# A study of the Patchawarra Formation
# Tirrawarra Field , Southern Cooper Basin
# South Australia

by

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# CONTENTS

# ABSTRACT

In the Permian Patchawarra Formation of the Tirrawarra Field sedimentary patterns exposed in core and interpreted from geophysical logs are recognised by the writer and previous workers to have modern analogues. Thus, for example, point bar sequences and lag gravels are identified. It is known that the modern deposition rates of such structures are quite rapid. However less than 1200 feet of Patchawarra Formation subcrops in the Tirrawarra Field and this was deposited over some 10 million years. Therefore considerable reworking of material must have occurred, particularly in view of the low gradient of the land surface at the time. Reworking of modern sediments is difficult to recognise in the field and so is not often considered in the interpretation of ancient sedimentary sections.

It is envisaged that meandering streams entering from the north, crossed and recrossed the Tirrawarra structure, depositing, eroding, transporting and then redepositing the sediments. Stacked point bar deposits occur on the high spots of the Tirrawarra anticline where structural growth (a slower rate of subsidence) has taken place. Sand percentages are found, in most cases, to be influenced by structure but elsewhere may reflect shore line patterns and preferential stream direction. In the latter two cases there are potential exploration targets outside the field area. High porosities occur in some low sand percentage

areas, and this too is of economic interest. Future work on the field might involve porosity investigation in the lower parts of the Patchawarra Formation.

## STATEMENT OF AUTHENTICITY AND AVAILABILITY

This thesis contains no material which has been excepted 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.

I consent to the thesis being made available for photocopying and loan if applicable, if accepted for the award of the degree.

Sean Kennedy.

# ACKNOWLEDGMENTS

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Finally I am greatly indebted to my family. My wife Cynthia has been a tower of strength, giving me constant moral support during these last two years. My children, Linda and Rohan, have also been most helpful with drafting assistance in the final few weeks.

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# CHAPTER 1 INTRODUCTION

## 1.1 Aim

The aim of this study is to investigate the sedimentary history of the Patchawarra Formation in the Tirrawarra Field of the Cooper Basin. Core logs are correlated with geophysical logs to determine parameters used to define different types of sedimentary rocks in wells where no core has been taken. Cores and well logs are then examined in order to build up a scenario of the environments of deposition. On the basis of core and well log patterns the Patchawarra Formation is subdivided into lithological units, each analysed qualitatively and quantitatively on a field wide basis.

From this analysis the structural and depositional history of the field is determined, with the aid of structural maps prepared from well and seismic data.

Sandstone porosities are investigated and, where possible, correlated with depositional and structural trends.

The task is to predict depositional and porosity trends off the Tirrawarra structure, where no well data are available. Hopefully this will aid future exploration and development of the southern Cooper Basin in general and the Tirrawarra Field in particular.

## 1.2 Cooper Basin

The Cooper Basin is a Permo-Triassic infrabasin of the Eromanga Basin located in the northeast corner of South Australia and the southwest corner of Queensland (Figure 1). It is oriented northeast and has an area of about 127 000 square kilometres. The sediments of the Cooper Basin unconformably overlie crystalline basement or earlier Palaeozoic Basins, and in turn are unconformably overlain by widespread Jurassic and Cretaceous sediments of the Eromanga Basin ( Thornton, 1979 ).

Two prominent arcuate anticlinal trends are to be found in the southern Cooper Basin. These divide the region into three "sub-basins", the Patchawarra, Nappamerri and Tenappera Troughs. These anticlinal trends are the Gidgealpa - Merrimelia - Innamincka High and the Murteree - Nappacoongee - Tickalara High. The position of these structural features is shown in Figure 2.

## 1.3 Patchawarra Formation

The Patchawarra Formation of Early Permian age forms part of the Gidgealpa Group and its stratigraphic position is shown in Figure 3. The Formation is the thickest of the Gidgealpa Group formations and exhibits the greatest variation in thickness. It is absent only near the Basin margins where it is overlapped by younger Permian sediments, or on some of the structural highs within the Basin (Williams,1982). Its maximum known thickness is 1309 feet in Jack Lake 1.

The Patchawarra Formation consists of an interstratified sequence of sandstone, shale, siltstone and

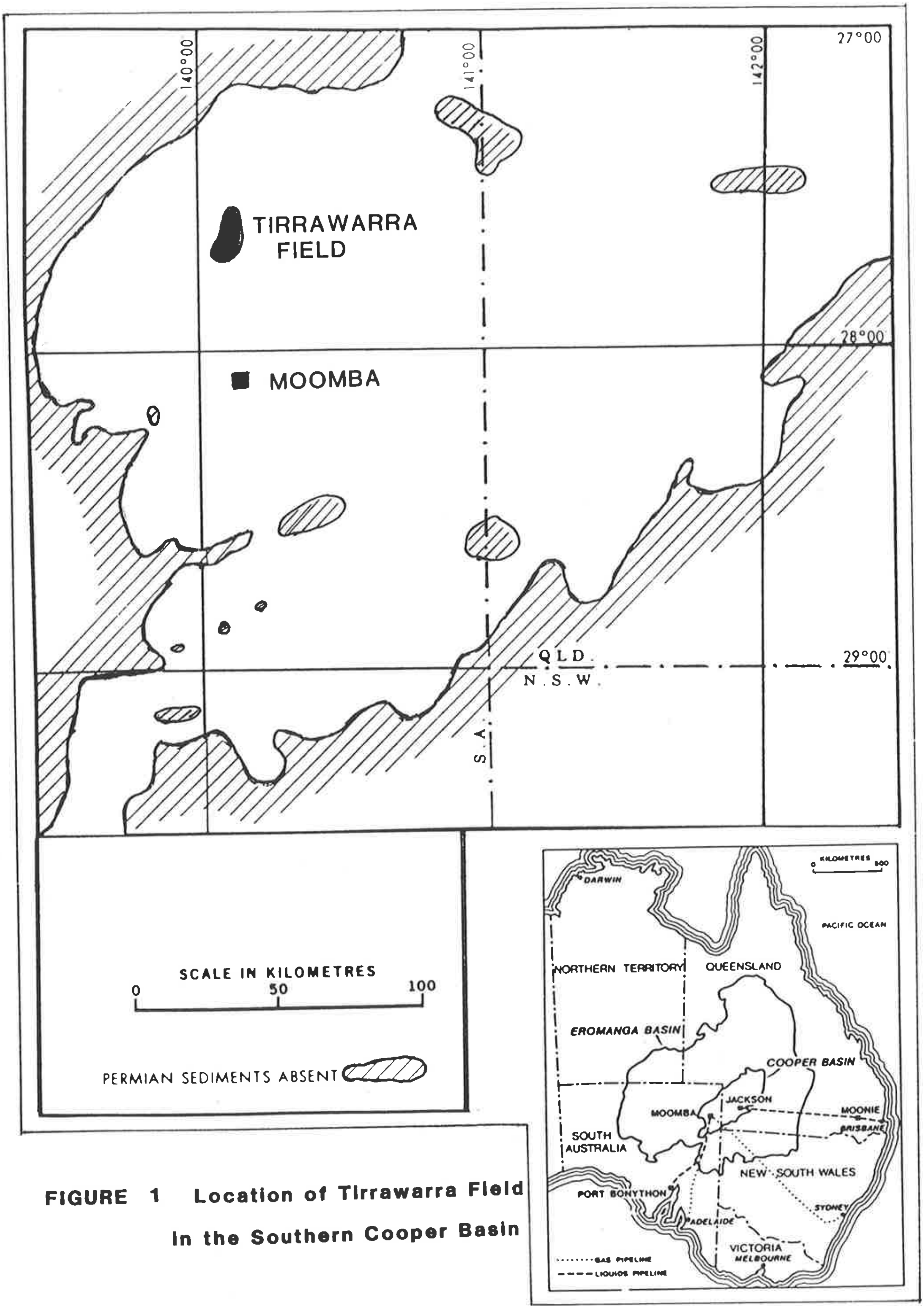


**FIGURE 1 Location of Tirrawarra Field in the Southern Cooper Basin**

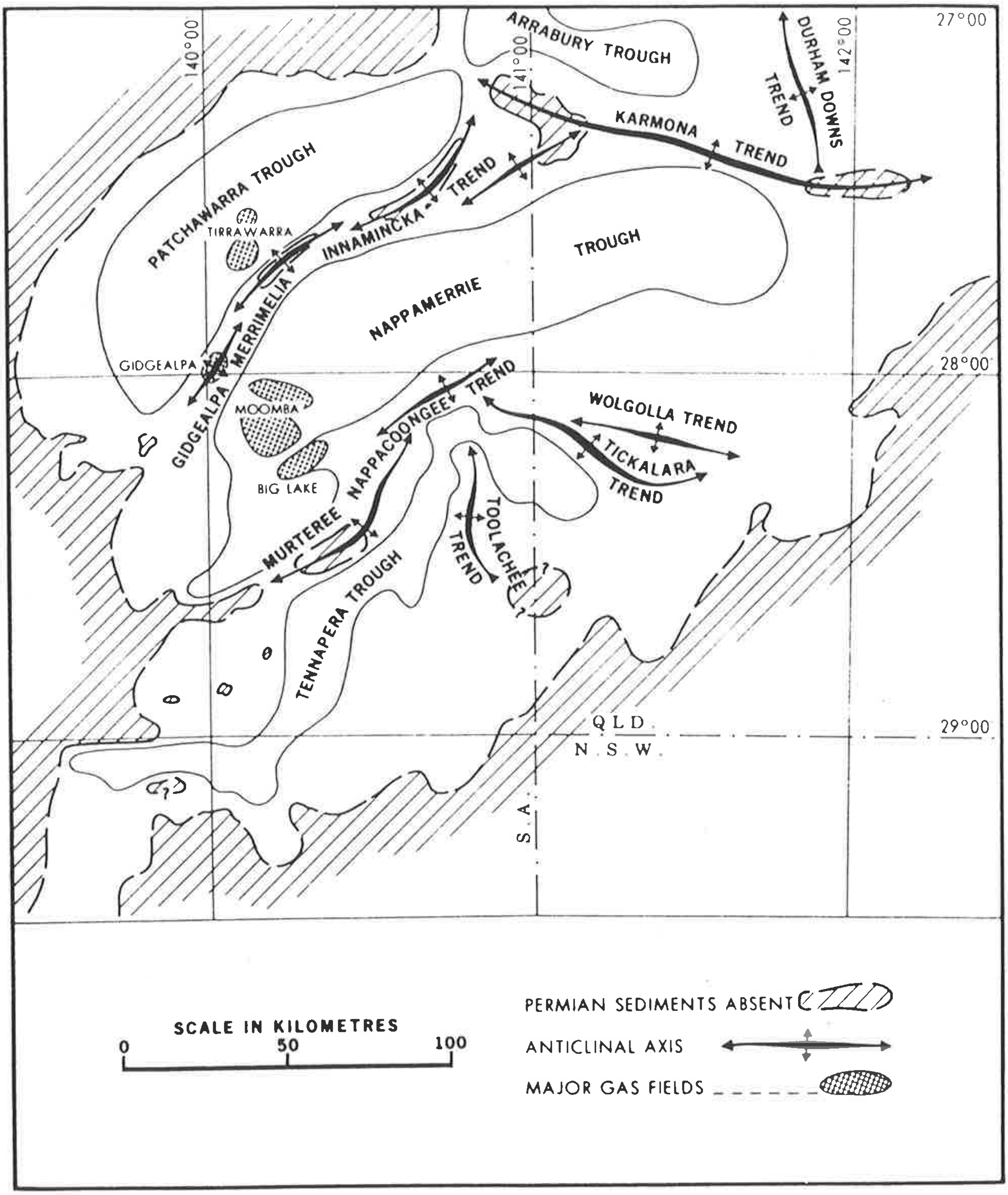


**FIGURE 2** **Southern Cooper Basin -Major Structural Elements**

**(From Thornton, 1979 after Battersby, 1976.)**

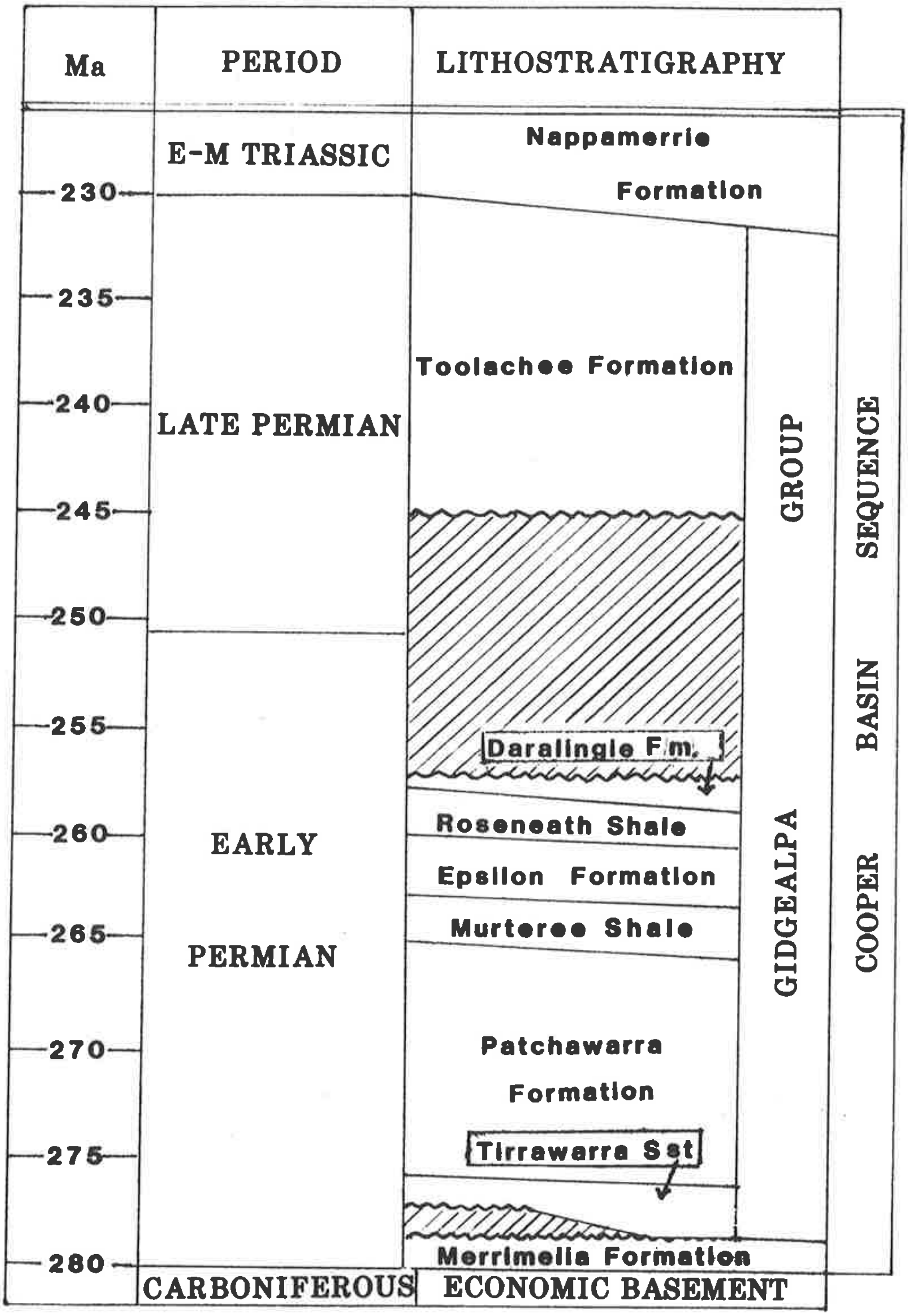


**FIGURE 3** Stratigraphy of the Gidgealpa Group

( modified from Thornton, 1979 )

coal. It is thought to have been deposited in a mixed-load fluvial environment. The Formation was defined from sections measured in the Patchawarra Trough by Kapel (1979) who subdivided the Patchawarra Formation into three lithologically distinct sub-units. His lower division comprises mostly carbonaceous mudrocks with thinly interbedded coals and minor shales. The middle division consists of thickly interbedded sandstones, coals and mudrocks. Kapel's upper division consists of a mudrock dominant sequence.

The Patchawarra Formation conformably overlies the fluvial Tirrawarra Sandstone and is overlain by the lacustrine Murteree Shale.

The Formation is confined wholly to the sub-surface and its characteristics have been determined by examination of core and geophysical logs in this study.

Sandstones of the Patchawarra Formation are, together with the Toolachee and Epsilon Formations, the principal gas producers of the Cooper Basin.

## 1.4 Tirrawarra Field

The Tirrawarra Field lies in the southwestern section of the Cooper Basin in northeastern South Australia and is centred about 50 kilometres north-northwest of Moomba (Figure 1). It is a large domal anticline of area 15 500 acres and vertical closure 250 feet, situated in the central-eastern part of the Patchawarra trough at a depth of 8 000-10 000 feet below M.S.L.

The field measures 9 kilometres north-south by 9 kilometres east-west, the main structural trend being northeast-southwest, the same as that of the Patchawarra Trough and of the Cooper Basin in general. Seismic interpretation indicates that the Tirrawarra Field is faulted at the Tirrawarra Sandstone and Patchawarra Formation levels, the faults also trending northeast. However, the structure is completely draped at the Toolachee Formation level (Thornton, 1979). Draping is defined as the general structural concordance of warped strata, lying above hard core, to the surface of that core, due either to initial dip or to differential compaction, or to both ( American Geological Institute, 1979 ).

The Tirrawarra Field was discovered in May 1971 by Bridge Oil, with the drilling of Tirrawarra 1. The field is a major producer of oil from the Tirrawarra Sandstone and gas from the Patchawarra and Toolachee Formations.

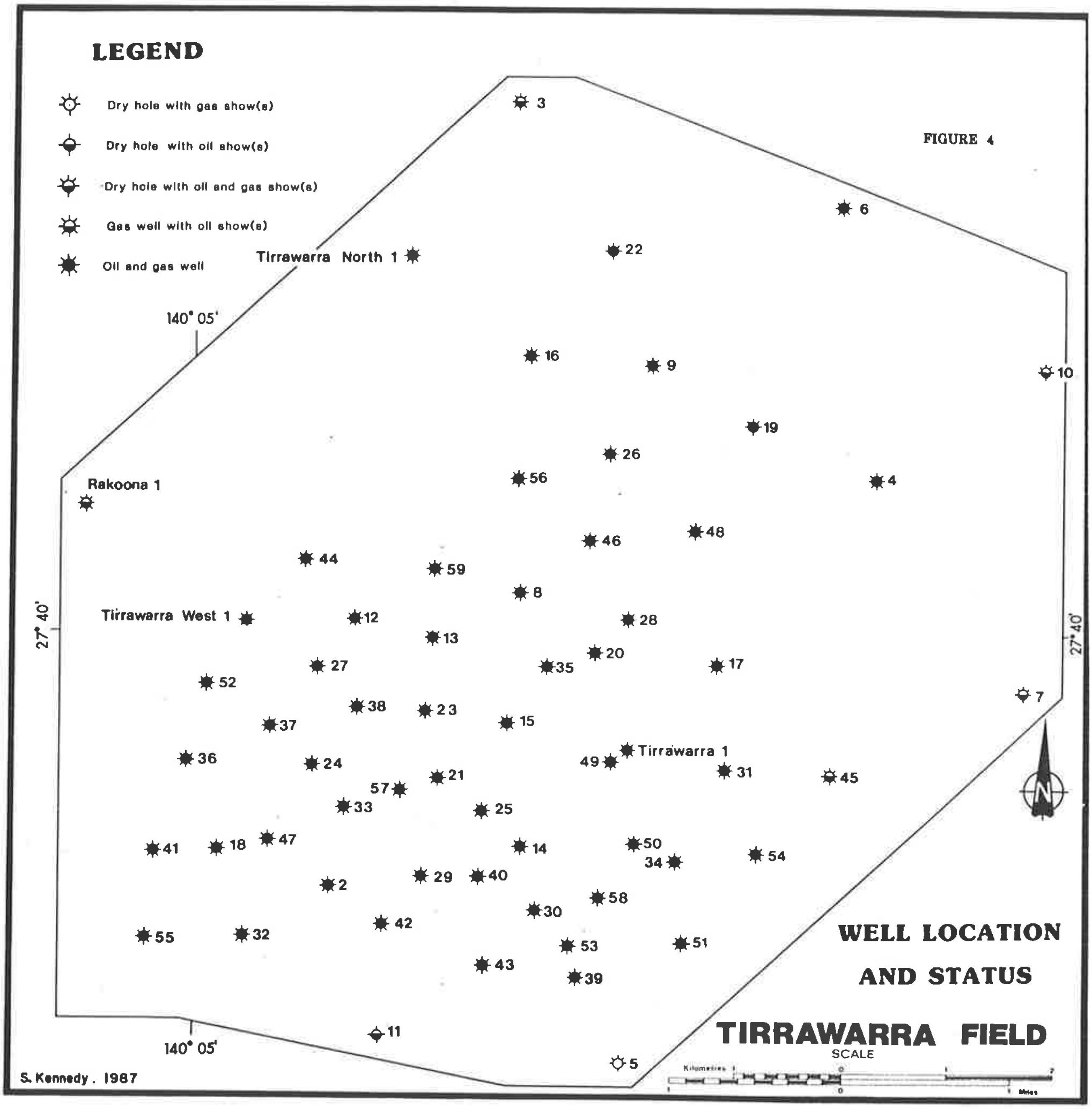
To the present date there have been 62 wells drilled on the structure, comprising Tirrawarra 1 to Tirrawarra 59, together with Tirrawarra North 1, Tirrawarra West 1 and Rakoona 1, providing excellent control over an area of less than 100 square kilometres. Well status and location is shown on Figure 4.

### 1.5 Measurements used

Depths to structure and thickness of units are measured and quoted in feet, as composite logs from each well, obtained from SANTOS use this system of measurement.

Surface distances (for example between wells) are given in kilometres.

The Wentworth scale is used to describe grain sizes in composite logs.


LEGEND
Dry hole with gas show(s)
Dry hole with oil show(s)
Dry hole with oil and gas show(s)
Gas well with oil show(s)
Oil and gas well
FIGURE 4
140° 05'
27° 40'
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
3
6
22
16
9
10
19
26
56
4
48
46
44
59
8
12
28
13
20
35
17
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2
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58
30
55
32
42
53
51
43
39
11
5
WELL LOCATION AND STATUS
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
S. Kennedy. 1987

FIGURE 4

# CHAPTER 2 PREVIOUS STUDIES

Much research has been done by other workers both in the geology of the Gidgealpa Group in the Cooper Basin, and in the general theory of sedimentology of fluvial and fluvio-deltaic systems. These studies are considered separately.

## 2.1 GEOLOGY OF THE GIDGEALPA GROUP

### Kapel (1966 and 1972)

In the earlier paper Kapel summarised previous studies on what was then known as the Cooper's Creek Basin. The Gidgealpa Group was recognised to be of Permian age and at that stage was referred to as the Gidgealpa Formation. It was divided into lower, middle and upper sub-units. Kapel recognised the main northeast to southwest structural trend of the basin and accurately outlined its boundaries from geophysical work and the small number of wells that had been drilled at that time.

In 1972 Kapel, in a report on the Patchawarra Trough of the Cooper Basin, changed the name Gidgealpa Formation to Gidgealpa Group and equated his previous lower sub-unit with the Tirrawarra Formation, Moorari Beds and Patchawarra Formation. Kapel considered that the Patchawarra Formation was deposited in a deltaic environment, whereas the intermittent Moorari Beds below were deposited on an upper deltaic flood plain. Kapel divided the Patchawarra Formation into three lithological sub-units.

### Stuart, (1976)

Stuart used core, cuttings and wireline log data from southern Cooper Basin wells to divide each well into genetic units of different depositional environment on the basis of log character and lithology. Environments defined include lake, delta, distributary, point bar and flood plain. Distributions of these environments were then included in time slice maps, the boundaries of which were picked by log correlation, using such marker horizons as lake beds and coal beds. These were then tied to palynologic findings.

Stuart then analysed his defined depositional models, and using facies relationships and thickness variations, determined the main depositional and structural axis of the southern Cooper Basin. In addition he showed that differential downwarping of the basin resulted from pronounced earth movements of varying magnitude, and that these movements were connected with subsurface asymmetrical anticlines and associated faults.

He suggested a compressive regime within the basin caused northeast-southwest folds and faults.

Stuart discussed the importance of stratigraphic traps, particularly those consisting of delta-fringe sandstones. He recognised the economic potential of these sandstones and outlined areas where they are found.

Stuart suggested that the Murteree Shale, which overlies the Patchawarra Formation, was deposited in an open basin with restricted access to the sea. Thus shorelines may provide a basis for stratigraphic traps. He recognised sand shoreline deposits by the presence of narrow V-shaped burrows as distinct from worm tubes which represent flood plain environments.

**Battersby, (1976)**

Battersby summarised the exploration and development history of the Cooper Basin up to that time and discusses the tectonic and depositional history of the basin. His summary of the relevant part of that history follows.

1. Epeirogenic downwarping of older sediments in Late Carboniferous.
2. Deposition of continental Permo-Triassic with contemperaneous faulting along major pre-Permian structural trends.
3. Uplift and erosion in Middle-Late Triassic.
4. Major epeirogenic downwarping of most of eastern Australia initiating the Great Artesian Basin in Early Jurassic time.
5. Continental Jurassic deposition.
6. Marine transgression in Late Jurassic to Early Cretaceous.
7. Regression in Late Cretaceous.
8. Regional folding and faulting in Tertiary.

Battersby made the point that no sediments of definite marine origin have been found in the Permo-Triassic Cooper Basin, although marine sediments of Jurassic-Cretaceous age overlie it.

Permian sediments (which include the Patchawarra Formation ) vary greatly in thickness, and this variation throughout the southern Cooper Basin was attributed by Battersby (in part after Stuart, 1976) to one or more of the following causes :- growth faulting, transgressive onlap, non deposition and differential compaction.

Battersby recognised three large-scale cycles of deposition in the Permo- Triassic, each of which show a typical fining-upwards in grain size overlain by fine-grained lacustrine sediments. He considered that the recurrence of these cycles suggests an upward decrease in depositional energy. He believed the source of Permian sediments was to the south.

Pre-Permian compaction was important in determining Permian deposition patterns according to Battersby, and Patchawarra Formation deposition transgressed from low areas onto pre-Permian structures. Thickness variations of the upper part of the Patchawarra Formation are in many areas due to the effects of differential compaction over the buried pre-Permian features. In particular the presence of thick coals may have enhanced the effects of compaction.

Battersby discussed hydrocarbon formation and entrapment in detail. He considered that the hydrocarbons had a terrestial plant origin and that migration occurred soon after deposition. Long-distance migration may have been possible through interconnecting point bar deposits.

Battersby's idea of the structure and geology of Tirrawarra Field was based on only eleven wells drilled at the time and on seismic surveys. He noted a general northerly thinning of the Patchawarra Formation in this field.

**Thornton, (1978 and 1979)**

This author carried out a regional stratigraphic analysis of the southern Cooper Basin, using quantitative data mainly derived from wireline logs. From this analysis he reconstructed the palaeogeographic and depositional history of the southern Cooper Basin.

Thornton concluded that the Gidgealpa Group was deposited in an environment where geomorphic relief was diminishing with time. Initially the Tirrawarra Sandstone was deposited by braided streams, possibly on a glacially scoured surface. The braided stream system was succeeded by a mixed-load dominated environment as topographic gradients declined. This period of deposition is now represented by the coals, shales and sands of the Patchawarra Formation, which were derived from the south. The Cooper Basin subsequently was invaded from the east by an inland sea in which was deposited the Murteree Shale.

Thornton showed that deposition of the Patchawarra Formation was thicker in the Patchawarra Trough than elsewhere and that the three lithological units described earlier by Kapel (1972 ) were only applicable in this region.

Thornton made environmental reconstructions of the southern Cooper Basin on the basis of facies analyses carried out on the sediments deposited at different times. He used maps of sandstone percentage, shale percentage, coal percentage, sandstone-shale ratio and clastic ratio as a guide in reconstructing maps of depositional environments.

Thornton also emphasised the importance of stratigraphic traps for hydrocarbon accumulation (as Stuart did), and stated that these should be targeted in future exploration. Various types of stratigraphic traps were discussed, including valley traps due to onlap, pinchouts of reservoir formations, delta front sandstone bodies enclosed in shales, and sandstone channel bodies on the flanks of monoclines.

### Williams, (1982)

Williams conducted a detailed study of Patchawarra Formation core randomly selected from several southern Cooper Basin wells, including Tirrawarra 1, 2, 3 and 5.

Williams extended Kapel's tripartite division of the Patchawarra Formation, with some modification, to the Merrimelia, Mudrangie and Gidgealpa Fields, situated on the adjacent Gidgealpa-Merrimelia-Innamincka Ridge.

Williams interpreted the Patchawarra Formation as deposits of the transitional lower delta plain, away from the main distributary network.

He described a lower division, which he termed Facies Association 1, dominated by carbonaceous, fine-grained sediments and commonly arranged in upward coarsening or heterolithic sequences. He suggested, as had Thornton (1979) that these sequences are consistent with deposition in an environment dominated by interdistributary or paludal sedimentation into which sand splays were periodically introduced.

Williams' middle division of the Formation, termed Facies Association 2, is dominated by thick sandstone beds, commonly with basal intraformational conglomerates overlying scoured surfaces. Williams considered these sands, which are arranged in upward-fining sequences, to be point bar deposits, although finer sands may represent abandonment fills, levees, or back swamp deposits. He interpreted Facies Association 2 as being deposited in the lower delta plain / upper delta plain environment where distributary channels cut through lake deposits, interdistributary bay fills and swamp sediments.

The upper division of the formation, Facies Association 3, was described by Williams as thin, consisting for the most part of finer grained sediments. Upward-coarsening sequences are common and Williams argued that they are probably crevasse splay deposits. He suggested that deposition occurred in largely subaqueous wind-affected lakes or bays with associated swamps, small channels and levees.

### Moore and Castro , (1984)

These authors pointed out the importance of stratigraphic traps in meandering systems, suggesting such traps are common in upper delta-plain sequences where narrow, fining-upwards and discontinuous sandstones are present.

In contrast, lower delta plain sands are typically upward coarsening and laterally extensive. Structural traps are more common than stratigraphic traps in this area , particularly if growth faults are present.

The authors discussed the usefulness of seismic interpretation of facies but believe that in the Cooper Basin resolution is inadequate in most cases at reservoir depths.

## 2.2 SEDIMENTOLOGY OF FLUVIO-DELTAIC SYSTEMS

### Facies and Facies Association Concepts.

Many facies defined in isolation from the sequence containing them could have ambiguous interpretations. Walker (1984) gave the example of a cross-bedded sandstone facies that could be formed in a meandering or braided river, a tidal channel, an offshore area dominated by along-shore currents, or on an open shelf dominated by tidal currents. The procedure recommended by Walker and earlier workers is to analyse all the facies communally. The sequences in which facies occur thus can contribute as much information about the environment of deposition as the facies themselves.

### History of Fluvial Sand Studies.

Walker and Cant (1984) summarised the history of sandy fluvial studies in the past 40 years, following on a previous historical review of Miall (1978). Barrell (1913) noted upward-fining sequences in the Devonian Catskill Formation of New York State. Dixon (1921) noted similar upward-fining sequences in the South Wales coalfield.

In the early 1960's two separate lines of study evolved, namely studies of recent and ancient fluvial sediments. Workers from the Shell Oil Company extensively studied point bar systems of the Brazos River in Texas, and documented the upward-fining model for meandering streams (Walker and Cant, 1984 ). This included vertical changes in sedimentary structures (giant ripple bedding, overlain by horizontal bedding, overlain by small ripple bedding ). Allen (1964, 1965, 1970, 1985 ) has made several studies of recent fluvial systems.

## Meandering Systems and the Channel and Point Bar.

The principal site of sandstone deposition in fluvial systems is associated with the channel as this is where transport velocities reach sufficient levels to move sand and larger sized sediment. The main environments of deposition are the channel itself and in prograding bars. It is thought that the thick sandstones of the Patchawarra Formation were deposited in a meandering system (Thornton 1979). Figure 5 shows the main geographical and sedimentological elements of such a river system. Erosion occurs on the outer banks of the meander loops with deposition on the inner parts of the loops. the point bar is the main depositional environment in the channel and this progrades laterally and down stream across the flood plain. Coarse material or lag is deposited on the channel floor and this only moves at peak flood time. Lag consists of gravel with waterlogged plant material and partly consolidated blocks of mud derived from erosion of the cut bank (Walker and Cant 1984).

In the channel, sand is transported as bedload and becomes cross bedded as a result of being deposited as migrating dunes. These range in height from 30 cm to one metre and are preserved in the rock record as trough cross-beds above lag deposits (Walker and Cant, 1984). Still higher on the point bar where depths are shallower, ripples are preserved in finer sand. Plane beds may be deposited

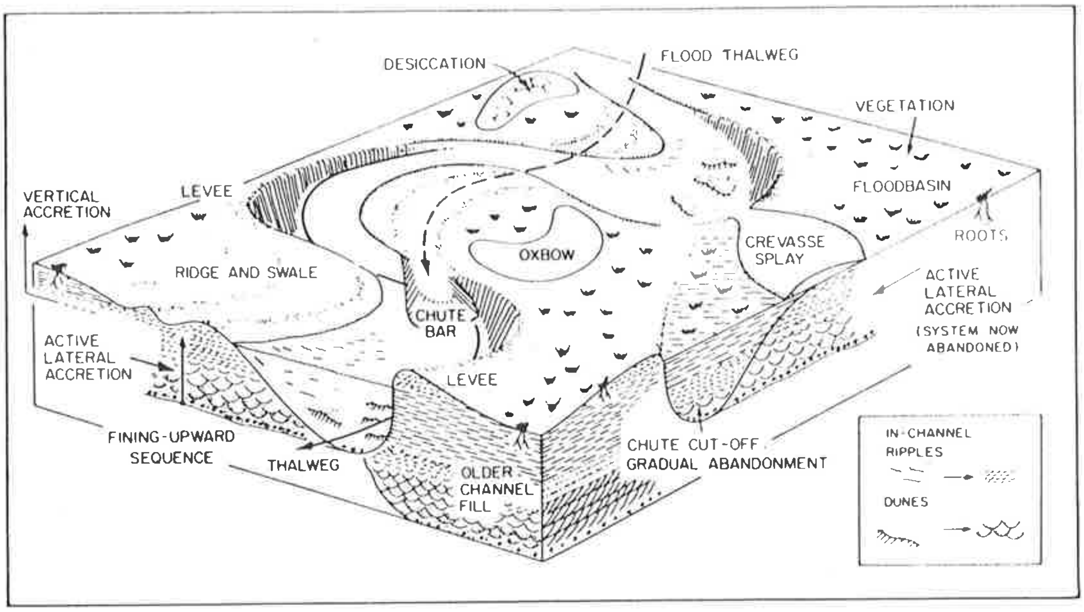

**FIGURE 5 Main elements of a modern meandering system.**

**(From Walker, 1984)**

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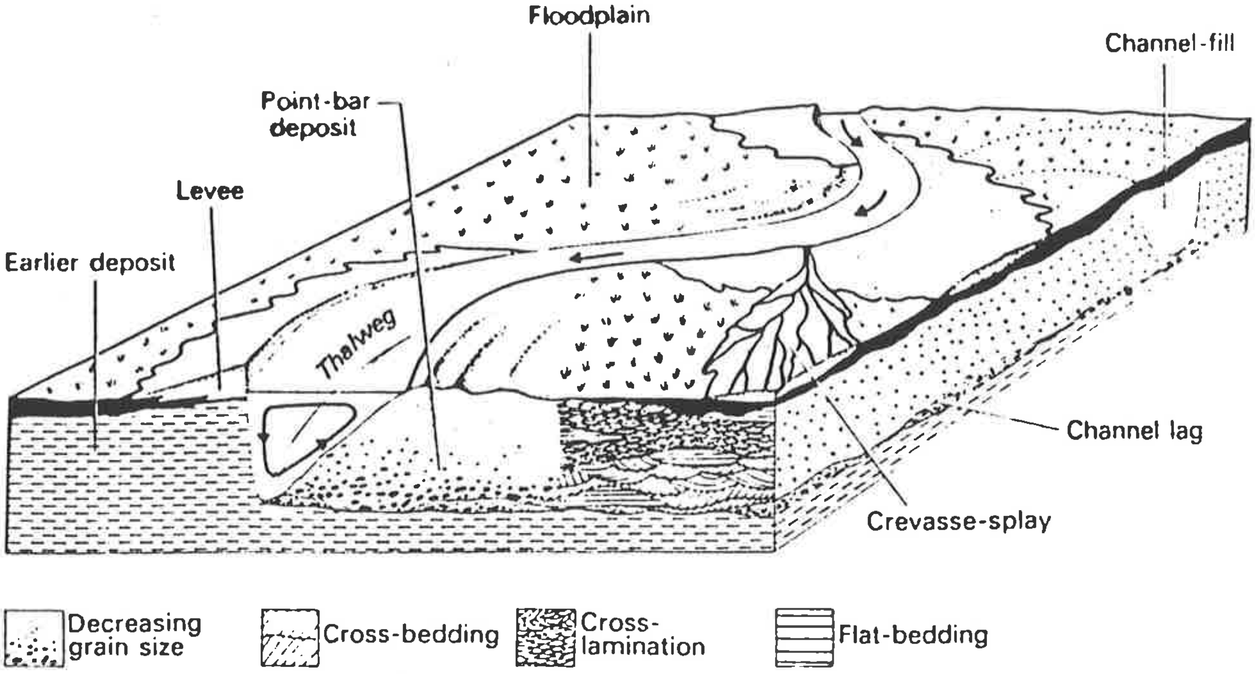


**FIGURE 6 Spiral Flow in a meander loop.**

**( after Allen , 1964 ).**

with higher velocities and shallow depths. However these plane beds may be deposited high or low on the point bar depending on river depths and velocities. They are of varying grain sizes, but more commonly are fine grained, and can be preserved interbedded with trough cross bedding or with ripples (Walker and Cant, 1984).

