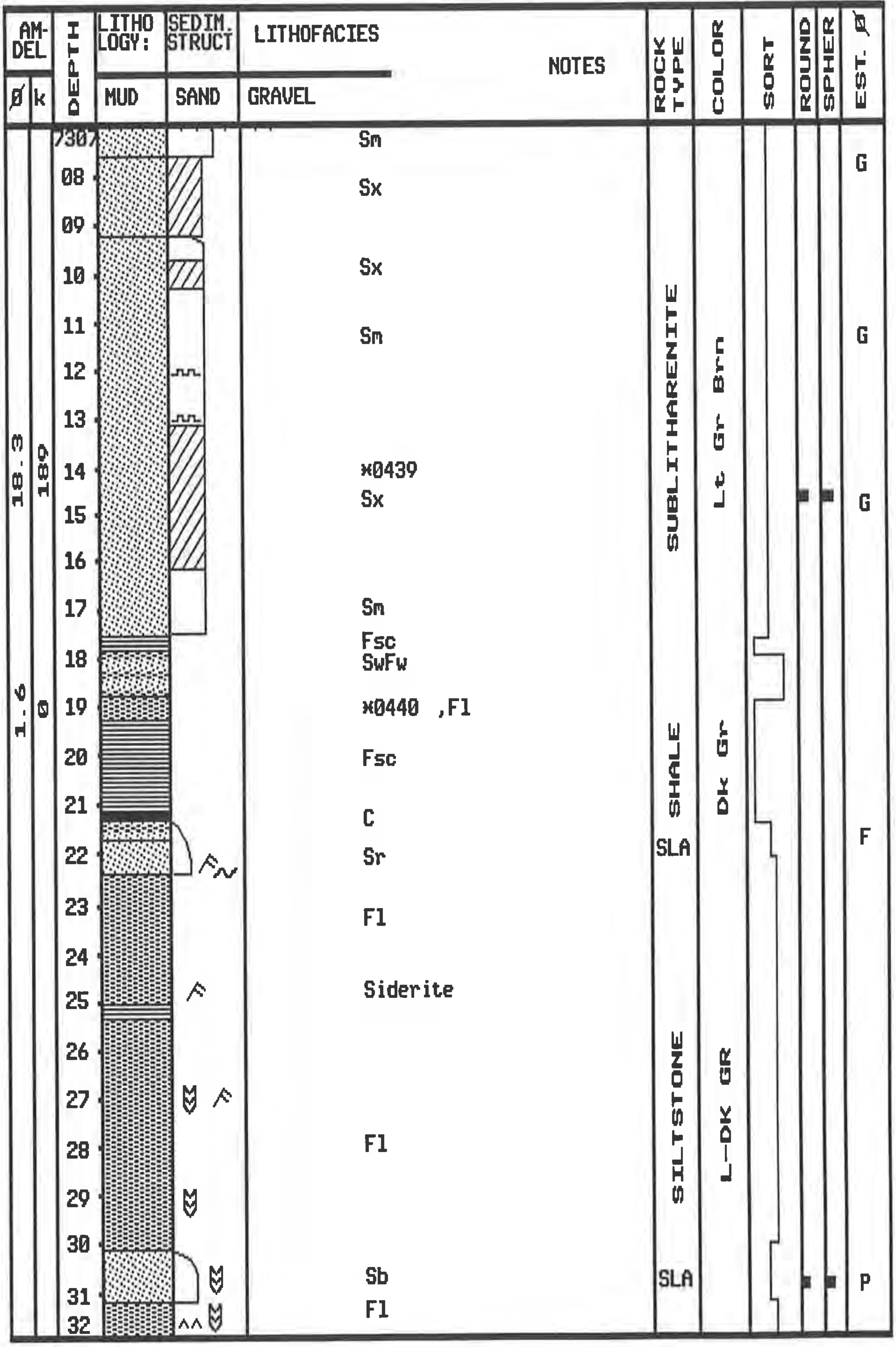


AM-DEL ø	AM-DEL k	DEPTH	LITHOLOGY: MUD / SEDIM. STRUCT: SAND / LITHOFACIES: GRAVEL	NOTES	ROCK TYPE	COLOR	SORT	ROUND	SPHER	EST. ø
		7380								
		81			SANDY SILTSTONE	DK GRY				
—	—	82		×0433 SwFw, Heavily bioturbated sandy lense						
		83								N
		84								
		85		Fsc, Siderite						
		86		SwFw						
		87		Sx	SLA					P
		88		Sr, Siderite SwFw						
11.7	0.5	89		Sr ×0434						P
		90								

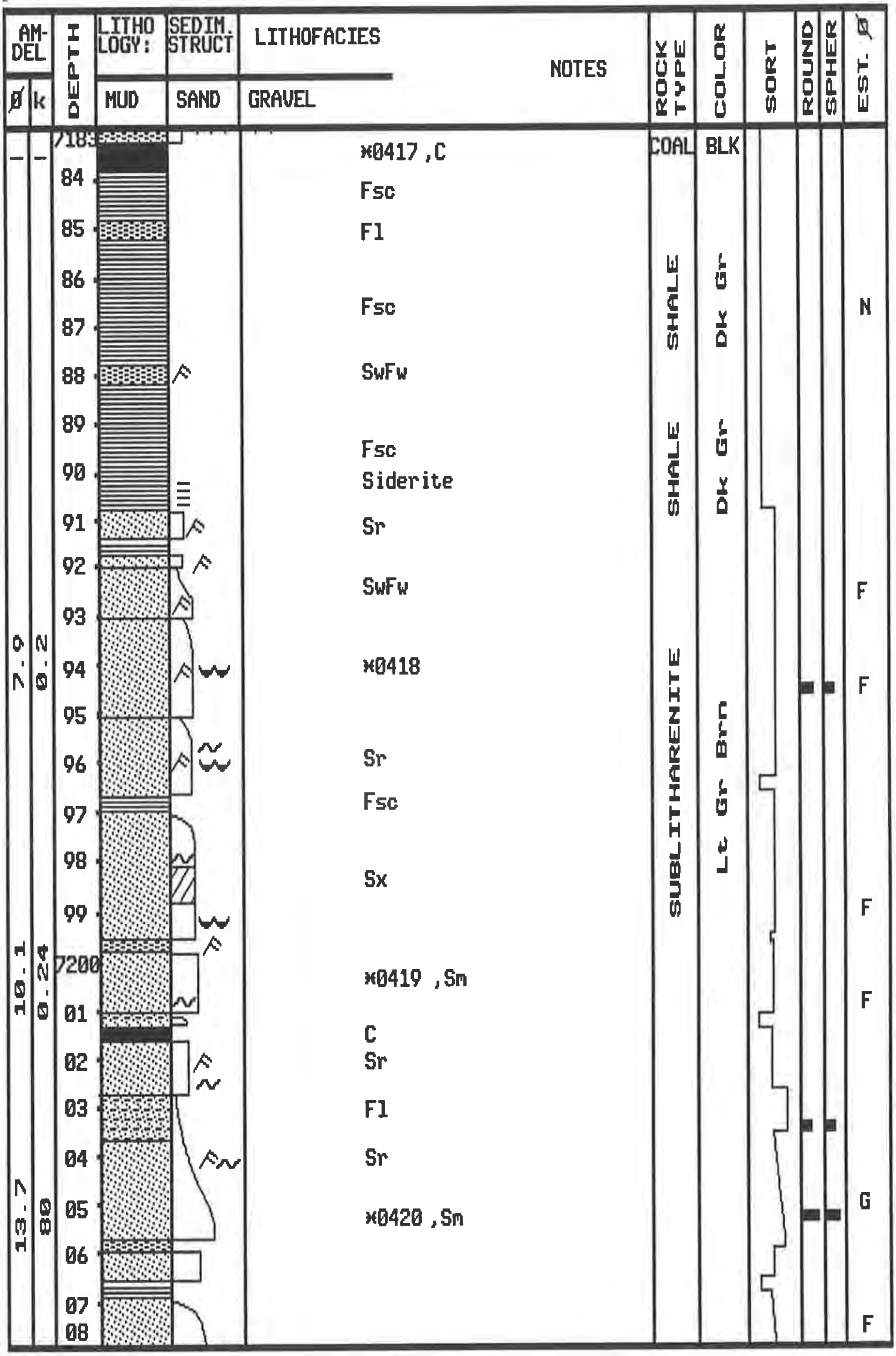
TOOLACHEE 9/PATCHAWARRA/CORE 1/7282-7307/PAGE 1



TOOLACHEE 9/PATCHAWARRA/CORE 1/7307-7332/PAGE 2



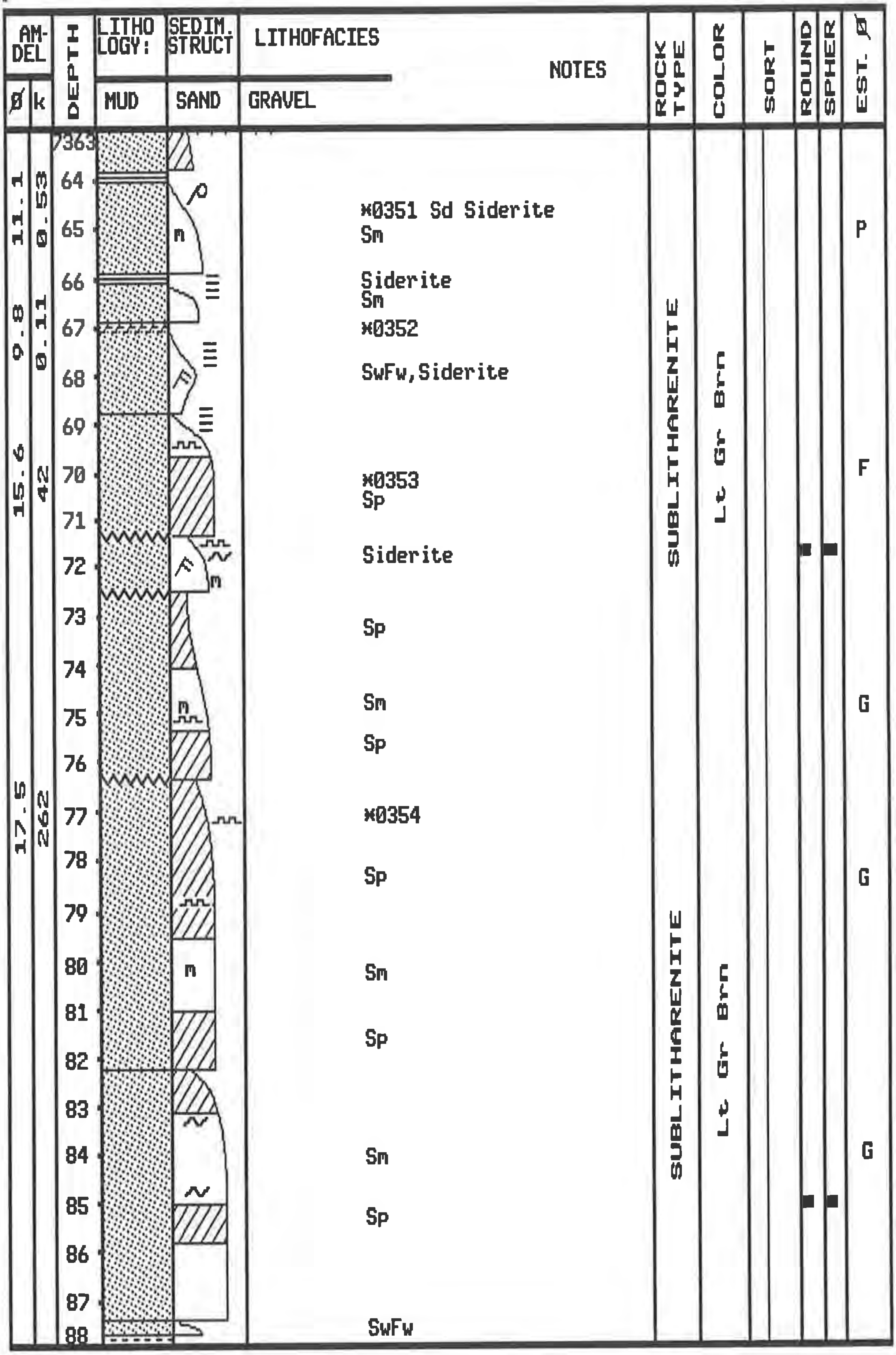
TOOLACHEE 12/PATCHAWARRA/CORE 1/7183-7208'/PAGE 1