The upward-fining grain size is due to spiralling flow of the meander loop. As flow enters the bend, a helical overturn develops, surface flow being directed against the cut bank where it turns down and along the point bar surface (Figure 6 ). Flow across the point bar tends to sort the sediment which becomes finer on the shallower parts of the bar away from the region of highest flow energy. This is the basic cause of the upward-fining (Miall, 1981). As the cut bank erodes, caving material may fall into the channel to be covered by sand and thus preserved. The point bar progrades and meander loops migrate down stream. The point bar may then be overlain by flood plain deposits if the river changes its course. A typical stratigraphic section of point bar and overlying flood plain deposits is given in Figure 7.

Meander loops may be temporarily (chute cut off) or permanently (neck cut off) abandoned. Each of these occurrences produces a characteristic mid-channel avulsive depositional sequence (Figure 8). With chute cut off the water flow gradually decreases and low flow-regime sedimentary strucures are formed, particularly ripple cross lamination. When abandonment is complete, fine grained sediment only is deposited in the oxbow lake during flooding from the main stream. During neck cut off, the

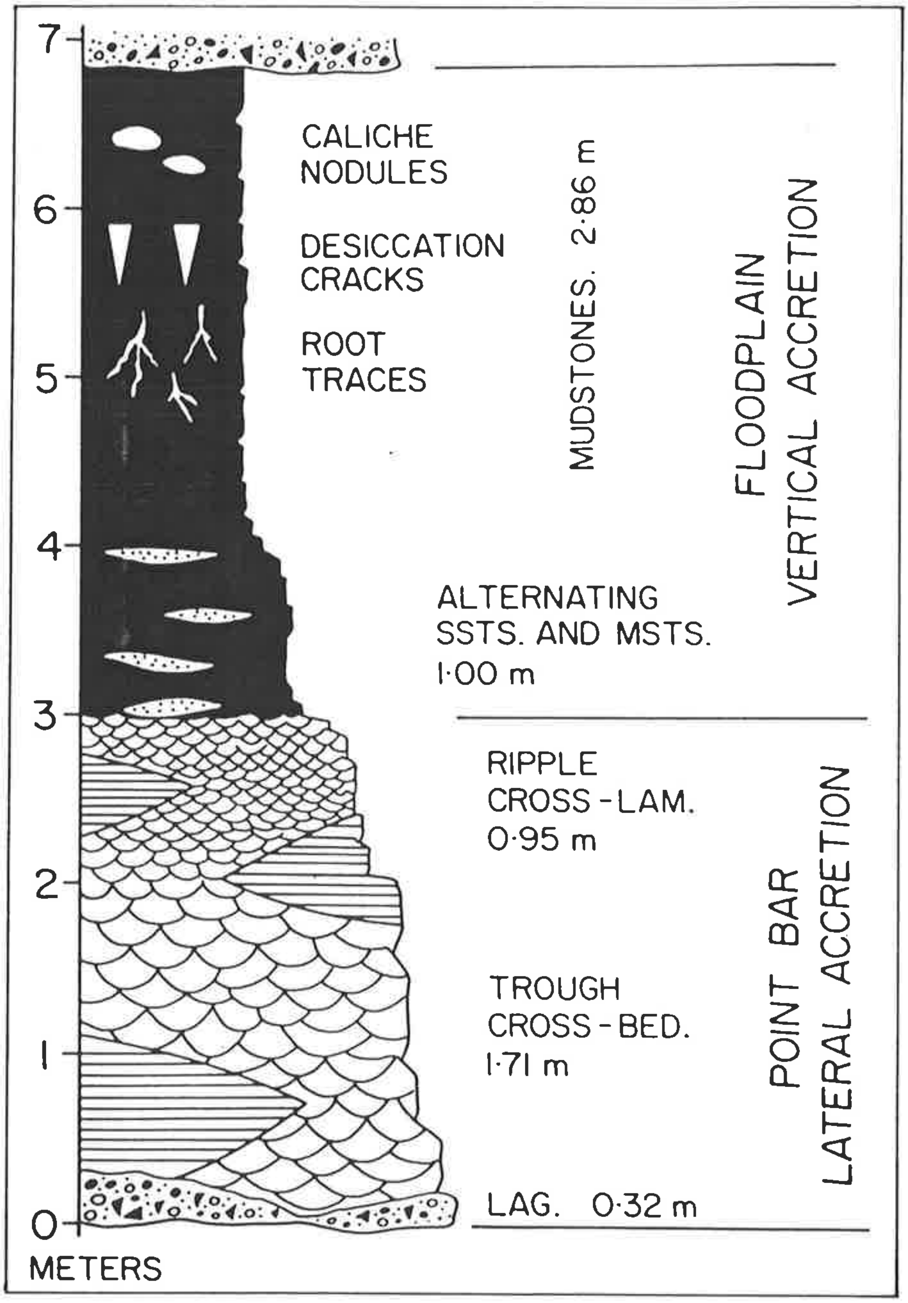


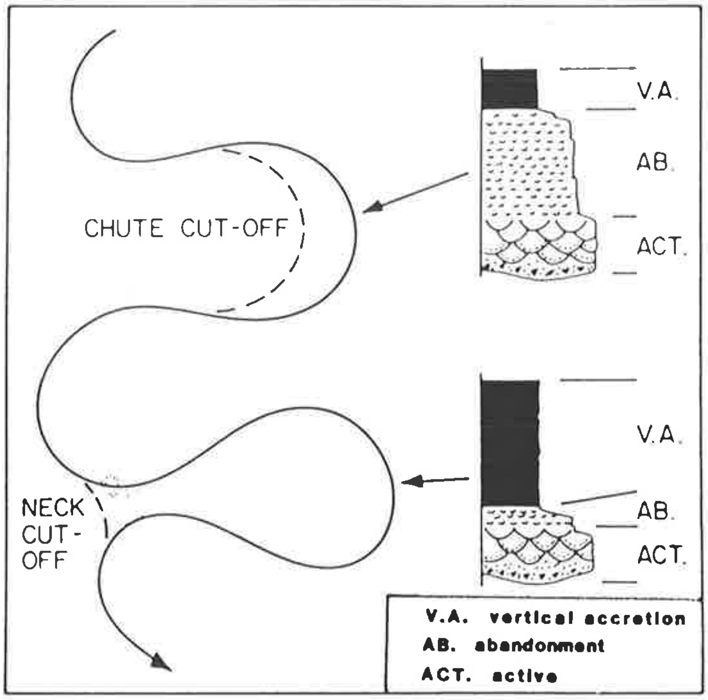
**FIGURE 7** Typical point bar stratigraphic section

(From Walker, 1984 after Allen, 1970)

**FIGURE 8**

**Types of abandonment in meander loops**

**( from Walker, 1984 ).**



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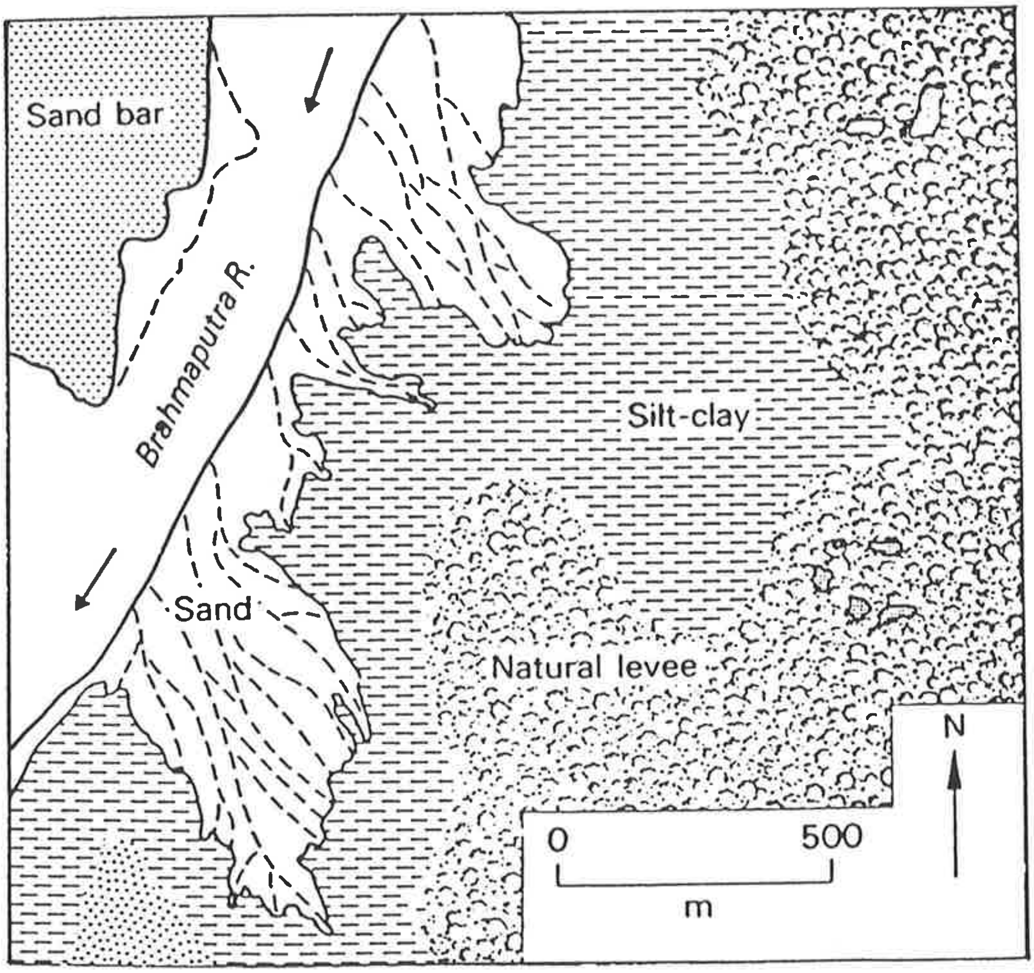


**FIGURE 9** **Crevasse splays in the Brahmaputra ( after Coleman, 1969 )**

meander loop is suddenly breached. Sand rapidly plugs the entrance to and exit from the loop. Flow in the abandoned channel stops rapidly and flood introduced deposits dominate the abandoned channel forming "mud plugs" in the stratigraphic record.

Levees are long low ridges of mainly fine material, flanking a river channel. They are formed when the river overflows its banks and suspended material is deposited as the river's velocity decreases away from its centre. As deposited material raises a river's bed, the river level may rise above the surrounding plain so that only the levees prevent the water overflowing. Crevasse splays form when meandering streams laterally breach their levee banks, often at flood time, and deposit their load over the flood plain. Crevasse splays may occur on flood plains (Figures 5 and 9) or are associated with a deltaic distributary channel and deltaic deposits (Figure 10). Such deposits often have coarsening up layers, beginning with a sharp base and parallel lamination, which is succeeded vertically by ripple cross lamination.

## History of Delta Studies

As previously mentioned, some Cooper Basin workers consider the Patchawarra Formation to have been deposited in a deltaic environment.

Interest in deltas was stimulated early this century by the fact that the sediments of many deltas contain large amounts of fossil fuels (Miall, 1984). This is particularly true of the United States Gulf Coast of Louisiana and Texas. Research into deltaic sedimentation has, in the past

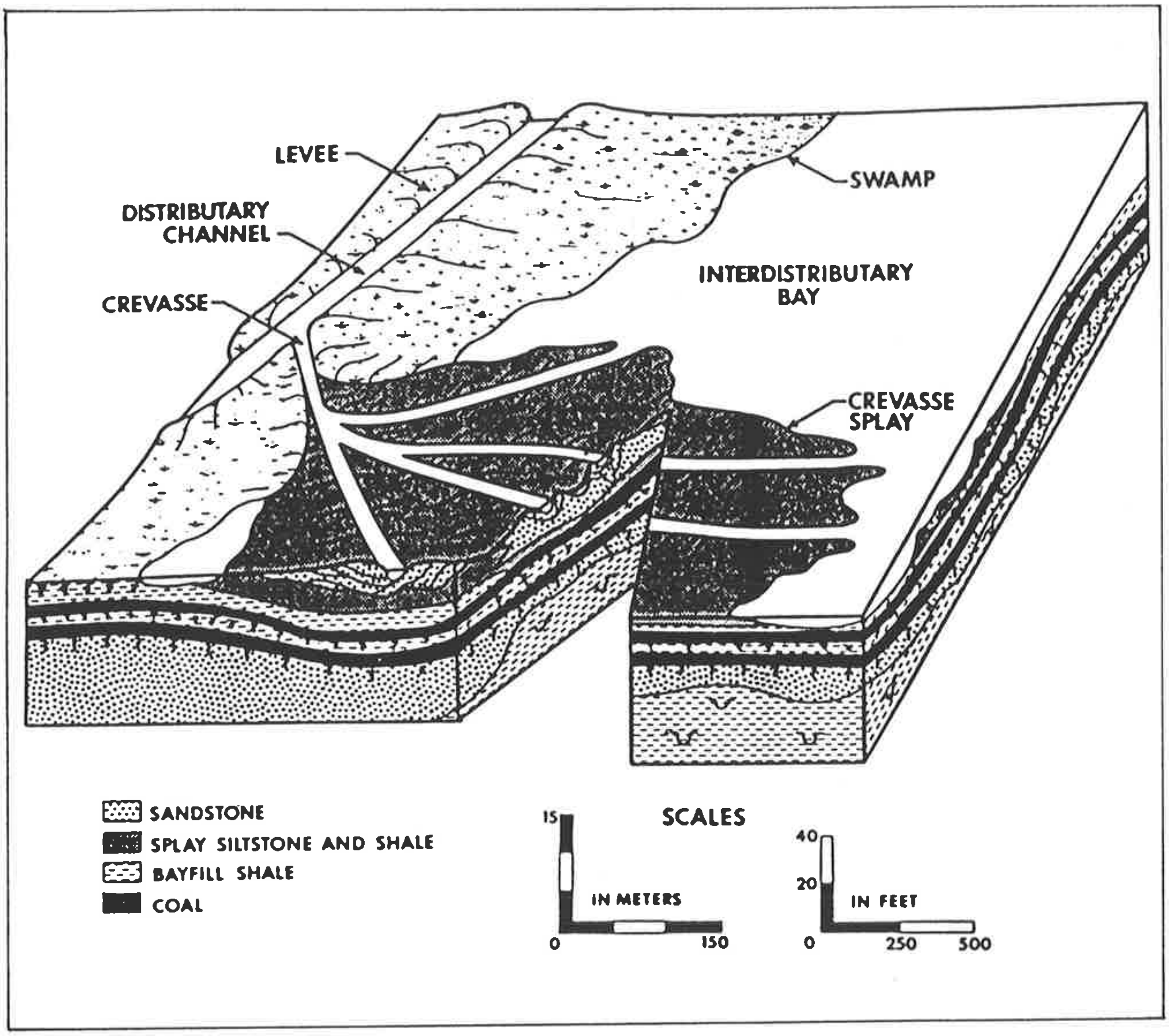


**FIGURE 10** **Crevasse Splay Geometry (after Baganz, 1975)**

40 years, been dominated by studies of both modern and ancient Gulf Coast delta systems. Fisk (1944, 1947, 1948, 1952, 1954, 1955) pioneered Mississippi Delta studies by establishing the depositional framework of the modern delta with the aid of many thousands of shallow boreholes (Miall, 1984). Kolb and Van Lopic (1966) and Coleman and Gagliano (1964,1965) were also involved in investigation of depositional environments and cyclic sedimentation in the Mississippi Delta. Allen (1970) contributed to the study of deltas with his work on the Niger Delta, this being another major area of hydrocarbon accumulation.

Fisher et al (1969) proposed a three fold subdivision of deltas into river-, wave-, and tide-dominated types. As it is generally considered that there is no open marine influence in the deposition patterns of the Patchawarra Formation, the latter two types are not relevant here.

## Delta Systems

It is possible that river-dominated deltas were important in determining the sedimentation patterns of the Patchawarra Formation. Miall (1984) discussed the environments developed in such a system, and these are summarised in Figure 11.

The main sediment load is deposited in a distributary mouth bar which becomes finer grained towards the open water as the river's competence is reduced on slowing down. The mouth bar progrades towards the open water if there is no ocean current or significant wave action. Interdistributary bays, located between the mouth bars are

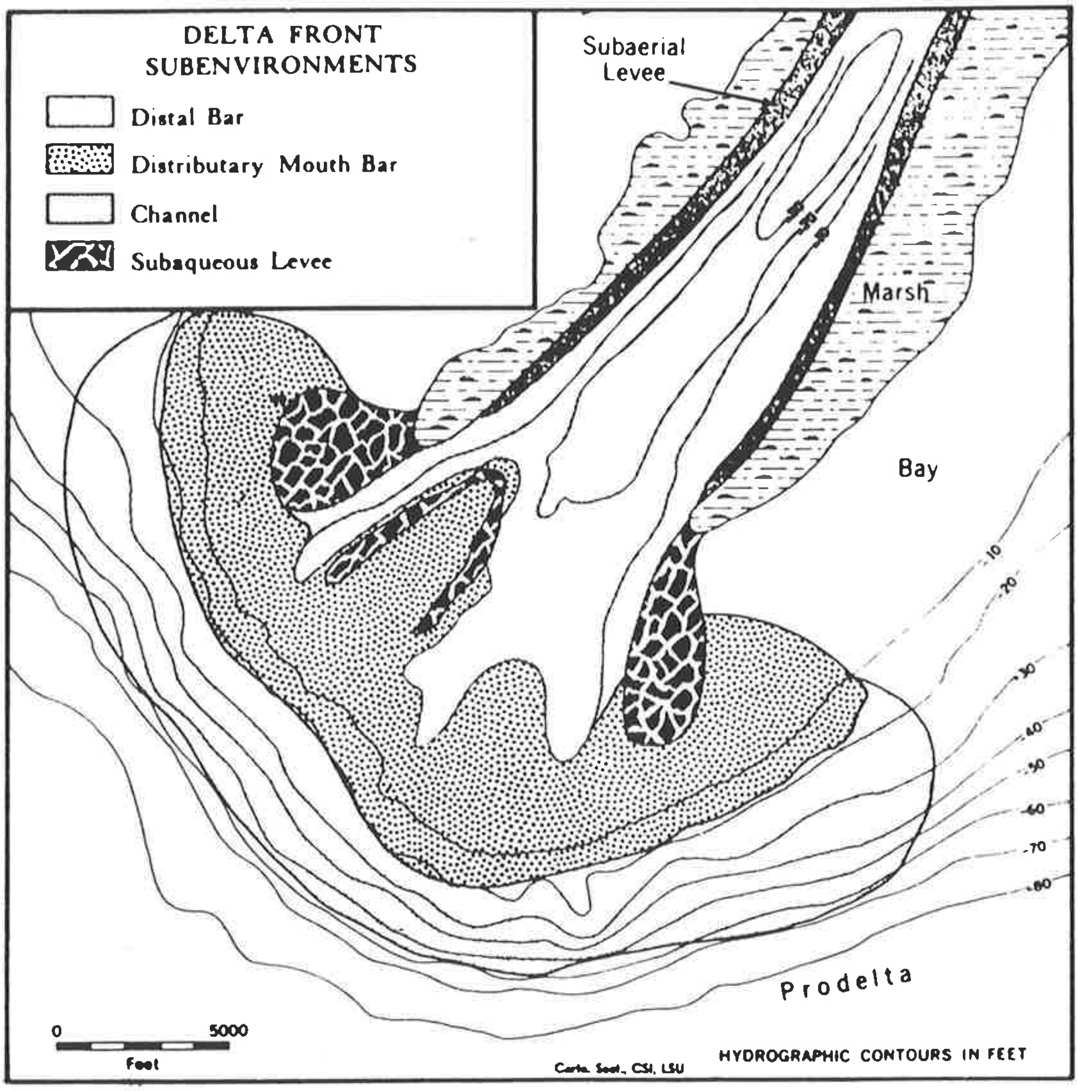


**FIGURE 11.** Subenvironments at a distributary mouth in a river dominated delta.

(From Miall, 1984 after Coleman & Gagliano, 1965) areas of low energy which are dominated by muddy sedimentation and abundant organic activity. These bays eventually fill with sediment and become marshes. Subaerial levees are breached in places resulting in crevasse splays which prograde into the interdistributary bays.

Friedman and Sanders (1978 ) distinguished between delta patterns formed by rivers flowing into fresh water lakes with those formed by rivers flowing into the sea. Different depositional patterns are caused by density contrasts between the moving and still bodies of water. When rivers flow into lakes there is no density contrast and there is a general spreading, slowing down and diffusing of the entering water. The bed load accumulates on a steep slope (foreset beds) at the angle of repose of the particles. The density of a river flowing into the sea is lower than that of the sea water. A wedge of the denser sea water enters the lower reaches of the channel and this forces the water in the channel out of contact with the floor. Mixing occurs along the sloping interface between the two bodies of water. A surface current flows out of the channel, but a bottom current flows in. The bed load stops at the tip of the salt water wedge and sediments accumulate to form a distributary mouth bar as described above.

# CHAPTER 3 CORE INVESTIGATION

## 3.1 Introduction

The Patchawarra Formation has been cored in 13 of the 62 wells in the Tirrawarra Field. All core taken was examined in this study, a total of 1293 feet. A summary of core investigated, together with the distribution of wells from which Patchawarra core has been taken is shown in Figure 12. Most of the core is stored at the South Australian Department of Mines and Energy Core Library in Glenside, but a small amount is held at the SANTOS Core Library, Gilman.

Graphical lithological logging of the core was carried out, and the core logs displayed at the scale of 1 inch = 10 feet. Corresponding gamma and sonic logs were then plotted by computer at the same scale.

The purpose of core investigation was twofold :-

(1) To confirm or otherwise check gamma log and sonic log parameters routinely used to define sandstone, shale and coal.

(11) To appraise, by lithological logging, sedimentary structure and texture, in order to develop a scenario of ancient environments.

After examination of cores the results were extrapolated to uncored wells using the geophysical logs. Sedimentary trends were observed in the cores and these corresponded to observed and repeatable gamma and sonic log patterns.

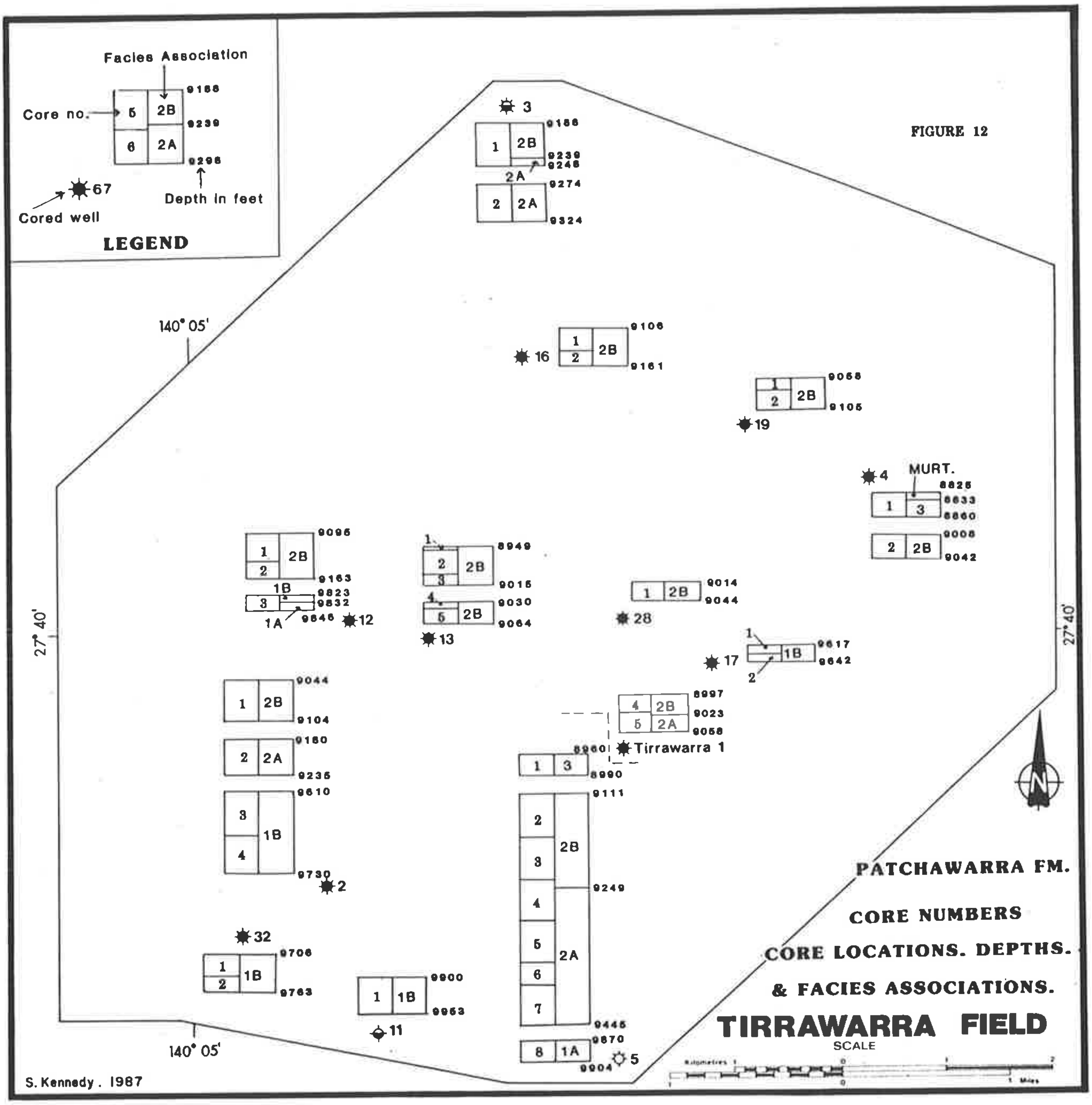


FIGURE 12
LEGEND
Facies Association
Core no.
Depth in feet
Cored well
5
2B
6
2A
9186
9239
9298
67
140° 05'
140° 05'
27° 40'
27° 40'
3
16
19
4
MURT.
12
13
28
17
Tirrawarra 1
2
32
11
5
PATCHAWARRA FM.
CORE NUMBERS
CORE LOCATIONS. DEPTHS.
& FACIES ASSOCIATIONS.
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
N
S. Kennedy . 1987

FIGURE 12

## 3.2 Gamma Log and Sonic Log Parameters

Readings from two types of down-hole geophysical tool have been used to attempt to reliably correlate with lithological boundaries.

The gamma ray tool measures the natural gamma radioactivity of the surrounding rocks. The tool can be used to distinguish between thorium, uranium and potassium 40, however its principal use in the Cooper Basin is to measure the properties of the sandstone and to distinguish between sandstone and finer grained rocks. K 40 is a common radioactive isotope and is found in many clays, glauconite and micas. Generally in this environment an increase in gamma ray count indicates an increase in silt or shale content of the rock. Silts and shales are usually much more radioactive than sandstones, limestones or dolomites, because the former contain a higher clay percentage. Porter and Crocker (1972) found that the finer clastics are mainly illite rich and that this clay, being potassium rich, responds to the gamma ray tool. The unit of gamma count is the A.P.I. with an arbitrary scale from 0 to 200. 100 on the A.P.I. scale is normally taken as the boundary between sand (<100 A.P.I.) and shale (>100 A.P.I.) (Bowler, 1986).

The sonic tool measures the time it takes for a compressional sound wave to pass through one foot of formation, adjacent to the well bore. The velocity of sound depends on such factors as the density of the rock and its porosity. Velocity is decreased by a decrease in density or an increase in porosity. Coal is considerably less dense than sandstone or shale and sound waves therefore travel slower through coal compared with sandstone and shale. Sonic measurements are made in microseconds per foot, that is the amount of time in microseconds the sound takes to travel through one foot of formation. Thus a slow medium, such as coal, will have a higher sonic count than a relatively fast medium such as shale (Bowler, 1986). 90 microseconds/foot is the traditional boundary between coal (>90 microseconds/foot) and sand and shale (<90 microseconds/foot). The sonic tool has a sensitivity of 2 feet, hence layers less than 2 feet thick will not give a response to it.

### 3.3 Geophysical and Lithological Log Correlation.

Core logs and geophysical logs were depth matched in the following way. An approximate match was first obtained by comparing depths from the core logs (these were obtained from the core itself) with those of the computer produced geophysical logs. The appropriate geophysical and core logs (which were at the same scale) were then placed side by side and adjusted until where possible a major change in lithology corresponded with the expected major change in geophysical parameters. For example in Tirrawarra 1, Cores 4 and 5 (Figure 15.1), the thick Patchawarra Coal is overlain by a coarse grained sand at core depth 9025 feet. In the geophysical log, there is a drop in sonic count below 90 microseconds/foot, and a drop in gamma count below 100 A.P.I. above the depth of 9037 feet. Therefore the two logs have been matched at these depths. That is 9025 feet core log depth is equivalent to 9037 feet geophysical log depth.

It was not always possible to find just one major change in lithology which unambiguously matched a major geophysical change. In such cases, perhaps two or more matchings of lithology and geophysical logs were used. For example, in Tirrawarra 2, Core 1 (Figure 15.2 ), mudstone overlies fine grained sandstone at core depth 9077 feet. This corresponds to a rise in gamma count to above 100 A.P.I. at 9086 feet geophysical log depth. In addition, coal overlain by sandstone at core depth 9063 feet corresponds to a drop in gamma count below 100 A.P.I., and a drop in sonic count to less than 90 microseconds/foot at 9072 feet on the geophysical log. Therefore in Tirrawarra 2 , Core 1 9077 ft core log depth = 9086 ft geophysical log depth and 9063 ft core log depth = 9072 ft geophysical log depth. It is noted that there is a constant difference of 9 feet between lithological and geophysical logs in this case. This indicates the correlation is correct. Gamma ray values and sonic values also match each other in this and all other cases, as would be expected for two tools mounted on the same probe.

## 3.4 Gamma Log Measurements and Core Logging

After core logs and geophysical logs were depth matched, shale-sand boundaries on the core logs were projected across onto the corresponding gamma logs. (see Figure 13 of Tirrawarra 5, Core 7 ). Gamma ray counts for each boundary were then obtained from computer-generated information. The measurements are shown in Table 1. A total of 111 boundaries were examined. About half of these boundaries are sharp, where there is a sudden change in

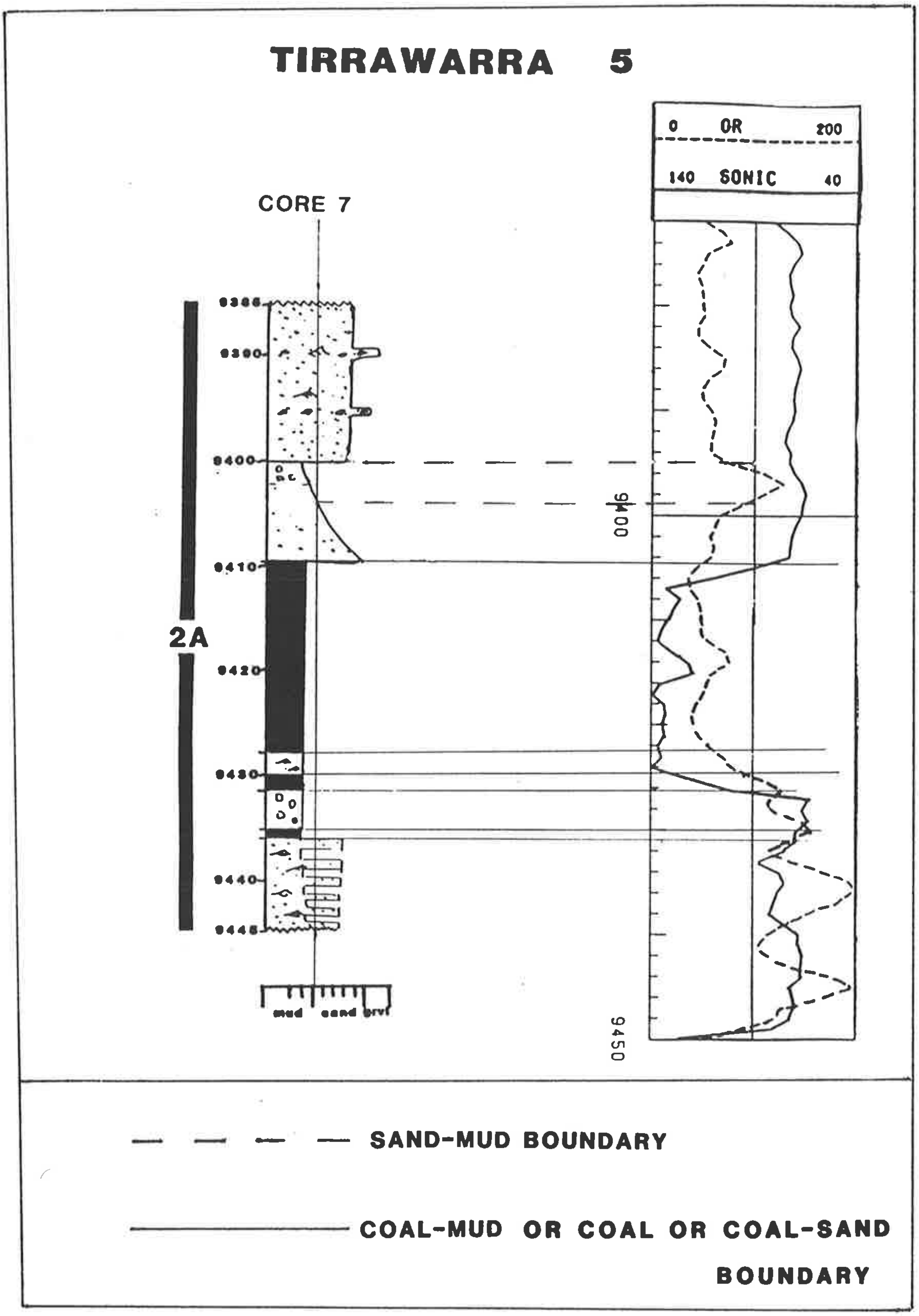


FIGURE 13 Tirrawarra 5, Core 7 showing method used to correlate core logs with geophysical logs

grain size from shale size to medium or coarse sand size (or gravel) or vice versa over a few centimetres. An example of this is at core depth 9363 feet in Tirrawarra 5, Core 6 (Figure 15.14 ) where shale sized particles are overlain by gravel sized particles. The other half of the boundaries are gradational where there is an almost imperceptable change in grain size from sand to shale or vice versa over several feet. An example of this is around core depth 9404 feet in Tirrawarra 5, Core 7 (Figure 15.15) where sand gradually gives way to shale.