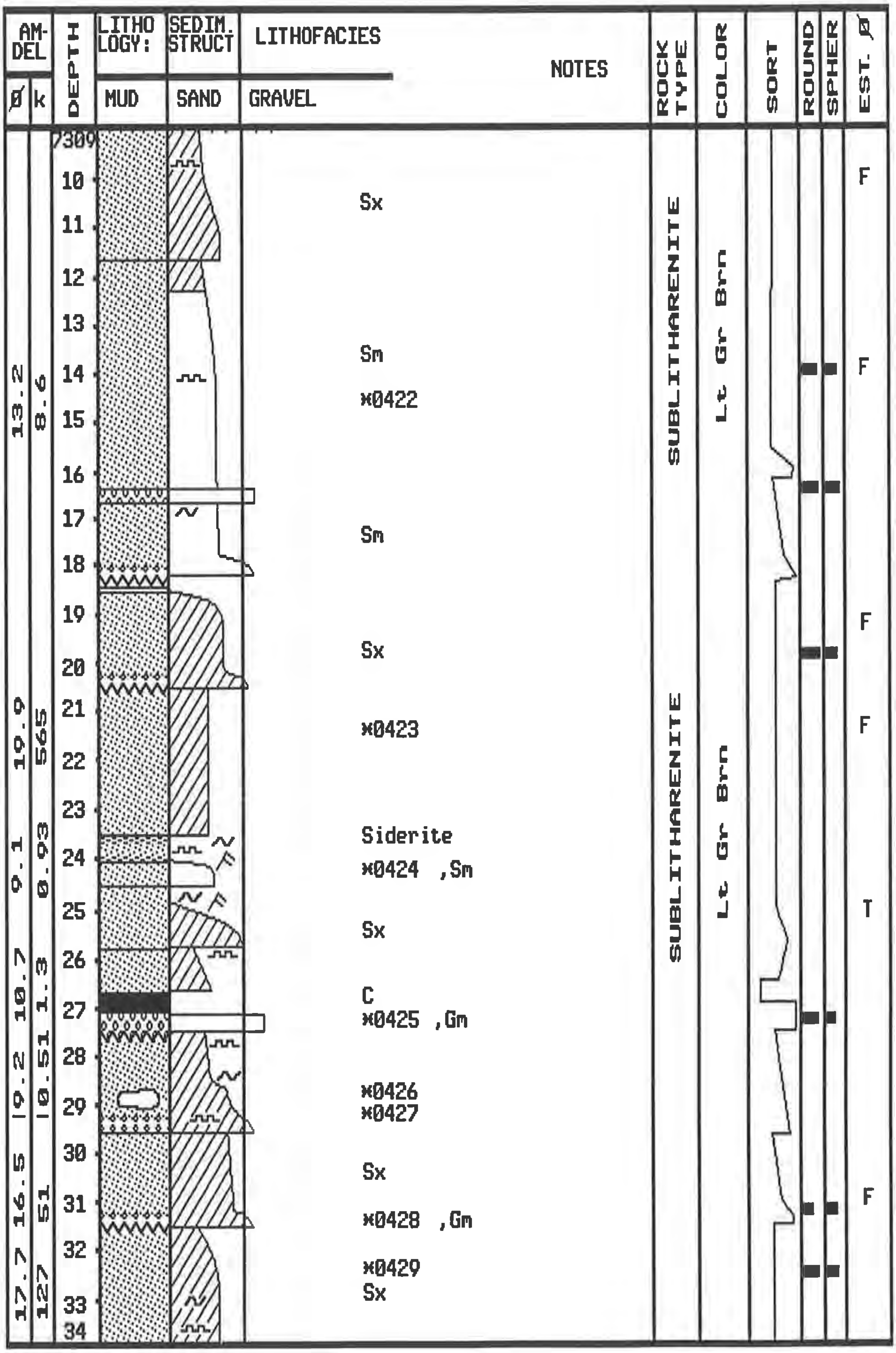
TOOLACHEE 12/PATCHAWARRA/CORE 1/7208-7213'/PAGE 2

AM-DEL Ø	AM-DEL k	DEPTH	LITHOLOGY: MUD	SEDIM. STRUCT: SAND	LITHOFACIES: GRAVEL	NOTES	ROCK TYPE	COLOR	SORT	ROUND	SPHER	EST. Ø
3.8	0.03	7208			×0421 Sr							F
		09			SwFw		SLA					
		10			Fl		SH					N
		11			Sr							T
		12			SwFw Siderite bands		SLT					
		13										

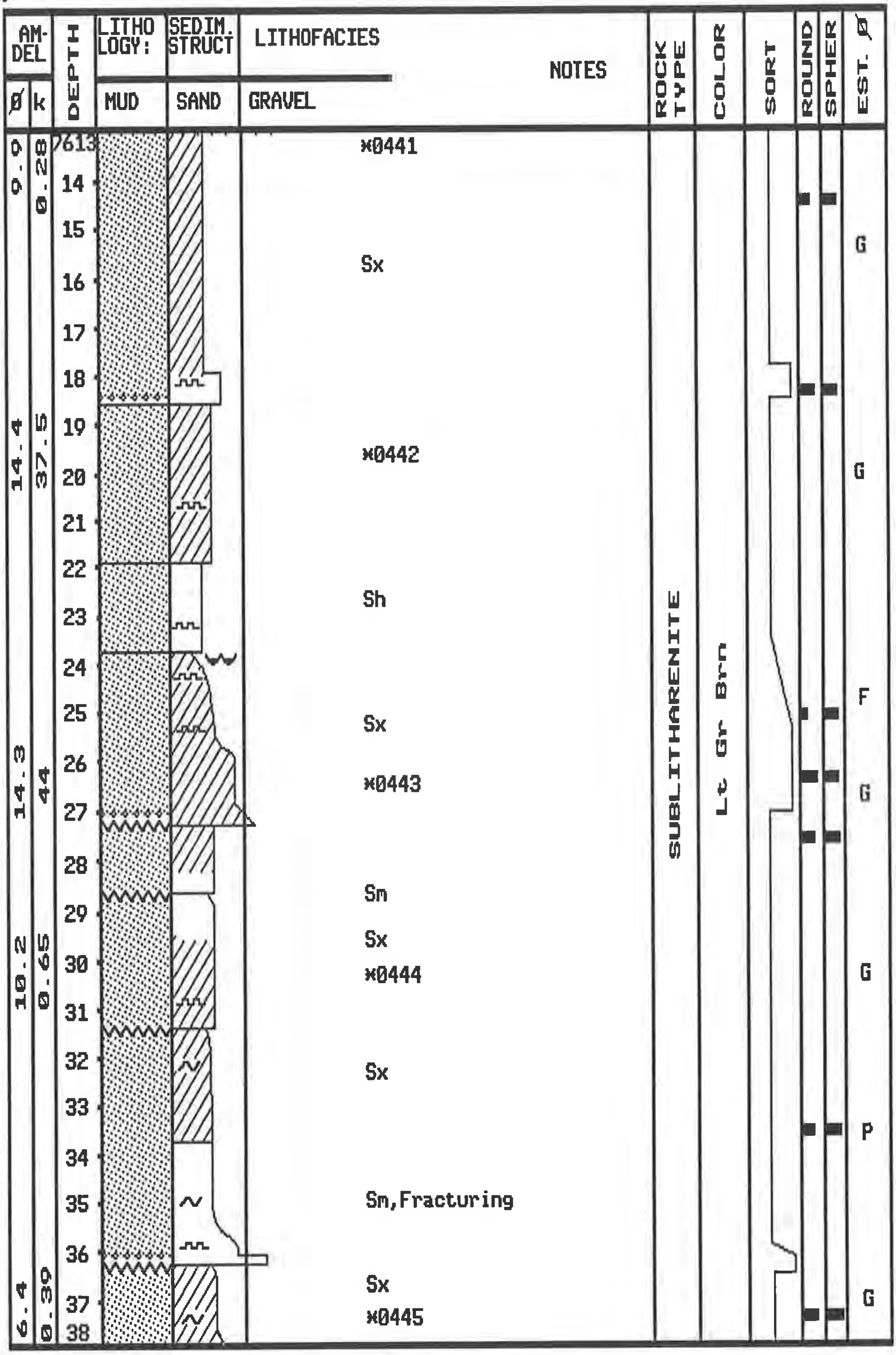
TOOLACHEE 15/PATCHAWARRA/CORE 1/ 7363-7388'/PAGE 1



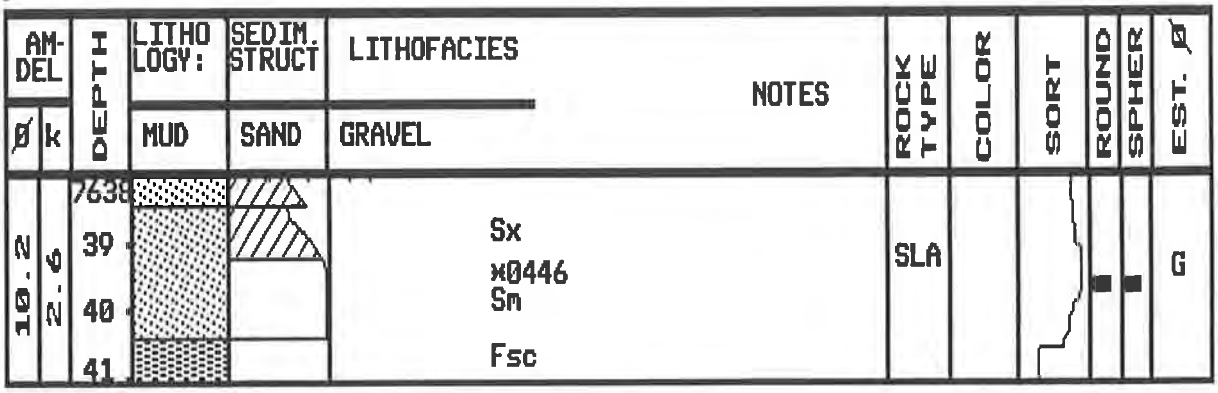
TOOLACHEE 18/PATCHAWARRA/CORE 1/ 7309-7334'/PAGE 1



TOOLACHEE 19/PATCHAWARRA/CORE 1/ 7613-7638/PAGE 1



TOOLACHEE 19/PATCHAWARRA/CORE 1/7638-7641'/PAGE 2



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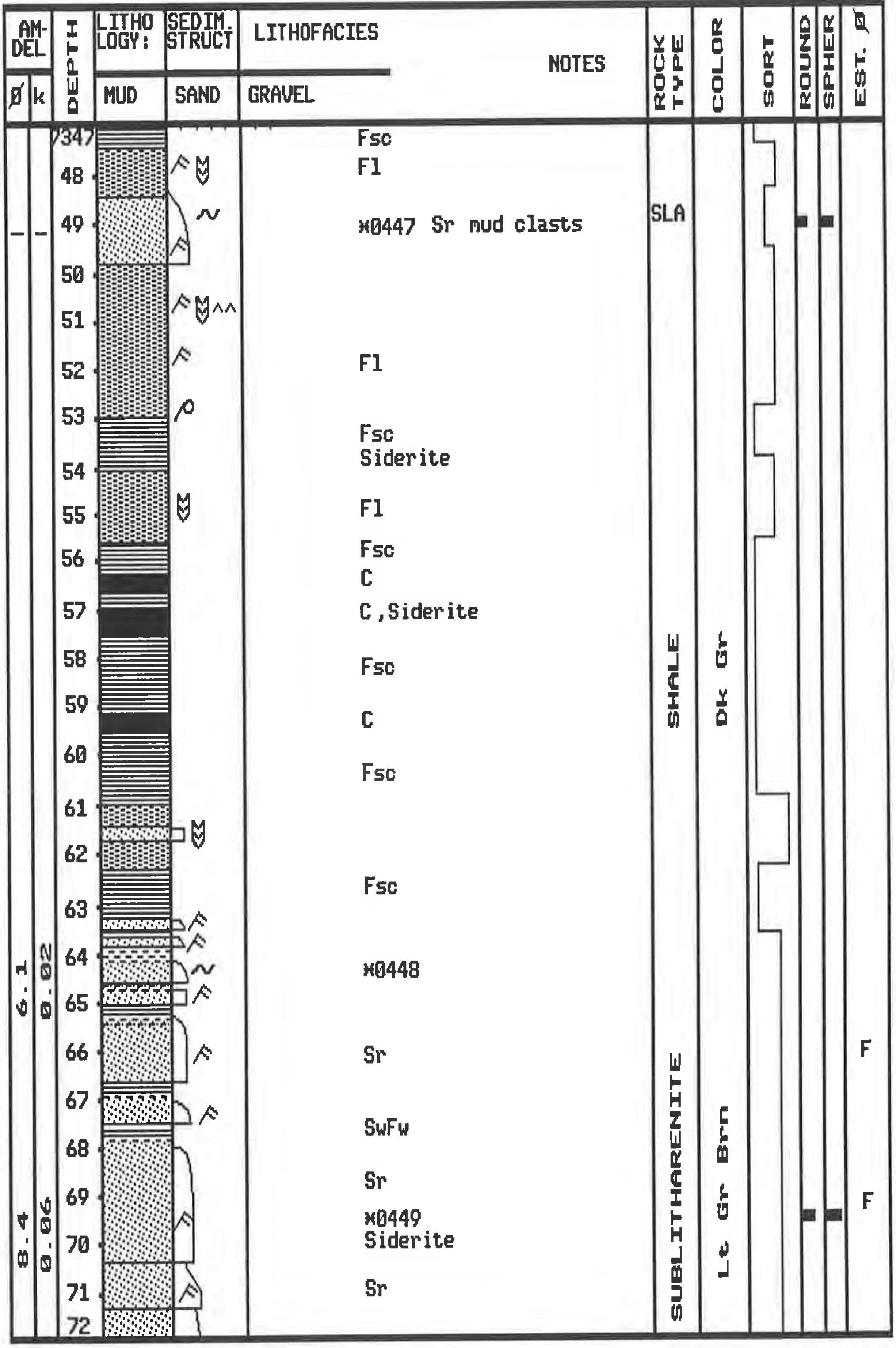
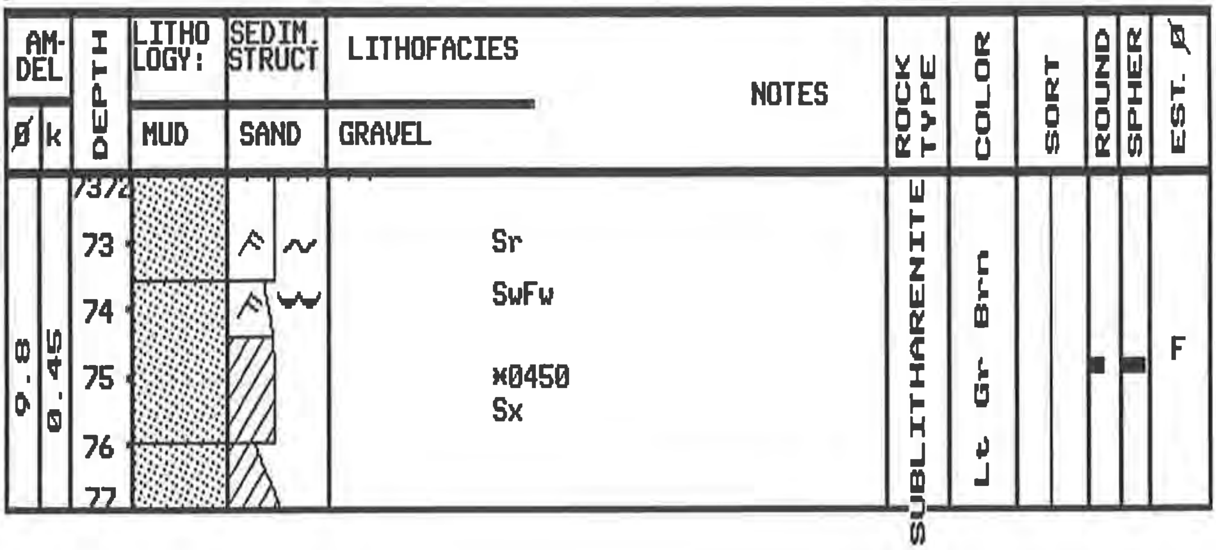


TOOLACHEE 21/PATCHAWARRA/CORE 1/ 7372-7377'/PAGE 2



Appendix 2
Petrological details

Appendix 2: Petrological details

Section:	Contents:
1	Abbreviations used
2	Thin section details
3	Thin section sedimentary estimates
4	Modal estimates
5	Porosity details

1 Abbreviations

Ave	Average grain size (mm)
C.M.	Carbonaceous material (%)
Epsil	Epsilon
Frac	Fracture porosity (%)
Ill	Illite (%)
Kao	Kaolin (%)
Max	Maximum grain size (mm)
Mic	Micritic siderite (%)
Min	Minimum grain size (mm)
Murt	Murteree
Oil stain	Oil staining (1=absent, 2=rare, 3=common)
Other	Other rock constituents (%)
Patc	Patchawarra
Plug perm	Core plug permeability (md)
Plug por	Core plug porosity (%)
Prim	Primary porosity
Qtz	Quartz (%)
RF	Rock fragments (%)
Roundness	Roundness, 0.1=angular, 0.9=well rounded
Sec	Secondary porosity
Spar	Sparry siderite (%)
Sphericity	Sphericity, 0.3=low, 0.9=high
Tool	Toolachee
Type	Type of other rock constituent

Appendix 2, Section 1 Thin section details

Sample No.	Well Name	Well No.	Depth	Formation
0162	Toolachee	3	7345'3"	Patc
0163	Toolachee	3	7380'5"	Patc
0164	Toolachee	3	7397'	Patc
0165	Toolachee	3	7410'7"	Patc
0166	Toolachee	3	7418'6"	Patc
0167	Toolachee	3	7428'	Patc
0168	Toolachee	3	7437'9"	Patc
0169	Toolachee	3	7438'3"	Patc
0170	Toolachee	3	7442'5"	Patc
0171	Toolachee	3	7445'6"	Patc
0172	Toolachee	3	7457'3"	Patc
0173	Toolachee	3	7461'4"	Patc
0313	Toolachee	3	7198'	Patc
0314	Toolachee	3	7204'11"	Patc
0315	Toolachee	3	7211'	Patc
0316	Toolachee	3	7220'3"	Patc
0317	Toolachee	3	7226'1"	Patc
0318	Toolachee	3	7232'	Patc
0319	Toolachee	3	7244'7"	Patc
0320	Toolachee	3	7252'	Patc
0321	Toolachee	3	7271'	Patc
0322	Toolachee	3	7284'4"	Patc
0323	Toolachee	3	7290'	Patc
0324	Toolachee	3	7302'	Patc
0325	Toolachee	3	7313'10"	Patc
0326	Toolachee	3	7327'3"	Patc
0327	Toolachee	3	7334'6"	Patc
0328	Toolachee	3	7340'	Patc
0341	Toolachee	1	6491'7"	Epsil
0342	Toolachee	1	6891'	Patc
0343	Toolachee	1	6899'	Patc
0344	Toolachee	1	6905'	Patc
0346	Toolachee	1	6914'6"	Patc
0347	Toolachee	1	6917'9"	Patc
0348	Toolachee	1	6949'11"	Patc
0349	Toolachee	1	6952'9"	Patc
0350	Toolachee	1	6958'10"	Patc
0351	Toolachee	15	7364'7"	Patc
0352	Toolachee	15	7367'3"	Patc
0353	Toolachee	15	7370'2"	Patc
0354	Toolachee	15	7377'	Patc
0355	Toolachee	15	7382'3"	Patc
0383	Toolachee	5	7307'4"	Patc
0384	Toolachee	5	7313'	Patc
0385	Toolachee	5	7343'	Patc
0386	Toolachee	5	7357'6"	Patc
0387	Toolachee	5	7363'	Patc
0388	Toolachee	5	7385'4"	Patc
0389	Toolachee	5	7393'9"	Patc

Appendix 2, Section 1 Thin section details (Cont)

Sample No.	Well Name	Well No.	Depth	Formation
0411	Toolachee	5	7226'	Patc
0412	Toolachee	5	7247'3"	Patc
0413	Toolachee	5	7247'8"	Patc
0414	Toolachee	5	7265'	Patc
0415	Toolachee	5	7271'9"	Patc
0416	Toolachee	5	7277'3"	Patc
0417	Toolachee	12	7183'5"	Patc
0418	Toolachee	12	7194'	Patc
0419	Toolachee	12	7200'2"	Patc
0420	Toolachee	12	7205'2"	Patc
0421	Toolachee	12	7208'3"	Patc
0422	Toolachee	18	7314'6"	Patc
0423	Toolachee	18	7321'4"	Patc
0424	Toolachee	18	7324'4"	Patc
0425	Toolachee	18	7327'3"	Patc
0426	Toolachee	18	7328'10"	Patc
0427	Toolachee	18	7329'1"	Patc
0428	Toolachee	18	7331'7"	Patc
0429	Toolachee	18	7332'6"	Patc
0430	Toolachee	8	7331'	Patc
0431	Toolachee	8	7340'	Patc
0432	Toolachee	8	7351'8"	Patc
0433	Toolachee	8	7381'9"	Patc
0434	Toolachee	8	7390'	Patc
0435	Toolachee	9	7296'	Patc
0436	Toolachee	9	7298'10"	Patc
0437	Toolachee	9	7302'9"	Patc
0438	Toolachee	9	7304'5"	Patc
0439	Toolachee	9	7314'	Patc
0440	Toolachee	9	7319'	Patc
0441	Toolachee	19	7613.25	Patc
0442	Toolachee	19	7619.5	Patc
0443	Toolachee	19	7626.5	Patc
0444	Toolachee	19	7630.3	Patc
0445	Toolachee	19	7637.25	Patc
0446	Toolachee	19	7639.5	Patc
0447	Toolachee	21	7349'2"	Patc
0448	Toolachee	21	7364'8"	Patc
0449	Toolachee	21	7369'8"	Patc
0450	Toolachee	21	7375'	Patc
0527	Toolachee	6	7355'	Patc
0528	Toolachee	6	7397'	Patc
0529	Toolachee	6	7413'6"	Patc
0530	Toolachee	6	7420'	Patc
0531	Toolachee	6	7473'4"	Patc
0532	Toolachee	6	7556'11"	Patc
0533	Toolachee	6	7589'	Patc
0534	Toolachee	6	7634'	Patc
0535	Toolachee	6	7638	Patc

Appendix 2, Section 1 Thin section details (Cont)

Sample No.	Well Name	Well No.	Depth	Formation
0536	Toolachee	6	7641'2"	Patc
0550	Toolachee	1	6051'	Tool
0551	Toolachee	1	6056'	Tool
0552	Toolachee	1	6063'	Tool
0553	Toolachee	1	6071'8"	Tool
0554	Toolachee	1	6484'1"	Epsil
0555	Toolachee	34	6874'8"	Epsil
0556	Toolachee	34	6882'	Epsil
0557	Toolachee	34	6893'3"	Epsil
0558	Toolachee	34	6896'	Epsil
0559	Toolachee	34	6908'6"	Epsil
0560	Toolachee	32	6761'6"	Epsil
0561	Toolachee	32	6775'	Epsil
0562	Toolachee	32	6783'2"	Epsil
0563	Toolachee	32	6786'	Epsil
0564	Munkarie	2	6847'3"	Epsil
0565	Munkarie	2	6863'2"	Epsil
0566	Munkarie	2	6879'	Epsil
0567	Munkarie	2	6893'	Epsil
0568	Munkarie	2	6894'2"	Epsil
0569	Munkarie	2	6908'4"	Epsil
0570	Munkarie	2	7240'4"	Patc
0571	Munkarie	2	7258'	Patc
0572	Munkarie	2	7377'	Patc
0573	Brumby	1	7371'	Patc
0574	Brumby	1	7404'3"	Patc
0575	Brumby	1	7411'	Patc
0576	Brumby	1	7459'6"	Patc
0577	Brumby	1	7489'7"	Patc

Appendix 2, Section 2 Thin section sedimentary details

No.	Grain size (mm)			Round ness	Spher- icity	Sorting
	Min	Ave	Max			
0162	0.10	0.45	0.65	0.7	0.7	good
0163	0.05	0.20	0.55	0.3	0.5	poor
0164	0.05	0.10	4.90	0.7	0.7	very poor
0165	0.06	0.12	0.20	0.5	0.5	moderate
0166	0.10	0.25	0.30	0.5	0.7	moderate
0167	0.00	0.50	2.30	0.5	0.7	Moderate
0168	0.05	0.26	0.51	0.3	0.0	poor
0169	0.05	0.15	0.51	0.7	0.5	poor
0170	0.05	0.19	0.51	0.3	0.5	poor
0171	0.01	0.08	0.40	0.1	0.5	fair
0172	0.05	0.10	0.20	0.7	0.5	Poor
0173	0.09	0.18	0.65	0.7	0.5	moderate
0313	0.02	0.14	0.30	0.5	0.7	moderate

Appendix 2, Section 2 Thin section sedimentary details (Cont)

No.	Grain size (mm) Min	Ave	Max	Roundness	Sphericity	Sorting
0314	0.05	0.20	0.40	0.3	0.7	fair
0315	0.06	0.35	3.10	0.5	0.5	poor
0316	0.01	0.06	0.11	0.1	0.7	moderate
0317	0.01	0.03	0.11	0.5	0.7	moderate
0318	0.01	0.11	0.40	0.5	0.7	good
0319	0.08	0.15	0.25	0.3	0.5	good
0320	0.04	0.10	0.25	0.3	0.5	fair
0321	0.10	0.27	1.10	0.3	0.7	moderate
0322	0.10	0.40	1.75	0.7	0.7	very good
0323	0.10	0.35	18.00	0.7	0.7	very poor
0324	0.02	0.16	0.40	0.7	0.5	moderate
0325	0.05	0.30	0.60	0.5	0.3	fair
0326	0.02	0.10	0.50	0.5	0.7	fair
0327	0.02	0.20	0.30	0.5	0.5	fair
0328	0.10	0.35	0.60	0.7	0.7	good
0341	0.01	0.05	0.25	0.3	0.5	good
0342	0.00	0.27	1.00	0.7	0.7	moderate
0343	0.10	0.25	0.55	0.7	0.7	good
0344	0.05	0.30	2.50	0.3	0.5	poor
0345	0.02	0.11	0.50	0.5	0.7	poor
0346	0.05	0.21	1.30	0.5	0.7	good
0347	0.05	0.16	20.00	0.3	0.7	very poor
0348	0.02	0.30	10.00	0.5	0.5	very poor
0349	0.05	0.30	1.75	0.3	0.5	moderate
0350	0.02	0.24	1.50	0.3	0.5	poor
0351	0.05	0.20	0.50	0.5	0.5	fair
0352	0.02	0.17	0.30	0.5	0.5	moderate
0353	0.04	0.24	0.50	0.7	0.7	good
0354	0.04	0.30	0.45	0.5	0.7	good
0355	0.05	0.75	3.10	0.9	0.5	poor
0383	0.05	0.20	0.51	0.3	0.5	fair
0384	0.01	0.05	0.10	0.3	0.5	fair
0385	0.05	0.26	0.45	0.5	0.7	moderate
0386	0.04	0.34	1.30	0.7	0.5	poor
0387	0.05	0.30	1.40	0.5	0.5	fair
0388	0.04	0.25	1.10	0.5	0.5	fair
0389	0.06	0.35	2.10	0.9	0.7	good
0411	0.01	0.14	0.35	0.5	0.5	fair
0412	0.03	0.25	0.50	0.5	0.7	moderate
0413	0.00	0.00	0.00	0.0	0.0	poor
0414	0.01	0.12	0.80	0.3	0.5	fair
0415	0.02	0.10	0.50	0.5	0.5	moderate
0416	0.02	0.25	0.40	0.5	0.7	fair
0417	0.00	0.00	0.00	0.0	0.0	very good
0418	0.04	0.13	1.00	0.3	0.3	fair
0419	0.02	0.16	0.35	0.3	0.5	moderate
0420	0.04	0.40	3.00	0.7	0.5	fair
0421	0.02	0.11	0.55	0.9	0.5	fair

Appendix 2, Section 2 Thin section sedimentary details (Cont)