The average gamma ray value for shale-sand boundaries was calculated at 99.4 A.P.I. units. This corresponds very well with the figure of 100 A.P.I. units traditionally used to define this boundary when core is absent, and justifies the choice of 100 A.P.I. units as the boundary used in shale and sand calculations in this study. However it should be noted that much of the core was logged as heterolithic interbeds in which very thin (in the order of centimetres) beds or laminae of sand and shale alternate. It is evident that the gamma ray tool does not respond to such changes in lithology and no attempt has been made to correlate boundaries with gamma log values when layers are less than 0.5 feet thick.

## 3.5 Sonic Log Measurements and Core Logging.

Coal-sand and coal-shale boundaries were likewise marked on core logs and projected onto the corresponding sonic logs. (See Figure 13 of Tirrawarra 5, Core 7). Sonic counts obtained from computer information were alloted to each of the 80 boundaries measured. Values are shown in Table 2 .

The average sonic count for coal boundaries was calculated at 94.3 microseconds per foot. This is slightly higher than the traditional value of 90 microseconds per foot. Reasons for this discrepancy might be :-

(1) Core loss. Coal is often lost during recovery and it is therefore hard to define exact boundaries. For example in Tirrawarra 13, core was lost during recovery from about 8999 feet to 9004 feet (Figure 15.21).

(11) Carbonaceous shale. Some occurrences of this were found to have a sonic count greater than or equal to 90 microseconds per foot. For example in Tirrawarra 2, Core 1, the carbonaceous shale at 9069 feet has a sonic reading of about 105 microseconds per foot. (Figure 15.2).

(111) Thin coal layers. Most coal seams of one foot or less in thickness were found to have a sonic count of less than 90 microseconds per foot. This is because of the two foot resolution of the instrument. The boundaries of the seven thin seams found in the core were found to have an average sonic count of 73 microseconds per foot.

Because of boundary uncertainty in core investigation, the traditional figure of 90 seconds per foot has been used to define coal boundaries in coal thickness calculations in this study.

## 3.6 Lithological Logging

Descriptions of core lithological logs are given in Chapter 4 "Core Descriptions and Sedimentary Environments."

The key to these logs is given in Figure 14, and the lithological logs themselves, together with corresponding

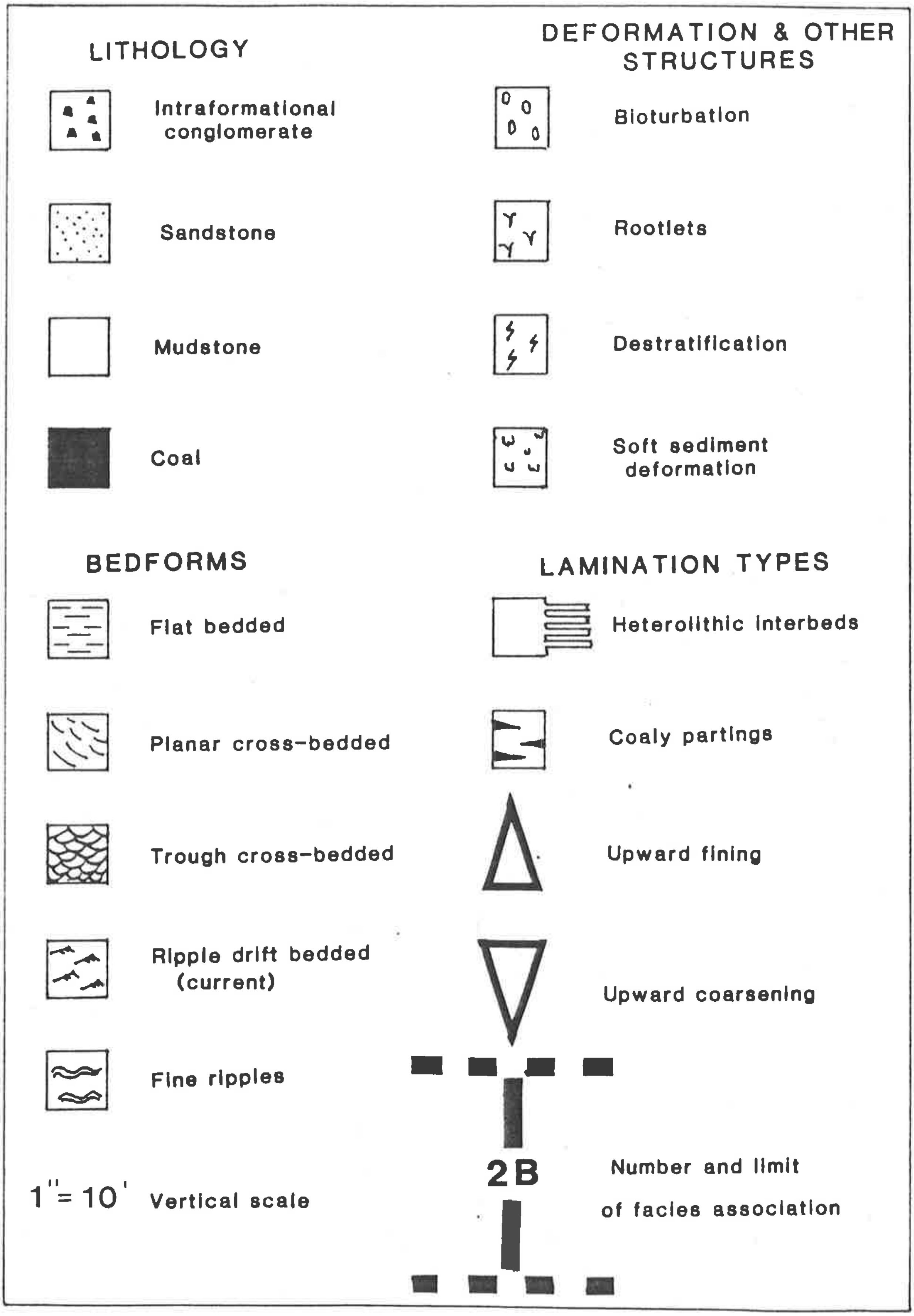


**FIGURE 14** Key to Core Facies Logs (Modified after Williams, 1982)

geophysical logs are shown in Figures 15.1 to 15.27 . Most of these lithological logs have included with them a brief environmental interpretation. Core boundaries are shown in Table 12.

# CHAPTER 4 CORE DESCRIPTIONS AND SEDIMENTARY ENVIRONMENTS

**Tirrawarra 1** (Figure 15.1) :- 55 feet of continuous core has been taken. Both Facies Associations 2A and 2B are represented. Facies Association 2A is present entirely as the Patchawarra Coal. The coal is autochthonous and indicates a well vegetated swamp deposit.

The base of Facies Association 2B consists of a coarse blocky sandstone with some coal inclusions. This could well represent a channel lag deposit, the coal indicating that vegetation has fallen into the stream and was rapidly buried. This channel lag is overlain by a small upward-fining sequence with bioturbation near the top. This is probably a point bar deposit.

**Tirrawarra 2** (Figures 15.2-15.5) :- 235 feet of core has been taken. Although not continuous, the core represents Facies Associations 1B, 2A and 2B.

The core from Facies Association 1B consists of alternating muds and thin coals. A few mud sequences coarsen upwards into fine sands. These are possibly indicative of bay or lake fill. The coals represent small, discontinuous swamps.

Facies Association 2A consists largely of upward-fining sequences, which indicate deposition in point bars. Some of these are stacked, having their tops eroded off before deposition of the next upward-fining sequence.

One mid channel gravel bar is present at 9219 feet. Thin coals are also present and these represent vegetated swamps.

Facies Association 2B contains one excellent thick upward-fining sequence overlain by two thinner ones. The thick sequence commences with a medium grained sandstone containing some intraformational pebbles, possibly introduced by bank collapse into the stream bed. Further up, planar cross bedding is present, and above this, trough cross bedding. This in turn is progressively overlain by finely rippled sand, well bedded muds, carbonaceous shale and coal. It is considered to be a particularly fine example of a point bar deposit.

Tirrawarra 3 (Figure 15.6-15.7) :- Both Facies Association 2A and 2B are represented in the 110 feet of core.

The cored section of Facies Association 2A Commences with autochthonous coal representing a vegetated swamp environment. This is sharply overlain by medium to coarse sands indicating rapid encroachment by a stream. The sands fine up and alter to non stratified (bioturbated?) mud and finally a thin coal band. This in turn is overlain by a thin upward-coarsening sequence, possibly a crevasse splay deposit.

Facies Association 2B overlies a cored section of the Patchawarra Coal so the boundary is visible. The base of this Facies Association consists of a thin upward-coarsening sequence, possibly a crevasse splay deposit. This in turn is overlain by four upward-fining sequences which are probably point bar deposits. Above this, at 9194 feet, lies a coarse sandstone with intraformational pebbles, possibly introduced by bank collapse.

Tirrawarra 4 (Figures 15.8-15.9) :- Representative sections of Facies Association 2B and 3 have been cored, and 69 feet of core has been taken.

A well bedded shale, partly carbonaceous, lies at the base of the cored section of Facies Association 2B. This is overlain by a very thin channel lag deposit containing bank collapse material. The channel was soon abandoned as shown by the coal directly above it. More sandstone overlies the coal and this develops into an upward-fining sequence containing ripple marks. It is probably a point bar deposit.

The cored section of Facies Association 3 consists almost entirely of mudrock. Some is well bedded, but other parts are bioturbated and structureless. Some heterolithic interbeds are present at the top and these give way to the overlying grey, well bedded Murteree Shale which was probably deposited in a lake.

Tirrawarra 5 (Figures 15.10-15.16) :- The Patchawarra Formation has been extensively cored and Facies Associations 1A, 2A, 2B and 3 are represented. 398 feet of core has been taken, including 334 feet of continuous core from 9111 feet to 9445 feet. This helps to build up a picture of environmental conditions throughout a long period of time. However Tirrawarra 5 is at the southern extremity of Tirrawarra Field and is probably not typical of the whole field. This is confirmed by sedimentation rates and patterns which will be discussed later. Williams (1982) has extensively studied the core from Tirrawarra 5.

The boundary between Facies Association 1A and the underlying Tirrawarra Sandstone has been cored. This boundary is sharply defined. The Tirrawarra Sandstone is coarse and may be a braided stream deposit. The lower part of Facies Association 1A consists of thin upward-fining and upward-coarsening sequences together with mudrocks and coals. Unfortunately this part of the core does not include any of the thick sands by which the Facies Association is defined. These occur just above the cored section.

All but the lower 24 feet of Facies Association 2A has been cored. The cored section commences at 9445 feet with heterolithic interbeds which may represent an overbank deposit brought about by variable current flow. This is overlain by a thick autochthonous coal, indicating a well vegetated swamp. A upward-fining sequence, probably a point bar, follows, then commencing at 9400 feet, a coarse and thick sand has been deposited. This contains intraformational pebbles, probably introduced as bank collapse particles in a lag deposit. Several truncated upward-fining sequences follow, containing such features as scoured bases, planar and trough cross bedding, ripple marks and bank collapse structures. They are probably stacked point bar deposits. At 9311 feet these give way to the thick (60 feet plus) autochthonous Patchawarra Coal which indicates a long quiescent period of deposition in a vegetated swamp.

Facies Association 2B commences, by definition, at the top of the Patchawarra Coal, at 9249 feet. Heterolithic interbeds were deposited first, then as streams were re-established in the area, more sand was deposited. Upward-fining sequences, culminating in coals are common, suggesting point bar deposits. At about 9165 feet, two thin upward-coarsening sequences, containing soft sediment deformation structures, suggest crevasse splay input. The top 15 feet of Facies Association 2B has not been cored.

The small cored section from the middle of Facies Association 3 consists mainly of non stratified mudrocks. Two, thin upward-coarsening sequences may represent bay or lake fill.

Tirrawarra 11 (Figure 15.17) :- Only the lowermost part of Facies Association 1B has been cored. The cored section of 53 feet contains three small upward-coarsening sequences which may represent bay or lake fill. Thin coal bands are also present, suggesting vegetated swamps.

Tirrawarra 12 (Figures 15.18-15.20) :- A total of 87 feet, representing Facies Associations 1A, 1B and 2B, has been cored. Unfortunately this core has not been split and it is therefore difficult to obtain a detailed picture of texture and structure.

All Facies Association 1A is present. The lower half consists of a mudstone wich forms a sharp boundary with the underlying Tirrawarra Sandstone. This mudstone abruptly gives way to the sandstone layer which helps define this Facies Association 1A.

Facies Association 1B commences at 9832 feet with mudstone which changes within 10 feet to a carbonaceous shale, then to coal. The cored section ends here.

The central part of Facies Association 2B, from 9095 to 9163 feet, has been cored. It is difficult to obtain an accurate picture of grain size and other features, But it appears that three upward-fining sequences are present, representing point bar deposits.

Tirrawarra 13 (Figure 15.21-15.22) :- This well is one of the most interesting in the whole field. It is at or near the centre of an area of structural growth as will be discussed later. While 94 feet of core has been taken, this has not been split, and furthermore was stored in cardboard, so could not be wet brushed, to obtain at least some details of structure and texture.

Only part of Facies Association 2B is represented in core: three upward-fining sequences, commencing at about 9055 feet, are present. The topmost of these is overlain by a thick mudrock which contains carbonaceous layers at the top. This mudrock may represent an overbank deposit.

Tirrawarra 16 (Figure 15.23) :- Only the lower section of Facies Association 2B has been cored, a total of 55 feet.

An upward-fining sequence, containing ripple marks in the central part, culminates in a carbonaceous shale at 9144 feet. This is probably a point bar deposit. Above this, another upward-fining sequence is truncated at 9131 feet by a thick coarse sandstone, which may be a main channel deposit. At 9177 feet this is abruptly overlain by a carbonaceous shale, suggesting the channel has been abandoned.

Tirrawarra 17 (Figure 15.24) :- In this well only 23 feet of Patchawarra Formation has been cored, this being from the lowermost part of Facies Association 1B.

This commences, at 9640 feet, with heterolithic interbeds which overlie the Tirrawarra Sandstone. The cored section consists for the most part of these beds which contain prominent bedding planes and may represent bay or lake fill.

Tirrawarra 19 (Figure 15.25) :- The lower part of Facies Association 2B has been cored, a total of 47 feet.

At least two, possibly three, upward-fining sequences are present, containing such features as basal scour marks, ripple marks, planar cross bedding and soft sediment deformation. These are probably point bar deposits. At the top of the cored section, commencing at about 9067 feet is a uniformly coarse sandstone which may be a channel lag deposit.

Tirrawarra 28 (Figure 15.26) :- Only 30 feet of Patchawarra Formation has been cored, this being from Facies Association 2B. Two upward-fining sequences, commencing at 9041 feet, are present. These exhibit ripple marks, and further up, bioturbation, and are likely to be point bar deposits. A coarse sand abruptly overlying the topmost of these at 9018 feet may be a channel lag deposit.

Tirrawarra 32 (Figure 15.27) :- 56 feet of Patchawarra Formation has been cored, all from the lower part of Facies Association 1B. A thin coal band abruptly overlies the coarse Tirrawarra Sandstone. This suggests that the channel in which the Tirrawarra Sandstone was deposited was rapidly abandoned, and a coal swamp succeeded it. Above the coal are thin alternating sands and mudrocks, possibly suggesting crevasse splay deposits. Above 9730 feet, mudrocks containing bioturbation features and rootlets, with thin coals, probably represent a flood plain deposit.