No.	Grain size (mm) Min	Ave	Max	Roundness	Sphericity	Sorting
0422	0.05	0.34	1.80	0.3	0.5	fair
0423	0.05	0.45	1.50	0.5	0.9	moderate
0424	0.05	0.70	4.50	0.7	0.3	poor
0425	0.05	0.51	5.80	0.5	0.7	very poor
0426	0.05	1.00	6.60	0.9	0.5	fair
0427	0.01	0.03	0.05	0.1	0.5	good
0428	0.01	0.35	5.10	0.3	0.5	fair
0429	0.00	0.45	1.80	0.5	0.5	fair
0430	0.02	0.18	0.40	0.3	0.5	moderate
0431	0.05	0.25	0.65	0.3	0.5	fair
0432	0.02	0.30	1.40	0.3	0.5	poor
0433	0.03	0.15	0.75	0.3	0.5	poor
0434	0.04	0.25	0.70	0.5	0.7	fair
0435	0.02	0.10	0.30	0.1	0.3	fair
0436	0.03	0.23	0.40	0.7	0.5	moderate
0437	0.03	0.55	3.75	0.5	0.3	very poor
0438	0.04	0.52	3.00	0.5	0.3	very poor
0439	0.04	0.38	1.60	0.5	0.5	poor
0440	0.05	0.35	1.30	0.3	0.5	good
0441	0.05	0.26	0.70	0.7	0.5	good
0442	0.02	0.50	2.10	0.1	0.3	fair
0443	0.02	0.80	3.10	0.5	0.3	poor
0444	0.05	0.31	1.25	0.7	0.5	fair
0445	0.03	0.55	1.00	0.7	0.5	fair
0446	0.05	0.60	1.50	0.3	0.5	fair
0447	0.04	0.12	0.45	0.1	0.3	moderate
0448	0.02	0.15	1.90	0.3	0.5	fair
0449	0.01	0.15	0.35	0.5	0.5	moderate
0450	0.05	0.27	0.80	0.3	0.5	fair
0527	0.01	0.11	1.00	0.5	0.3	moderate
0528	0.01	0.15	0.30	0.3	0.1	moderate
0529	0.00	0.05	0.10	0.1	0.3	good
0530	0.01	0.13	4.70	0.7	0.5	good
0531	0.04	0.70	2.75	0.5	0.3	poor
0532	1.00	2.20	6.50	0.3	0.5	very poor
0533	0.05	0.70	3.70	0.5	0.7	fair
0534	0.05	0.45	1.50	0.7	0.5	moderate
0535	0.05	0.74	10.50	0.7	0.7	fair
0536	0.06	0.60	2.25	0.5	0.5	poor
0550	0.05	0.50	3.20	0.7	0.7	poor
0551	0.05	0.65	5.00	0.5	0.5	poor
0552	0.09	0.55	5.40	0.7	0.7	moderate
0553	0.02	0.20	0.60	0.3	0.5	poor
0554	0.01	0.05	0.15	0.5	0.7	good
0555	0.03	0.15	0.40	0.7	0.5	good
0556	0.06	0.21	0.50	0.5	0.5	moderate
0557	0.05	0.26	0.50	0.7	0.7	moderate
0558	0.03	0.14	0.80	0.3	0.5	moderate

Appendix 2, Section 2 Thin section sedimentary details (Cont)

No.	Grain size (mm) Min	Ave	Max	Roundness	Sphericity	Sorting
0559	0.02	0.15	0.30	0.5	0.5	moderate
0560	0.02	0.15	0.30	0.5	0.5	moderate
0561	0.02	0.19	0.45	0.3	0.5	moderate
0562	0.01	0.06	0.25	0.5	0.7	moderate
0563	0.05	0.35	0.70	0.5	0.7	poor
0564	0.02	0.15	0.30	0.5	0.7	good
0565	0.04	0.26	0.50	0.7	0.7	moderate
0566	0.05	0.25	0.70	0.9	0.7	moderate
0567	0.04	0.40	1.10	0.7	0.5	moderate
0568	0.04	0.17	0.30	0.7	0.5	moderate
0569	0.04	0.20	0.35	0.5	0.5	moderate
0570	0.03	0.11	0.35	0.5	0.5	poor
0571	0.04	0.19	0.60	0.5	0.7	moderate
0572	0.05	0.22	0.70	0.5	0.7	poor
0573	0.08	0.39	5.50	0.7	0.5	poor
0574	0.10	1.30	2.70	0.3	0.5	poor
0575	0.02	0.11	0.20	0.5	0.5	moderate
0576	0.06	0.51	4.00	0.3	0.5	poor
0577	0.10	0.60	3.60	0.7	0.5	poor

Appendix 2 Section 3 Petrological modal estimates

Sample No.	Qtz	Rock constituents (%) Kao	Ill	RF	Spar	CM	Other	Oil stain
0270	70	7	5	15	0	3	1 (MUSC)	A
0550	80	7	0	10	0	1	3 (FELDSPAR,MUSC)	A
0551	60	8	2	25	3	0	2 (MUSCOVITE)	A
0552	73	7	3	15	0	0	2 (MUSCOVITE)	A
0553	60	10	15	7	0	3	4 (MUSC,TOURMALINE)	R
0554	50	6	6	0	30	3	5 (MUSCOVITE)	A
0341	40	7	8	5	20	0	10(MUSC,BIOTITE)	A
0342	85	6	1	5	0	0	3 (MUSCOVITE)	A
0343	80	8	2	7	0	0	3 (MUSC,TOURMALINE)	A
0344	65	9	1	20	0	0	5 (MUSCOVITE)	A
0345	60	15	10	2	7	1	5 (MUSCOVITE)	A
0346	65	11	4	10	4	0	6 (MUSCOVITE)	
0347	70	6	4	15	2	2	1 (MUSCOVITE)	C
0348	35	9	1	45	5	0	5 (MUSCOVITE,ZIRCON)	A
0349	72	13	2	10	2	0	1 (MUSCOVITE)	A
0350	70	7	5	15	2	1	0 (MUSCOVITE)	A
0313	65	10	15	4	4	0	2 (MUSCOVITE)	A
0314	70	7	3	12	5	0	3 (MICA)	A
0315	70	8	2	13	4	1	2 (MUSC.,TOURM.,ZIR)	R
0316	60	8	12	0	7	3	10(MUSCOVITE)	N
0317	5	2	2	0	80	10	1 (MUSCOVITE)	A
0318	70	6	9	4	5	2	4 (MUSCOVITE)	A
0319	55	11	4	15	5	5	5 (MUSCOVITE)	A

Appendix 2 Section 3 Petrological modal estimates

Sample No.	Qtz	Rock constituents (%) Kao	Ill	RF	Spar	CM	Other	Oil stain
0320	55	17	3	10	5	1	9 MICA	A
0321	75	6	1	15	0	0	3 MUSCOVITE	A
0322	80	9	1	7	0	0	3 MUSCOVITE	A
0323	60	9	1	25	0	0	5 MUSCOVITE	A
0324	65	10	5	10	3	1	6 MUSC.,TOURM.,ZIR	A
0325	75	5	0	15	1	0	4 MUSC.,TOURM.,ZIR	A
0326	55	12	13	5	7	1	8 MUSCOVITE	A
0327	70	5	5	15	1	0	4 MUSCOVITE	A
0328	80	9	1	8	0	0	0 TOURMALINE	A
0162	85	4	0	8	1	0	2 MUSCOVITE	A
0163	64	4	3	7	10	6	4 MUSCOVITE	A
0164	75	5	4	7	5	1	3 MUSCOVITE	R
0165	60	12	8	10	5	1	4 MUSCOVITE	A
0166	75	9	1	10	1	0	4 MUSC.,TOURM.,ZIR	A
0167	85	5	0	10	0	0	0 MUSCOVITE	A
0168	50	11	9	25	1	0	4 MUSCOVITE	A
0169	60	10	10	10	5	1	4 MUSC,TOURMALINE	A
0170	45	10	20	10	10	2	3 MUSCOVITE	A
0171	25	10	20	0	40	1	4 MUSCOVITE	A
0172	65	14	6	5	5	2	3 MUSCOVITE	A
0173	70	7	3	15	0	0	3 MUSC.TOURMALINE	A
0411	72	7	8	3	5	1	4 MUSC,TOURMALINE	A
0412	75	7	3	5	6	0	3 MUSCOVITE	A
0413	0	0	0	0	0	99	1	Y
0414	65	12	8	5	6	0	4 MUSC,TOURMALINE	A
0415	70	7	8	2	5	3	5 MUSCOVITE	A
0416	70	7	5	8	5	0	5 MUSCOVITE	A
0383	55	15	10	10	3	0	7 MUSCOVITE,OPAQUES	A
0384	60	14	11	0	5	0	10 MUSCOVITE	A
0385	75	8	2	10	3	0	2 MUSCOVITE	A
0386	55	16	4	15	5	0	5 MUSCOVITE	A
0387	60	9	1	25	3	0	2 MUSCOVITE	A
0388	60	15	5	15	2	0	3 MUSCOVITE	A
0389	85	8	2	5	3	0	2 MUSCOVITE	A
0527	65	11	9	5	7	1	2 MUSCOVITE	A
0528	60	8	12	8	5	1	6 MUSC,TOURMALINE	A
0529	10	5	5	0	50	30	0	A
0530	76	5	3	8	4	1	3 MUSC,TOURMALINE	A
0531	60	9	1	25	2	0	3 MUSCOVITE	R
0532	55	10	0	33	0	0	2 MUSCOVITE	A
0533	76	8	0	15	0	0	2 MUSC,FELDSPAR	A
0534	60	15	0	20	3	0	2 MUSCOVITE	A
0535	78	9	1	5	5	0	2 MUSCOVITE	A
0536	70	8	1	15	6	0	0 MUSCOVITE	A
0430	70	8	7	8	7	1	4 MUSCOVITE	A
0431	70	8	2	5	1	0	12 TOPAZ,TOURM.,OP.	A
0432	70	8	4	8	5	2	3 MICA	A
0433	65	4	6	12	4	2	7 MUSC,0PAQUES	A

Appendix 2 Section 3 Petrological modal estimates

Sample No.	Qtz	Rock constituents (%) Kao	Ill	RF	Spar	CM	Other	Oil stain
0434	75	6	1	12	3	0	3 MUSCOVITE	A
0435	70	5	5	9	5	1	5 MUSCOVITE	A
0436	75	6	0	9	7	0	3 MUSCOVITE	A
0437	70	9	1	15	3	0	2 MUSC,FELDSPAR	R
0438	70	12	3	10	2	0	3 MUSC,PLAGIOCLAS	A
0439	72	6	0	15	1	0	6 MUSC.,TOURM.,ZIR	A
0440	80	6	0	8	3	2	1 MUSCOVITE	A
0417	1	0	0	0	0	99	0	R
0418	60	7	8	5	10	5	5 MUSCOVITE	A
0419	65	12	8	5	6	0	4 MUSCOVITE	A
0420	65	13	7	10	3	0	2 MUSCOVITE	A
0421	65	15	10	5	2	0	3 MUSC.,TOURM.,ZIR	A
0351	70	12	3	10	1	0	4 MUSCOVITE	A
0352	60	16	4	2	8	8	4 MUSCOVITE	A
0353	80	7	1	10	1	0	1 MUSCOVITE	A
0354	80	8	2	6	1	0	3 MUSC,OPAQUES	C
0355	80	9	1	5	3	0	2 MUSCOVITE	A
0422	80	10	0	5	0	0	5 MUCS.,ZIRC,OP	A
0423	82	10	0	5	1	0	2 MUSC,FELDSPAR	R
0424	70	14	1	9	4	0	2 MUSCOVITE	R
0425	70	5	0	20	3	0	2 MUSCOVITE	A
0426	70	7	0	20	2	0	1 MUSC,TOURMALINE	A
0427	0	0	0	0	0	0	0	A
0428	80	9	1	5	2	0	2 MUSC,OPAQUES	R
0429	80	5	1	11	1	0	2 MUSC,TOURMALINE	A
0441	60	10	6	17	0	0	7 MUSC,FELD,FE ST	R
0442	80	9	1	8	1	0	1 MUSCOVITE	R
0443	70	10	0	15	0	0	5 MUSCOVITE	A
0444	60	18	2	15	4	0	1 MUSCOVITE	R
0445	75	9	1	10	3	0	2 MUSCOVITE	A
0446	65	17	0	15	1	0	2 MUSC.,CHALC,OPX	R
0447	65	7	8	5	2	5	8 MUSC,TOURM.ZIRC	A
0448	65	5	5	15	5	1	4 MUSCOVITE	A
0449	60	10	6	8	10	1	5 MUSC,TOURMALINE	A
0450	75	9	1	8	3	0	4 MUSCOVITE	A
0560	75	8	6	6	4	2	3 MUSCOVITE	A
0561	45	5	9	10	20	7	4 MUSCOVITE	A
0562	34	16	24	0	10	6	10 MUSCOVITE	A
0563	72	6	4	10	5	2	2 MUSCOVITE	A
0555	70	5	8	10	5	0	2 MUSC.,FELDSPAR	A
0556	65	10	6	12	6	0	1 MUSCOVITE	C
0557	76	6	2	12	3	0	1 MUSC,TOURMALINE	A
0558	50	7	6	10	20	5	3 MUSCOVITE	A(10)
0559	67	10	8	5	5	2	3 MUSC.,TOURMALINE	R
0564	60	13	12	3	5	5	2 MUSCOVITE	R
0565	72	8	4	8	0	6	4 MUSC.,FELD,TOURM	C
0566	75	10	2	8	3	0	2 MUSCOVITE	A
0567	75	9	2	10	4	0	0 MUSCOVITE	A

Appendix 2 Section 3 Petrological modal estimates

Sample No.	Qtz	Rock constituents (%) Kao	Ill	RF	Spar	CM	Other	Oil stain
0568	0	0	0	0	0	0	0	
0569	70	3	3	6	15	0	1 MUSC,TOUR,	A
0570	75	4	6	4	8	0	3 MUSCOVITE	A
0571	65	9	8	5	7	3	3 MUSC,TOUR,ZIRCON	A
0572	70	7	3	15	3	1	1 MUSCOVITE	A
0573	80	8	0	10	2	0	0 FELDSPAR,MUSC	R
0574	60	10	0	20	10	0	0	R
0575	70	7	8	7	5	0	3 MUSCOVITE	A
0576	35	10	0	45	6	1	3 MUSC,TOURMALINE	A
0577	84	5	0	10	0	0	1 MUSC,TOURMALINE	A

Section 3 Porosity details

Sample No.	Section porosity: Prim	Sec	Plug Frac	Plug por	perm
0550	11	7	0	20.4	292.00
0551	7	15	0	22.0	236.00
0552	10	10	0	19.4	298.00
0553	3	0	2	0.0	0.00
0554	5	0	0	0.0	0.00
0341	1	0	0	0.0	0.00
0342	8	5	0	10.3	0.10
0343	14	6	0	20.0	63.00
0344	12	4	0	16.2	5.30
0345	3	0	0	7.9	0.10
0346	9	6	0	15.5	14.60
0347	5	0	0	6.0	0.10
0348	4	7	0	11.9	0.40
0349	8	5	0	11.1	0.40
0350	5	0	0	7.5	1.59
0313	1	0	0	10.5	0.00
0314	4	0	0	11.9	0.50
0315	5	9	0	14.0	2.10
0316	1	0	0	3.5	0.00
0317	0	0	0	6.0	0.30
0318	2	0	0	5.0	0.20
0319	3	0	0	6.0	0.30
0320	4	0	0	8.8	0.00
0321	4	7	0	11.8	0.50
0322	12	8	0	19.9	720.00
0323	9	3	0	15.9	20.30
0324	5	2	0	11.3	11.90
0325	6	9	0	15.4	4.60
0326	5	0	0	7.0	0.00
0327	2	10	0	10.8	0.70

Sample No.	Section porosity: Prim	Sec	Plug Frac	Plug por	perm
0328	7	7	0	13.5	4.60
0162	7	13	0	19.6	89.00
0163	1	0	0	0.0	0.00
0164	2	0	0	0.0	0.00
0165	4	0	0	10.7	0.00
0166	3	0	0	3.2	0.00
0167	7	8	0	14.2	15.50
0168	1	5	0	0.0	0.00
0169	2	0	0	0.0	0.00
0170	3	0	0	0.0	0.00
0171	0	0	0	0.0	0.00
0172	1	0	0	0.0	0.00
0173	2	0	0	13.5	3.10
0411	4	0	0	11.3	0.50
0412	3	4	0	7.6	2.88
0414	2	0	0	11.0	0.50
0415	4	1	0	6.2	0.03
0416	6	0	0	10.1	0.50
0383	5	0	0	9.2	0.00
0384	6	0	0	10.7	0.50
0385	3	1	0	9.1	0.58
0386	4	0	0	10.1	0.50
0387	9	4	0	15.4	6.57
0388	3	1	0	12.7	0.50
0389	10	5	0	14.3	1.46
0527	6	3	0	11.0	1.60
0528	6	0	0	8.4	0.00
0529	0	0	0	0.0	0.00
0530	5	0	0	7.9	0.00
0531	6	14	0	19.3	69.80
0532	14	8	0	22.4	6077.00
0533	7	18	0	17.6	221.00
0534	4	10	1	13.0	5.20
0535	8	7	0	14.3	18.50
0536	8	3	0	16.4	103.00
0430	3	0	0	11.9	0.50
0431	4	7	0	14.7	1.60
0432	3	0	0	8.2	0.00
0433	1	0	0	0.0	0.00
0434	2	0	0	11.7	0.50
0435	1	0	0	3.1	0.00
0436	5	2	0	7.7	0.07
0437	4	8	0	12.7	5.30
0438	7	8	0	10.2	7.16
0439	12	13	0	18.3	189.00
0440	3	0	0	1.6	0.00
0417	0	0	0	0.0	0.00
0418	6	0	0	7.9	0.20
0419	3	0	0	10.1	0.24
0420	8	4	0	13.7	80.00
0421	3	0	0	3.8	0.03

(12)

Sample No.	Section porosity: Prim	Sec	Plug Frac	Plug por	perm
0351	7	4	0	11.1	0.53
0352	0	0	0	9.8	0.11
0353	7	5	0	15.6	42.00
0354	15	4	0	17.5	262.00
0355	7	9	0	14.3	64.00
0422	4	8	0	13.2	8.60
0423	15	5	0	19.9	565.00
0424	6	2	0	9.1	0.93
0425	4	6	0	10.7	1.30
0426	7	12	0	9.2	0.51
0427	0	0	0	0.0	0.00
0428	10	15	0	16.5	51.00
0429	6	10	0	17.9	127.00
0441	5	0	0	9.9	0.28
0442	8	12	0	14.4	37.50
0443	6	12	0	14.3	44.00
0444	3	1	0	10.2	0.65
0445	7	13	0	6.4	0.39
0446	5	5	0	10.2	2.60
0447	2	0	0	0.0	0.00
0448	2	0	0	6.1	0.02
0449	2	1	0	8.4	0.06
0450	4	6	0	9.8	0.45
0560	4	0	0	11.0	1.50
0561	7	0	0	7.2	1.50
0563	4	1	0	7.5	14.00
0555	6	4	0	10.3	0.20
0556	8	2	0	12.3	0.90
0557	5	8	0	10.3	22.00
0558	4	2	0	7.1	0.00
0559	4	0	0	8.9	0.00
0564	5	0	0	10.4	1.00
0565	10	4	0	16.2	13.30
0566	9	8	0	17.7	53.90
0567	5	7	0	12.8	34.90
0568	0	0	0	15.3	21.60
0569	3	1	0		
0570	6	0	0	6.2	1.00
0571	2	6	0	9.5	1.00
0572	6	4	0	15.2	23.20
0573	10	10	0	19.1	133.00
0574	7	9	0	16.2	17.30
0575	2	0	0	0.0	0.00
0576	1	0	0	12.0	10.10
0577	7	15	0	17.6	439.00

Appendix 3
XRD Data

Appendix 3: XRD data.

Section **Contents**

1 Methods

Bulk mineral identification of all samples was carried out by X-Ray Diffraction (XRD) analysis. Samples of total rock were wet ground for 30 seconds using ethanol in a tungsten-carbide mill, then oven dried at temperatures less than 100^{o} C. Samples were run as front mounted powder pressings from 3 to 75^{o} 2ˇ at 4^{o} per minute in a "Siemens" X-Ray diffractometer at 50kV and 35mA using Co K‾ radiation.

These proceedures follow guidelines for sample handling outlined by Phillips (1989). Interpretation of results used data captured from the diffractometer and analysed using the program XPLOT (Raven & Self 1988). Broad estimates of mineral abundance are made by comparing the relative peak count sizes of the scan angles for each mineral present.

Dickite was recognised from the presence of a peak with a `d' spacing of 3.79 A, which differentiates it from kaolinite which has a nearby peak at 3.74 A.

The ratio of illite to kaolin was calculated by measuring the height of the illite/muscovite peak at approximately 10 A and the height of the kaolin peak at 7 A, then dividing twice the illite peak height with the kaolin peak height.

2 Results

The results of the analysis of XRD traces are tabulated in Table 1 overleaf. Abbreviations used are:

D=dominant
C=codominant
M=minor
T=trace
A=absent

i/k=illite to kaolin ratio
Qtz=quartz
Kaol=kaolinite
Dick=dickite
Sid=siderite

3 References

Phillips S.P. 1988. Sample preparation proceedures for X-Ray diffaction. Unpublished memo to the National Centre for Petroleum Geology and Geophysics, Adelaide.

Raven M. & Self P.G. 1988. XPLOT-user manual, manipulation of powder X-Ray diffraction data. *CSIRO Technical Memorandum* **30/1988**, 29p.

Table 1: XRD details.

Well Name	No.	Sample	Qtz	Kaol	Dick	ill.	Sid	i/k
TOOLACHEE	01	0550	D	A	S	M	A	0.86
TOOLACHEE	01	0551	D	A	S	M	A	0.65
TOOLACHEE	01	0552	D	A	M	T	A	0.82
TOOLACHEE	01	0553	D	S	A	S	A	1.92
TOOLACHEE	01	0554	C	S	S	S	C	1.22
TOOLACHEE	01	0341	D	S	A	S	S	1.67
TOOLACHEE	01	0342	D	A	S	M	M	1.10
TOOLACHEE	01	0343	D	A	S	S	M	1.56
TOOLACHEE	01	0344	D	A	S	M	M	0.94
TOOLACHEE	01	0345	D	A	S	S	S	1.53
TOOLACHEE	01	0346	D	A	S	S	M	1.31
TOOLACHEE	01	0347	D	S	A	S	S	1.33
TOOLACHEE	01	0348	D	A	S	M	M	0.79
TOOLACHEE	01	0349	D	A	S	M	M	0.75
TOOLACHEE	01	0350	D	S	A	S	S	1.22
TOOLACHEE	03	0313	D	S	A	S	S	1.56
TOOLACHEE	03	0314	D	A	S	S	S	1.70
TOOLACHEE	03	0315	D	A	S	S	S	0.83
TOOLACHEE	03	0316	D	S	A	S	S	2.22
TOOLACHEE	03	0317	S	S	A	S	D	2.77
TOOLACHEE	03	0318	D	S	A	S	S	1.85
TOOLACHEE	03	0319	D	S	A	S	S	1.50
TOOLACHEE	03	0320	D	S	A	S	A	1.81
TOOLACHEE	03	0321	D	A	D	M	M	0.77
TOOLACHEE	03	0322	D	A	S	A	A	0.00
TOOLACHEE	03	0323	D	A	S	M	A	0.32
TOOLACHEE	03	0324	D	S	A	S	A	1.04
TOOLACHEE	03	0325	D	A	S	M	M	0.68
TOOLACHEE	03	0326	D	S	A	S	S	0.88
TOOLACHEE	03	0327	D	A	S	M	A	0.69
TOOLACHEE	03	0328	D	A	S	A	A	0.00
TOOLACHEE	03	0162	D	A	S	M	A	0.22
TOOLACHEE	03	0163	D	S	A	S	S	1.53
TOOLACHEE	03	0164	D	S	A	S	S	1.10
TOOLACHEE	03	0165	D	S	A	S	S	1.33
TOOLACHEE	03	0166	D	A	S	M	M	0.76
TOOLACHEE	03	0167	D	A	S	A	A	0.00

(3)

Well Name	No.	Sample	Qtz	Kaol	Dick	ill.	Sid	i/k
TOOLACHEE	03	0168	D	S	A	S	S	0.83
TOOLACHEE	03	0169	D	S	A	S	S	0.99
TOOLACHEE	03	0170	D	S	A	S	S	1.17
TOOLACHEE	03	0171	D	S	A	S	S	0.79
TOOLACHEE	03	0172	D	S	A	S	S	1.66
TOOLACHEE	03	0173	D	A	S	M	A	0.72
TOOLACHEE	05	0411	D	S	A	S	S	1.72
TOOLACHEE	05	0412	D	A	S	S	S	1.47
TOOLACHEE	05	0413	A	A	A	A	A	0.00
TOOLACHEE	05	0414	D	S	S	S	S	1.49
TOOLACHEE	05	0415	D	S	A	S	S	1.53
TOOLACHEE	05	0416	D	A	S	S	S	1.23
TOOLACHEE	05	0383	D	S	A	S	S	2.00
TOOLACHEE	05	0384	D	S	A	S	S	1.88
TOOLACHEE	05	0385	D	A	S	M	T	0.00
TOOLACHEE	05	0386	D	S	A	S	M	0.76
TOOLACHEE	05	0387	D	A	S	M	M	0.56
TOOLACHEE	05	0388	D	A	S	S	M	0.62
TOOLACHEE	05	0389	D	A	S	A	A	0.00
TOOLACHEE	06	0527	D	S	A	S	M	1.52
TOOLACHEE	06	0528	D	S	A	S	S	1.88
TOOLACHEE	06	0529	S	S	A	S	D	2.08
TOOLACHEE	06	0530	D	S	A	S	M	1.59
TOOLACHEE	06	0531	D	A	S	M	M	0.76
TOOLACHEE	06	0532	D	A	S	A	A	0.00
TOOLACHEE	06	0533	D	A	S	A	A	0.00
TOOLACHEE	06	0534	D	A	S	A	A	0.00
TOOLACHEE	06	0535	D	A	S	M	A	0.37
TOOLACHEE	06	0536	D	A	S	M	S	0.29
TOOLACHEE	08	0430	D	M	S	S	S	1.75
TOOLACHEE	08	0431	D	A	S	S	S	1.28
TOOLACHEE	08	0432	D	S	S	S	S	1.43
TOOLACHEE	08	0433	D	A	S	S	S	1.57
TOOLACHEE	08	0434	D	S	M	S	M	2.14
TOOLACHEE	09	0435	D	S	A	S	S	3.24
TOOLACHEE	09	0436	D	A	S	S	S	1.30
TOOLACHEE	09	0437	D	A	M	M	S	1.90
TOOLACHEE	09	0438	D	A	S	M	S	0.55
TOOLACHEE	09	0439	D	A	M	T	A	1.00
TOOLACHEE	09	0440	D	A	M	T	M	1.18
TOOLACHEE	12	0417	A	A	A	A	A	0.00
TOOLACHEE	12	0418	D	S	A	S	S	1.06
TOOLACHEE	12	0419	D	S	S	S	S	0.91
TOOLACHEE	12	0420	D	A	S	S	S	1.85
TOOLACHEE	12	0421	D	S	A	S	M	1.56
TOOLACHEE	15	0351	D	A	S	M	M	1.03
TOOLACHEE	15	0352	D	S	A	S	S	0.91
TOOLACHEE	15	0353	D	A	S	M	M	0.92
TOOLACHEE	15	0354	D	A	S	M	M	0.48
TOOLACHEE	15	0355	D	A	S	M	A	0.28
TOOLACHEE	18	0422	D	A	S	A	A	0.00
TOOLACHEE	18	0423	D	A	S	A	A	0.00