# TIRRAWARRA 1

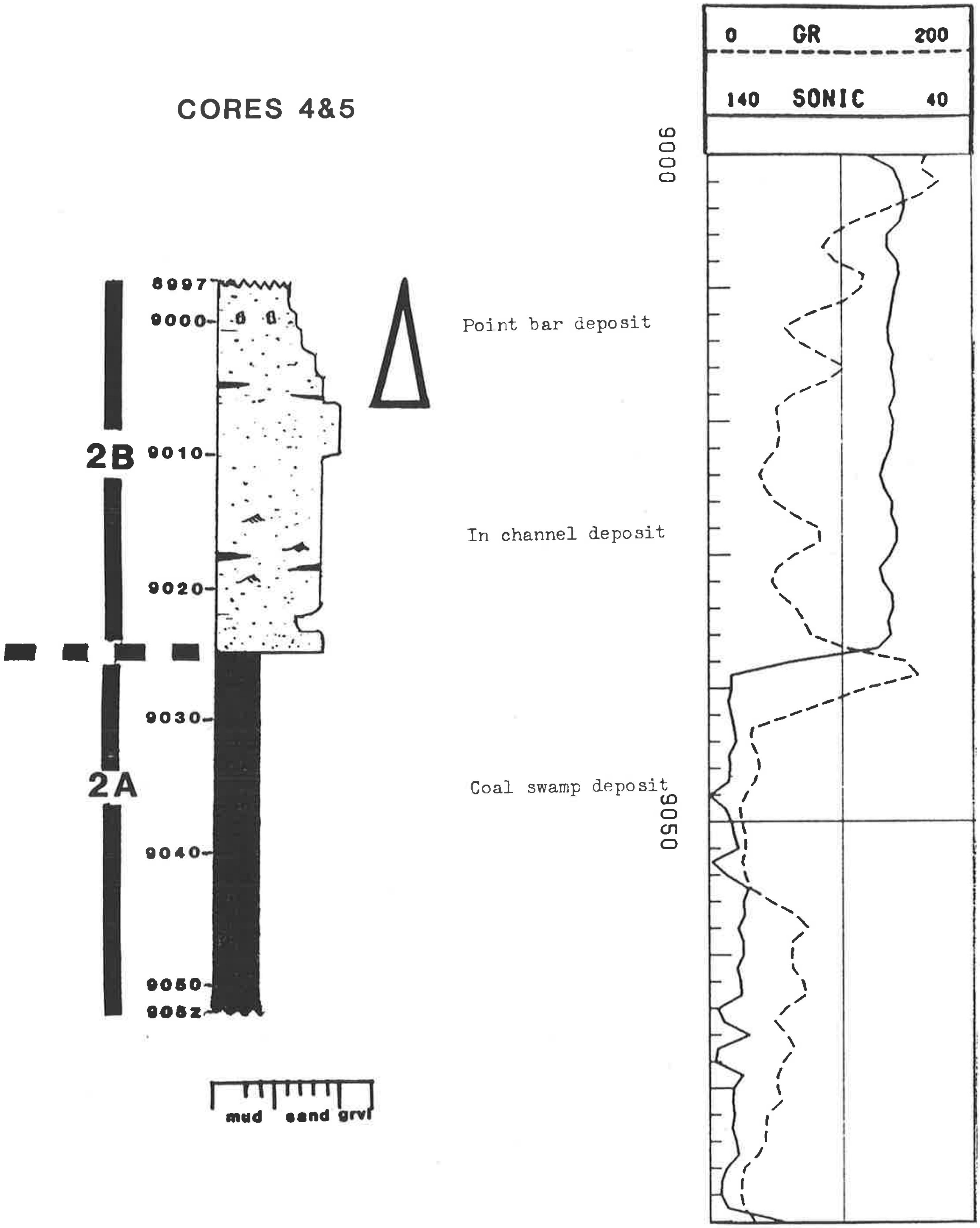


Figure 15.1

# TIRRAWARRA 2

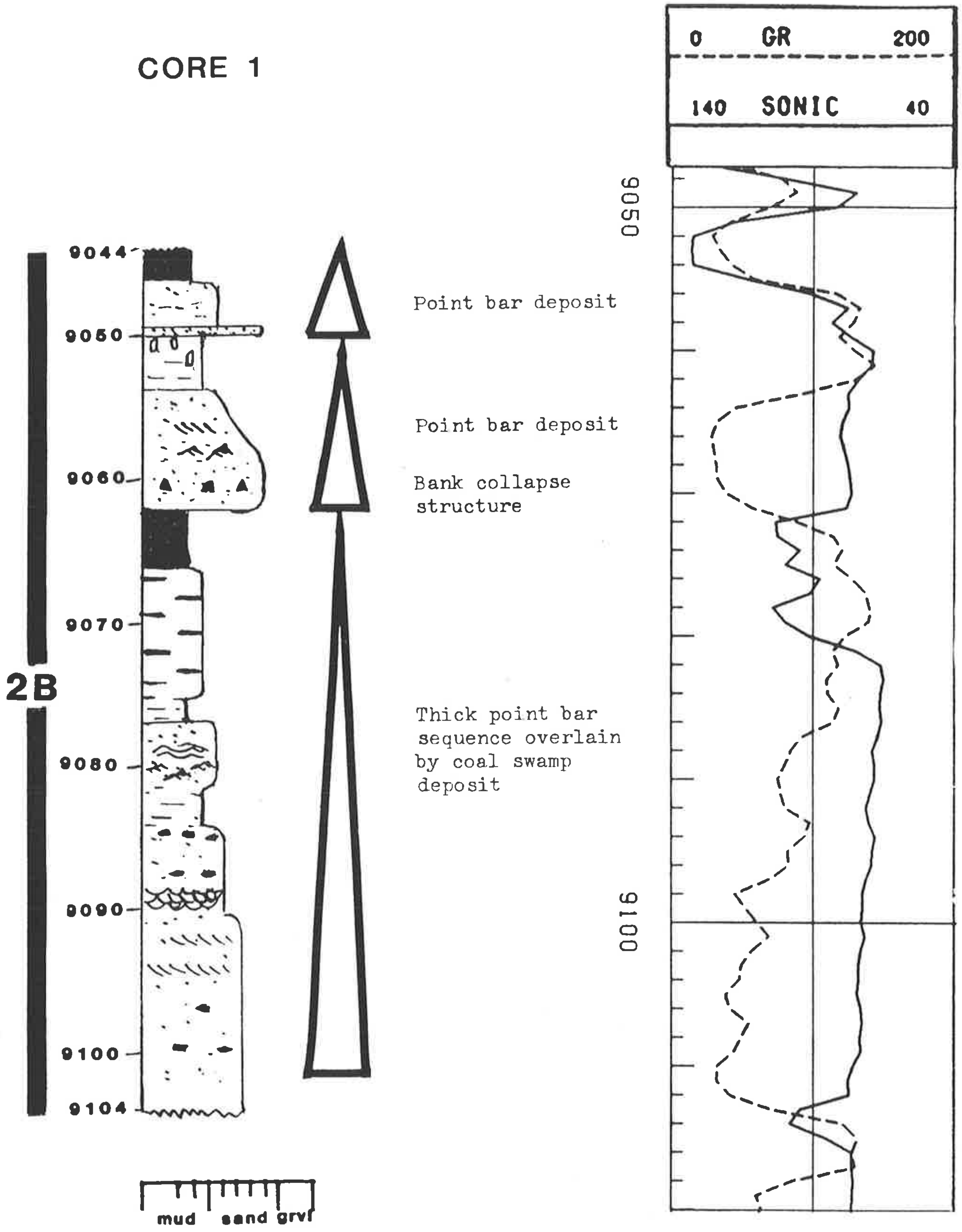


Figure 15.2

# TIRRAWARRA 2

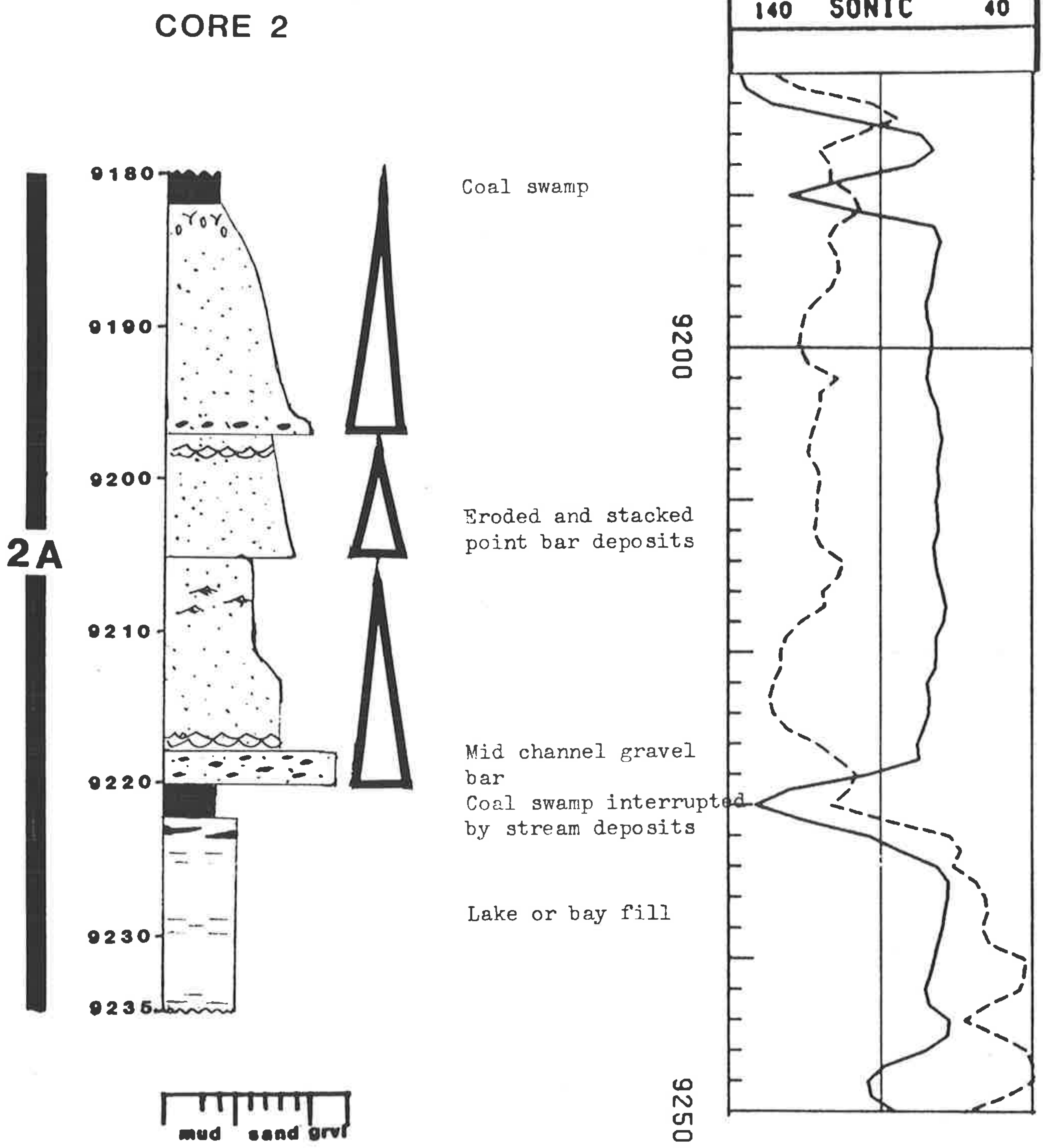


Figure 15.3

# TIRRAWARRA 2

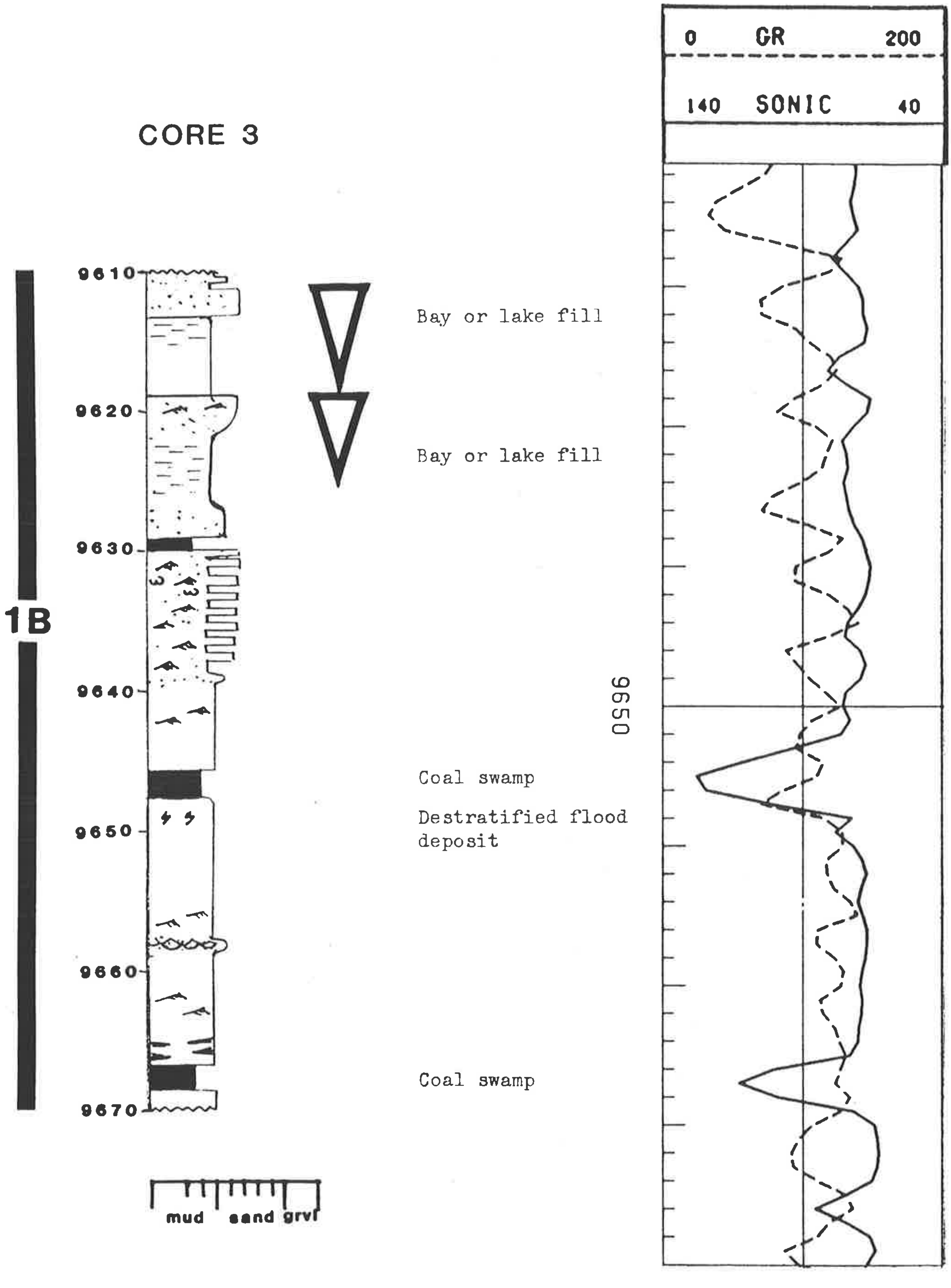


Figure 15.4

# TIRRAWARRA 2

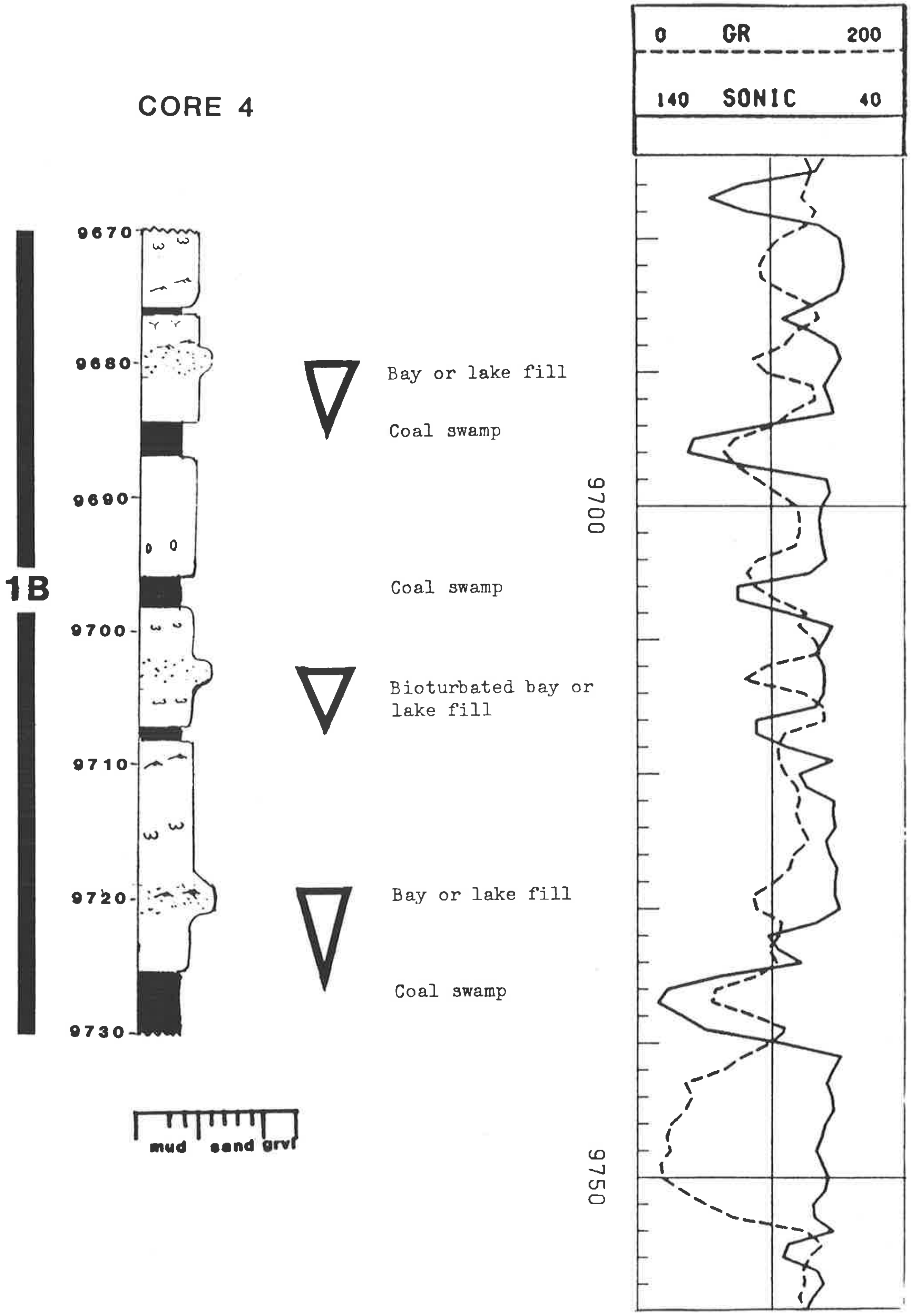


Figure 15.5

# TIRRAWARRA 3

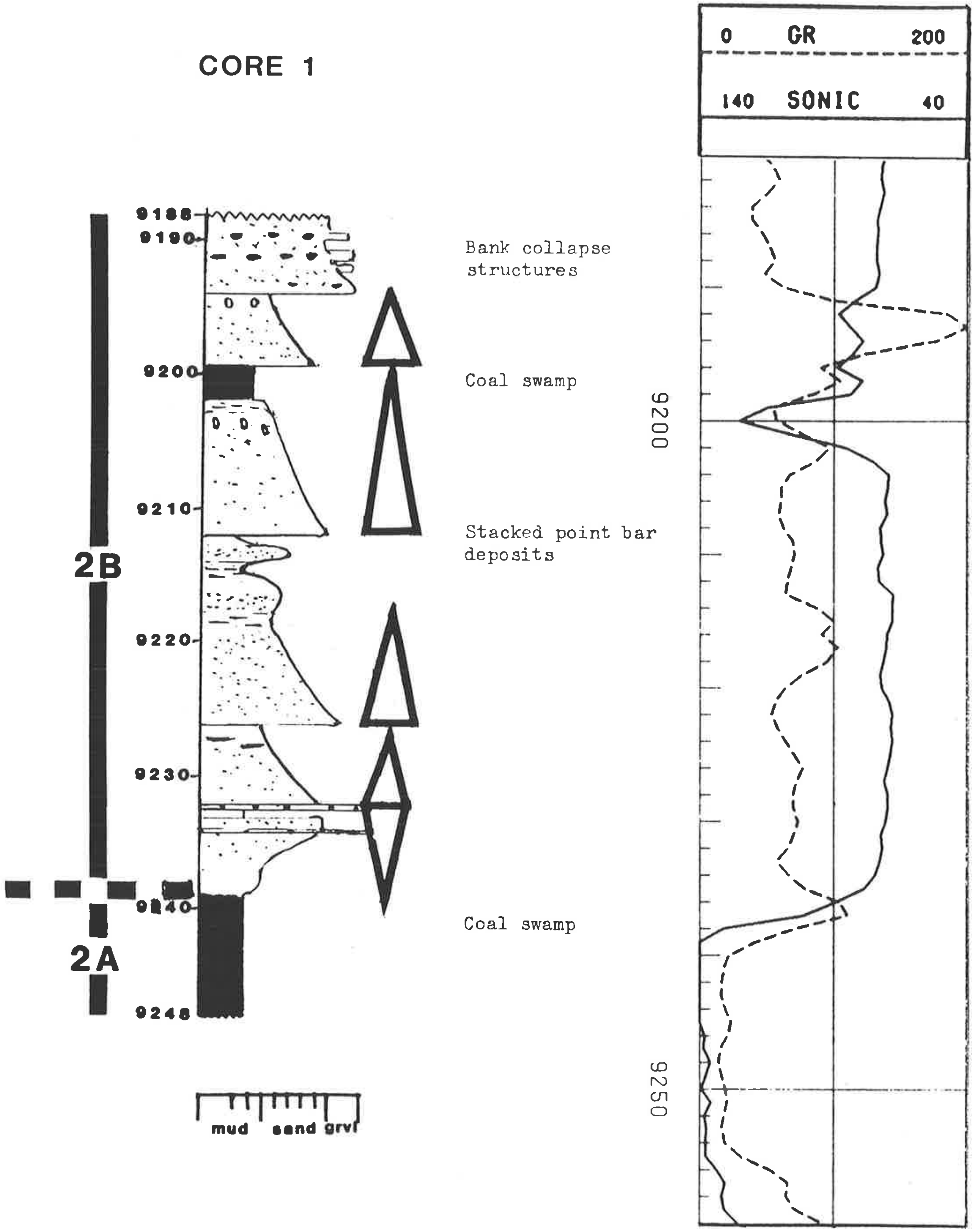


Figure 15.6

# TIRRAWARRA 3

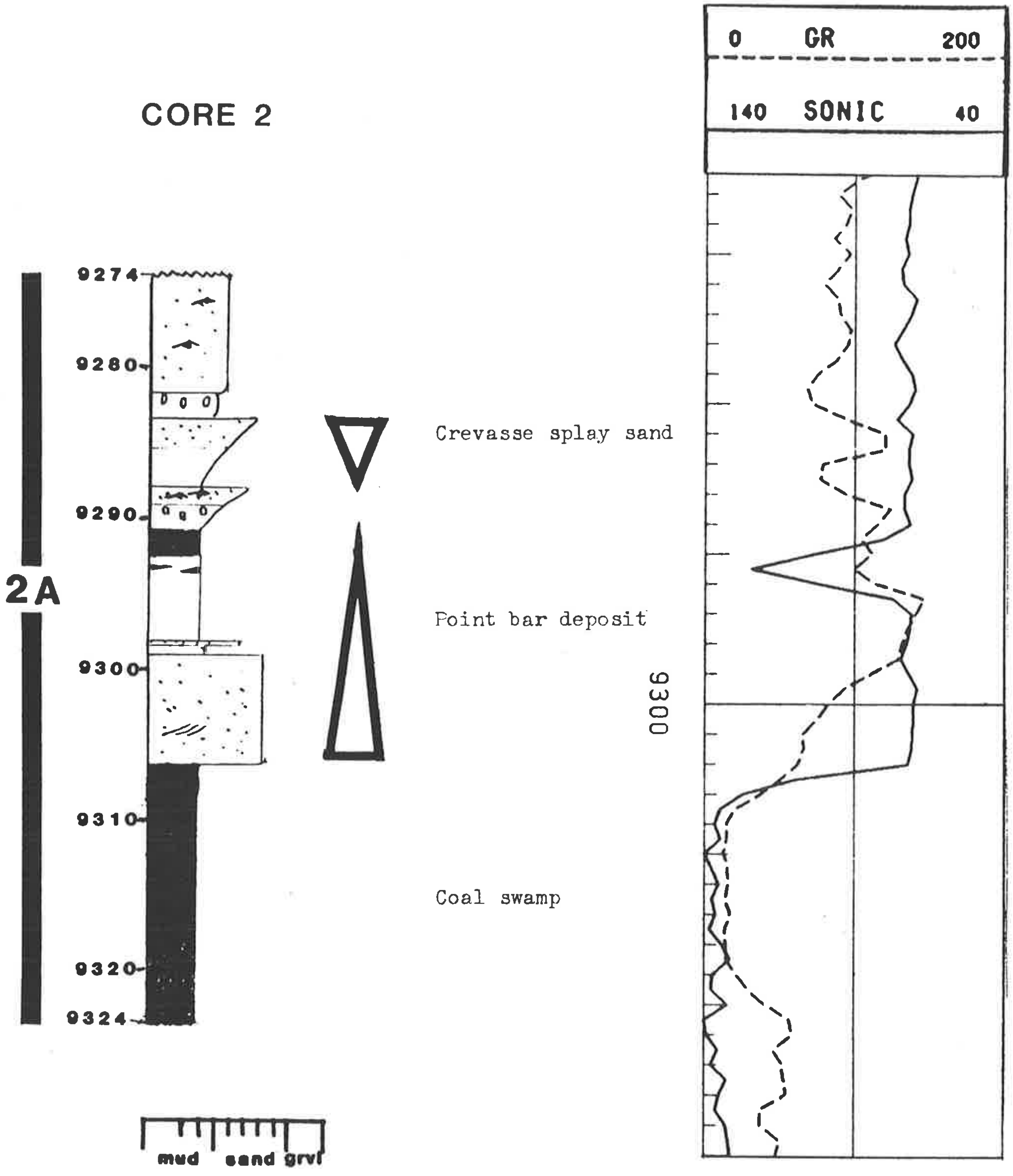


Figure 15.7

# TIRRAWARRA 4

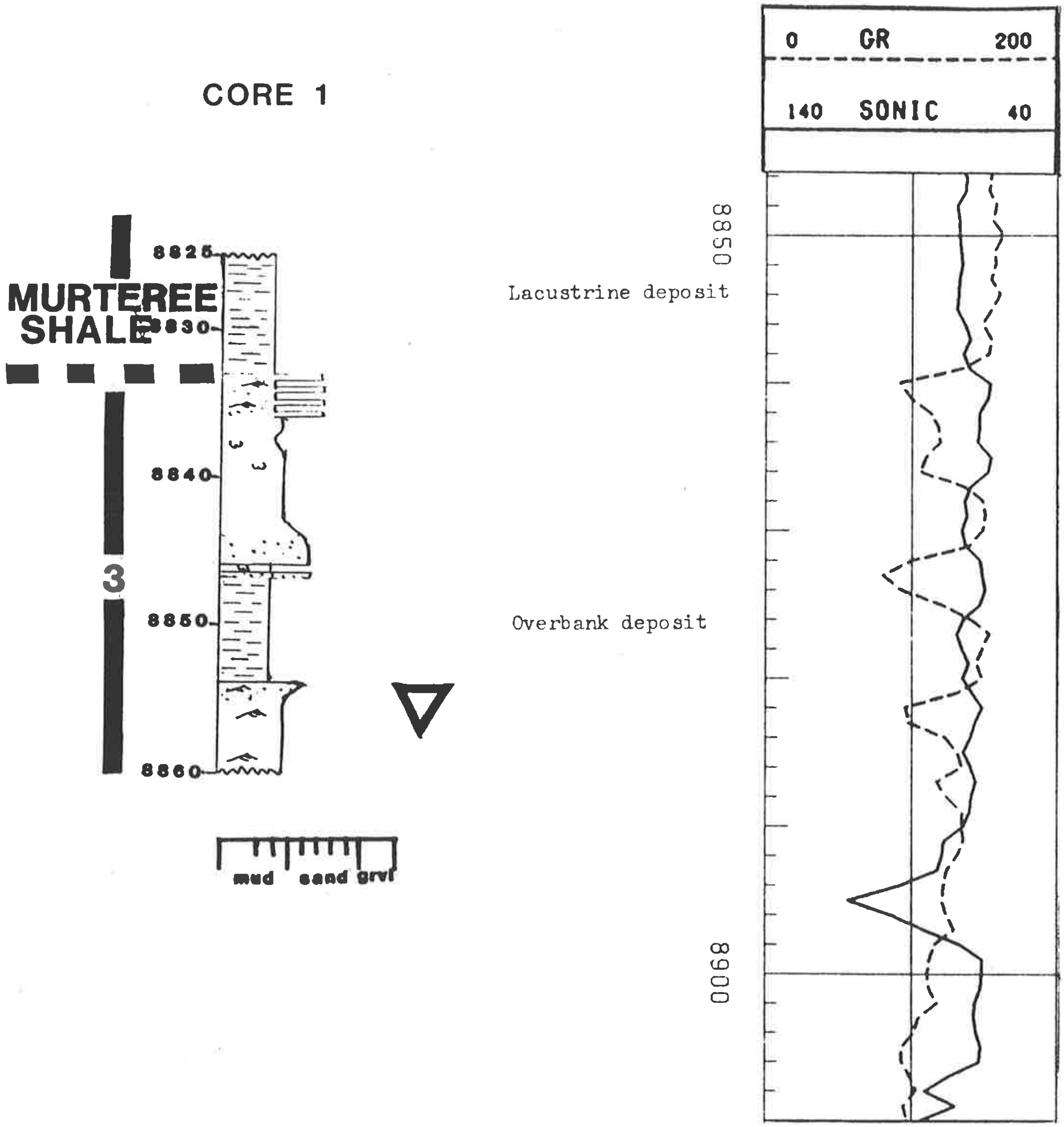


Figure 15.8

# TIRRAWARRA 4

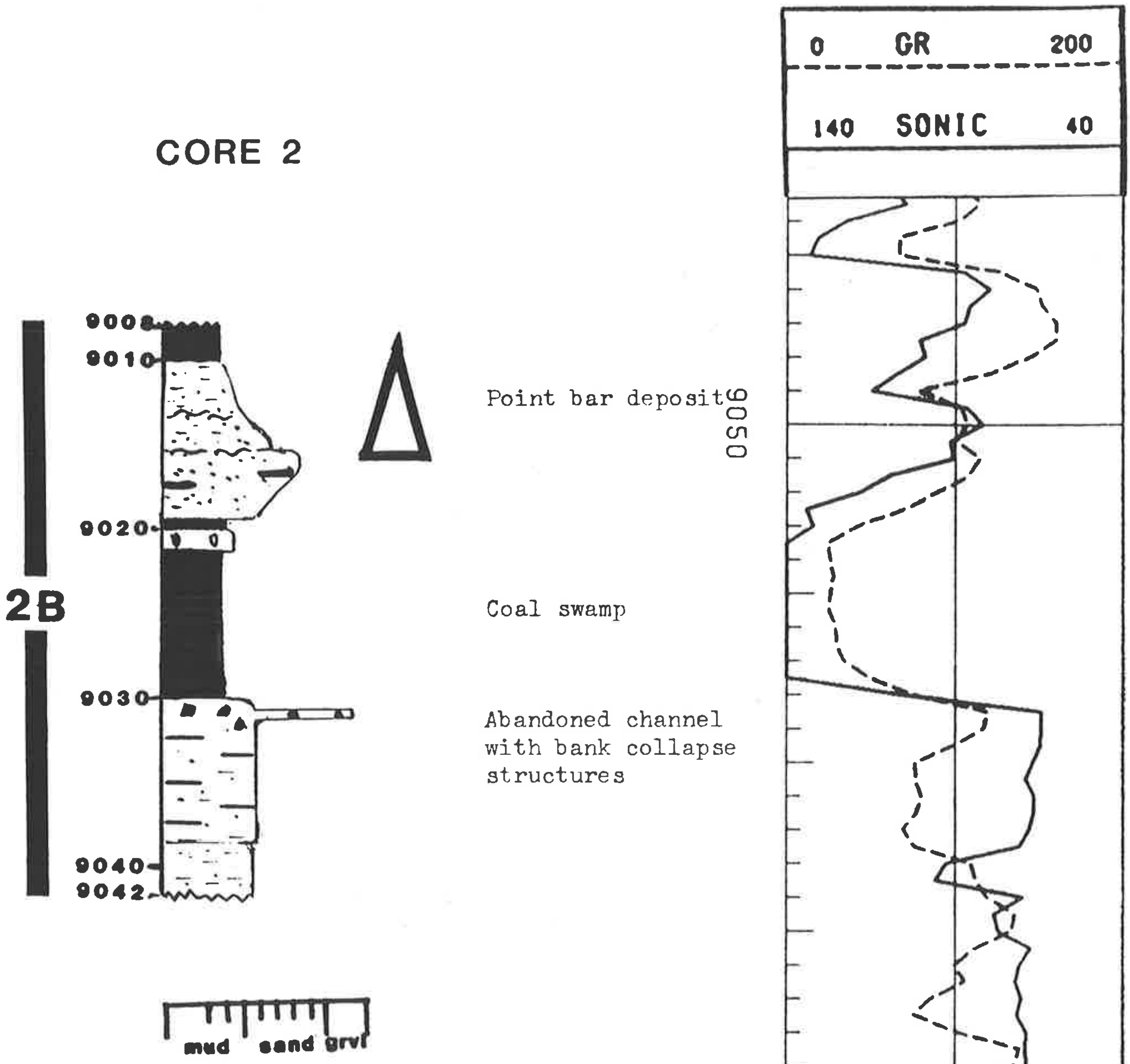


Figure 15.9

# TIRRAWARRA 5

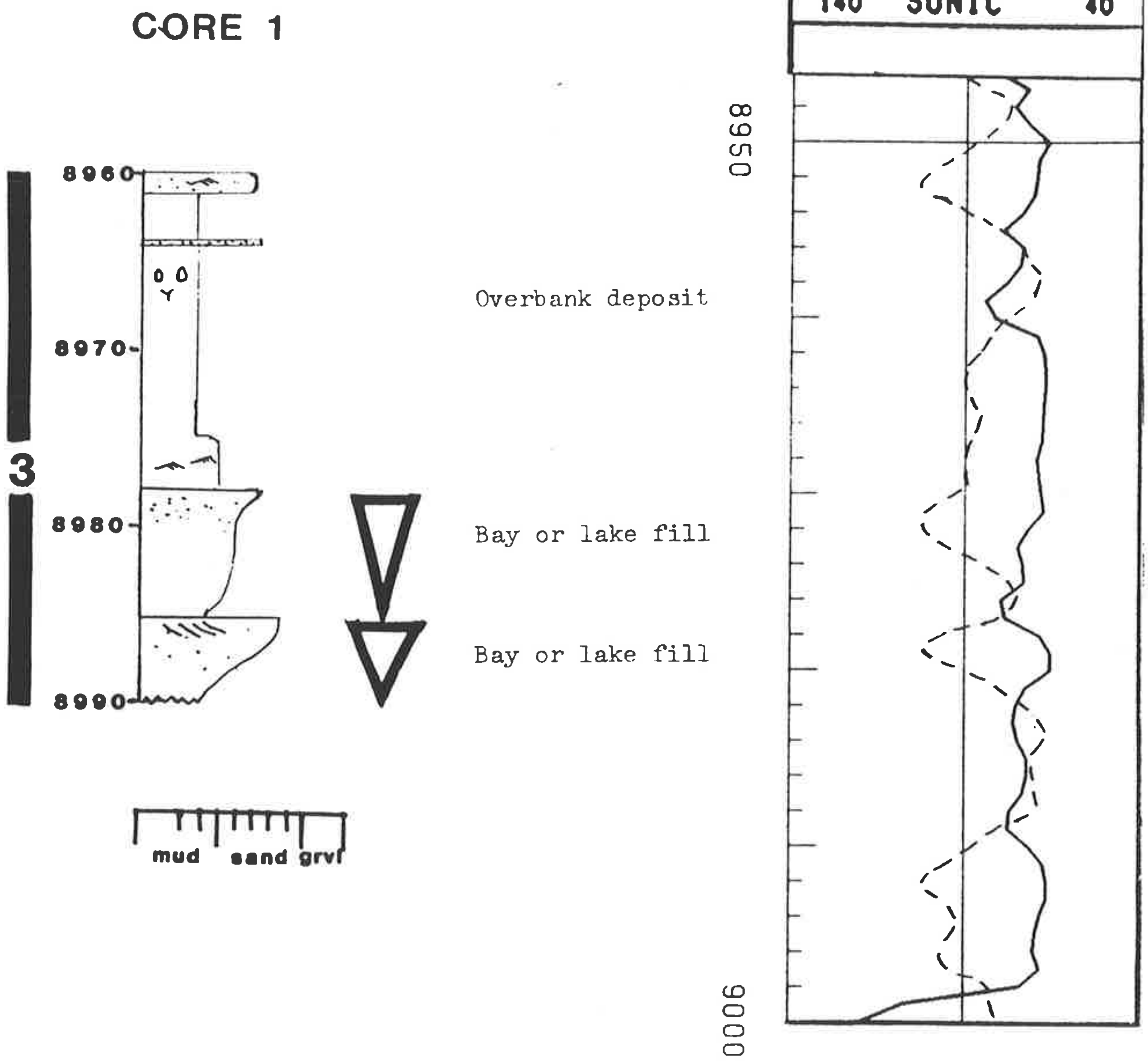


Figure 15.10

# TIRRAWARRA 5

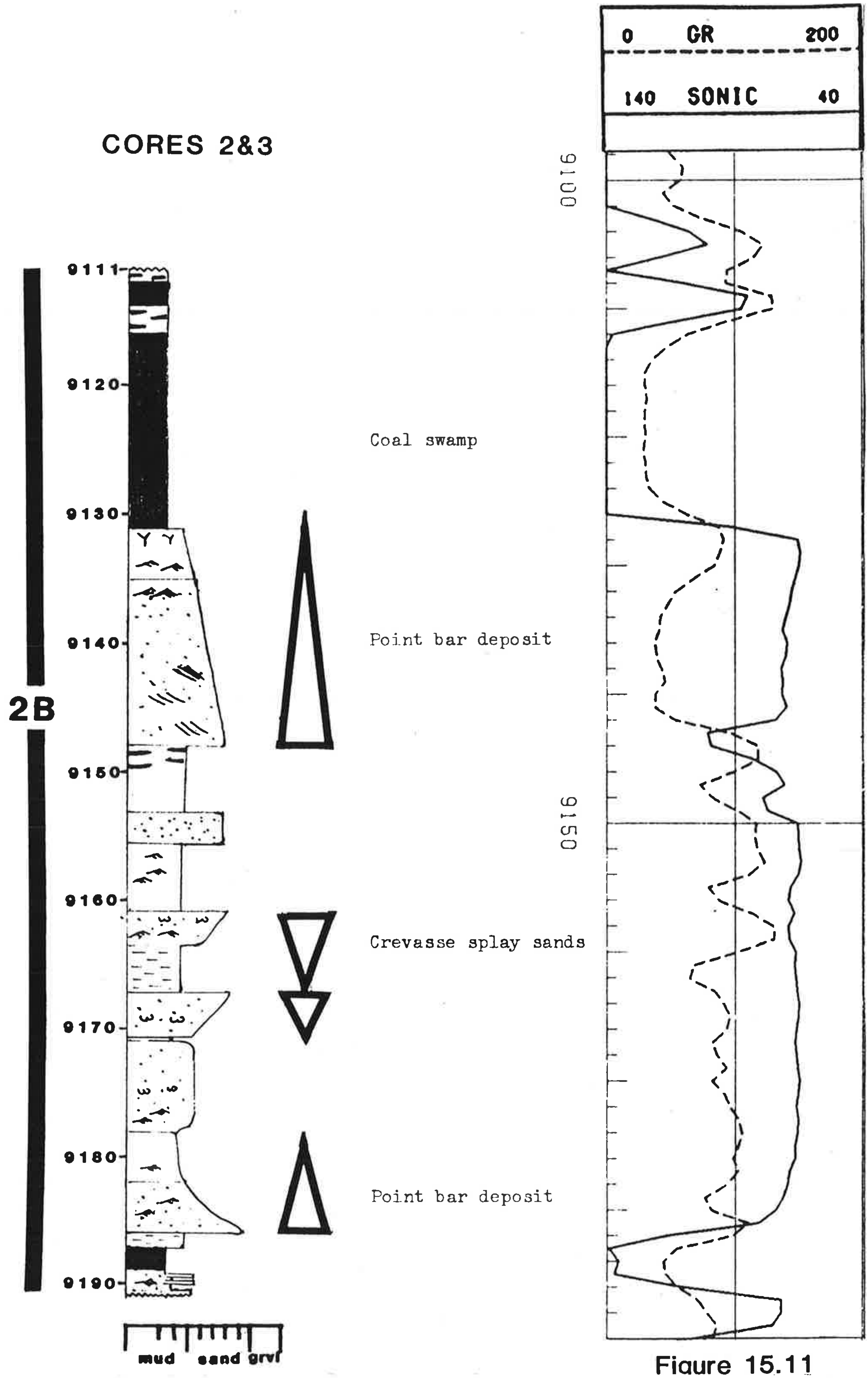


Figure 15.11