Well Name	No.	Sample	Qtz	(4) Kaol	Dick	ill.	Sid	i/k
TOOLACHEE	18	0424	D	A	S	M	S	0.11
TOOLACHEE	18	0425	D	A	S	A	A	0.00
TOOLACHEE	18	0426	D	A	S	A	A	0.00
TOOLACHEE	18	0427	D	S	A	S	S	2.95
TOOLACHEE	18	0428	D	A	S	M	A	0.36
TOOLACHEE	18	0429	D	A	S	M	M	0.39
TOOLACHEE	19	0441	D	S	A	S	A	0.95
TOOLACHEE	19	0442	D	A	S	M	A	0.25
TOOLACHEE	19	0443	D	A	S	A	A	0.00
TOOLACHEE	19	0444	D	A	S	M	S	0.25
TOOLACHEE	19	0445	D	A	S	M	A	0.27
TOOLACHEE	19	0446	D	A	S	A	A	0.00
TOOLACHEE	21	0447	D	S	A	S	S	2.18
TOOLACHEE	21	0448	D	S	A	S	S	2.30
TOOLACHEE	21	0449	D	S	A	S	S	1.13
TOOLACHEE	21	0450	D	A	S	A	M	0.00
TOOLACHEE	32	0560	D	A	S	M	M	1.00
TOOLACHEE	32	0561	D	S	A	S	S	2.09
TOOLACHEE	32	0562	D	S	A	S	S	3.00
TOOLACHEE	32	0563	D	A	M	M	M	1.10
TOOLACHEE	34	0555	D	M	M	M	T	2.00
TOOLACHEE	34	0556	D	A	S	S	S	0.75
TOOLACHEE	34	0557	D	A	S	T	A	0.44
TOOLACHEE	34	0558	D	A	S	S	S	2.67
TOOLACHEE	34	0559	Q	S	A	S	S	3.50
MUNKARIE	02	0564	D	S	A	S	T	1.60
MUNKARIE	02	0565	D	A	S	M	A	0.78
MUNKARIE	02	0566	D	A	M	A	A	0.00
MUNKARIE	02	0567	D	A	S	T	T	0.70
MUNKARIE	02	0568	D	A	S	T	A	0.67
MUNKARIE	02	0569	C	M	M	M	C	1.87
MUNKARIE	02	0570	D	S	A	S	S	1.05
MUNKARIE	02	0571	C	M	S	M	C	1.17
MUNKARIE	02	0572	D	A	S	M	M	0.68
BRUMBY	01	0573	D	A	S	T	S	0.40
BRUMBY	01	0574	C	A	S	T	C	0.62
BRUMBY	01	0575	C	M	T	M	C	1.15
BRUMBY	01	0576	S	S	S	S	D	1.64
BRUMBY	01	0577	D	A	S	A	A	0.00

Table 1 XRD determination of bulk mineralogy.

APPENDIX 4
GENETIC INCREMENTS OF STRATA CORRELATIONS

APPENDIX 4: Genetic Increments of Strata Correlations

Section: **Contents:**

1 Introduction

This appendix contains the details of subdivision and correlation of the Toolachee Formation using genetic increments of strata as outlined in chapter 4. Details of the subdivision of the Epsilon and Patchawarra Formations can be found in Smith (1987) and Faridi and Hunt (1987) respectively.

2 Abbreviations used

dist.	distributry
interdist.	interdistributry

3 Depositional association determination

Depositional associations were determined using gamma ray and sonic well log characteristics taken from Schlumberger well logs. Outlined below are the log signitures corresponding to each depositional association recognised in the study area. The depositional environment of each association is based on a greater than 50% dominance of an association by a particular environment.

Channel sequence
Coal
Flood basin
Overbank sediments
Prograde
Stacked channels

4 Sand thickness determination

Sand thickness was based on a 120 API cutoff on the gamma ray trace. Everything to the left of the 120 degree line was regarded as sand providing that the sonic log did not indicate coal. Some well logs covering the Toolachee Formation were unavailable for sand thichness determination.

5 GIS correlation details

WELLNAME	ASS.	SAND	TOP	DEPOSITIONAL ASSOCIATION
BRUMBY 1	1		5980	Channel sequence
BRUMBY 1	2		6060	Prograde (interdist.channel)
BRUMBY 1	3		6195	Prograde (dist. mouth bar)
BRUMBY 1	4		6260	Stacked channels
BRUMBY 1	5		6340	Prograde \flood basin
BRUMBY 1	6		6430	Channel sequence
BRUMBY 1	7		6455	Channel sequence
BRUMBY 2	1	6	6060	Stacked channel sequences
BRUMBY 2	2	22	6147	Prograde (interdist.channel)
BRUMBY 2	3	8	6276	Channel sequence
BRUMBY 2	4	58	6330	Stacked channels
BRUMBY 2	5	26	6420	Channel sequence

WELLNAME	ASS.	SAND	TOP	DEPOSITIONAL ASSOCIATION
BRUMBY 2	6	0	6503	Flood basin
BRUMBY 2	7	34	6530	Channel sequence
BRUMBY 3	1	4	6045	Prograde
BRUMBY 3	2	10	6108	Overbank sediments
BRUMBY 3	3	6	6254	Prograde\coal
BRUMBY 3	4	50	6311	Stacked channels
BRUMBY 3	5	20	6400	Overbank sediments
BRUMBY 3	6	10	6486	Channel sequence
BRUMBY 3	7	52	6510	Channel sequence
MUNKARIE 1	1	9	5856	Overbank sediments
MUNKARIE 1	2	24	5907	Progrades (shore\overbank)
MUNKARIE 1	3	10	6002	Channel sequence
MUNKARIE 1	4	54	6068	Stacked channels
MUNKARIE 1	5	22	6183	Channel in overbank
MUNKARIE 1	6	2	6270	Flood basin
MUNKARIE 1	7	42	6307	Channel sequence
MUNKARIE 2	1	2	5812	Flood basin
MUNKARIE 2	2	18	5858	Major prograde
MUNKARIE 2	3	18	5948	Channel sequence
MUNKARIE 2	4	70	6012	Stacked channels
MUNKARIE 2	5	4	6137	Flood basin
MUNKARIE 2	6	23	6234	Channel sequence
MUNKARIE 2	7	40	6272	Stacked channels
MUNKARIE 3	1	1	5963	Flood basin
MUNKARIE 3	2	14	6009	Prograde(shore\overbank)
MUNKARIE 3	3	18	6120	Channel sequence
MUNKARIE 3	4	22	6172	Channel\overbank
MUNKARIE 3	5	20	6275	Overbank sediments
MUNKARIE 3	6	29	6359	Channel sequence
MUNKARIE 3	7	38	6420	Channel sequence
MUNKARIE 4	1	13	5792	Channel sequence
MUNKARIE 4	2	9	5834	Prograde
MUNKARIE 4	3	16	5920	Channel sequence
MUNKARIE 4	4	65	5978	Stacked channels
MUNKARIE 4	5	22	6094	Overbank sediments
MUNKARIE 4	6	20	6198	Channel sequence
MUNKARIE 4	7	46	6240	Channel sequence
MUNKARIE 5	1	2	5902	Overbank sediments
MUNKARIE 5	2	14	5944	Prograde(shore)
MUNKARIE 5	3	34	6038	Channel sequence
MUNKARIE 5	4	54	6122	Stacked channels
MUNKARIE 5	5	18	6247	Prograde
MUNKARIE 5	6	2	6240	Overbank sediments
MUNKARIE 5	7	50	6362	Channel sequence
MUNKARIE 6	1	3	5814	Overbank sediments
MUNKARIE 6	2	10	5860	Overbank sediments
MUNKARIE 6	3	24	5956	Channel sequence
MUNKARIE 6	4	73	6021	Stacked channels
MUNKARIE 6	5	24	6146	Overbank\prograding sands
MUNKARIE 6	6	11	6248	Channel sequence
MUNKARIE 6	7	16	6276	Channel sequence

WELLNAME	ASS.	SAND	TOP	DEPOSITIONAL ASSOCIATION
TOOLACHEE 1	1	8	5880	Overbank sediments
TOOLACHEE 1	2	22	5922	Overbank\prograde (shore)
TOOLACHEE 1	3	24	6012	Channel sequence
TOOLACHEE 1	4	16	6074	Overbank\thick prograde
TOOLACHEE 1	5	7	6151	Minor channel sequence
TOOLACHEE 1	6	22	6190	Thick channel sequence
TOOLACHEE 1	7	14	7224	Channel sequence
TOOLACHEE 2	1	0	6055	Flood basin
TOOLACHEE 2	2	26	6094	Dist. mouth bar (major prograde)
TOOLACHEE 2	3	6	6176	Flood basin
TOOLACHEE 2	4	19	6239	Channel in overbank
TOOLACHEE 2	5	20	6310	Overbank (prograde)\channel
TOOLACHEE 2	6	26	6406	Stacked channels
TOOLACHEE 2	7	0	6438	Coal
TOOLACHEE 3	1	5	6060	Overbank sediments
TOOLACHEE 3	2	16	6090	Overbank sediments
TOOLACHEE 3	4	25	6240	Stacked channel sequences
TOOLACHEE 3	5	4	6335	Overbank sediments
TOOLACHEE 3	6	11	6370	channel sequences
TOOLACHEE 3	7	17	6420	channel sequences
TOOLACHEE 4	1	4	6109	Flood basin
TOOLACHEE 4	2	12	6152	Overbank (prograde)
TOOLACHEE 4	3	12	6246	Channel sequence
TOOLACHEE 4	4	26	6320	Stacked channel\overbank (prograde)
TOOLACHEE 4	5	25	6385	Channel in overbank (prograde)
TOOLACHEE 4	6	6	6496	Overbank
TOOLACHEE 4	7	0	6525	Coal
TOOLACHEE 5	1	10	6242	Thin channel sequences
TOOLACHEE 5	2	5	6285	Overbank sediments
TOOLACHEE 5	3	0	6360	Flood basin
TOOLACHEE 5	4	48	6420	Stacked channel sequences
TOOLACHEE 5	5	12	6509	Prograde (overbank)
TOOLACHEE 5	6	15	6554	Channel sequence
TOOLACHEE 5	7	30	6593	Stacked channel sequences
TOOLACHEE 6	1	0	6120	Flood basin
TOOLACHEE 6	2	0	6166	Overbank sediments
TOOLACHEE 6	3	30	6254	Stacked channel sequences
TOOLACHEE 6	4	50	6326	Stacked channel sequences
TOOLACHEE 6	5	6	6423	Overbank sediments
TOOLACHEE 6	6	27	6498	Channel sequence
TOOLACHEE 6	7	0	6540	Coal
TOOLACHEE 7	1	24	6084	Flood basin
TOOLACHEE 7	2	18	6132	Overbank with prograde
TOOLACHEE 7	3	6	6242	Overbank (prograde)\coal
TOOLACHEE 7	4	44	6304	Stacked channels
TOOLACHEE 7	5	6	6396	Overbank sediments
TOOLACHEE 7	6	43	6440	Channel sequence
TOOLACHEE 7	7	0	6500	Coal

WELLNAME	ASS.	SAND	TOP	DEPOSITIONAL ASSOCIATION
TOOLACHEE 8	1	2	6150	Overbank sediments(prograde)
TOOLACHEE 8	2	22	6192	Overbank sediments(prograde)
TOOLACHEE 8	3	12	6308	Channel sequence
TOOLACHEE 8	4	18	6364	Channel sequence
TOOLACHEE 8	5	14	6432	Overbank sediments(prograde)
TOOLACHEE 8	6	10	6506	Channel sequence
TOOLACHEE 8	7	18	6530	Channel sequence
TOOLACHEE 9	1	0	6127	Overbank sediments
TOOLACHEE 9	2	11	6184	Progrades
TOOLACHEE 9	3	10	6278	Channel sequence
TOOLACHEE 9	4	42	6335	Stacked channels
TOOLACHEE 9	5	32	6428	Dist.Channel sequence(Prograde)
TOOLACHEE 9	6	25	6512	Channel sequence
TOOLACHEE 9	7	16	6565	Channel sequence
TOOLACHEE 10	1	2	6032	Overbank sediments
TOOLACHEE 10	2	20	6106	Stacked channels
TOOLACHEE 10	3	35	6183	Channel sequence
TOOLACHEE 10	4	55	6256	Channel sequence
TOOLACHEE 10	5	7	6348	Overbank sediments
TOOLACHEE 10	6	21	6398	Channel sequence
TOOLACHEE 10	7	12	6442	Channel in flood basin
TOOLACHEE 11	1	0	6091	Overbank sediments
TOOLACHEE 11	2	10	6138	Overbank sediments
TOOLACHEE 11	3	6	6236	Channel sequence
TOOLACHEE 11	4	29	6294	Stacked channels
TOOLACHEE 11	5	2	6372	Prograde in overbank
TOOLACHEE 11	6	21	6441	Channel sequence
TOOLACHEE 11	7	0	6484	Coal
TOOLACHEE 12	1	0	6107	Overbank sediments
TOOLACHEE 12	2	4	6150	Prograde in overbank
TOOLACHEE 12	3	26	6257	Stacked channel sequences
TOOLACHEE 12	4	20	6325	Minor channel sequence
TOOLACHEE 12	5	0	6393	Overbank sediments
TOOLACHEE 12	6	0	6430	Coal
TOOLACHEE 12	7	25	6444	Channel sequence
TOOLACHEE 13	1	2	6082	Overbank sediments
TOOLACHEE 13	2	6	6136	Prograde in overbank
TOOLACHEE 13	3	42	6222	Channel sequence\shore
TOOLACHEE 13	4	31	6310	Stacked channels
TOOLACHEE 13	5	4	6397	Prograde (shore) into flood basin
TOOLACHEE 13	6	30	6453	Channel sequence
TOOLACHEE 13	7	0	6509	Coal
TOOLACHEE 14	1	0	6091	Overbank sediments
TOOLACHEE 14	2	6	6131	Prograding sediments
TOOLACHEE 14	3	16	6223	Channel sequence
TOOLACHEE 14	4	30	6289	Channel sequence
TOOLACHEE 14	5	12	6364	Channel sequence/flood basin
TOOLACHEE 14	6	14	6432	Channel sequence
TOOLACHEE 14	7	6	6468	Channel sequence

WELLNAME	ASS.	SAND	TOP	DEPOSITIONAL ASSOCIATION
TOOLACHEE 15	1	0	6014	Overbank sediments
TOOLACHEE 15	2	5	6065	Prograding sediments
TOOLACHEE 15	3	19	6164	Channel sequence
TOOLACHEE 15	4	14	6230	Channel sequence
TOOLACHEE 15	5	12	6303	Channel sequence
TOOLACHEE 15	6	36	6343	Channel sequence
TOOLACHEE 15	7	0	6400	Coal
TOOLACHEE 16	1	0	5899	Overbank sediments
TOOLACHEE 16	2	8	5938	Overbank sediments
TOOLACHEE 16	3	28	6017	Channel sequence
TOOLACHEE 16	4	32	6084	Stacked channels
TOOLACHEE 16	5	8	6159	Overbank sediments
TOOLACHEE 16	6	28	6204	Thick channel sequence
TOOLACHEE 16	7	0	6244	Coal
TOOLACHEE 17	1	0	6094	Flood basin
TOOLACHEE 17	2	10	6142	Prograde (shore)
TOOLACHEE 17	3	52	6230	Stacked channels
TOOLACHEE 17	4	32	6328	Channel sequence
TOOLACHEE 17	5	4	6428	Prograde in overbank
TOOLACHEE 17	6	32	6478	Channel sequence
TOOLACHEE 17	7			
TOOLACHEE 18	1	0	6022	Flood basin
TOOLACHEE 18	2	8	6073	Major prograde
TOOLACHEE 18	3	5	6183	Channel with thick coal
TOOLACHEE 18	4	35	6237	Stacked channels
TOOLACHEE 18	5	6	6327	Prograde
TOOLACHEE 18	6	8	6372	Channel sequence
TOOLACHEE 18	7	31	6415	Channel sequence
TOOLACHEE 19	1	2	6129	Flood basin
TOOLACHEE 19	2	8	6178	Overbank sediments
TOOLACHEE 19	3	38	6272	Stacked channels
TOOLACHEE 19	4	8	6358	Overbank sediments
TOOLACHEE 19	5	2	6444	Overbank sediments
TOOLACHEE 19	6	19	6495	Channel sequence
TOOLACHEE 19	7	0	6542	Coal
TOOLACHEE 20	1	0	6088	Flood basin
TOOLACHEE 20	2	14	6137	Progrades (shore)
TOOLACHEE 20	3	4	6252	Overbank\Flood basin
TOOLACHEE 20	4	20	6312	Channel sequencse
TOOLACHEE 20	5	4	6409	Overbank sediments
TOOLACHEE 20	6	26	6450	Channel sequence
TOOLACHEE 20	7	0	6504	Coal
TOOLACHEE 21	1	4	6213	Overbank sediments
TOOLACHEE 21	2	8	6264	Overbank sediments
TOOLACHEE 21	3	0	6350	Flood basin
TOOLACHEE 21	4	44	6403	Stacked channels
TOOLACHEE 21	5	46	6493	Channel overlain by prograde
TOOLACHEE 21	6	22	6610	Channel sequence
TOOLACHEE 21	7	0	6650	Coal
TOOLACHEE 22	Did not reach Toolachee Formation			

WELLNAME	ASS.	SAND	TOP	DEPOSITIONAL ASSOCIATION
TOOLACHEE 23	1	2	6210	Overbank sediments
TOOLACHEE 23	2	4	6254	Prograde (Overbank)
TOOLACHEE 23	3	26	6344	Channel sequence
TOOLACHEE 23	4	38	6408	Stacked channels
TOOLACHEE 23	5	9	6500	Prograde(shore\flood basin\shore)
TOOLACHEE 23	6	10	6555	Thin channel sequences
TOOLACHEE 23	7	30	6594	Channel sequence
TOOLACHEE 24	1	2	6140	Overbank sediments
TOOLACHEE 24	2	6	6188	Overbank sediments
TOOLACHEE 24	3	4	6290	Shore\flood basin
TOOLACHEE 24	4	12	6347	Stacked channels
TOOLACHEE 24	5	8	6409	Overbank sediments
TOOLACHEE 24	6	27	6472	Channel sequences
TOOLACHEE 24	7	0	6518	Coal
TOOLACHEE 25	1	4	6068	Prograde
TOOLACHEE 25	2	10	6118	Overbank sediments
TOOLACHEE 25	3	2	6229	Flood basin
TOOLACHEE 25	4	19	6280	Channel sequence\Overbank
TOOLACHEE 25	5	2	6372	Overbank sediments
TOOLACHEE 25	6	16	6417	Channel sequence
TOOLACHEE 25	7	34	6455	Channel sequence
TOOLACHEE 26	1	2	6050	Overbank sediments
TOOLACHEE 26	2	8	6097	Progrades (shore)
TOOLACHEE 26	3	4	6203	Channel sequence\coal
TOOLACHEE 26	4	24	6263	Channel sequences
TOOLACHEE 26	5	2	6344	Overbank sediments
TOOLACHEE 26	6	0	6385	Flood basin
TOOLACHEE 26	7	20	6414	Channel sequence
TOOLACHEE 27	1	4	6070	Overbank sediments
TOOLACHEE 27	2	7	6112	Overbank sediments
TOOLACHEE 27	3	37	6203	Channel sequence
TOOLACHEE 27	4	8	6284	Channel sequence
TOOLACHEE 27	5	40	6344	Channel sequence
TOOLACHEE 27	6	11	6406	Stacked channels
TOOLACHEE 27	7	11	6430	Channel sequence
TOOLACHEE 28	1	0	6024	Overbank sediments
TOOLACHEE 28	2	6	6068	Overbank sediments
TOOLACHEE 28	3	17	7170	Channel sequence
TOOLACHEE 28	4	44	6233	Stacked channels
TOOLACHEE 28	5	3	6330	Overbank sediments
TOOLACHEE 28	6	20	6370	Channel sequence
TOOLACHEE 28	7	44	6416	Channel sequence
TOOLACHEE 29	1	0	6023	Overbank sediments
TOOLACHEE 29	2	2	6060	Overbank sediments
TOOLACHEE 29	3	23	6143	Stacked channels
TOOLACHEE 29	4	38	6219	Stacked channels
TOOLACHEE 29	5	3	6308	Prograde in overbank
TOOLACHEE 29	6	19	6347	Channel sequence
TOOLACHEE 29	7	8	6388	Channel sequence

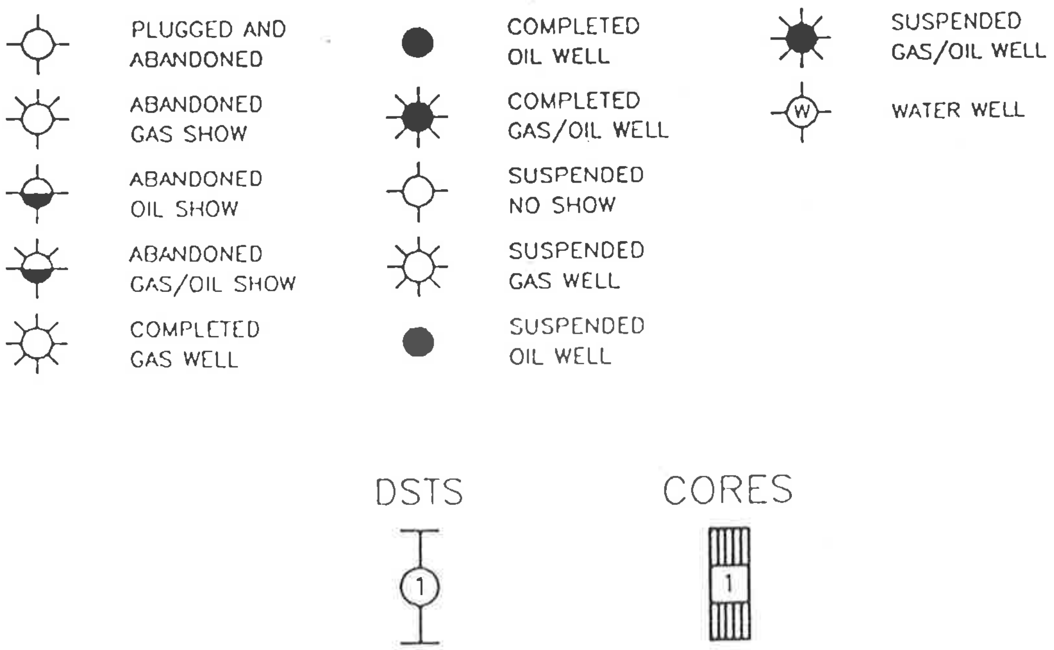
WELLNAME	ASS.	SAND	TOP	DEPOSITIONAL ASSOCIATION
TOOLACHEE 30	1	2	6136	Overbank sediments
TOOLACHEE 30	2	12	6187	Prograde in overbank
TOOLACHEE 30	3	39	6284	Channel sequence
TOOLACHEE 30	4	27	6376	Channel sequence
TOOLACHEE 30	5	5	6469	Overbank sediments
TOOLACHEE 30	6	40	6522	Thick channel sequence
TOOLACHEE 30	7	0	6576	Coal
TOOLACHEE 31	1	4	6127	Overbank sediments
TOOLACHEE 31	2	7	6176	Prograde
TOOLACHEE 31	3	27	6281	Channel sequence
TOOLACHEE 31	4	30	6350	Stacked channels
TOOLACHEE 31	5	8	6428	Overbank sediments
TOOLACHEE 31	6	4	6465	Overbank sediments
TOOLACHEE 31	7	43	6493	Channel sequence
TOOLACHEE 32	1	2	5981	Flood basin
TOOLACHEE 32	2	5	6028	Overbank sediments
TOOLACHEE 32	3	44	6124	Channel sequence
TOOLACHEE 32	4	36	6205	Stacked channels
TOOLACHEE 32	5	3	6287	Flood basin
TOOLACHEE 32	6	10	6335	Channel sequence
TOOLACHEE 32	7	12	6365	Channel sequence
TOOLACHEE 33	1	0	6058	Overbank sediments
TOOLACHEE 33	2	7	6098	Overbank sediments
TOOLACHEE 33	3	16	6188	Channel sequence
TOOLACHEE 33	4	22	6248	Stacked channels
TOOLACHEE 33	5	7	6307	Overbank sediments
TOOLACHEE 33	6	11	6362	Channel sequence
TOOLACHEE 33	7	13	6344	Channel sequence
TOOLACHEE 34	No Logs			
TOOLACHEE 35	1	0	6164	Flood basin
TOOLACHEE 35	2	8	6222	Overbank sediments
TOOLACHEE 35	3	0	6326	Overbank sediments
TOOLACHEE 35	4	42	6386	Thick channel sequence
TOOLACHEE 35	5	6	6478	Overbank sediments
TOOLACHEE 35	6	32	6544	Channel sequence
TOOLACHEE 35	7	0	6594	Channel sequence
TOOLACHEE 36	1	3	5895	Overbank sediments
TOOLACHEE 36	2	10	5947	Overbank sediments
TOOLACHEE 36	3	21	6043	Channel sequence
TOOLACHEE 36	4	14	6103	Minor channel in overbank
TOOLACHEE 36	5	9	6179	Overbank sediments
TOOLACHEE 36	6	20	6221	Channel sequence
TOOLACHEE 36	7	33	6264	Channel sequence
TOOLACHEE 37	1	2	6208	Overbank sediments
TOOLACHEE 37	2	32	6238	Major prograde
TOOLACHEE 37	3	2	6342	Channel sequence
TOOLACHEE 37	4	22	6396	Overbank\channel
TOOLACHEE 37	5	2	6472	Channel \prograde