# TIRRAWARRA 5

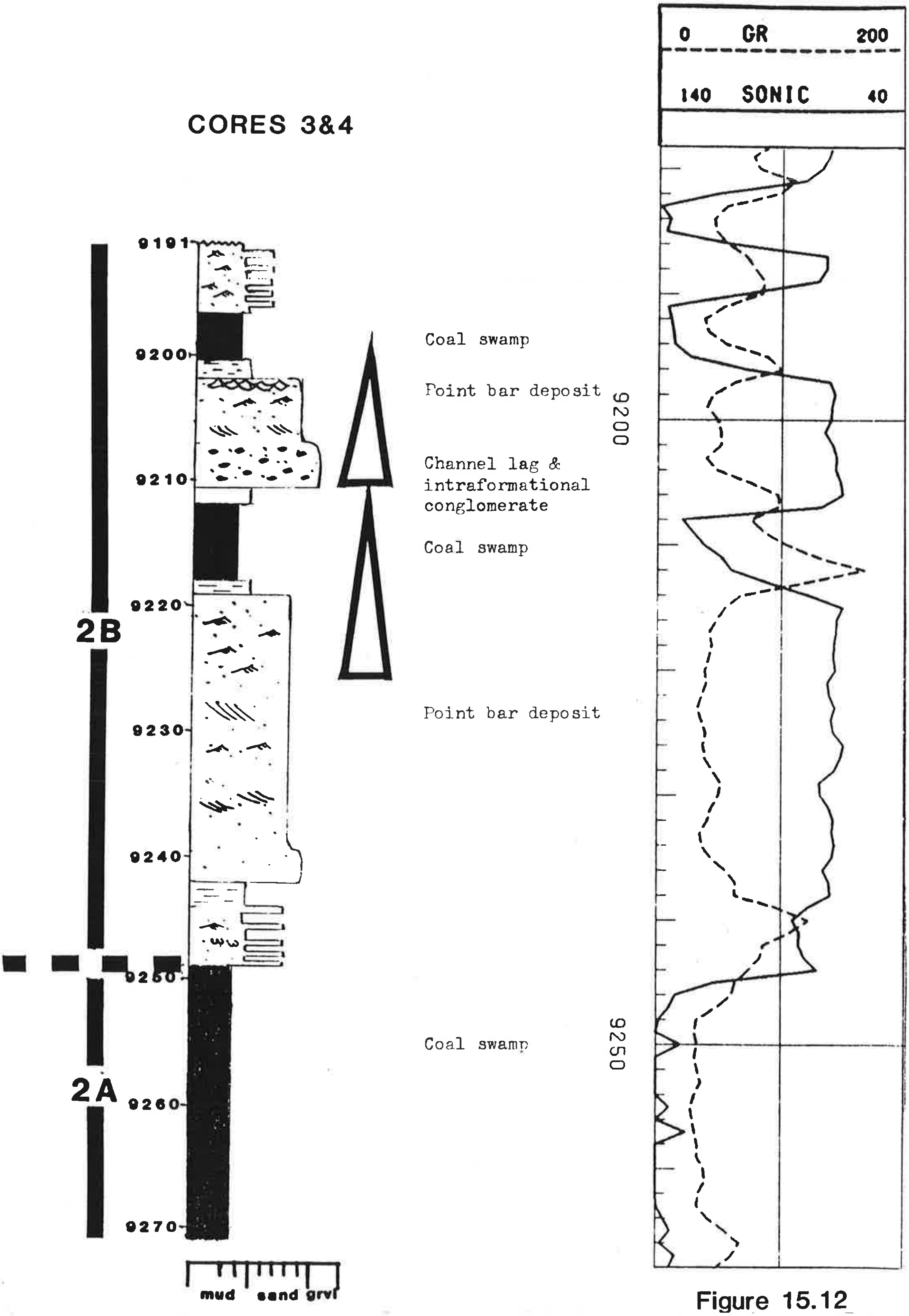


Figure 15.12

# TIRRAWARRA 5

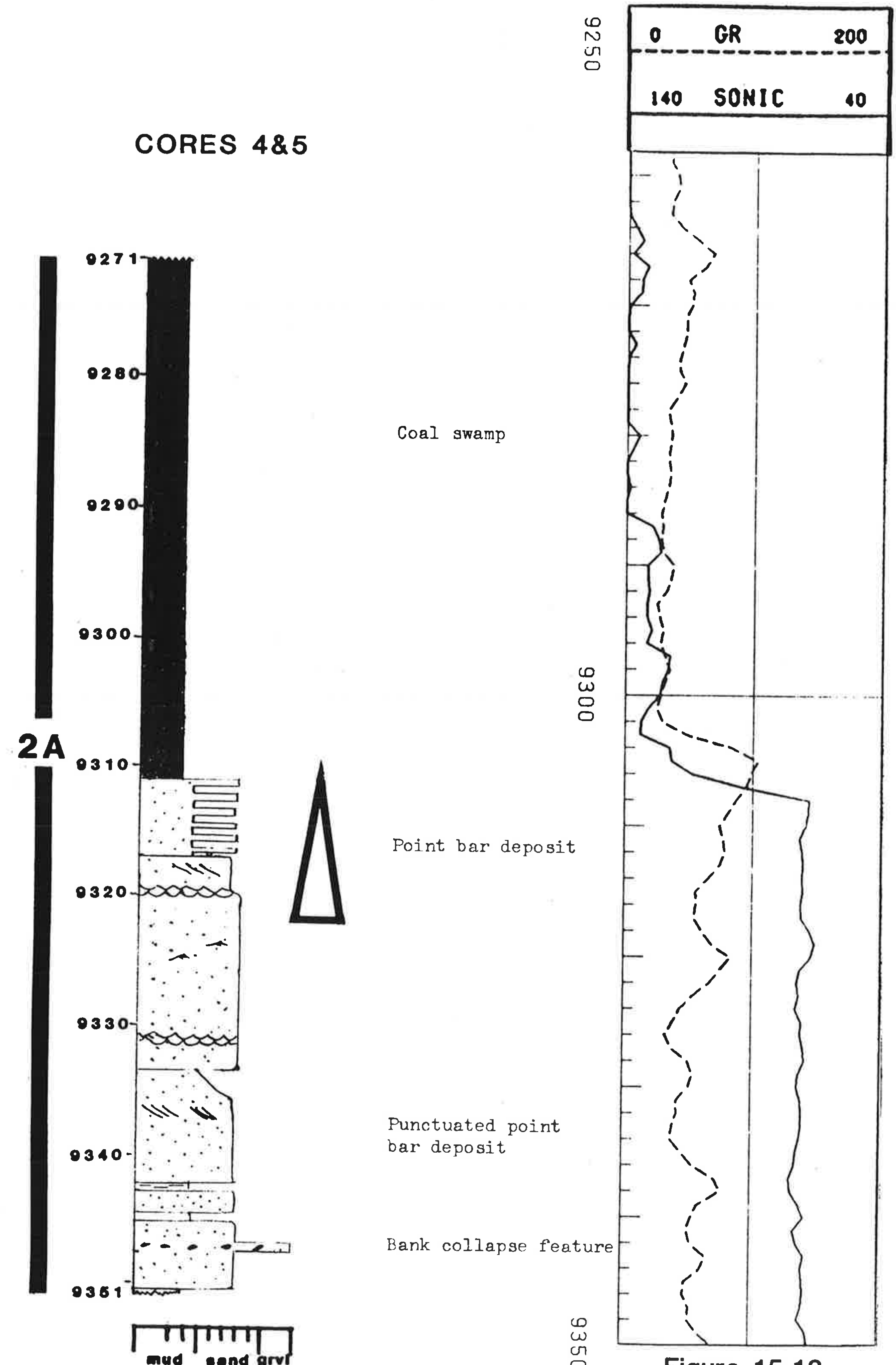


Figure 15.13

# TIRRAWARRA 5

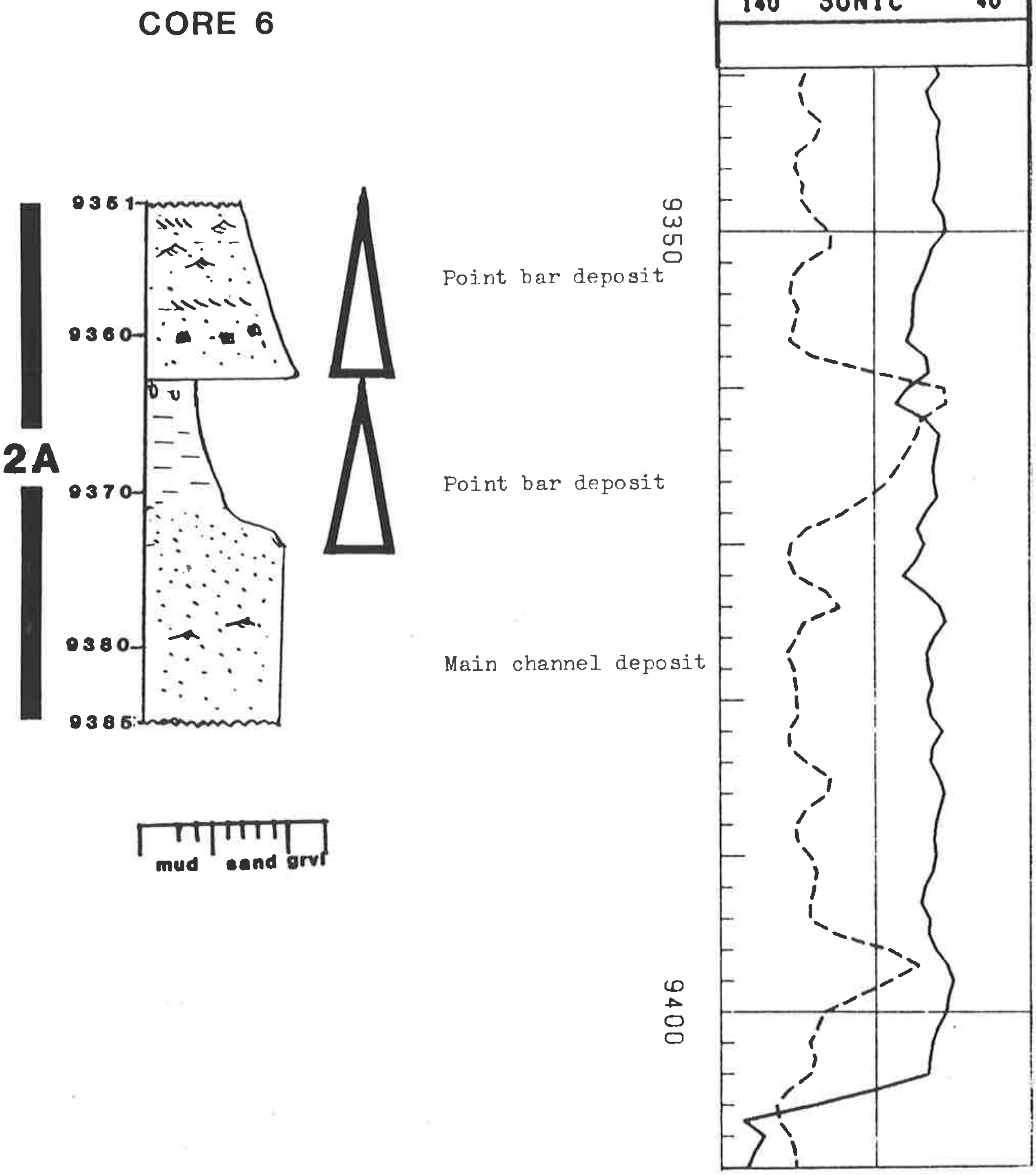


Figure 15.14

# TIRRAWARRA 5

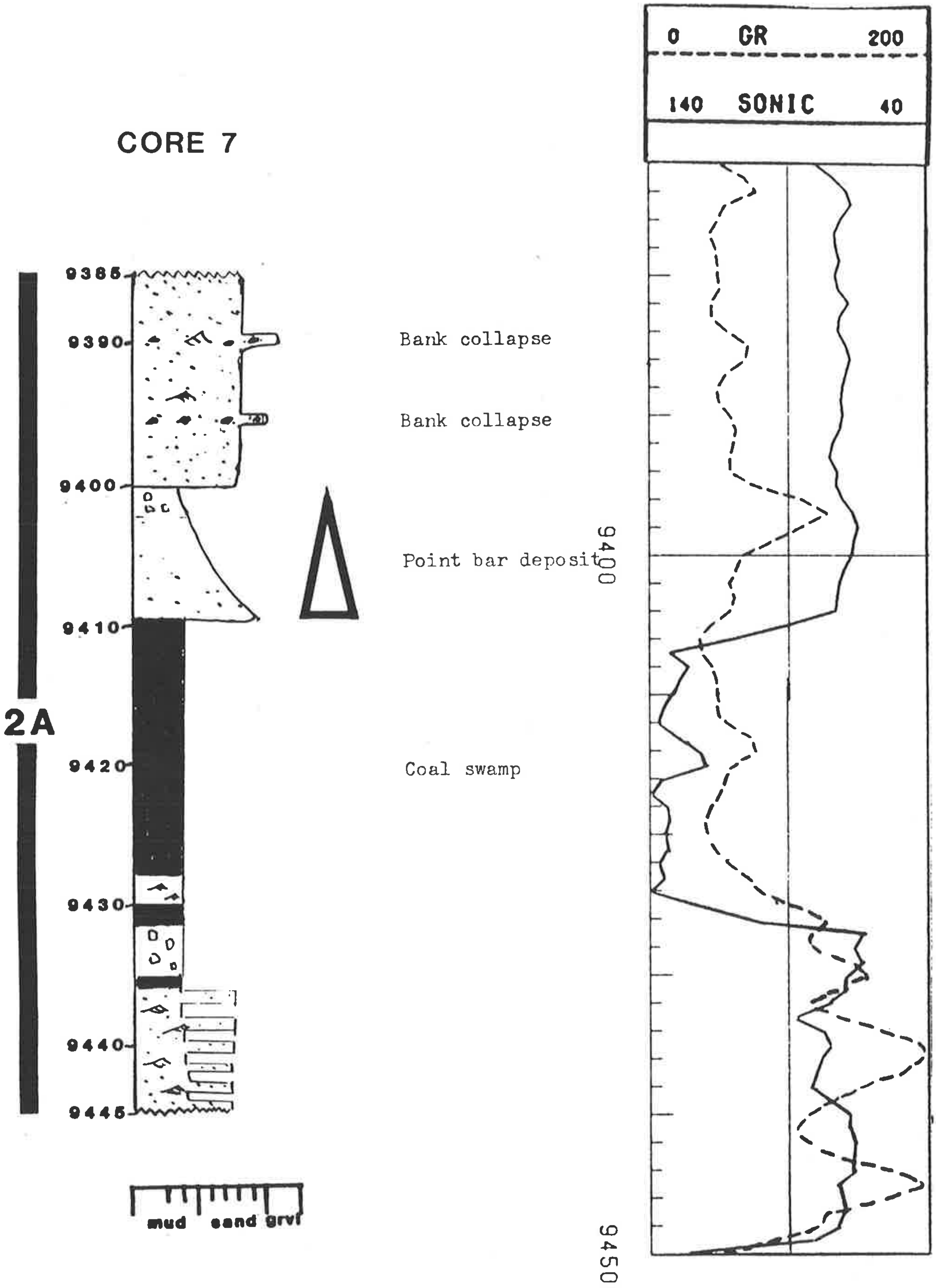


Figure 15.15

# TIRRAWARRA 5

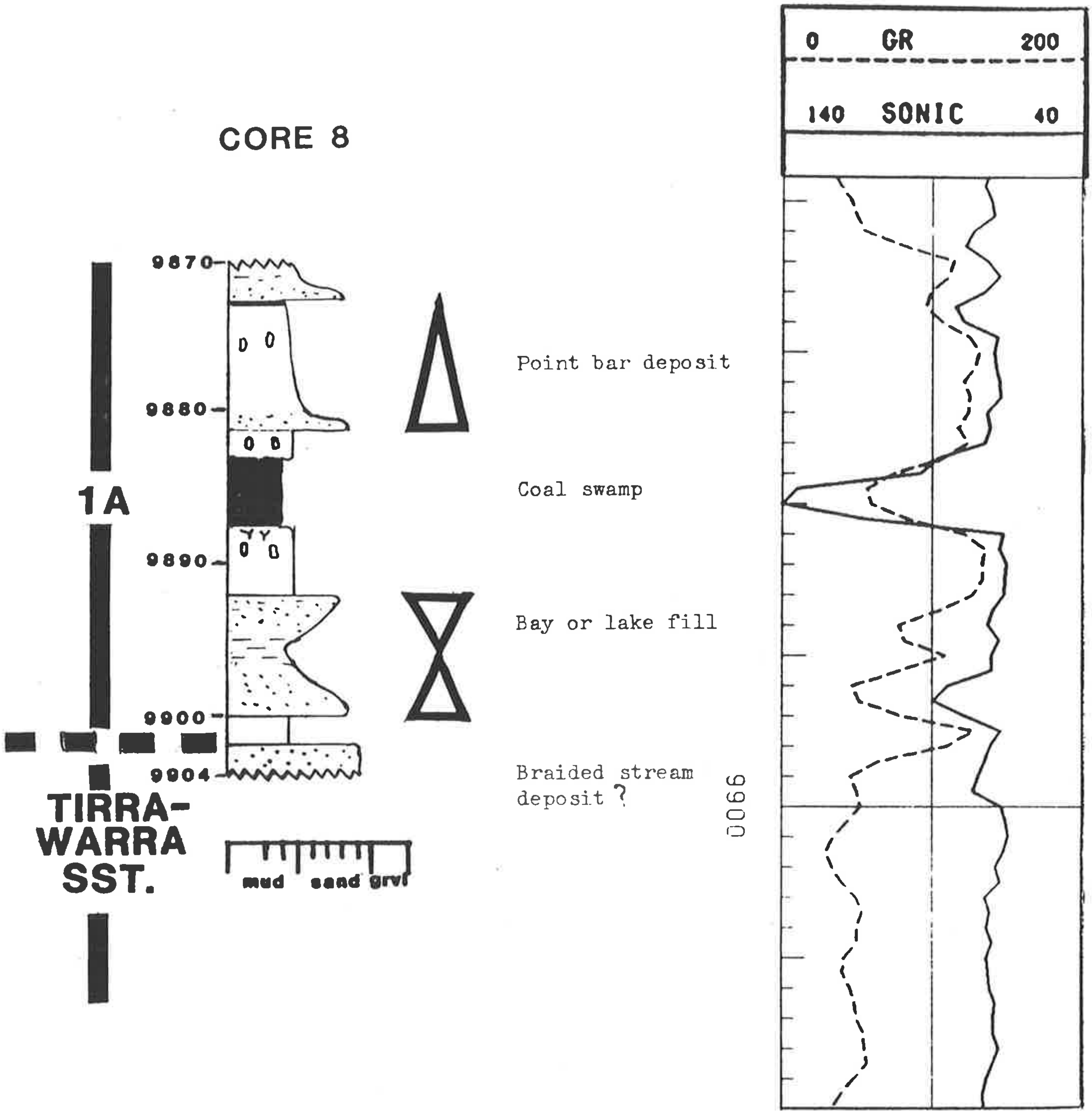


Figure 15.16

# TIRRAWARRA 11

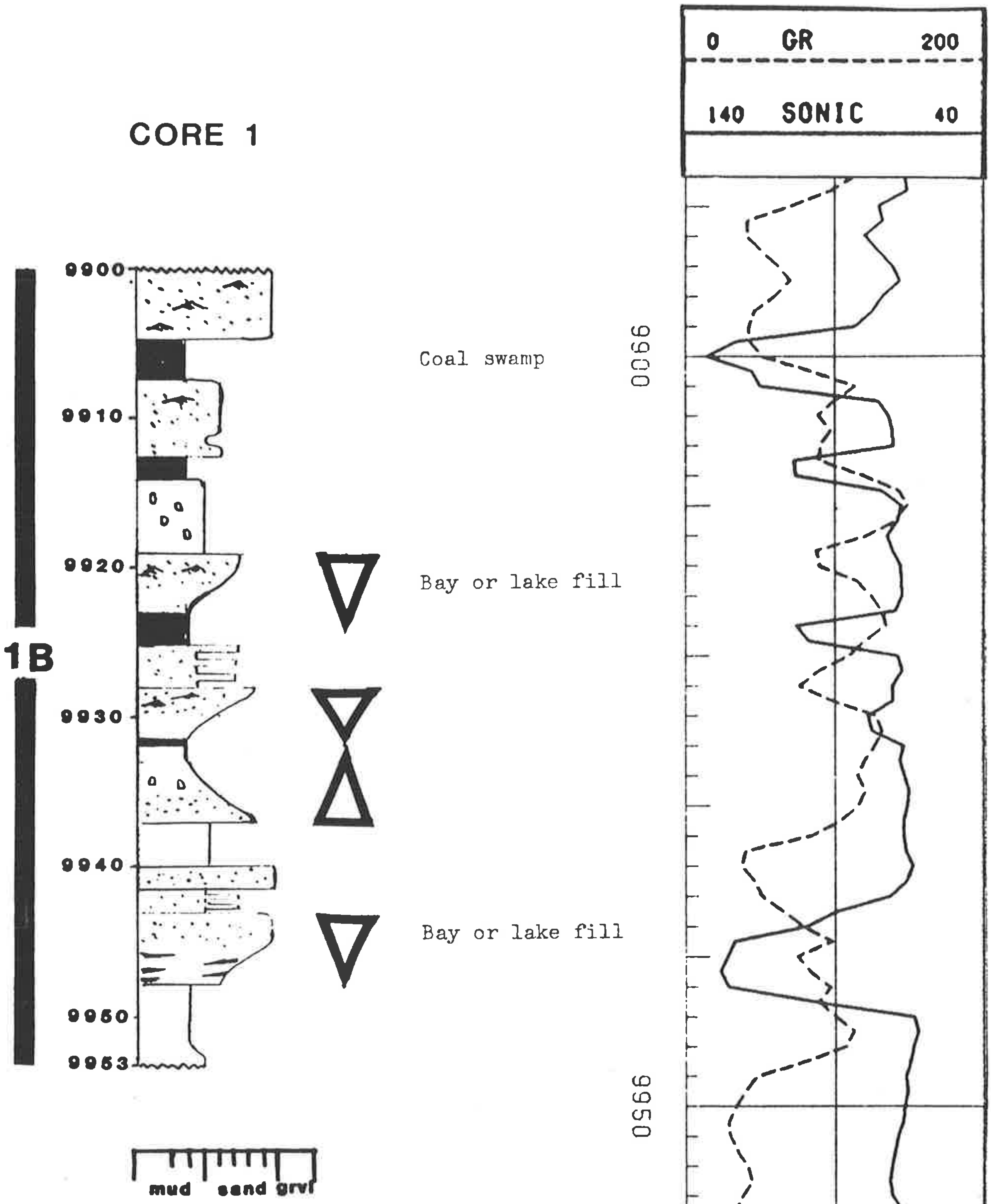


Figure 15.17

**TIRRAWARRA 12**

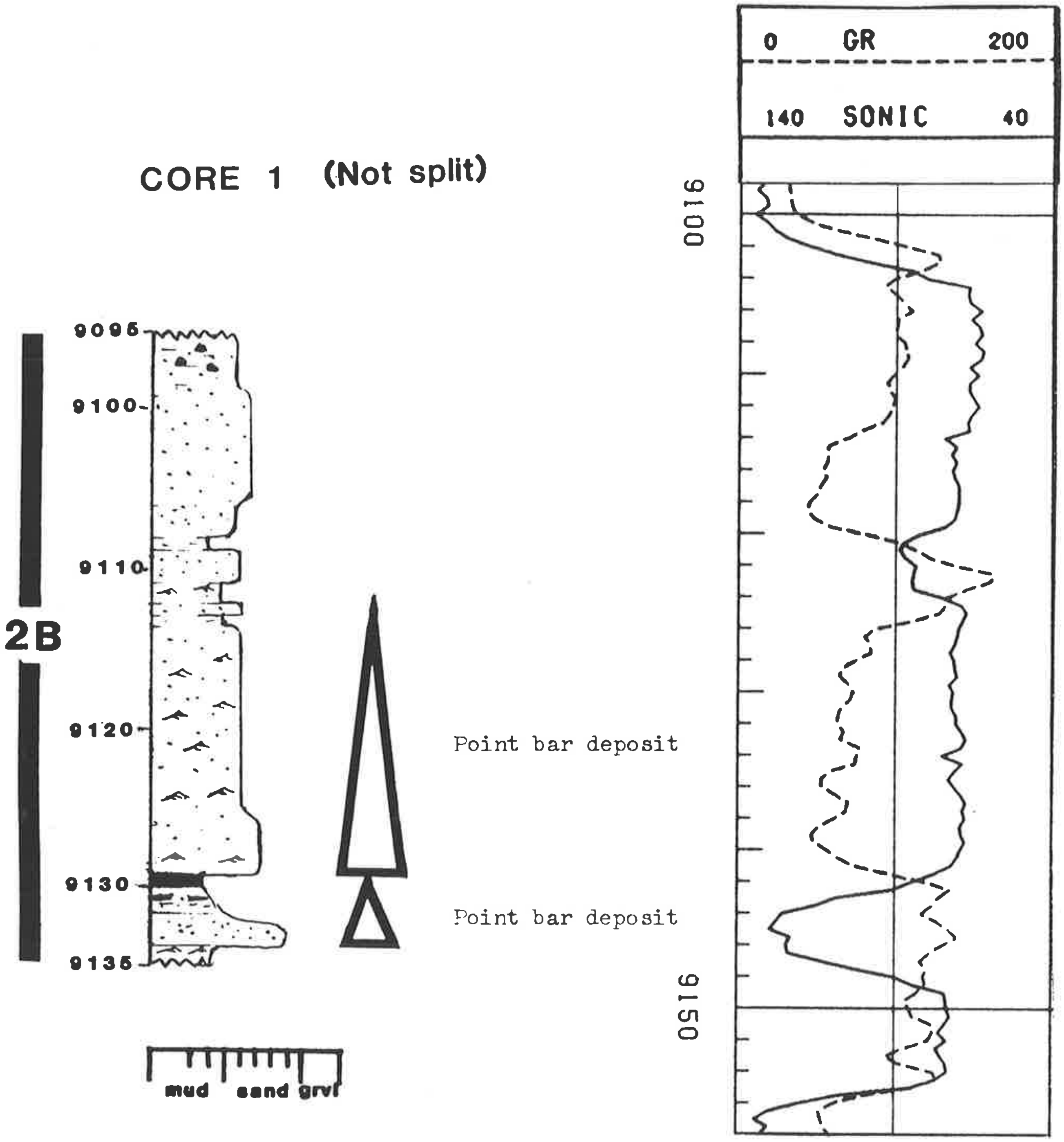


Figure 15.18

# TIRRAWARRA 12

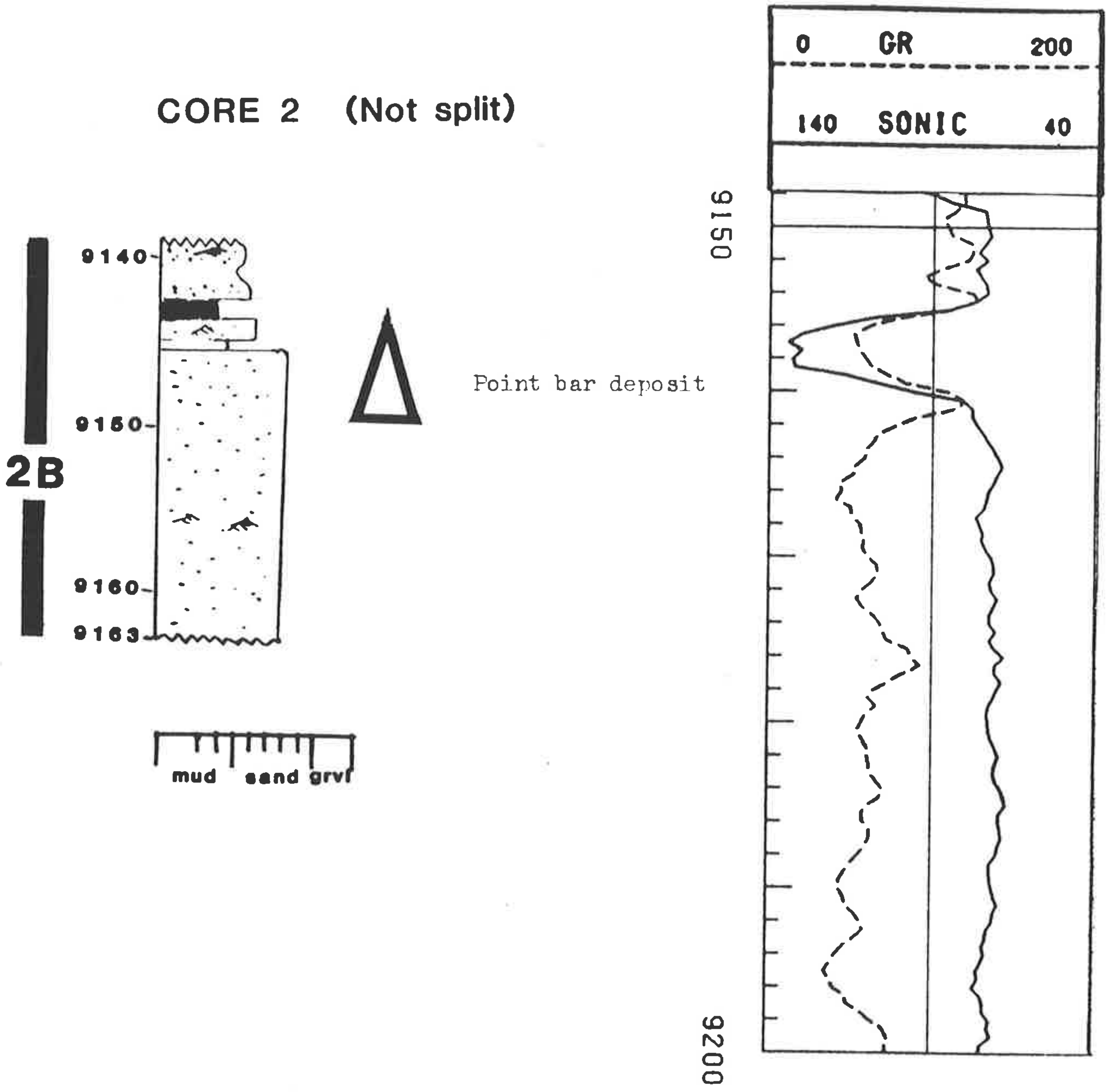


Figure 15.19

# TIRRAWARRA 12

CORE 3 (Not split)

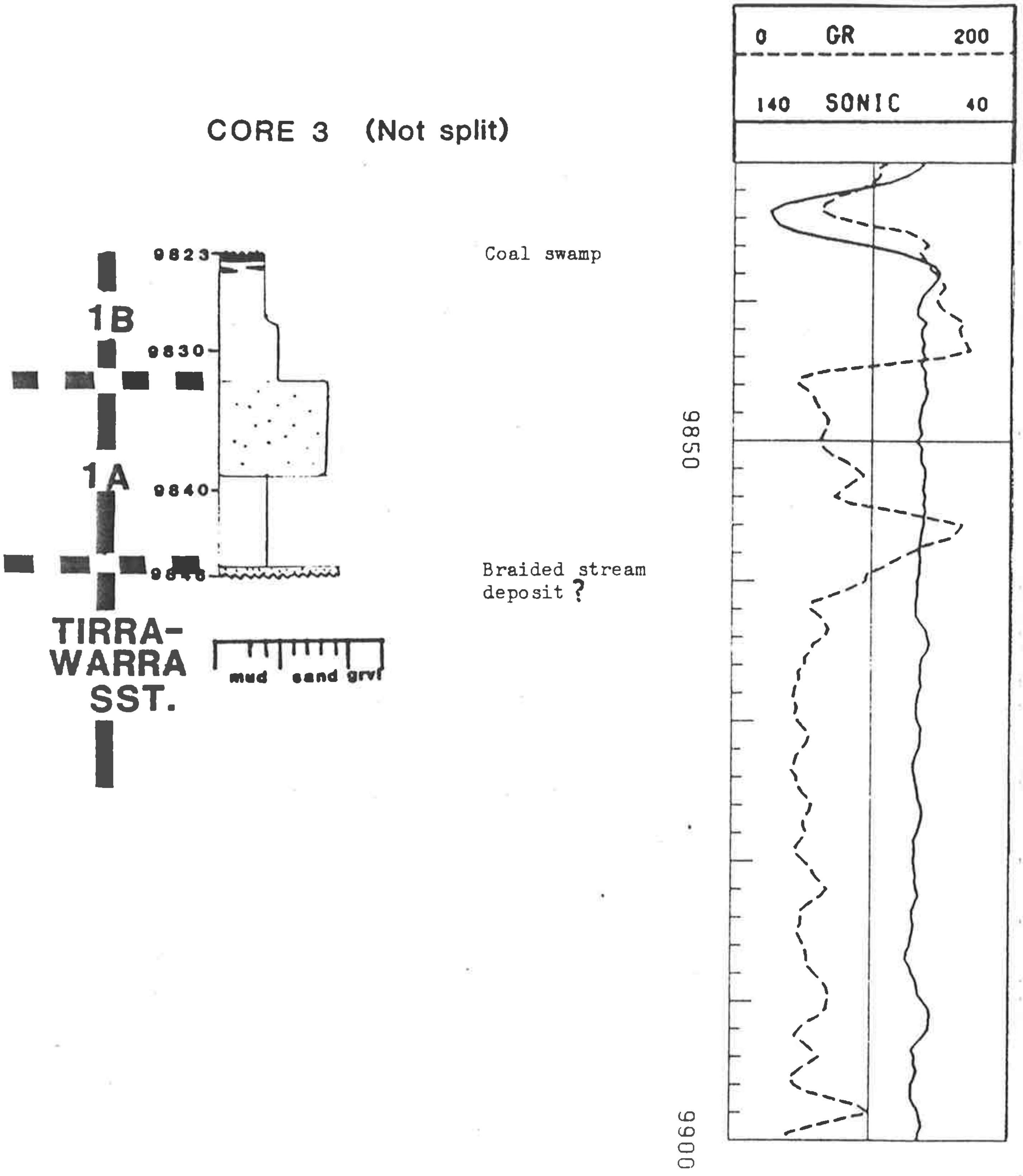


Figure 15.20

# TIRRAWARRA 13

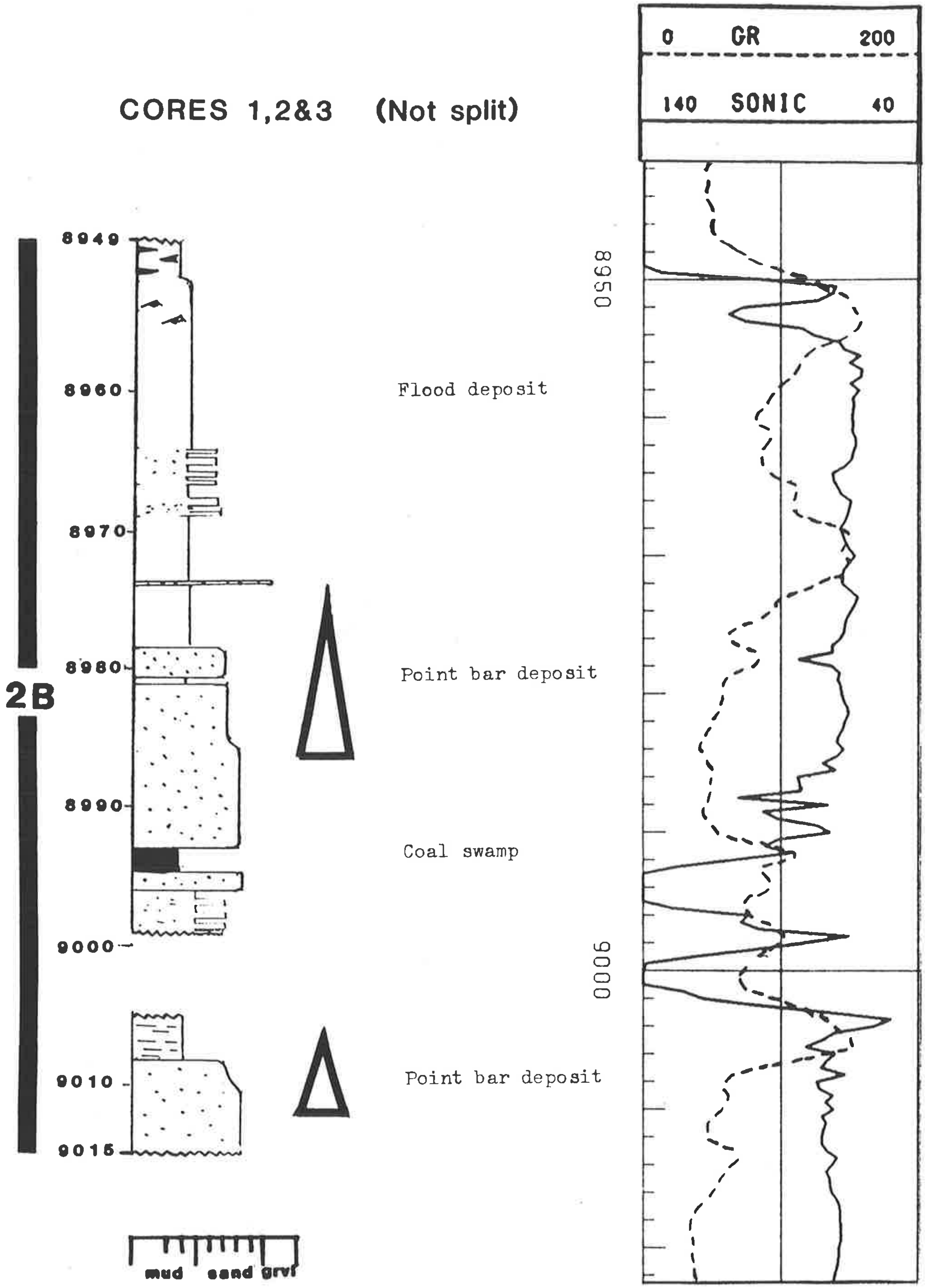


Figure 15.21

# TIRRAWARRA 13

CORES 4&5 (Not split)