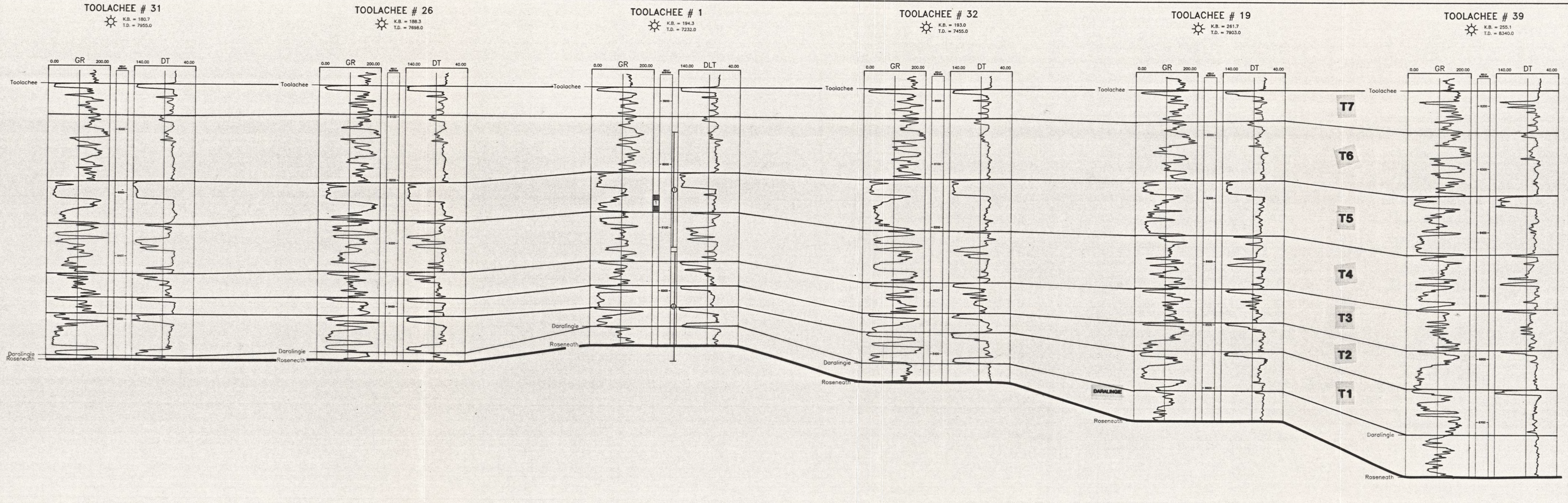
WELLNAME	ASS.	SAND	TOP	DEPOSITIONAL ASSOCIATION
TOOLACHEE 38	1	2	6059	Overbank sediments
TOOLACHEE 38	2	16	6110	Thin channel in overbank
TOOLACHEE 38	3	27	6206	Channel sequence
TOOLACHEE 38	4	48	6267	Stacked channels
TOOLACHEE 38	5	10	6362	Overbank \thin channel
TOOLACHEE 38	6	20	6433	Channel sequence
TOOLACHEE 38	7	13	6470	Prograde
TOOLACHEE 39	1	2	6176	Flood basin
TOOLACHEE 39	2	20	6240	Overbank sediments
TOOLACHEE 39	3	48	6342	Channel sequence
TOOLACHEE 39	4	30	6434	Stacked channels
TOOLACHEE 39	5	6	6521	Overbank sediments
TOOLACHEE 39	6	40	6586	Channel sequence
TOOLACHEE 39	7	15	6648	Prograding distributary channel
TOOLACHEE 40	1	0	6193	Overbank sediments
TOOLACHEE 40	2	14	6230	Overbank with prograde
TOOLACHEE 40	3	12	6330	Channel sequence
TOOLACHEE 40	4	30	6396	Stacked channels
TOOLACHEE 40	5	79	6486	Channel sequence
TOOLACHEE 40	6	36	6612	Stacked channels
TOOLACHEE 40	7	7	6674	Channel sequence
TOOLACHEE E 1	1		6298	Overbank sediments
TOOLACHEE E 1	2		6355	Prograde
TOOLACHEE E 1	3		6470	Flood basin
TOOLACHEE E 1	4		6520	Channel sequence
TOOLACHEE E 1	5		6630	Channel sequence
TOOLACHEE E 1	6		6740	Channel sequence
TOOLACHEE E 1	7		6795	Channel sequence
TOOLACHEE E 2	1	8	6283	Overbank sediments
TOOLACHEE E 2	2	14	6342	Prograde (shoreline)
TOOLACHEE E 2	3	18	6440	Channel sequence
TOOLACHEE E 2	4	54	6507	Stacked channels
TOOLACHEE E 2	5	18	6613	Channel sequence
TOOLACHEE E 2	6	22	6687	Prograde (shoreline)
TOOLACHEE E 2	7	0	6730	Coal

6 Cross sections

Six cross sections show correlations of the GIS units over the Toolachee and Patchawarra Formations.

WELL STATUS SYMBOLS

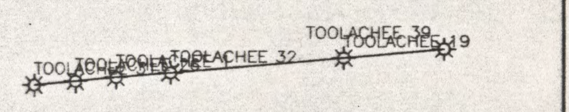




CROSS SECTION 1

SANTOS

LINE OF SECTION



SANTOS

TOOLACHEE FIELD

TOOLACHEE BLOCK

STRATIGRAPHIC CROSS SECTION

TOOLACHEE 31-26-1-32-19-39

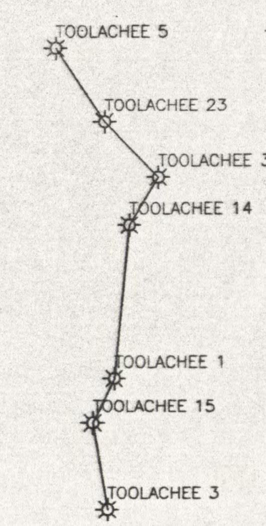
TOP TOOLACHEE TO ROSENEATH

VERTICAL SCALE 1 INCH TO 50 FEET	DRAFTED,DATE	DRAWING NUMBER
HORIZONTAL SCALE : DIAGRAMATIC		
DATUM :	CHIEF DRAFTSMAN	FILE # :
SUPERVISOR : D.ALSOP		ENCLOSURE
INTERPRETATION : D.ALSOP	DATE : 16-AUG-88	

CROSS SECTION 2

SANTOS

LINE OF SECTION



SANTOS

TOOLACHEE FIELD

TOOLACHEE BLOCK

STRATIGRAPHIC CROSS SECTION

TOOLACHEE 5-23-33-14-1-15-3

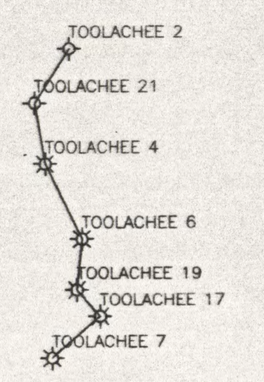
TOP TOOLACHEE TO ROSENEATH

VERTICAL SCALE 1 INCH TO 50 FEET	DRAFTED,DATE	DRAWING NUMBER
HORIZONTAL SCALE : DIAGRAMATIC		
DATUM :	CHIEF DRAFTSMAN	FILE # :
SUPERVISOR :		ENCLOSURE
INTERPRETATION : D.ALSOP	DATE : 18-AUG-88	

CROSS SECTION 3

SANTOS

LINE OF SECTION



SANTOS

TOOLACHEE FIELD

TOOLACHEE BLOCK

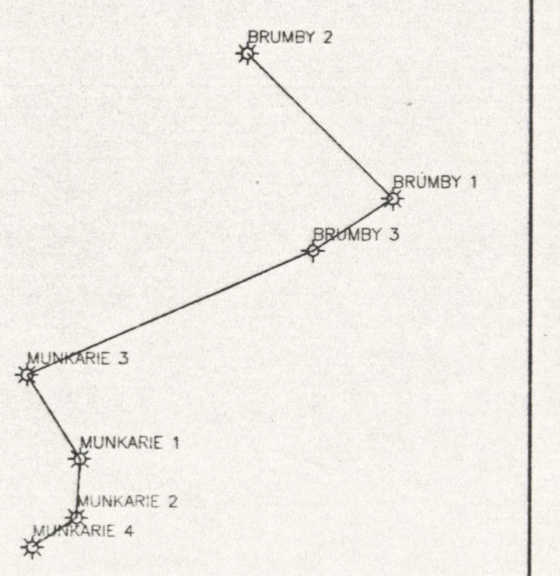
STRATIGRAPHIC CROSS SECTION
TOOLACHEE 2-21-4-6-19-17-7
TOP TOOLACHEE TO ROSENEATH

VERTICAL SCALE 1 INCH TO 50 FEET	DRAFTED.DATE	DRAWING NUMBER
HORIZONTAL SCALE : DIAGRAMATIC		
DATUM :	CHIEF DRAFTSMAN	FILE # :
SUPERVISOR : D.ALSOP		ENCLOSURE
INTERPRETATION : D.ALSOP	DATE : 18-AUG-88	

CROSS SECTION 4

SANTOS

LINE OF SECTION



SANTOS

MUNKARIE & BRUMBY FIELDS

TOOLACHEE BLOCK

STRATIGRAPHIC CROSS SECTION

MUNKARIE 4–2–1–BRUMBY 3–1–2

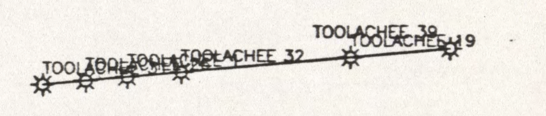
TOP TOOLACHEE TO ROSENEATH

VERTICAL SCALE 1 INCH TO 50 FEET	DRAFTED, DATE	DRAWING NUMBER
HORIZONTAL SCALE : DIAGRAMATIC		
DATUM	CHIEF DRAFTSMAN	FILE # :
SUPERVISOR :		ENCLOSURE
INTERPRETATION : D.ALSOP DATE : 18–AUG–88		

CROSS SECTION 5

SANTOS

LINE OF SECTION



SANTOS

TOOLACHEE FIELD

TOOLACHEE BLOCK

STRATIGRAPHIC CROSS SECTION

TOOLACHEE 31-26-1-32-19-39

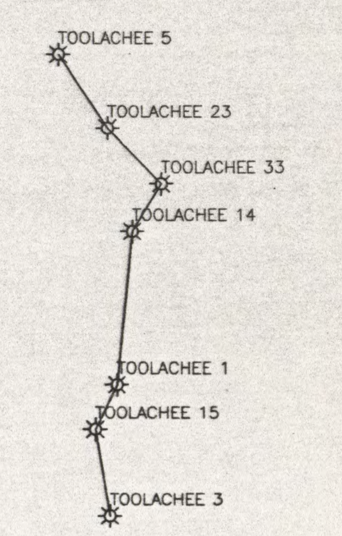
TOP PATCHAWARRA TO PRE-PERMIAN

VERTICAL SCALE 1 INCH TO 50 FEET	DRAFTED.DATE	DRAWING NUMBER
HORIZONTAL SCALE : DIAGRAMATIC		
	CHIEF DRAFTSMAN	FILE # :
SUPERVISOR : D.ALSOP		ENCLOSURE
INTERPRETATION : D.ALSOP	DATE : 16-AUG-88	

CROSS SECTION 6

SANTOS

LINE OF SECTION



SANTOS

TOOLACHEE FIELD

TOOLACHEE BLOCK

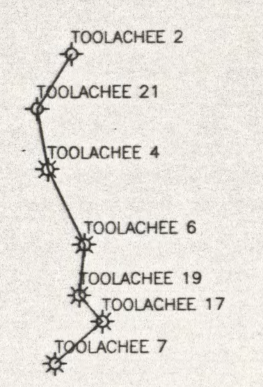
STRATIGRAPHIC CROSS SECTION
TOOLACHEE 5-23-33-14-1-15-3
TOP PATCHAWARRA TO PRE-PERMIAN

VERTICAL SCALE 1 INCH TO 50 FEET	DRAFTED, DATE	DRAWING NUMBER
HORIZONTAL SCALE : DIAGRAMATIC		
DATUM :	CHIEF DRAFTSMAN	FILE # :
SUPERVISOR :		ENCLOSURE
INTERPRETATION : D.ALSOP DATE : 17-AUG-88		

CROSS SECTION 7

SANTOS

LINE OF SECTION



SANTOS

TOOLACHEE FIELD

TOOLACHEE BLOCK

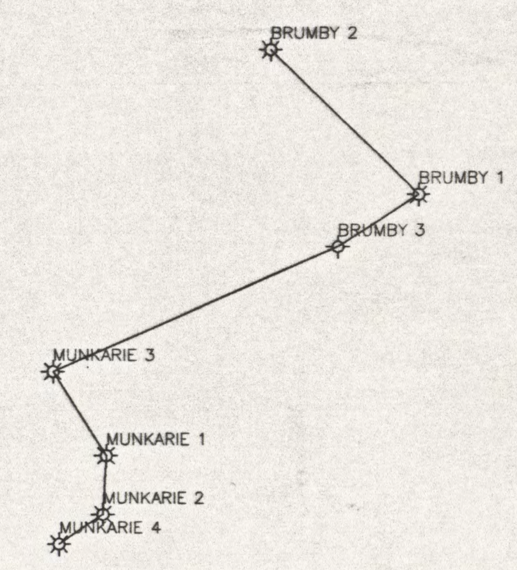
STRATIGRAPHIC CROSS SECTION
TOOLACHEE 2-21-4-6-19-17-7
TOP PATCHAWARRA TO PRE-PERMIAN

VERTICAL SCALE 1 INCH TO 50 FEET	DRAFTED, DATE	DRAWING NUMBER
HORIZONTAL SCALE : DIAGRAMATIC		
DATUM :	CHIEF DRAFTSMAN	FILE # :
SUPERVISOR : D.ALSOP		ENCLOSURE
INTERPRETATION : D.ALSOP	DATE : 17-AUG-88	

CROSS SECTION 8

SANTOS

LINE OF SECTION



SANTOS

MUNKARIE & BRUMBY FIELDS

TOOLACHEE BLOCK

STRATIGRAPHIC CROSS SECTION
MUNKARIE 4-2-1-BRUMBY 3-1-2
TOP PATCHAWARRA TO PRE-PERMIAN

VERTICAL SCALE 1 INCH TO 50 FEET	DRAFTED,DATE	DRAWING NUMBER
HORIZONTAL SCALE : DIAGRAMATIC		
DATUM :	CHIEF DRAFTSMAN	FILE # :
SUPERVISOR :		ENCLOSURE
INTERPRETATION : D.ALSOP DATE : 17-AUG-88		