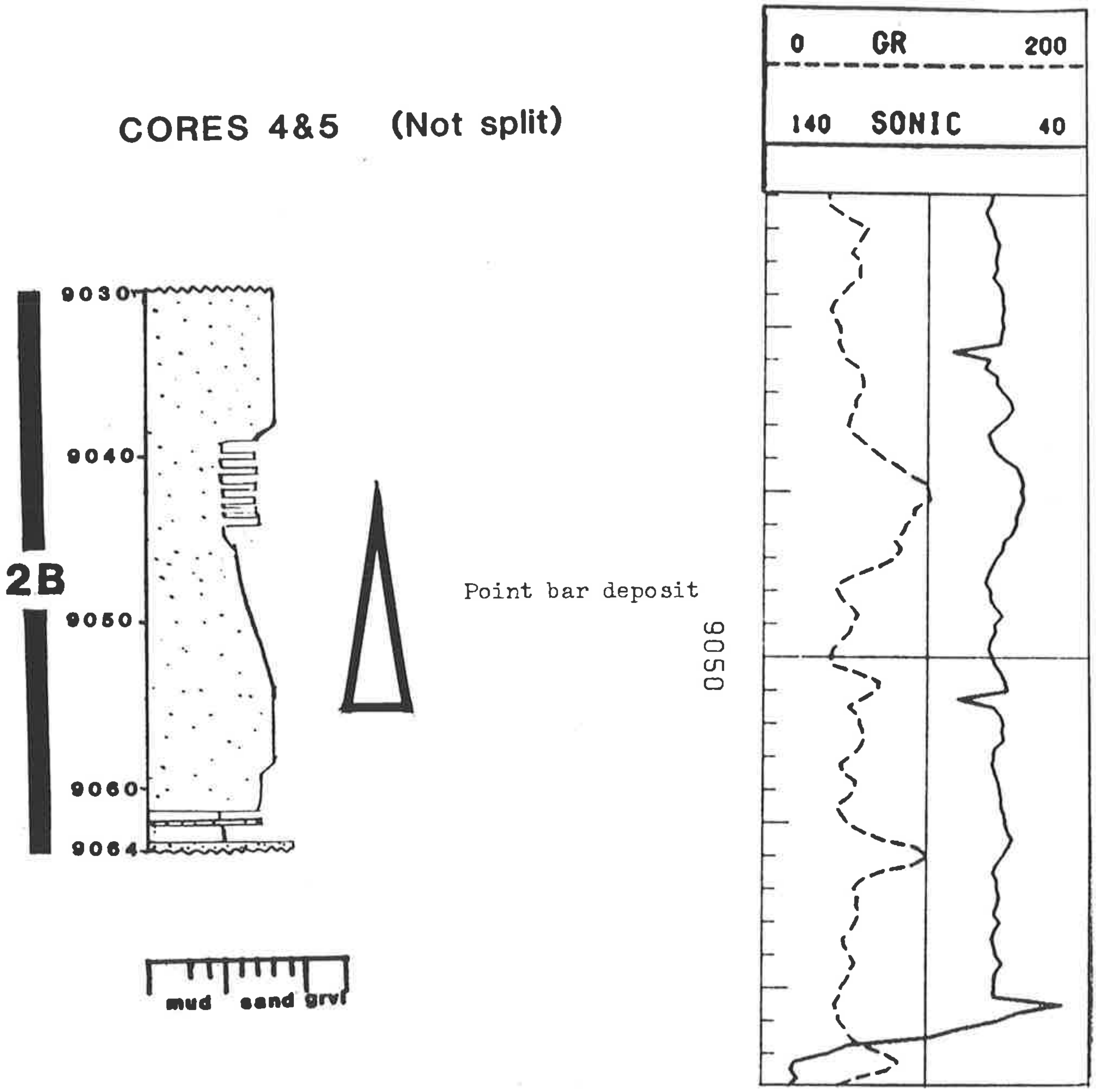


Figure 15.22

# TIRRAWARRA 16

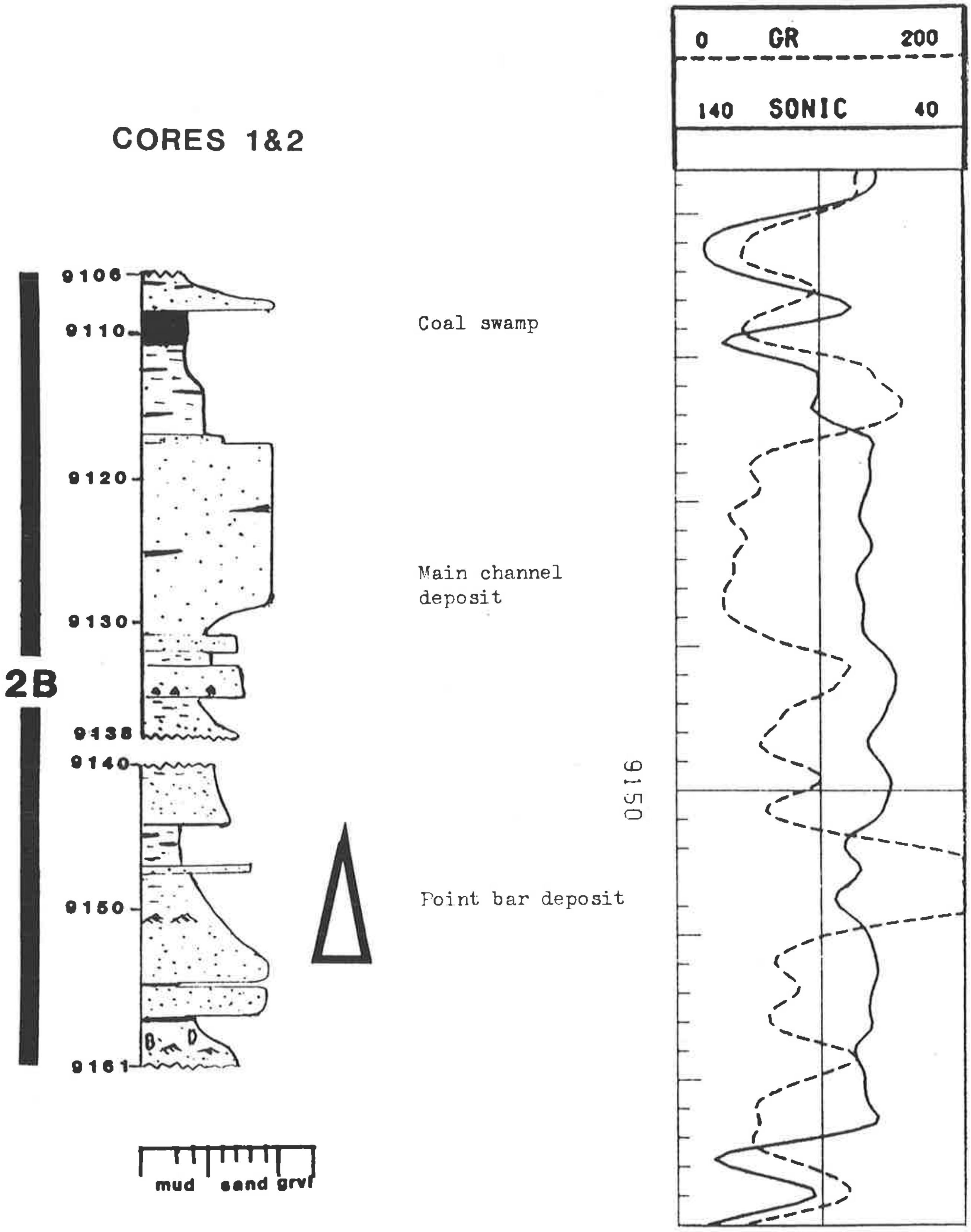


Figure 15.23

# TIRRAWARRA 17

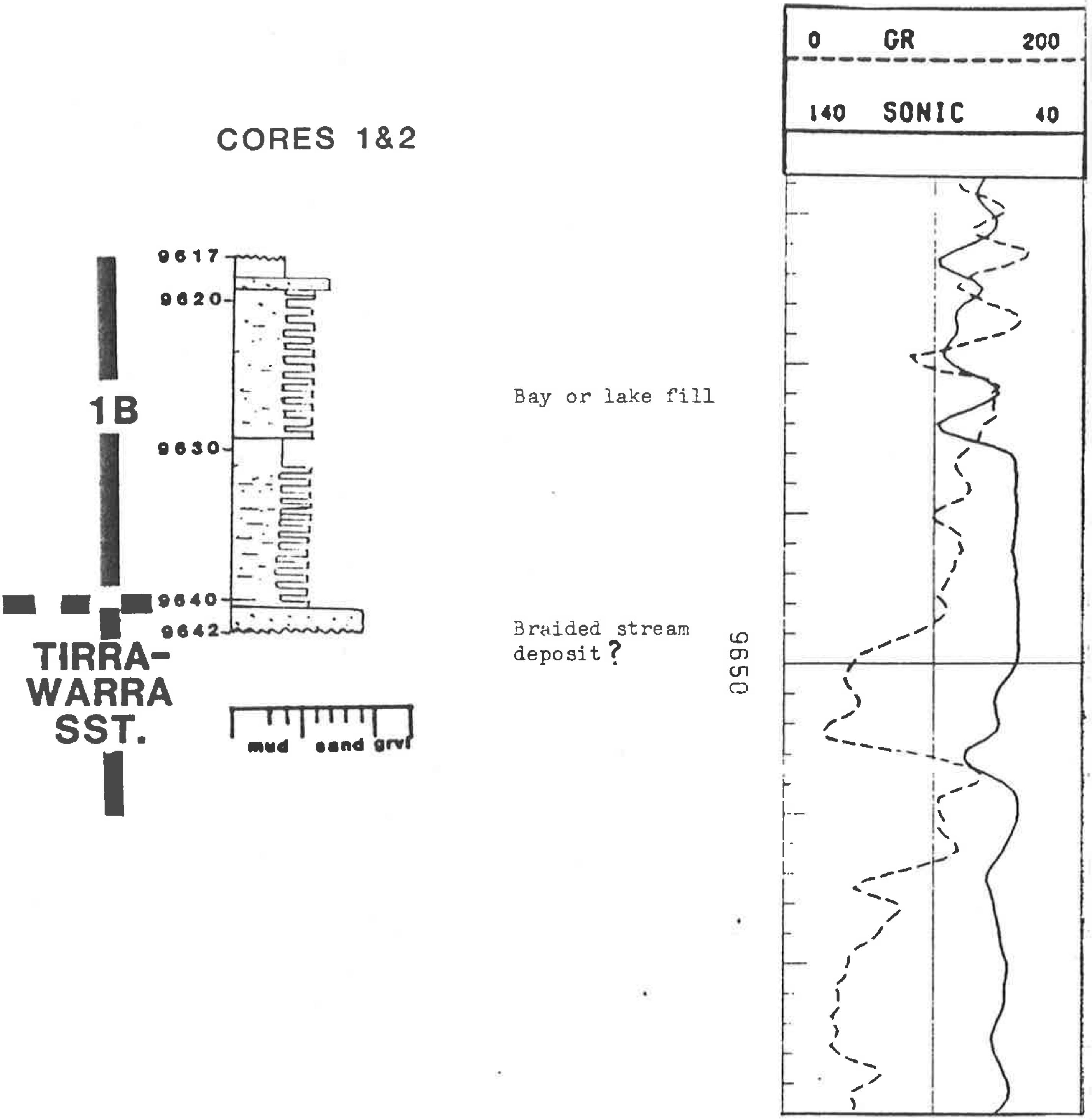


Figure 15.24

# TIRRAWARRA 19

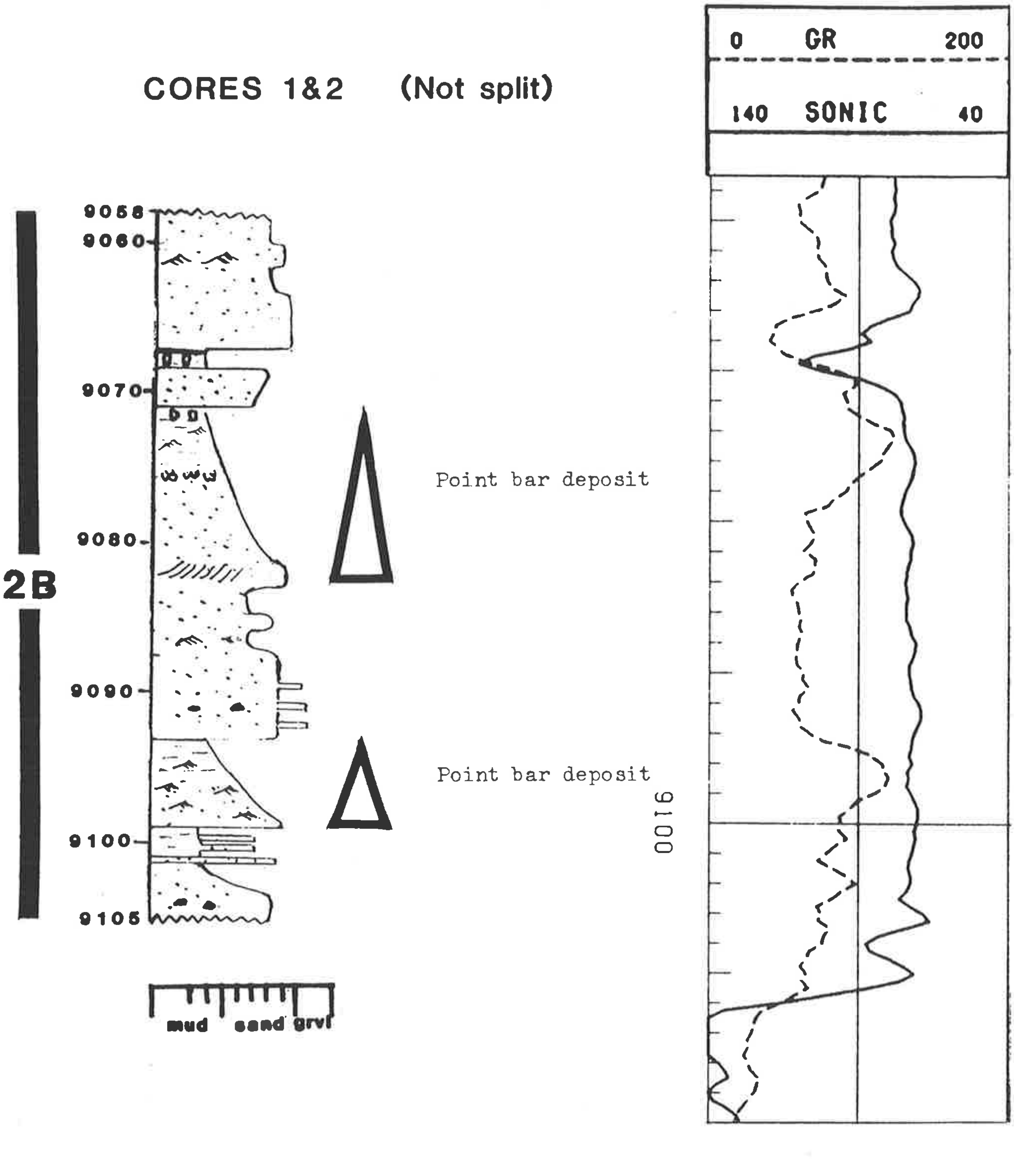


Figure 15.25

# TIRRAWARRA 28

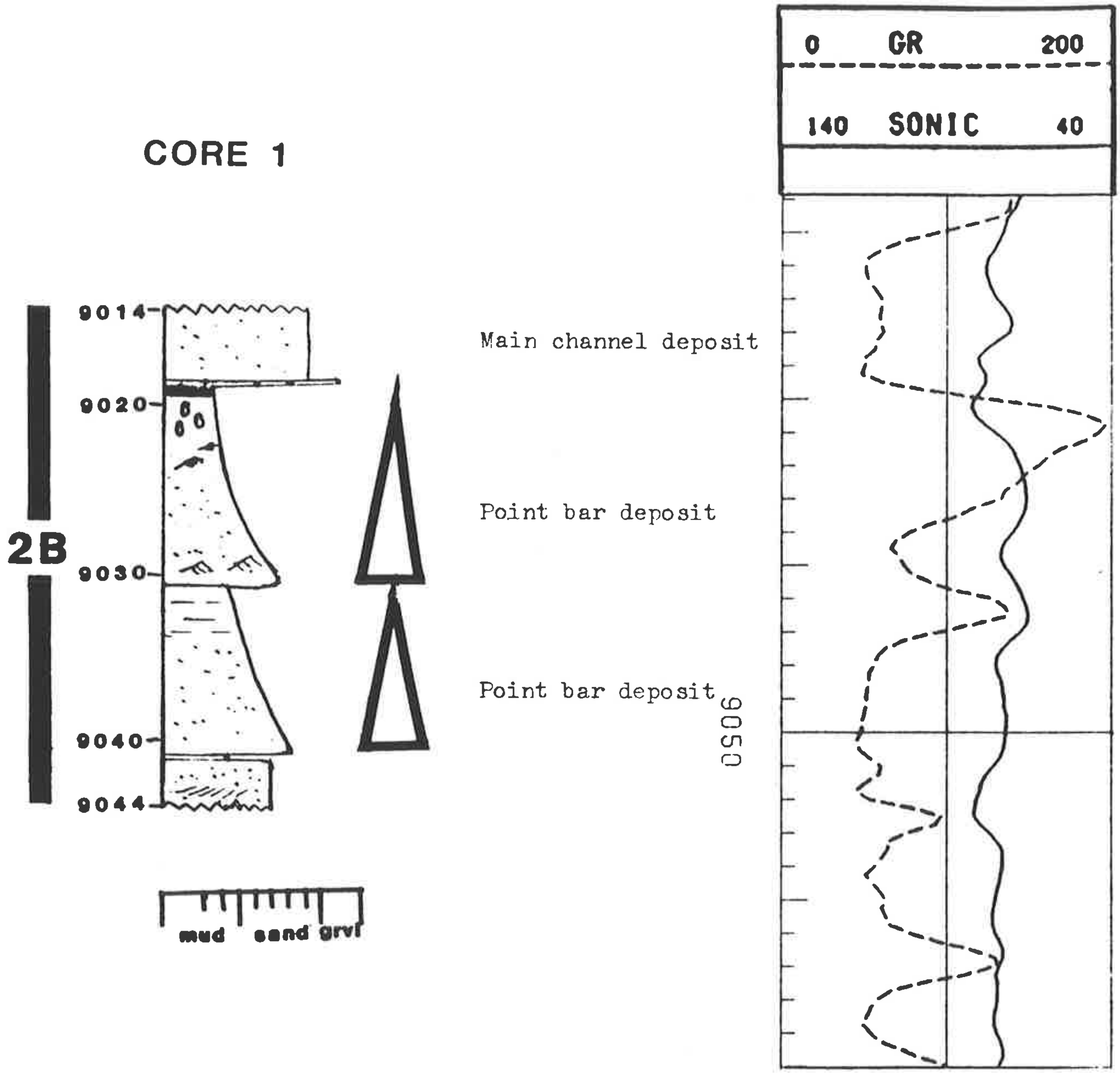


Figure 15.26

# TIRRAWARRA 32

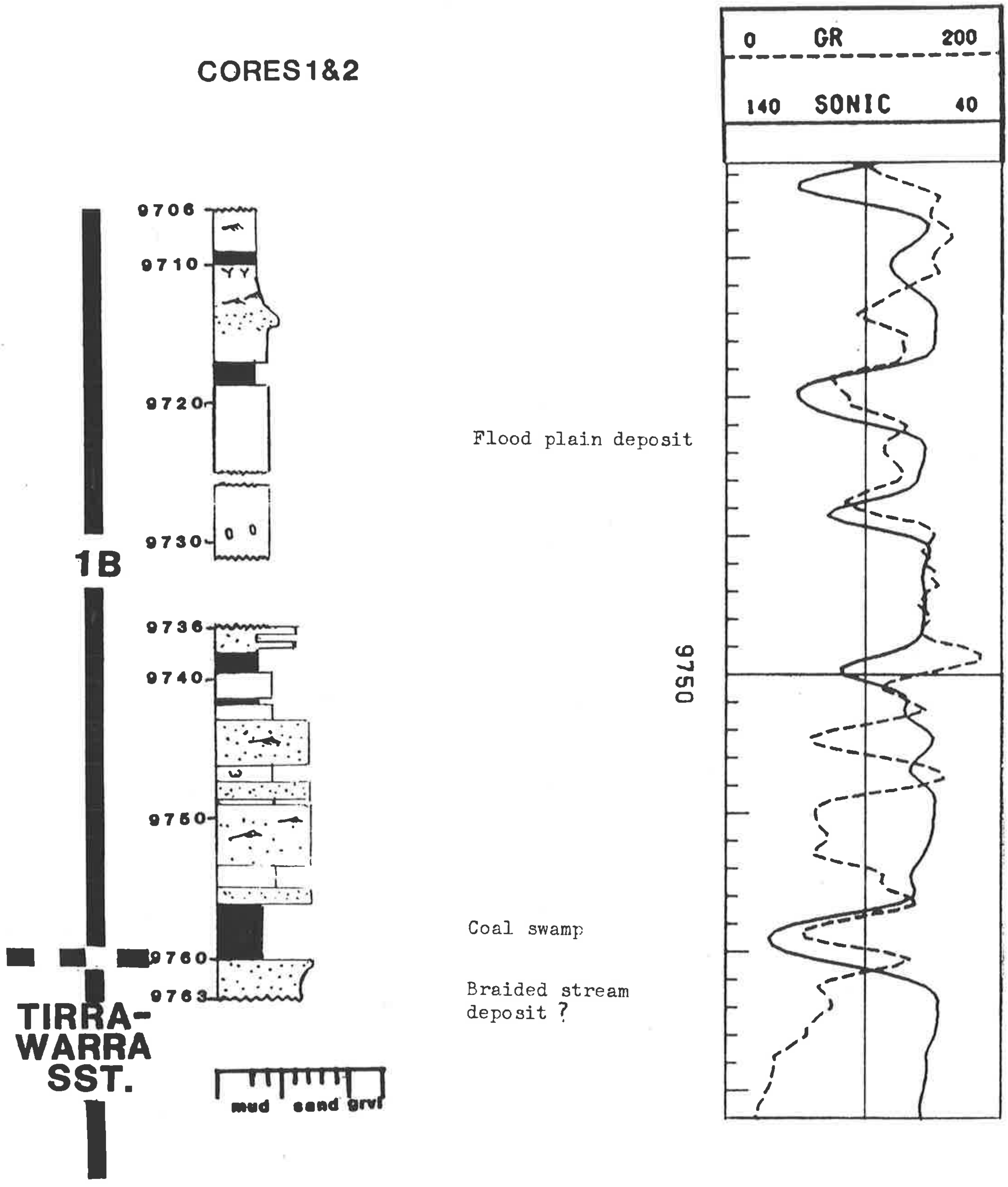


Figure 15.27

# CHAPTER 5 FACIES AND FACIES ASSOCIATIONS

## 5.1 FACIES OF THE PATCHAWARRA FORMATION

The facies of a sedimentary unit includes its lithology, bedforms and deformation structures. It is necessary to log rock cores very carefully and on a small scale in order to assess facies states.

In Williams' 1982 study of Gidgealpa Group core, 19 facies states were described. He assigned codes to these facies states and summarised qualitatively the frequency of their occurrence in the various formations of the Gidgealpa Group.

In the present study, a detailed analyses of 1199 feet of Patchawarra core from 12 of the 13 cored wells of the Tirrawarra Field disclosed 11 facies states. Core from Tirrawarra 13 was not analysed for facies as it had not been split and could not be washed to reveal internal detail, since it was stored in cardboard core trays.

Facies states identified from core of the 12 wells comprised one coal, three mudrocks, four sandstones, one interbedded mudrock-sandstone and two conglomerates. A description of these follows. The facies codes of Williams (1982) have been used.

**Coal - Facies C** Coal is extremely common in the Patchawarra Formation and seams reach a maximum thickness of 66 feet in Tirrawarra 11. This particular seam, termed by Battersby the Patchawarra Coal Seismic Horizon, is field wide. More commonly the coal seams are less than 10 feet thick. They frequently grade up from, or up into, carbonaceous mudrocks.

The coal facies contains plant debris, mudstone bands and thin gravel seams (produced by overbank flooding). Siderite replacement of coal in the form of pods and bands is common, this being an early diagenetic phase. Siderite has replaced the organic matter in reducing conditions (Hatch, Rastall and Black, 1938 ).

Some coals directly overlie non-carbonaceous, well bedded mudrocks or heterolithic interbeds with sharp, planar contacts. This implies that these coals are allochthonous. Williams (1982) suggested that thick allochthonous coals accumulated as large mats of vegetation floating in interdistributary bays or lakes. An example occurs in the core from Tirrawarra 5 where the Patchawarra Coal, at least 60 feet thick, directly overlies heterolithic interbeds at 9310 feet (Figures 15.12 and 15.13).

Other coals directly overlie rooted mudrocks and hence are probably autochthonous in origin. For example a coal bed overlies rooted, massive mudrock at 9182 feet in Tirrawarra 2, Core 2 (Figure 15.3).

**Massive and Bioturbated Mudrock - Facies Fm** This facies comprises a structureless mudrock of clay or silt grade, with no lamination preserved. The massive nature of this facies is produced either by suspension sedimentation from stilled flood waters, or the destruction of any lamination that may have been present by pedogenesis and/or bioturbation. It occurs as vertical accretion deposits in abandonment fills and as overbank or flood basin deposits.

Occurrences of this facies are up to 15 feet thick, as observed in core. Thick occurrences are commonly found both low in the Patchawarra Formation, for example Tirrawarra 5, Core 8, 9875 feet (Figure 15.16), and near the top of the Patchawarra Formation, for example Tirrawarra 2, Core 4, 9690 feet (Figure 15.5).

**Flat Laminated Mudrock - Facies Fl** This mudrock contains closely spaced bedding planes or laminations in both silt and clay grade. Williams (1982) suggests that deposition in an overbank, flood basin setting is indicated where this facies represents waning flood conditions, possibly following a crevasse splay encroachment into flood basins or backswamps. However these mudrocks may also have been deposited below wave base in lakes or restricted seas.

This facies has been found to occur in all parts of the Patchawarra Formation in the Tirrawarra Field, but is more common in the top half. It occurs up to 8 feet thick, for example Tirrawarra 4, Core 1, 8850 feet (Figure 15.8).

**Wave Rippled Mudrock - Facies Fw** This facies is comprised of usually silt grade material, with some fine sand containing starved ripples. It originates in a quiet lake or bay environment, where wind-driven waves generate ripples in the bottom sediments.

**Wave Rippled Sandstone - Facies Sw** Fine sand dominates this facies, with mud also being present. Flaser bedding is created by wind driven waves in the environment described above for Wave Rippled Mudrock.

**Heterolithic Interbeds - Facies Hi** This facies consists of thin (in the order of centimetres) alternating bands of fine sand or silt. These bands contain the ripple structures described in Fw and Sw. These ripple structures have been created in the way previously described.

Fw, Sw and Hi are commonly found together and occur at all levels of the Patchawarra Formation.

**Massive Sandstone - Facies Fm** This structureless sandstone facies has no visible bedding planes in the core examined. Bedforms may have been destroyed by fluid escape, such as occurs in crevasse splays. It is more common in coarse to medium sands than in fine sands. However lack of bedding in fine sands may be caused by bioturbation.

Occurrences of this facies are up to 18 feet thick in core, for example in Tirrawarra 1 , Core 4 at 9010 feet (Figure 15.1), but are usually much thinner. The facies is to be found throughout the Patchawarra Formation, but is more common in the middle part.

**Trough Cross Bedded Sandstone - Facies St** This facies is a common bedform of the Patchawarra Formation in the Tirrawarra Field. It is found in the upward-fining sequences which are a feature of the middle part of this formation and occurs in coarse to medium grained sandstone sediments. Williams (1982) considers this facies to be the product of dune migration under the lower flow regime.

Facies St has a maximum thickness of three feet in core. An example occurs in Tirrawarra 2, Core 1 at 9089 feet (Figure 15.2).

**Planar Cross Bedded Sandstone - Facies Sp** This facies is found commonly among the sandstones of the Patchawarra Formation, particularly in the middle part of the formation. The cross beds may be either tabular or asymptotic, although the latter are not often identified due to the small (about 100 mm) cross section represented by the core. The sand is commonly medium grained but the bedform also occurs in coarse grained sand.

The facies Sp occurs in thicknesses of up to 7 feet. An example is to be found in Tirrawarra 5, Core 1 at 9145 feet (Figure 15.10 ).

**Massive Conglomerate - Facies Gm** This facies occurs as channel lag, which in the cores examined was invariably intraformational and framework supported. It represents traction load under a high flow regime and provides information on stream power. It more commonly occurs in the middle part of the Patchawarra Formation.

Facies Gm is found in the core in layers up to 3 feet thick. An example of this facies occurs in Tirrawarra 2, Core 2 at 9219 feet (Figure 15.3 ).

**Chaotic Conglomerate - Facies Gc** This facies comprises a matrix supported conglomerate in which the clasts consist of semi-lithified to lithified intraformational debris of clay, silt, fine grained sand or coal. The facies indicates that material from the cut bank has suddenly collapsed into the channel, to be engulfed by the channel or channel margin deposits. This facies is a common feature of the middle part of the Patchawarra Formation.

Thicknesses of up to 5 feet are found in the core, an example occurring in Tirrawarra 3, Core 1 at 9190 feet (Figure 15.6 ).

## 5.2 FACIES ASSOCIATIONS OF THE PATCHAWARRA FORMATION

### Introduction

Facies Associations have been constructed, using as a guide the Patchawarra Formation sub-units of Kapel (1972), the divisions of Battersby (1976) and the facies associations of Williams (1982). (see Chapter 2 ).

Three Facies Associations have been created, two of which have been sub-divided. Facies Associations 1A and 1B, the lower most, together correspond with Williams' Facies Association 1 or Kapel's and Battersby's lower division. Facies Associations 2A and 2B, taken together, are essentially identical with Williams' Facies Association 2 or Kapel's and Battersby's middle division. Facies Association 3, the upper most, corresponds with Williams' Facies Association 3 and with the upper division of Kapel and Battersby.

Boundaries between the Facies Associations in this study have been set by lithological markers. It was found however that only 9 boundaries were present in the cores examined, the remainder of the boundaries for each cored well being in core breaks. It was thus necessary to identify geophysical patterns from gamma and sonic logs corresponding to the selected lithological boundary markers using methods described under Core Investigation. Thus boundaries have been determined for the Facies Associations not only in the cored wells where boundaries are in core breaks, but also in the 49 wells where no Patchawarra core was taken. A summary of the Facies Associations, together with defined boundaries, is shown in Figure 16, but more explanation is necessary here.

The base of Facies Association 1A (or of Facies Association 1B if 1A is absent) corresponds to the base of the Patchawarra Formation and the top of the Tirrawarra Sandstone. It is to be found in Tirrawarra 5, Core 8 at a depth of 9902 feet (Figure 15.16 ), and is marked by a change from the thick, coarse sands of the Tirrawarra Sandstone to shale of the lower part of the Patchawarra Formation, with a corresponding increase in gamma log reading above 100 A.P.I. units. This boundary has also been cut by Tirrawarra 12, Core 3 at 9846 feet (Figure 15.20 ) and by Tirrawarra 32, Core 2 at 9760 feet (Figure 15.27 ). In the latter case coal overlies the Tirrawarra Sandstone.

The top of Facies Association 1A corresponds with the top of a sandstone unit at least ten feet thick, the base of which is within 50 feet of the top of the Tirrawarra Sandstone. This boundary has been cut only by Tirrawarra 12, Core 3 at 9832 feet (Figure 15.20 ). This core has not been split, so internal details are hard to ascertain. However from interpretation of geophysical logs, the boundary appears to be the top of a coarsening up sequence.

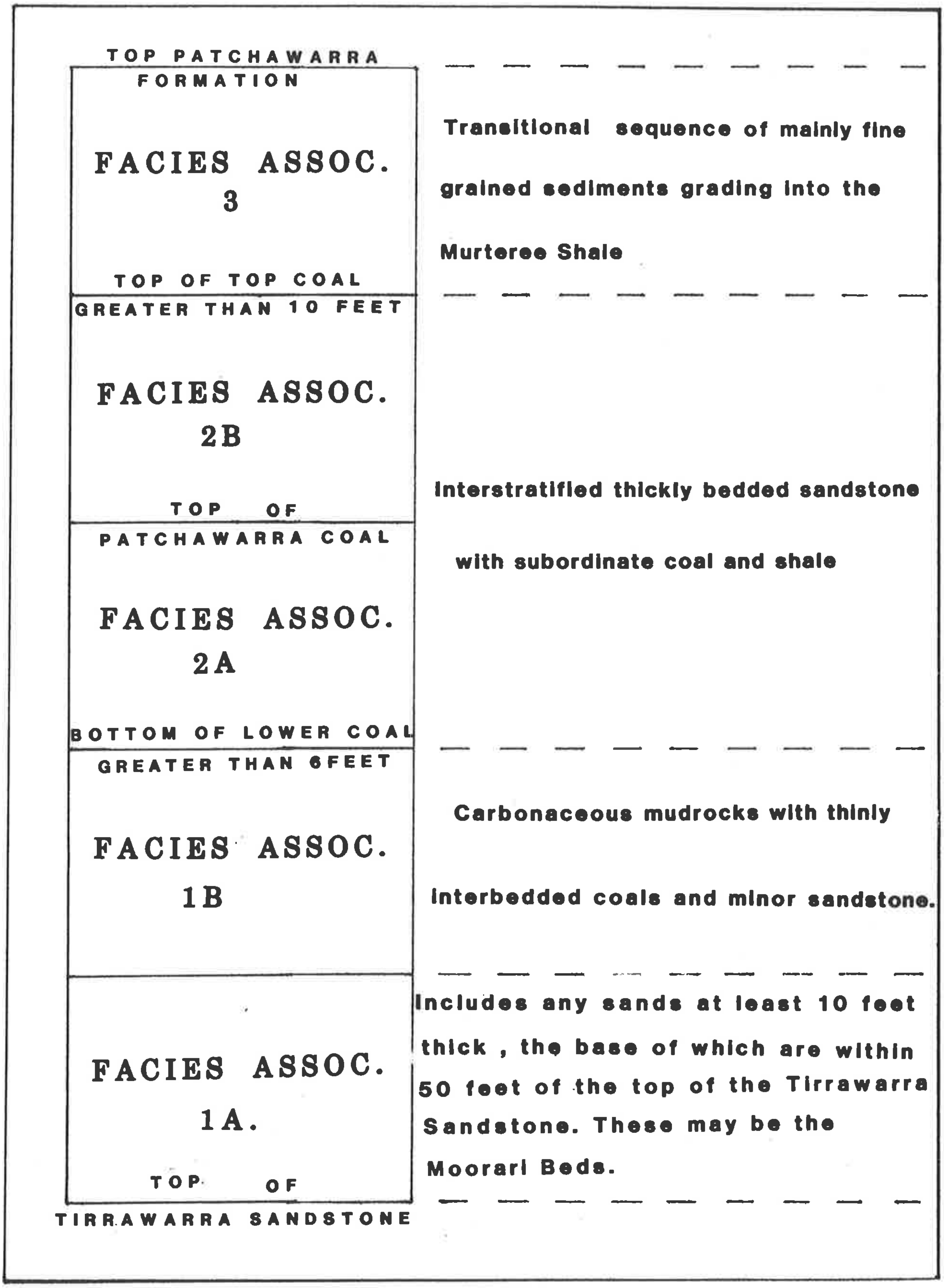


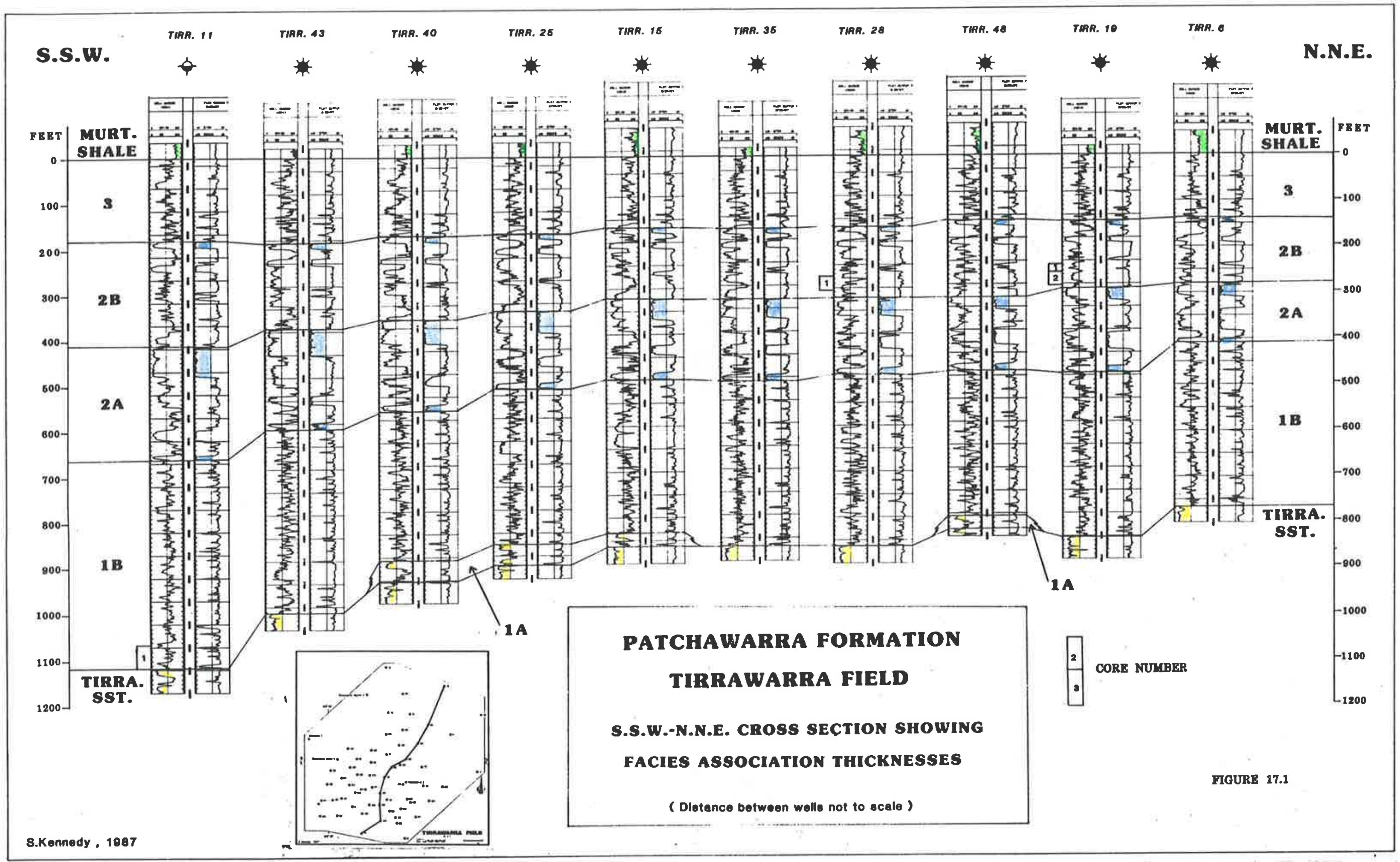
FIGURE 16 Subdivision of the Patchawarra Formation in Tirrawarra Field.

The top of Facies Association 1B and the base of Facies Association 2A corresponds with the base of the lowermost coal of the Patchawarra Formation, which has a thickness of at least 6 feet. This boundary is unfortunately not represented in core, and so has been defined entirely by geophysical interpretation. However an examination of the two cross sections (Figures 17.1 and 17.2 ) of gamma ray and sonic logs along and across the structural trend of the field, shows that the boundary is a reliable field wide marker.

The boundary between Facies Associations 2A and 2B has been defined as the top of the Patchawarra Coal. It has been cut by Tirrawarra 1, Core 1 at 9025 feet (Figure 15.1 ), Tirrawarra 3, Core 1 at 9239 feet (Figure 15.6 ) and by Tirrawarra 5, Core 4 at 9249 feet (Figure 15.12 ). As previously mentioned, the Patchawarra Coal is a thick, field wide marker, which is also present on seismic profiles. The top of the Patchawarra Coal is clearly represented in wells where no core has been cut, by a sudden drop in sonic count below 90 microseconds per foot. The boundary is visible in the two cross sections (Figures 17.1 and 17.2 ).

The top of Facies Association 2B and the base of Facies Association 3 is defined as the top of the top coal at least 6 feet thick, within the Patchawarra Formation. Unfortunately this boundary has not been cut by any cores, so has also been defined by geophysical means. Examination of the two cross sections shows that this boundary is also a well defined field wide marker (Figures 17.1 and 17.2 ).

The top of Facies Association 3 is also the top of the



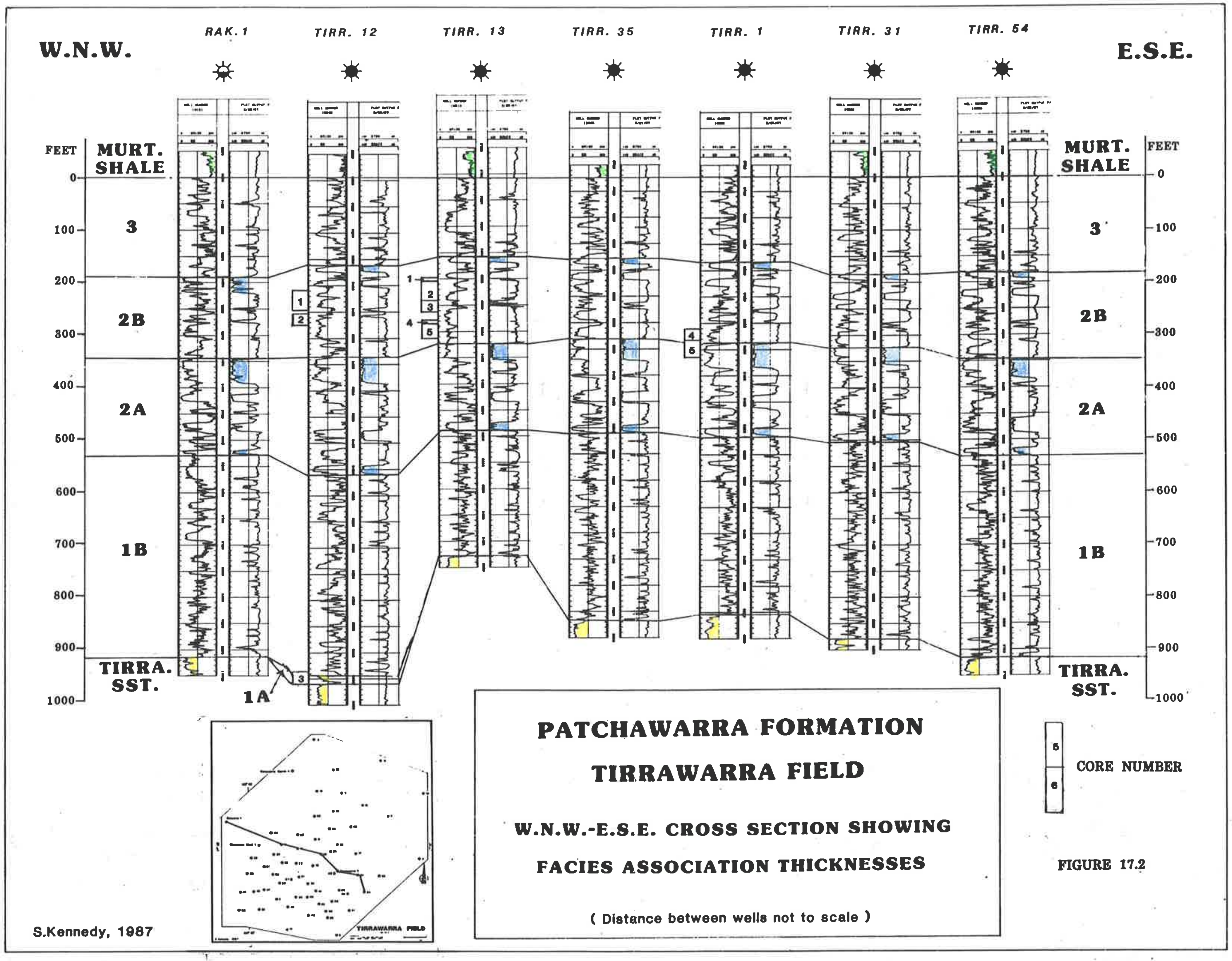
## PATCHAWARRA FORMATION
## TIRRAWARRA FIELD

S.S.W.-N.N.E. CROSS SECTION SHOWING FACIES ASSOCIATION THICKNESSES

( Distance between wells not to scale )

FIGURE 17.1

FIGURE 17.1



PATCHAWARRA FORMATION

TIRRAWARRA FIELD

W.N.W.-E.S.E. CROSS SECTION SHOWING FACIES ASSOCIATION THICKNESSES

( Distance between wells not to scale )

FIGURE 17.2

FIGURE 17.2

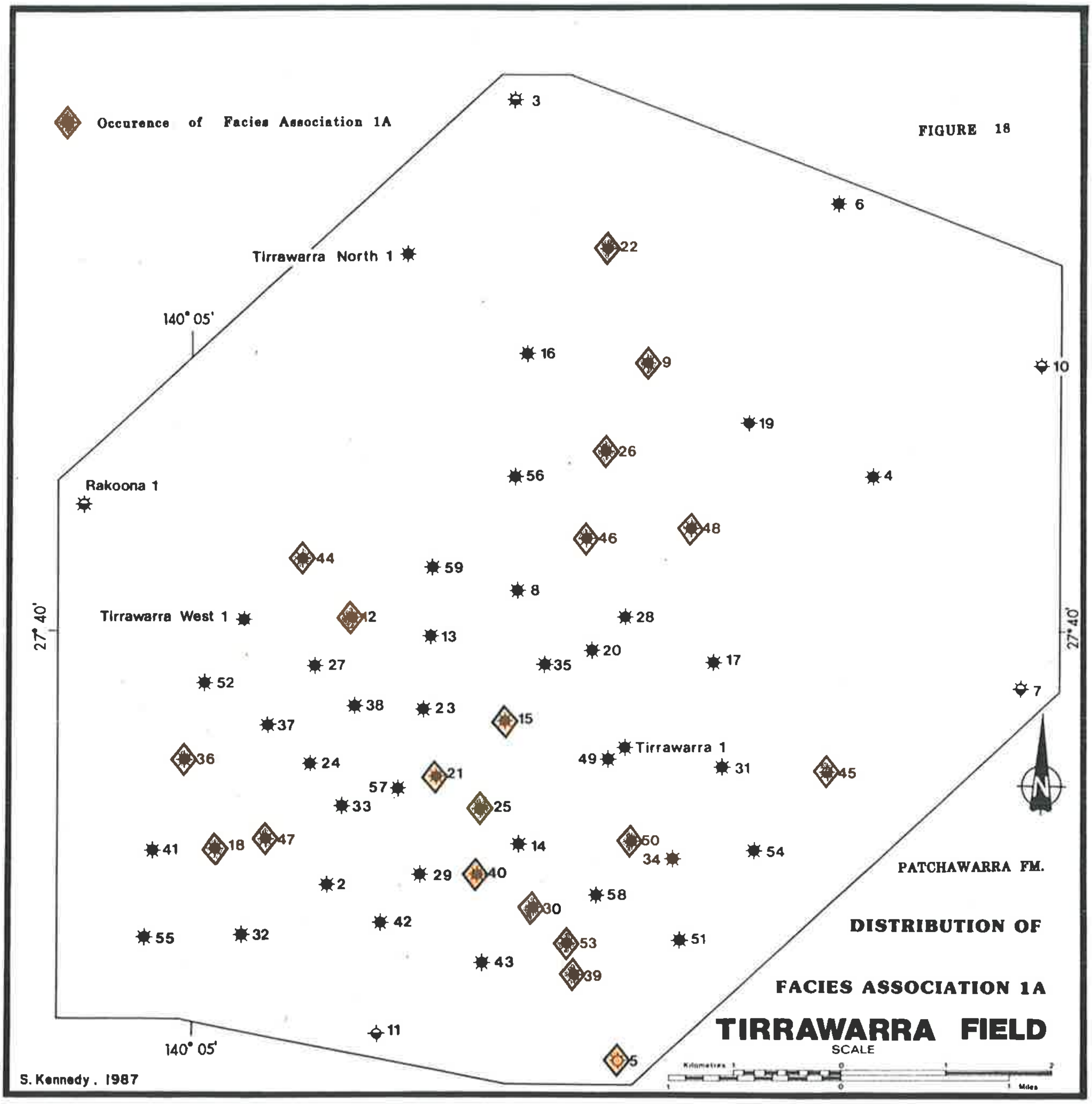
Patchawarra Formation. It has been cut by Tirrawarra 4, Core 1 at 8833 feet (Figure 15.8 ). Here heterolithic interbeds of the Patchawarra Formation are overlain by well bedded shales of the lacustrine Murteree Shale. It is observed that the Murteree Shale has a gamma count of about 170 A.P.I. which is high compared to that of the underlying Patchawarra Formation. This trend occurs field wide (see Figures 17.1 and 17.2 ) making this boundary easy to identify.

Core measurements have been made of the total footage of each previously described facies state occurring in each Facies Association. These measurements have been converted to percentage occurrence and are summarised in Table 3 (see list of Tables ). It is recognised that cores are not randomly cut in cored wells and so the percentage of facies observed in well cores may not accurately reflect the percentage in each Facies Association field wide. Nevertheless the percentage of facies observed in cores, and particularly their juxtaposition, can offer some clues as to the environments of deposition of Facies Associations. The Facies Associations will now be discussed in detail.

## Facies Association 1A

This Association occurs intermittently across the Tirrawarra Field, being identified in 20 of the 62 wells (Figure 18). Only two cores contain strata belonging to Facies Association 1A. These are Tirrawarra 5, Core 8 (Figure 15.16 ) and Tirrawarra 12, Core 3 (Figure 15.20 ).

The core from Tirrawarra 5 was cut too low to intersect



Occurence of Facies Association 1A
FIGURE 18
3
6
22
Tirrawarra North 1
140° 05'
16
9
10
19
26
4
56
Rakoona 1
46
48
44
59
8
Tirrawarra West 1
12
28
13
27° 40'
27° 40'
20
17
27
35
52
38
23
7
37
15
Tirrawarra 1
49
36
24
31
45
57
21
33
25
N
41
18
47
14
50
34
54
PATCHAWARRA FM.
2
29
40
58
30
DISTRIBUTION OF
55
32
42
53
51
43
39
FACIES ASSOCIATION 1A
11
TIRRAWARRA FIELD
SCALE
140° 05'
5
S. Kennedy. 1987

FIGURE 18

the thick sandstone by which the Facies Association is defined. Only shales, thin coals and thin sandstones immediately overlying the Tirrawarra Sandstone were intersected. The thick sandstone from Facies Association 1A in Tirrawarra 5 has been identified by gamma log interpretation.

In Tirrawarra 12, Core 3 (Figure 15.20), the Facies Association 1A sandstone is 7 feet thick from core investigation but 10 feet thick from gamma log interpretation. The latter is probably more accurate, since the core had not been split and some of it may have been missing, thus lithological features were hard to identify. The gamma log profile suggests an upward coarsening sandstone. This may be a shoreline sand.

Examination of wireline logs from wells intersecting Facies Association 1A shows gamma ray responses that indicate the presence of upward-fining, blocky and upward-coarsening sandstones up to 22 feet thick (Tirrawarra 39). The most common type is upward-fining, suggesting point bar deposits.

It is possible that Facies Association 1A is equivalent to the Moorari Beds defined by Kapel (1972) and discussed by Williams (1982). Kapel (1972) considered the Moorari Beds as belonging to the basal Patchawarra Formation, but Williams (1982) stated that Gostin (1973) may have ascribed them to the upper part of the Tirrawarra Sandstone.

Facies Association 1A reaches a maximum thickness of 59 feet at Tirrawarra 44 in the west-central part of the field.

### Facies Association 1B

This Association occurs in all 62 wells of the Tirrawarra Field. It has been intersected by cores from 5 of the 13 cored wells. Facies Association 1B directly overlies the Tirrawarra Sandstone where Facies Association 1A is absent.

In Tirrawarra 2, Cores 3 and 4 (Figures 15.4 and 15.5 ), 120 feet of Facies Association 1B is represented. Most of this consists of mudrocks, notably facies states Fm and Fw, although Fl is also present. Some thin coals directly overlie mudrocks. Fine rippled and massive sandstones overlie the Fl and Fm facies in several upward-coarsening sequences.

In Tirrawarra 11, Core 1 (Figure 15.17 ), 53 feet of Facies Association 1B has been cut. This directly overlies the Tirrawarra Sandstone. Three small upward-coarsening and one upward-fining sequences are present. Thin coal bands also occur. Fm is the most common facies state.

Just 9 feet of Facies Association 1B has been intersected by Tirrawarra 12, Core 3 (Figure 15.20 ). This core has not been split, but has been tentatively logged as Fm, overlain by a thin band of carbonaceous shale and coal.

In Tirrawarra 17, Cores 1 and 2 (Figure 15.24 ), the 23 feet of Facies Association 1B consists almost entirely of heterolithic interbeds.

Tirrawarra 32, Cores 1 and 2 (Figure 15.27 ) has cut 54 feet of Facies Association 1B. This consists mainly of facies Fm, but some coarser facies (notably Sw), and also coal are present. No upward- coarsening or upward-fining sequences exist in this cored section.

Facies Association 1B is the thickest of the Facies Associations described. It reaches a maximum thickness of 456 feet in Tirrawarra 11 at the southern end of the field and thins out to a minimum of 241 feet in Tirrawarra 13 near the centre of the field (Figure 19.1).

Sand percentages and total sand footages of this Facies Association and also Facies Associations 2A, 2B and 3 have been calculated for each well after using a cut-off obtained from core and gamma log parameters described under Core Investigation.

The highest log sand percentage in Facies Association 1B is 35.1 per cent in Tirrawarra West 1, while Rakoona 1 contains the maximum gross sand footage with 132 feet. The lowest sand percentage is 8.2 per cent in Tirrawarra 1 which also has the minimum of 28 feet of gross sand (Figures 19.2 and 19.3 ).

Facies Association 1A and 1B may have been deposited in an environment varying in time from lake (or restricted sea) to upper delta plain in character. Some fine sediments are interpreted as lake fill (Figure 15.4, 15.5). Upward-coarsening sandstones may represent shoreline sands or crevasse splay deposits (Figure 15.16). Thus it is likely that eustatic sea levels were high at some stages. However upward–fining sandstone sequences are interpreted as point bar deposits. A combination of upward-fining and upward-coarsening sand bodies is responsible for the high sand percentage at the southern end of the field in the Tirrawarra 5 and Tirrawarra 39 area (Figure 19.2).

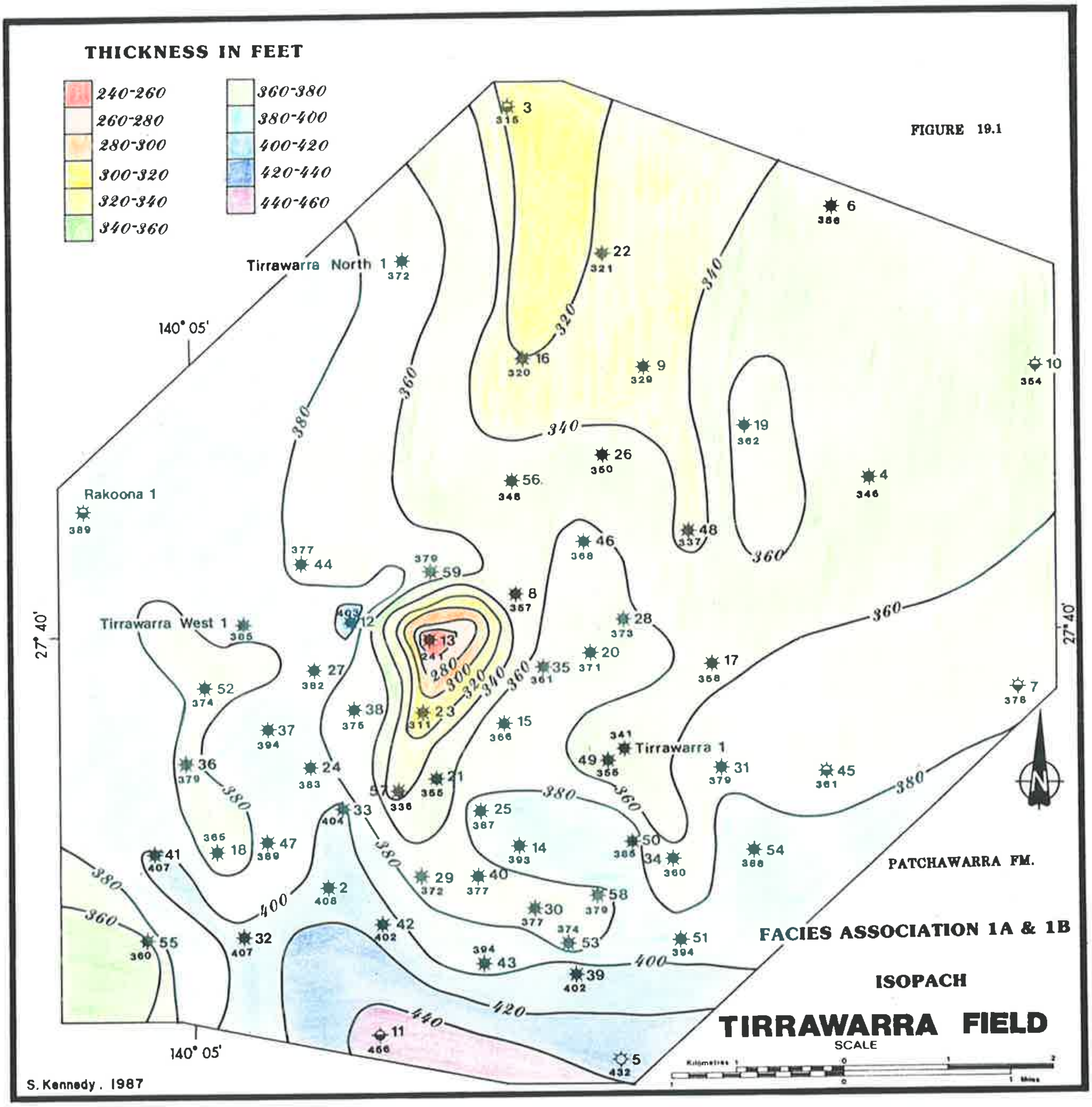

THICKNESS IN FEET
240-260
260-280
280-300
300-320
320-340
340-360
360-380
380-400
400-420
420-440
440-460
FIGURE 19.1
Tirrawarra North 1
372
Rakoona 1
389
Tirrawarra West 1
365
Tirrawarra 1
341
140° 05'
27° 40'
3 315
6 356
22 321
16 320
9 329
10 354
19 362
26 350
56 348
4 346
48 337
46 368
44 377
59 379
8 357
12 403
13 241
28 373
20 371
35 361
27 382
52 374
17 358
7 378
38 375
23 311
15 366
37 394
36 379
24 383
57 336
21 355
49 356
31 379
45 361
33 404
25 367
18 365
47 369
41 407
50 365
34 360
54 366
14 393
29 372
40 377
2 408
58 379
30 377
53 374
42 402
32 407
55 360
51 394
43 394
39 402
11 456
5 432
240
260
280
300
320
340
360
380
400
420
440
PATCHAWARRA FM.
FACIES ASSOCIATION 1A & 1B
ISOPACH
TIRRAWARRA FIELD
SCALE
Kilometres 1 0 1 2
1 0 1 Miles
N
S. Kennedy. 1987

FIGURE 19.1

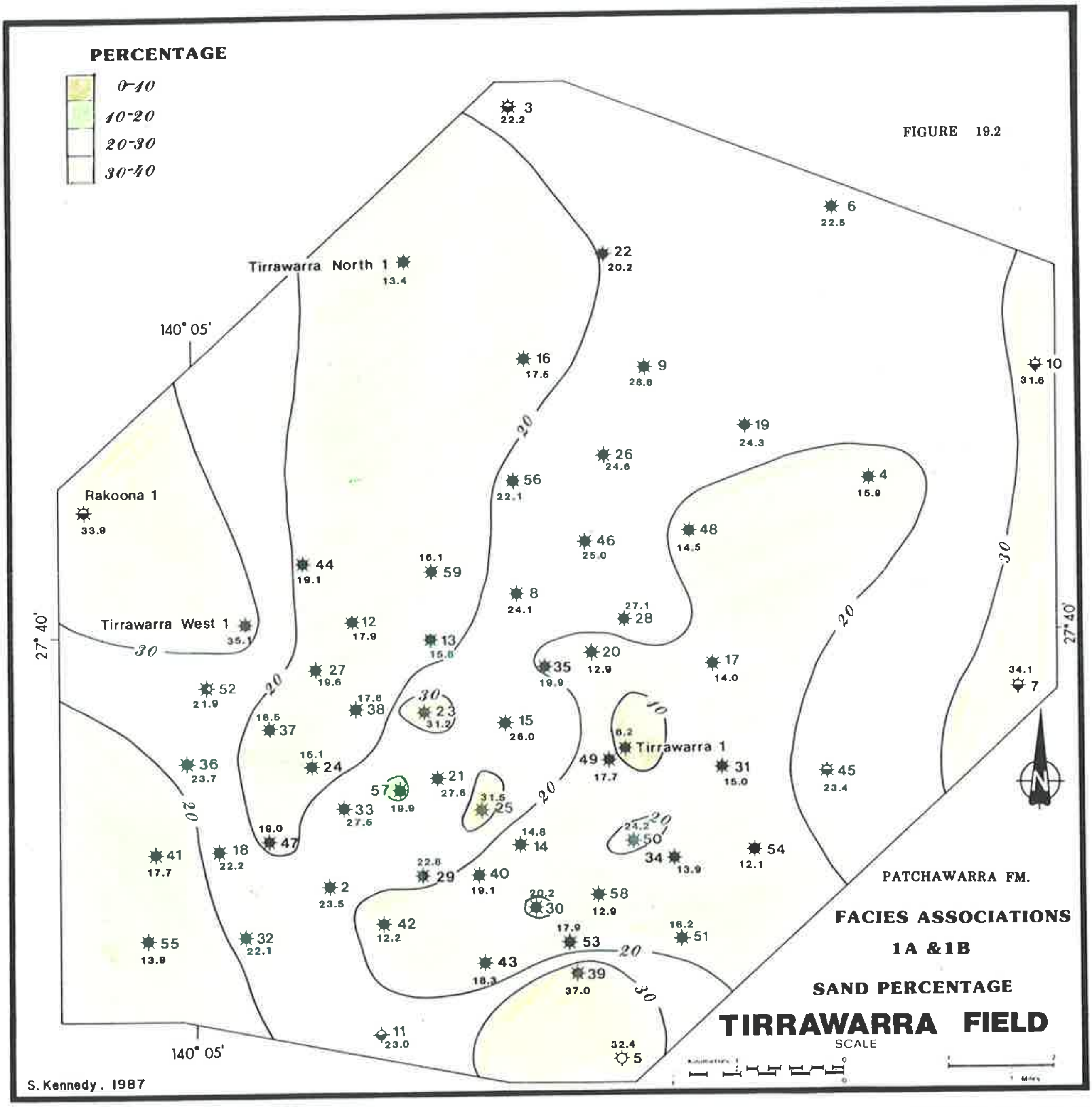

PERCENTAGE
0-10
10-20
20-30
30-40
FIGURE 19.2
3 22.2
6 22.5
22 20.2
Tirrawarra North 1 13.4
140° 05'
16 17.5
9 28.8
10 31.6
19 24.3
26 24.6
56 22.1
4 15.9
Rakoona 1 33.9
48 14.5
46 25.0
44 19.1
16.1 59
8 24.1
27.1 28
Tirrawarra West 1 35.1
12 17.9
13 15.8
20 12.9
35 19.9
17 14.0
34.1 7
27° 40'
52 21.9
27 19.6
17.6 38
23 31.2
15 26.0
18.5 37
8.2 Tirrawarra 1
49 17.7
31 15.0
36 23.7
15.1 24
57 19.9
21 27.6
31.5 25
45 23.4
33 27.5
19.0 47
14.8 14
24.2 50
34 13.9
54 12.1
41 17.7
18 22.2
22.8 29
40 19.1
2 23.5
20.2 30
58 12.9
42 12.2
17.9 53
16.2 51
55 13.9
32 22.1
43 18.3
39 37.0
11 23.0
32.4 5
10
20
30
PATCHAWARRA FM.
FACIES ASSOCIATIONS
1A &1B
SAND PERCENTAGE
TIRRAWARRA FIELD
SCALE
Kilometres 1 0
1 Miles
S. Kennedy. 1987

FIGURE 19.2

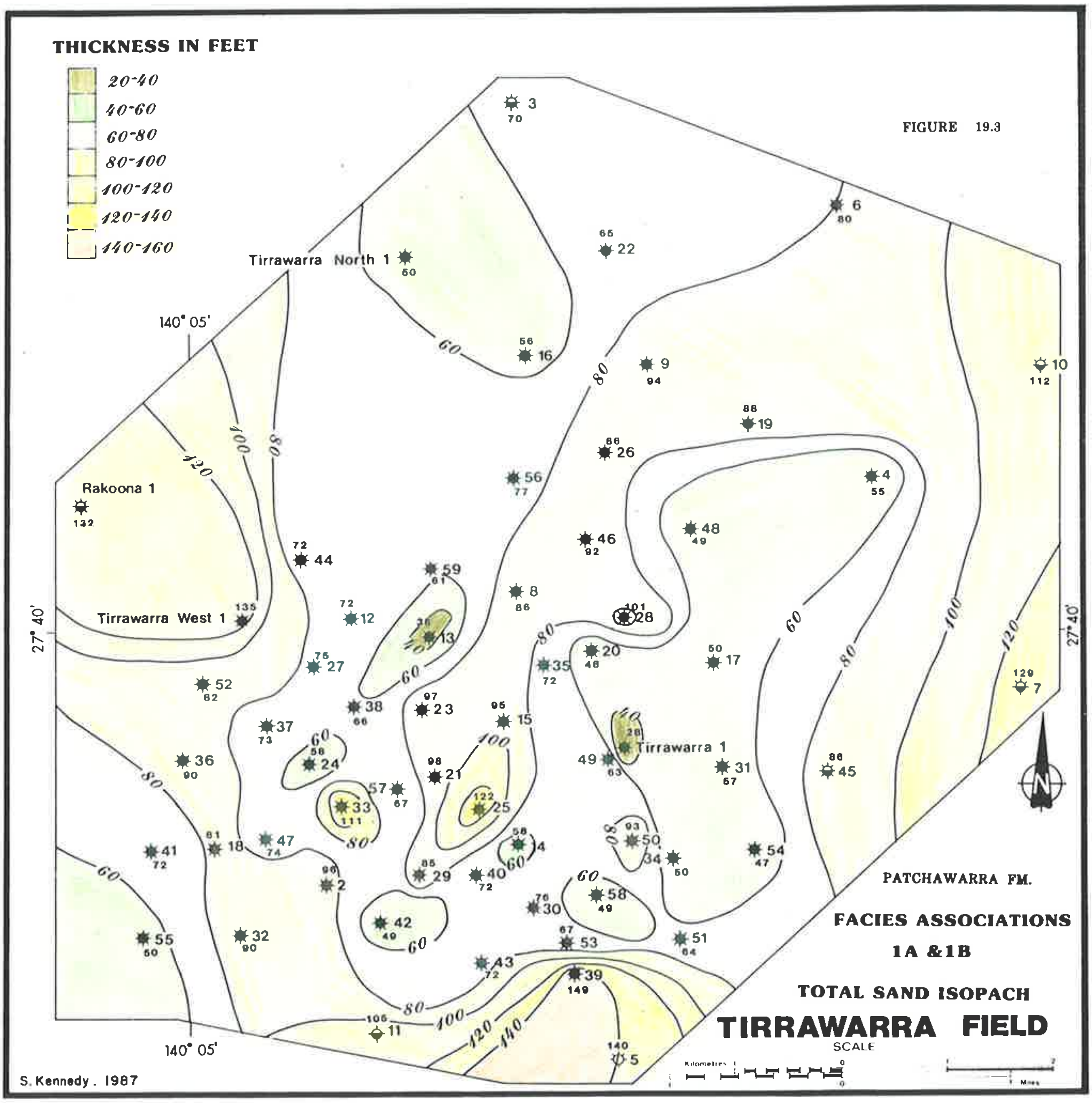

THICKNESS IN FEET
20-40
40-60
60-80
80-100
100-120
120-140
140-160
FIGURE 19.3
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
140° 05'
27° 40'
PATCHAWARRA FM.
FACIES ASSOCIATIONS
1A &1B
TOTAL SAND ISOPACH
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
N
S. Kennedy . 1987
60
80
100
120
140

FIGURE 19.3

### Facies Association 2A

This Facies Association equates to the lower half of Williams' (1982) Facies Association 2. It occurs field wide and is intersected by cores from Tirrawarra 1, 2, 3 and 5.

In Tirrawarra 1, Cores 4 and 5 (Figure 15.1 ), the 27 feet of Facies Association 2A core consists entirely of coal, which represents the Patchawarra Coal.

Core 2 from Tirrawarra 2 (Figure 15.3 ) consists of 45 feet of Facies Association 2A. 12 feet of flat laminated mudstone, capped by coal, is overlain by three successive upward-fining sequences, two of which commence with massive conglomerate. These conglomerates pass up into massive and wave rippled sandstone, and in the case of the topmost sequence, grades up into massive mudstone and coal.

In Tirrawarra 3, two separate cores have been cut in Facies Association 2A. In Core 2 (Figure 15.7 ), a section of 50 feet, planar cross bedded and massive sandstones abruptly overlie a thick coal. The sandstone then grades up into a massive mudstone which is gradually replaced by carbonaceous shale and thin coal. This upward-fining sequence is then overlain by another thin upward-fining sequence.

In Core 1 (Figure 15.6 ), 9 feet of Patchawarra Coal represents Facies Association 2A.

In Tirrawarra 5, Cores 4 to 7 (Figures 15.12 to 15.15 ), 196 continuous feet of Facies Association 2A is featured, and this represents all but the lower 24 feet of this Facies Association. The cored section commences with heterolithic interbeds which are overlain by massive mudstone, then a thick coal bed. An upward-fining sequence follows with massive sandstone gradually giving way to massive mudstone. Following this, a coarse and thick massive sandstone, containing thin chaotic conglomerate layers has been deposited. Several truncated upward-fining sequences follow, containing features such as planar and trough cross bedding, ripple marks and chaotic conglomerate. The top upward-fining sequence is overlain by the thick Patchawarra Coal.

Facies Association 2A has a maximum thickness of 245 feet in Tirrawarra 11 at the southern end of the field and in Tirrawarra 44 in the central- west part of the field. The minimum thickness is 129 feet in Tirrawarra 6 at the northern end of the field (Figure 20.1 ).

The highest log sand percentage is 40.0 per cent in Tirrawarra 5 at the southern end of the field, and this well also contains the maximum gross sand measurement of 88 feet for Facies Association 2A. Tirrawarra 56 in the central part of the field has the minimum of 4 feet of logged sand, or 2.6 per cent for this Facies Association (Figures 20.2 and 20.3 ).

The lower part of Facies Association 2A may have been deposited in an environment with relatively high eustatic water levels, as suggested by lake fill deposits and crevasse splay deposits interpreted from gamma ray patterns. Unfortunately only Tirrawarra 5 has core from this horizon (Figure 15.15).

However the top half of Facies Association 2A contains many upward-fining sequences as observed in core and in gamma ray patterns in composite logs. This suggests that point bars were deposited by meandering streams during a

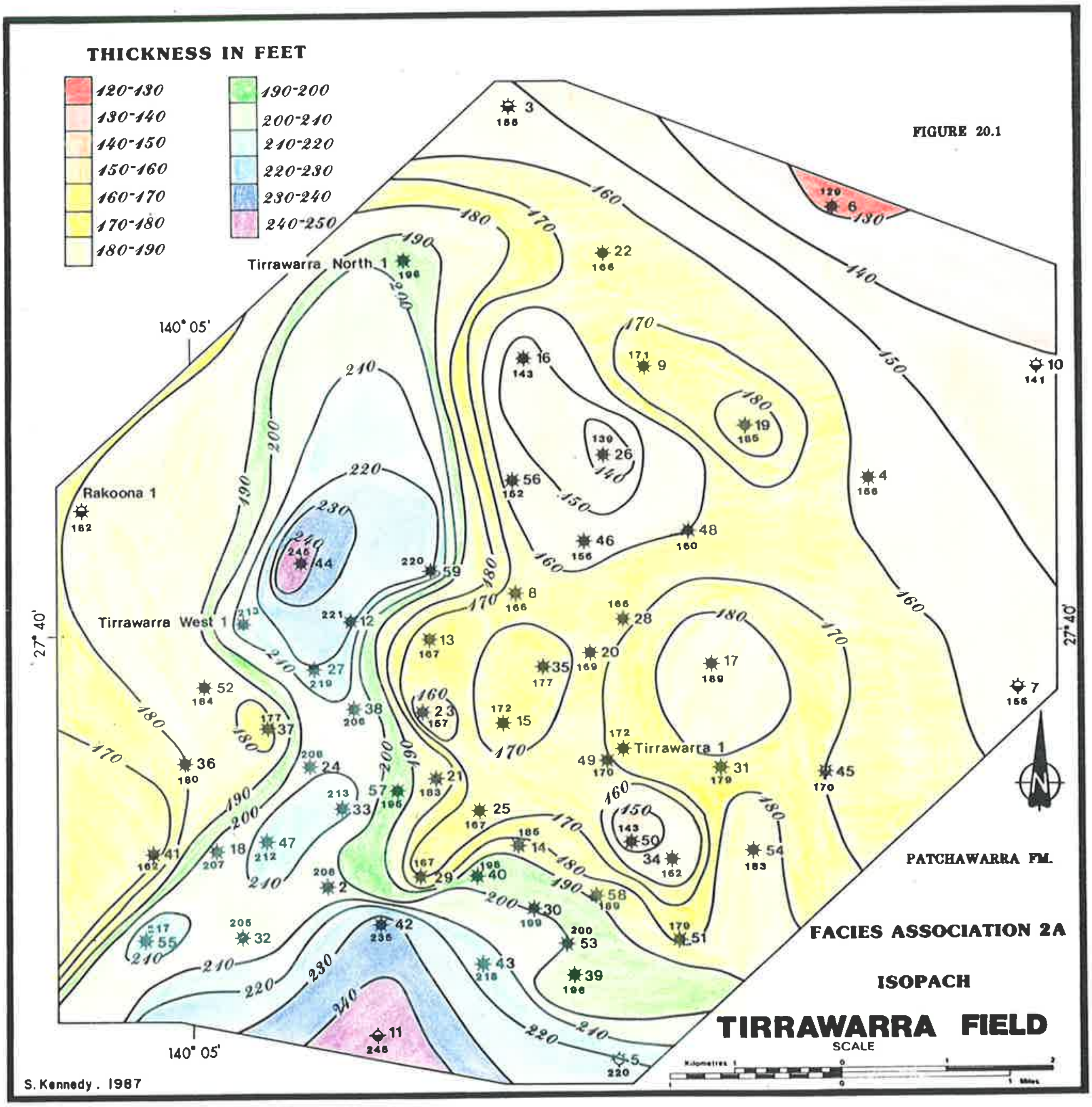

THICKNESS IN FEET
120-130
130-140
140-150
150-160
160-170
170-180
180-190
190-200
200-210
210-220
220-230
230-240
240-250
FIGURE 20.1
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
140° 05'
27° 40'
PATCHAWARRA FM.
FACIES ASSOCIATION 2A
ISOPACH
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
S. Kennedy. 1987

FIGURE 20.1

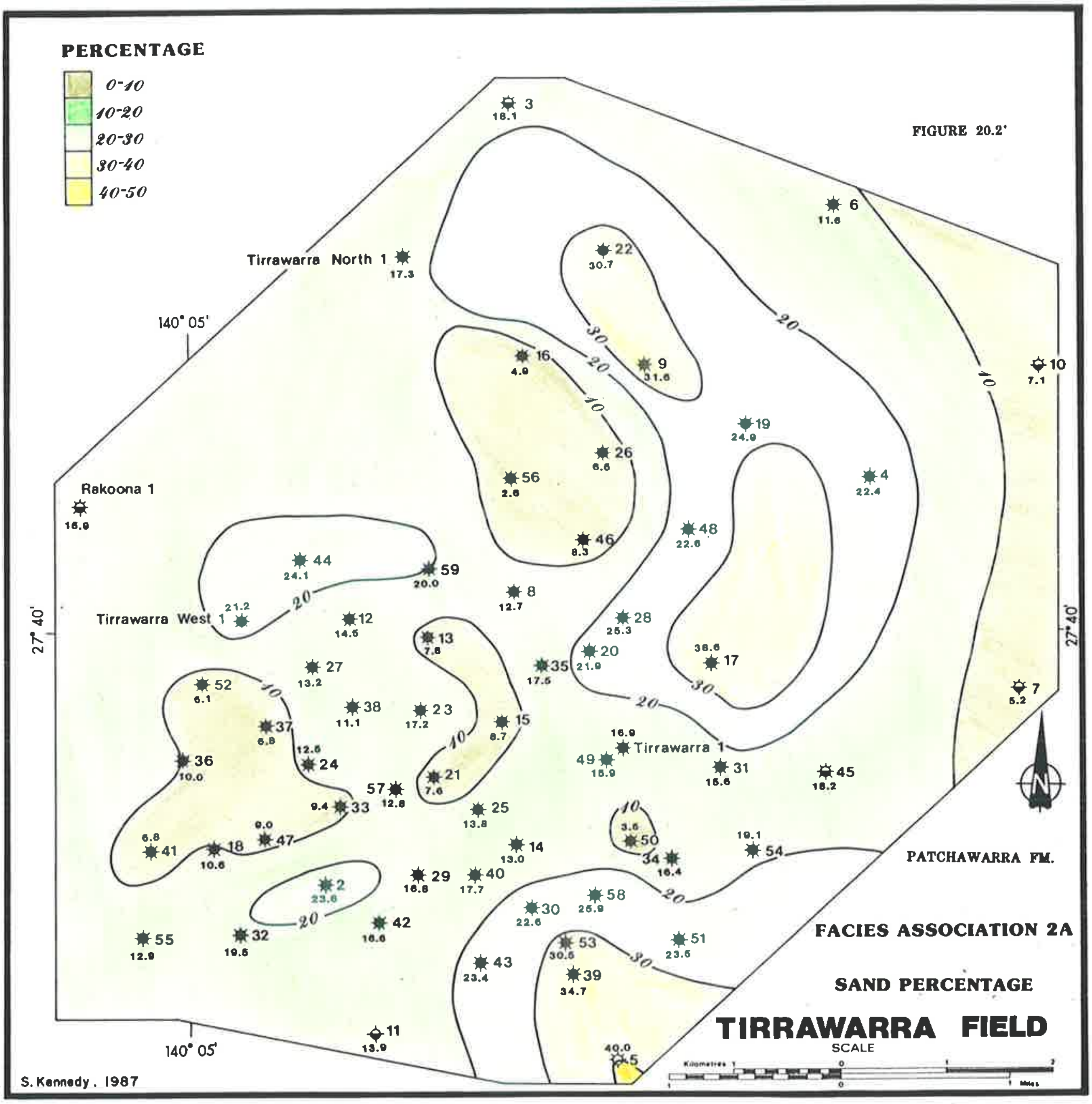

PERCENTAGE
0-10
10-20
20-30
30-40
40-50
FIGURE 20.2'
Tirrawarra North 1 17.3
Rakoona 1 16.9
Tirrawarra West 1 21.2
Tirrawarra 1 16.9
140° 05'
27° 40'
3 18.1
6 11.6
22 30.7
9 31.6
16 4.9
26 6.6
56 2.6
46 8.3
19 24.9
4 22.4
10 7.1
48 22.6
44 24.1
59 20.0
8 12.7
12 14.5
13 7.6
28 25.3
17 38.6
35 17.5
20 21.9
27 13.2
52 6.1
7 5.2
38 11.1
23 17.2
15 8.7
37 6.8
24 12.5
36 10.0
49 15.9
31 15.6
45 18.2
21 7.6
57 12.8
33 9.4
25 13.8
50 3.5
47 9.0
41 6.8
18 10.6
14 13.0
34 16.4
54 19.1
2 23.6
29 16.8
40 17.7
58 25.9
30 22.6
42 16.6
55 12.9
32 19.5
53 30.5
51 23.5
43 23.4
39 34.7
11 13.9
5 40.0
10
20
30
PATCHAWARRA FM.
FACIES ASSOCIATION 2A
SAND PERCENTAGE
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
N
S. Kennedy. 1987

FIGURE 20.2

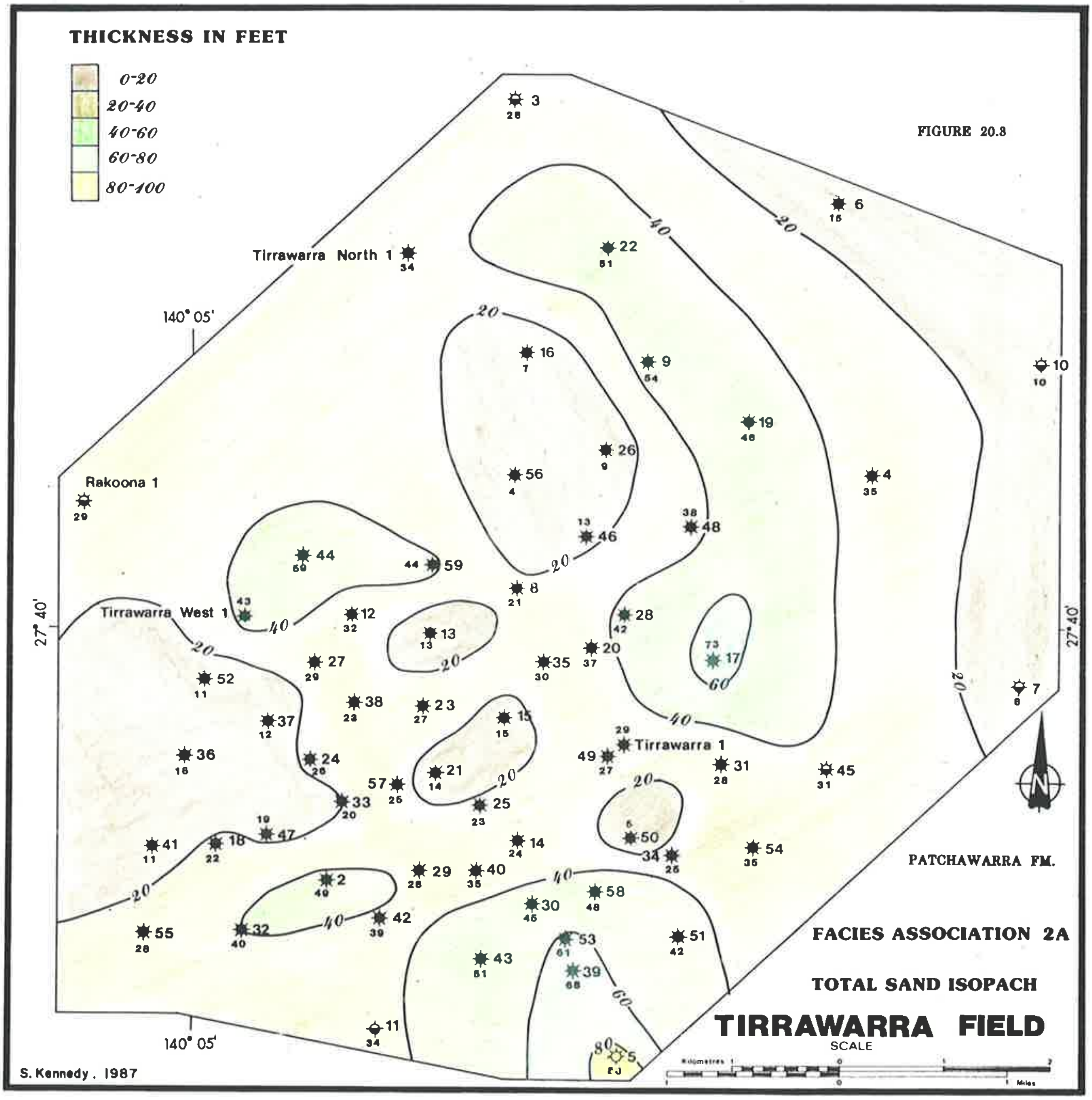

THICKNESS IN FEET
0-20
20-40
40-60
60-80
80-100
FIGURE 20.3
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
140° 05'
27° 40'
PATCHAWARRA FM.
FACIES ASSOCIATION 2A
TOTAL SAND ISOPACH
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
S. Kennedy . 1987
20
40
60
80

FIGURE 20.3

marine (or lake) regression. Facies Association 2A culminates in the Patchawarra Coal, indicating a large swamp covered the area, and perhaps suggesting a eustatic still-stand.

## Facies Association 2B

This Facies Association is equivalent to the top half of Williams' (1982) Facies Association 2, and is continuous across the field. It has been intersected by cores from Tirrawarra 1, 2, 3, 4, 5, 12, 13, 16, 19 and 28 and is thus well represented.

In Tirrawarra 1, Core 4 (Figure 15.1 ), 28 feet of the lower part of Facies Association 2B is present. This comprises thick, mainly massive sands. An upward-fining sequence occurs at the top of the cored section.

Tirrawarra 2, Core 1 (Figure 15.2 ) contains 60 feet of Facies Association 2B. Three upward-fining sequences are present. The lower one, which is 40 feet thick, commences with a massive, medium grained sandstone containing chaotic conglomerate. This unit is succeeded by a planar cross bedded sandstone, then trough cross bedded sandstone, wave rippled sandstone, flat laminated carbonaceous mudstone and finally coal. The other two upward-fining sequences are much thinner, being 12 feet and 6 feet thick respectively.

In Tirrawarra 3, Core 1 (Figure 15.6 ), 51 feet of Facies Association 2B is represented. The cored section directly overlies the Patchawarra Coal of Facies Association 2A. It commences with a 7 feet thick upward-coarsening sequence where massive mudstone gradually gives way to massive fine, medium then coarse sandstone. This sequence is then overlain by four upward-fining sequences, and in all of these, massive sandstone is gradually replaced by massive mudstone. Coal is present at the top of the middle upward-fining sequence.

In Tirrawarra 4, Core 2 (Figure 15.9 ), 34 feet of Facies Association 2B has been cored. The section represented commences with a flat laminated carbonaceous mudstone, which is overlain by a thin layer of chaotic conglomerate, then a 10 feet thick coal. This in turn is overlain by massive carbonaceous sandstone which develops into an upward-fining sequence, passing into flat laminated mudstone, then coal.

Facies Association 2B is well represented in the core from Tirrawarra 5, with a total section of 138 feet of continuous core being present in Cores 2 and 3 (Figures 15.11 and 15.12 ). The base of the Facies Association commences with heterolithic interbeds. These are overlain by about 25 feet of coarse grained sandstone which contains planar cross beds and wave ripples. Three upward-fining sequences follow, the central one commencing with massive conglomerate. Not far above the third upward-fining sequence, two thin upward-coarsening sequences occur. Finally at the top of the cored section, an 18 feet thick upward-fining sequence is overlain by a 17 feet thick coal seam containing some carbonaceous shales.

Tirrawarra 12, Cores 1 and 2 (Figures 15.18 and 15.19 ) contain 64 feet of Facies Association 2B. As previously mentioned, the cores had not been split, and internal details are hard to determine. Examination of corresponding gamma ray logs suggests the presence of at least three upward-fining sequences.

The same situation exists for Tirrawarra 13, where 94 feet of unsplit core of Facies Association 2 from Cores 1, 2, 3, 4 and 5 is present (Figures 15.21 and 15.22 ). Three upward-fining sequences have been tentatively identified from gamma log patterns.

In Tirrawarra 16, Cores 1 and 2 (Figure 15.23 ), 55 feet of Facies Association 2B is represented. An upward-fining sequence, containing ripple marks in the central part culminates in a carbonaceous shale. Above this, another upward-fining sequence is abruptly overlain by a coarse sandstone about 15 feet thick. This sandstone is itself overlain abruptly by a well bedded, carbonaceous shale.

The lower part of Facies Association 2B is represented by Cores 1 and 2 of Tirrawarra 19 (Figure 15.25 ). 47 feet of core is present, but it has not been split. Two upward-fining sequences occur. In these, rippled and massive sandstone are overlain by wave rippled mudstone.

Tirrawarra 28, Core 1 (Figure 15.26 ), contains 30 feet of Facies Association 2B. Two upward-fining sequences are present, in which sandstones gradually give way to mudstones. The topmost sequence is abruptly overlain by a thin conglomerate and coarse, massive sandstone.

Facies Association 2B is thickest at the southern end of the field with 230 feet in Tirrawarra 11 and thinnest in the central-west part of the field with 132 feet in Tirrawarra 4 (Figure 21.1 ).

Sand percentages are higher than in Facies Association 2A, but this is in part an artifact due to the fact that

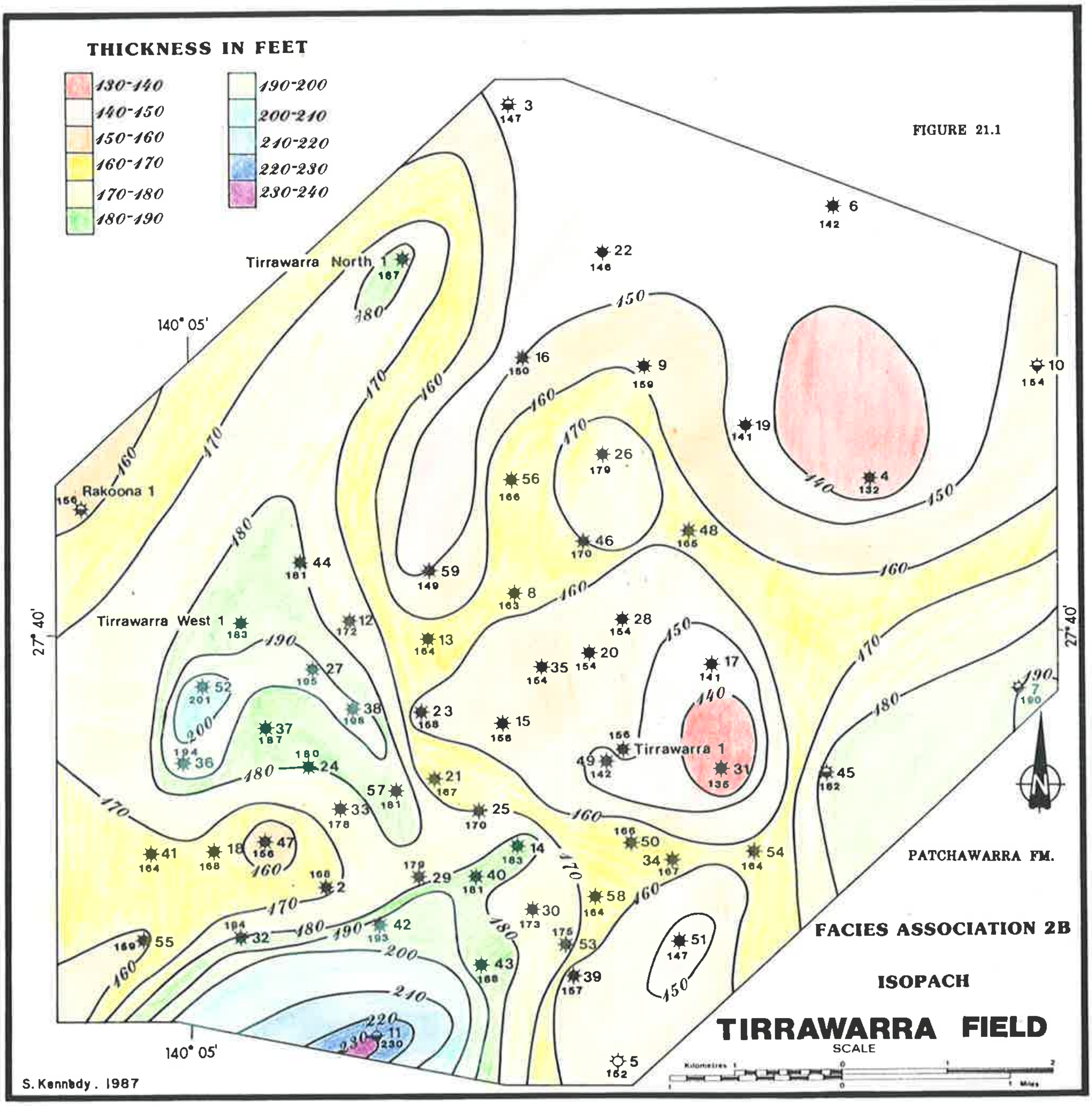

THICKNESS IN FEET
130-140
140-150
150-160
160-170
170-180
180-190
190-200
200-210
210-220
220-230
230-240
FIGURE 21.1
Tirrawarra North 1
Tirrawarra West 1
Tirrawarra 1
Rakoona 1
140° 05'
27° 40'
PATCHAWARRA FM.
FACIES ASSOCIATION 2B
ISOPACH
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
S. Kennedy. 1987

FIGURE 21.1

the thick Patchawarra Coal is included in 2A but not in 2B. The maximum sand percentage recorded was in the east-central field with 61.5 per cent in Tirrawarra 45. The greatest, logged gross sand thickness was 114 feet in Tirrawarra 17 on the eastern extremity.

A minimum percentage of sand, 18.7 per cent, occurs in the south in Tirrawarra 11, while Tirrawarra 17 in the central-east and Tirrawarra 55 in the south-west have only 31 feet of gross sand each. (Figures 21.2 and 21.3 ).

In conclusion upward fining sandstones are dominant in Facies Association 2B and this suggests deposition from meandering streams. The environment was probably that of an upper delta plain , with relatively low eustatic water levels.

The thick sandstones of Facies Associations 2A and 2B form the principal gas reservoirs of the Tirrawarra Field.

### Facies Association 3

This Facies Association equates with Williams' (1982) Facies Association 3. It has been intersected in core from Tirrawarra 4 and 5.

In Tirrawarra 4, Core 1 (Figure 15.8 ), 27 feet of Facies Association 3 is present. this consists almost entirely of mudrock. Some is well bedded, but other parts are bioturbated and structureless. Heterolithic interbeds are present at the top of the Facies Association and these are overlain by the grey, well bedded Murteree Shale.

Tirrawarra 5, Core 1 (Figure 15.10 ), contains 30 feet from the middle part of Facies Association 3. Two small upward- coarsening sequences are overlain by wave rippled

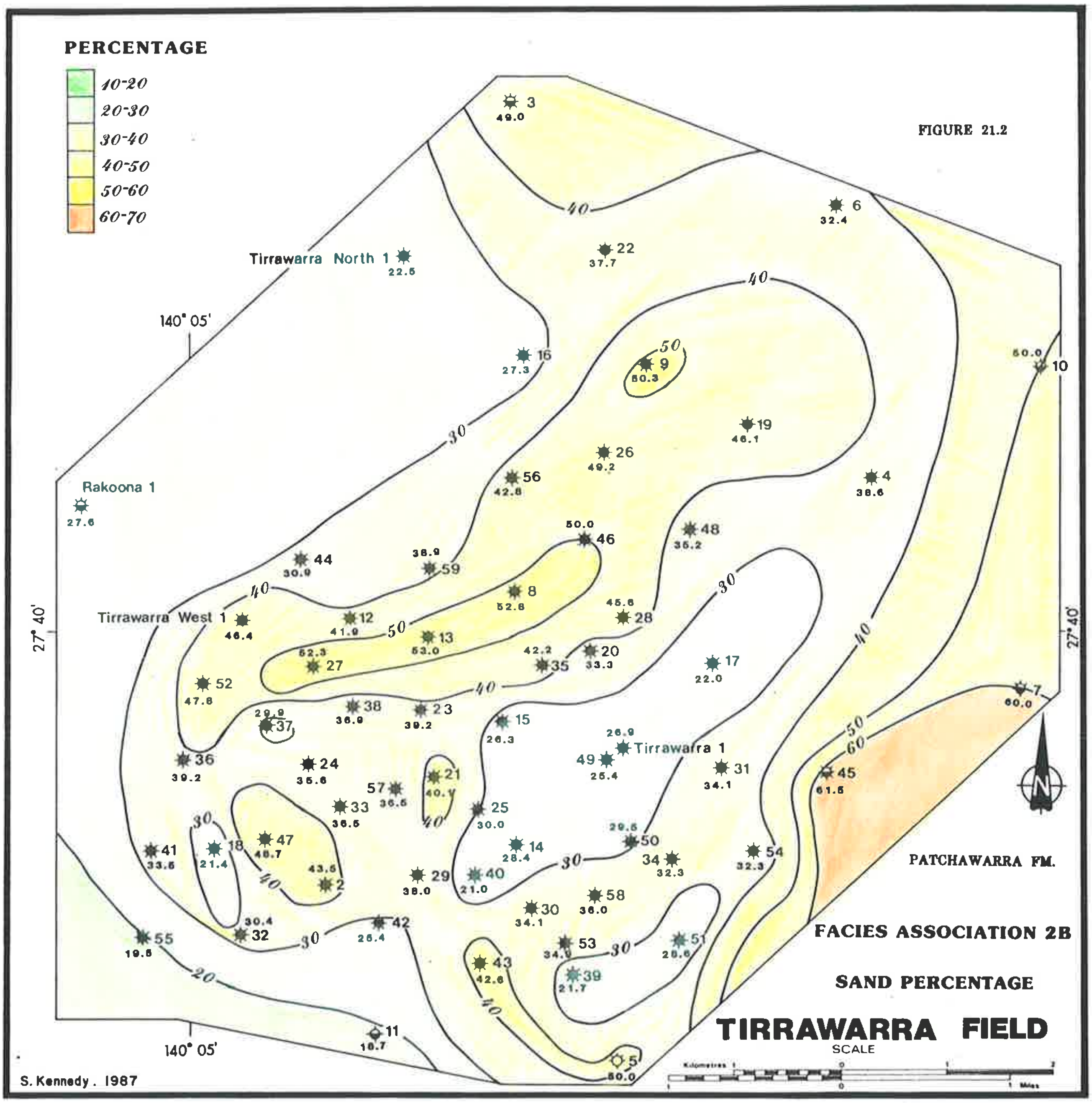

PERCENTAGE
10-20
20-30
30-40
40-50
50-60
60-70
FIGURE 21.2
Tirrawarra North 1
22.5
Rakoona 1
27.6
Tirrawarra West 1
46.4
Tirrawarra 1
26.9
140° 05'
27° 40'
N
PATCHAWARRA FM.
FACIES ASSOCIATION 2B
SAND PERCENTAGE
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
S. Kennedy . 1987
3 49.0
6 32.4
22 37.7
16 27.3
9 50.3
10 60.0
19 46.1
26 49.2
56 42.8
4 36.6
48 35.2
46 50.0
44 30.9
59 36.9
8 52.8
12 41.9
13 53.0
28 45.6
27 52.3
35 42.2
20 33.3
17 22.0
52 47.8
38 36.9
23 39.2
37 29.9
15 26.3
7 60.0
49 25.4
31 34.1
45 61.5
36 39.2
24 35.6
57 36.5
21 40.1
33 36.5
25 30.0
50 29.5
41 33.5
18 21.4
47 46.7
14 28.4
34 32.3
54 32.3
2 43.5
29 38.0
40 21.0
58 36.0
30 34.1
55 19.5
32 30.4
42 25.4
53 34.9
51 25.6
43 42.6
39 21.7
11 18.7
5 50.0
10 20 30 40 50 60

FIGURE 21.2

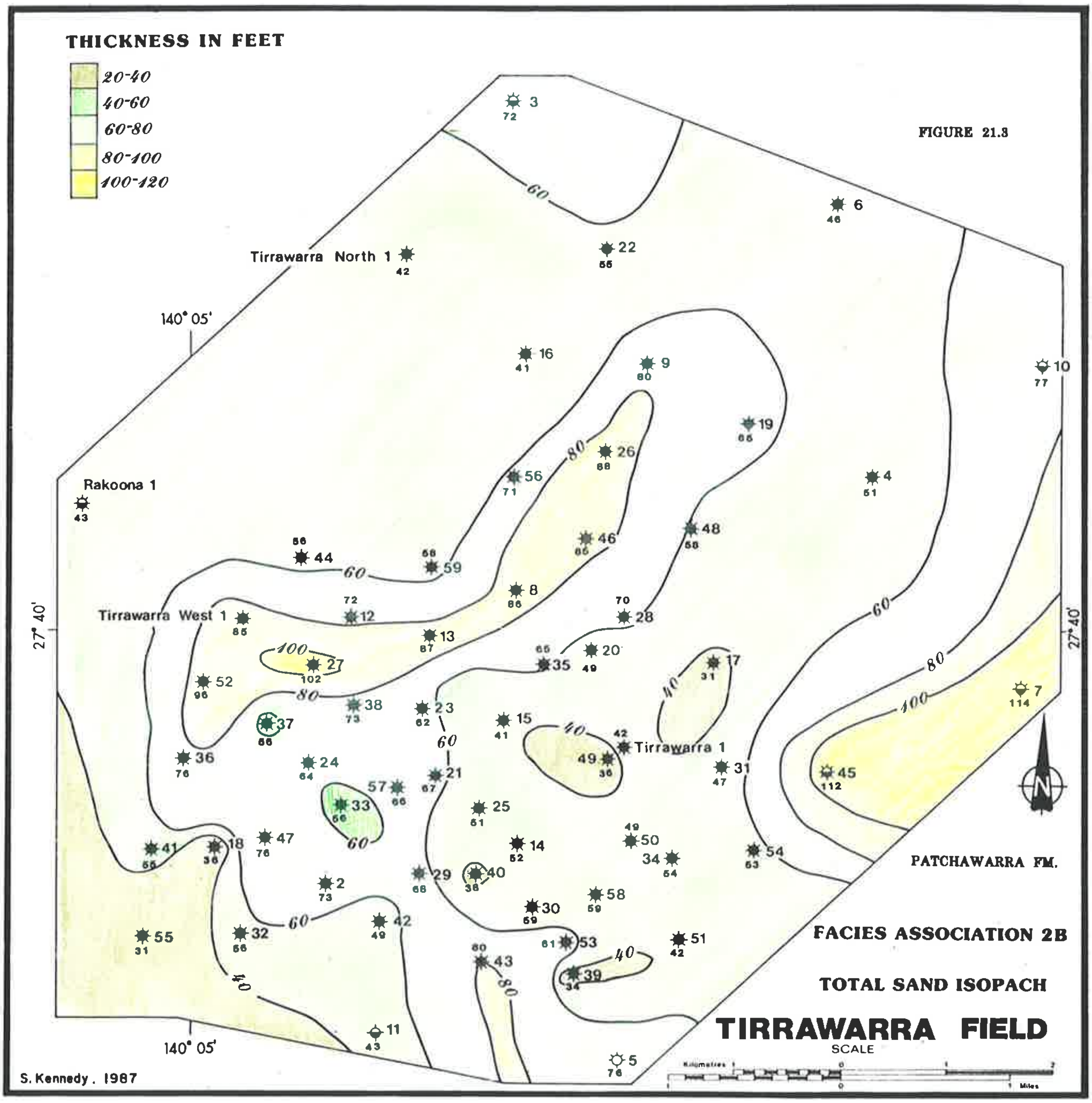

THICKNESS IN FEET
20-40
40-60
60-80
80-100
100-120
FIGURE 21.3
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
140° 05'
27° 40'
60
80
100
40
PATCHAWARRA FM.
FACIES ASSOCIATION 2B
TOTAL SAND ISOPACH
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
S. Kennedy. 1987

FIGURE 21.3

and massive mudrock.

Facies Association 3 is dominated by mudrocks. The Association thins progressively from south to north, the maximum thickness being 226 feet in Tirrawarra 55 in the south east and the minimum thickness being 136 feet in Tirrawarra 6 in the north (Figure 22.1 ).

Logged sand percentages are relatively low, compared to Facies Associations 2A and 2B. Tirrawarra West 1 shows the maximum at 40.0 per cent and also the maximum gross sand of 80 feet. Tirrawarra 15, in the centre of the field, has only 3.9 per cent of sand with 6 feet of gross sand (Figures 22.2 and 22.3 ).

Upward-fining sequences are much less common in Facies Association 3, the dominant lithology being of fine grained and heterolithic units. These were deposited during a marine transgression which continued during the deposition of the overlying Murteree Shale.

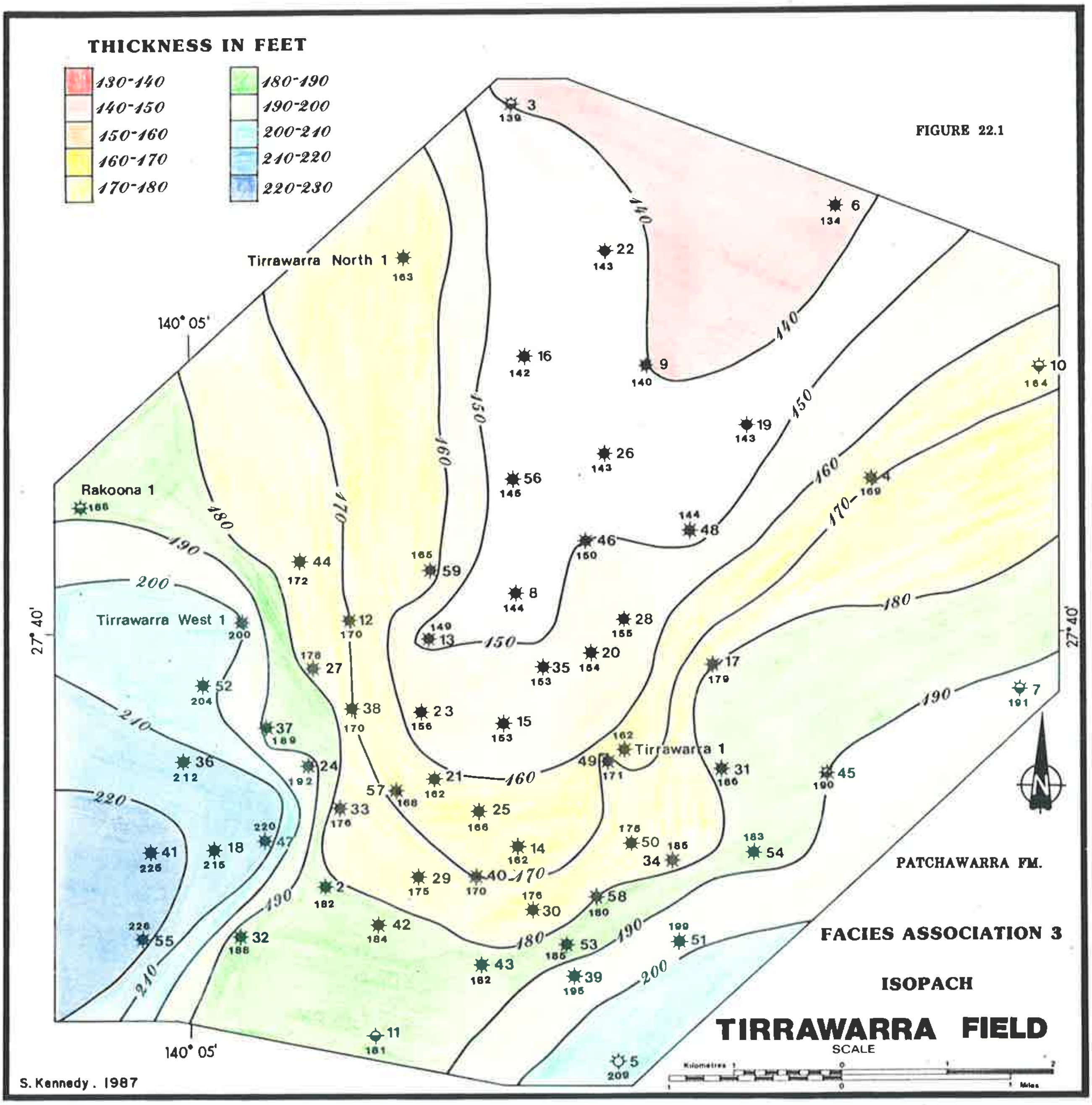

THICKNESS IN FEET
130-140
140-150
150-160
160-170
170-180
180-190
190-200
200-210
210-220
220-230
FIGURE 22.1
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
140° 05'
27° 40'
PATCHAWARRA FM.
FACIES ASSOCIATION 3
ISOPACH
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
S. Kennedy . 1987
140
150
160
170
180
190
200
210
220
3 139
6 134
22 143
9 140
16 142
10 164
19 143
26 143
56 145
4 169
48 144
46 150
8 144
59 165
44 172
12 170
13 149
28 155
20 154
35 153
17 179
27 178
52 204
38 170
23 156
15 153
7 191
37 189
36 212
24 192
57 168
21 162
49 171
Tirrawarra 1 162
31 186
45 190
33 176
25 166
50 178
34 185
54 183
14 162
41 226
18 215
47 220
2 182
29 175
40 170
30 176
58 180
51 199
42 184
55 226
32 188
53 186
43 182
39 195
11 181
5 209
Tirrawarra North 1 163
Rakoona 1 186
Tirrawarra West 1 200

FIGURE 22.1

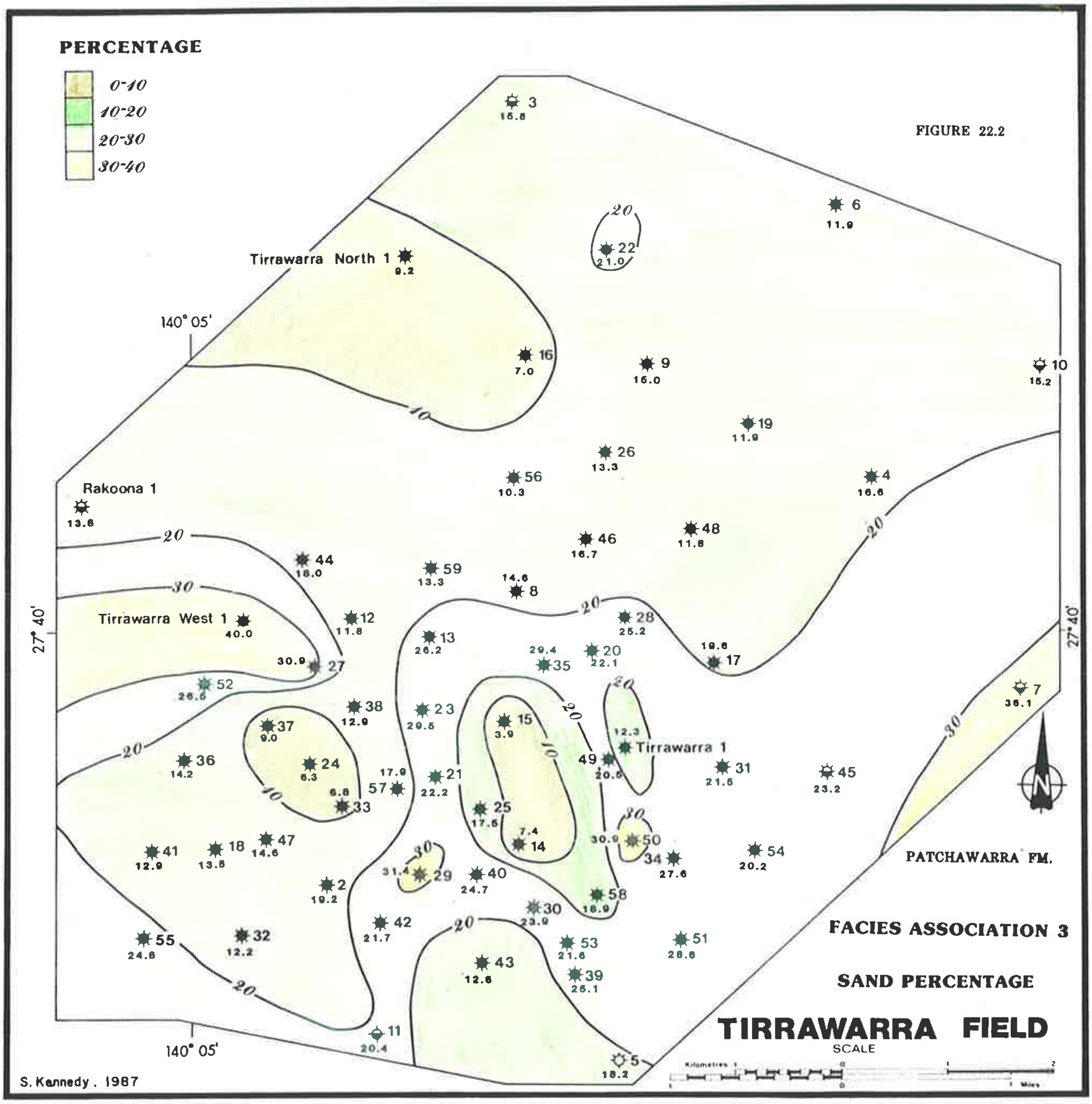

PERCENTAGE
0-10
10-20
20-30
30-40
FIGURE 22.2
3 15.8
6 11.9
22 21.0
Tirrawarra North 1 9.2
140° 05'
16 7.0
9 16.0
10 15.2
19 11.9
26 13.3
56 10.3
4 16.6
Rakoona 1 13.6
46 16.7
48 11.8
44 16.0
59 13.3
8 14.6
27° 40'
Tirrawarra West 1 40.0
12 11.8
28 25.2
17 19.6
13 26.2
20 22.1
35 29.4
27 30.9
52 26.5
7 36.1
38 12.9
23 20.5
15 3.9
37 9.0
Tirrawarra 1 12.3
49 20.5
31 21.5
45 23.2
36 14.2
24 6.3
57 17.9
21 22.2
33 6.8
25 17.5
14 7.4
50 30.9
34 27.6
54 20.2
41 12.9
18 13.5
47 14.6
29 31.4
40 24.7
58 18.9
PATCHAWARRA FM.
2 19.2
42 21.7
30 23.9
55 24.8
32 12.2
53 21.6
51 28.6
43 12.6
39 26.1
11 20.4
5 18.2
10
20
30
FACIES ASSOCIATION 3
SAND PERCENTAGE
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
S. Kennedy. 1987

FIGURE 22.2

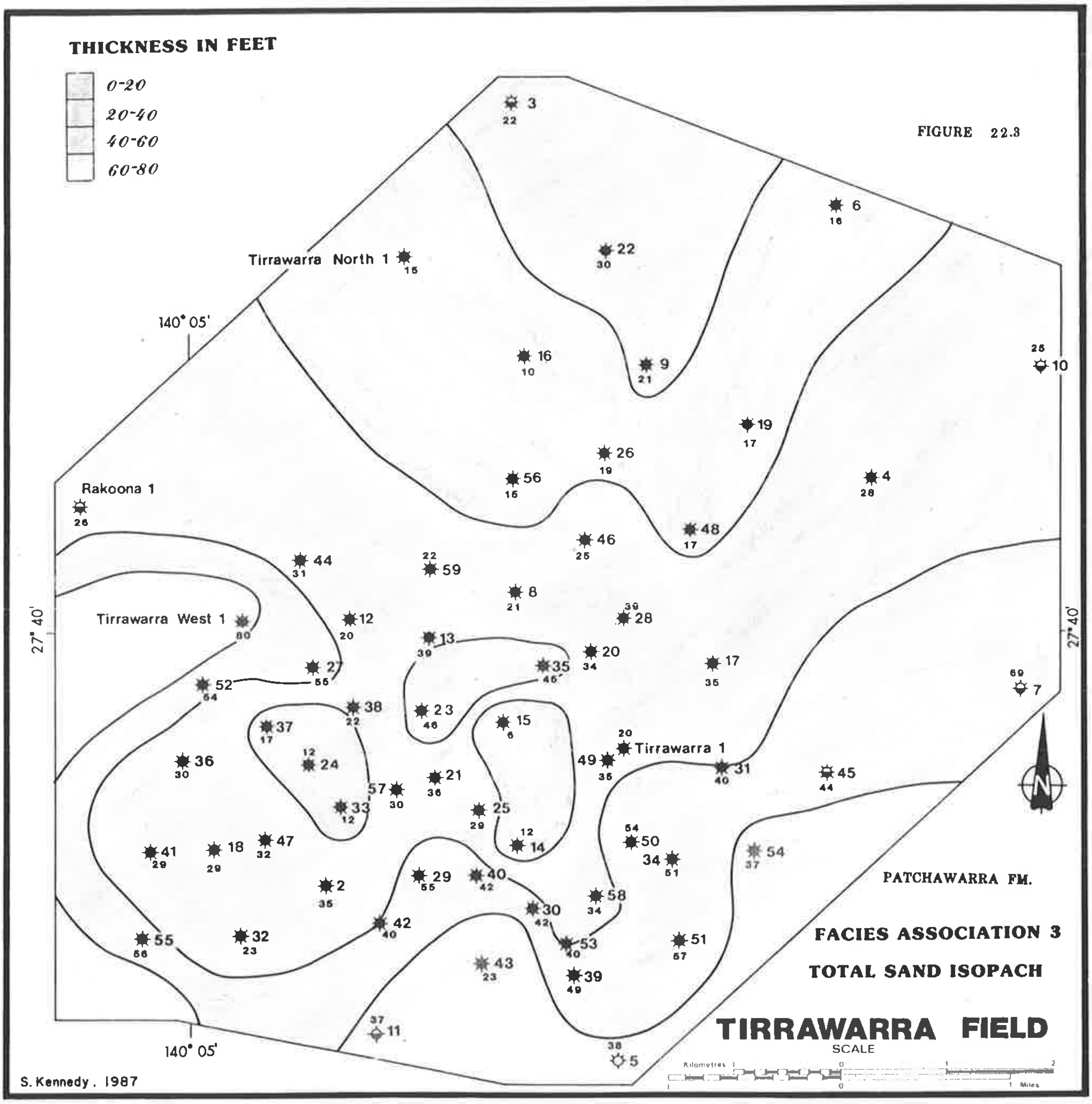
THICKNESS IN FEET
0-20
20-40
40-60
60-80
FIGURE 22.3
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
140° 05'
27° 40'
PATCHAWARRA FM.
FACIES ASSOCIATION 3
TOTAL SAND ISOPACH
TIRRAWARRA FIELD
SCALE
Kilometres 1 0 1 2
1 0 1 Miles
N
S. Kennedy, 1987
3 22
6 16
22 30
15
16 10
9 21
25 10
19 17
26 19
56 15
4 28
26
48 17
46 25
44 31
22 59
8 21
12 20
80
13 39
39 28
20 34
17 35
27 55
35 45
69 7
52 54
38 22
23 46
15 6
37 17
12 24
20
49 35
31 40
45 44
36 30
57 30
21 36
33 12
25 29
12 14
54 50
34 51
54 37
41 29
18 29
47 32
2 35
29 55
40 42
58 34
30 42
42 40
55 56
32 23
53 40
51 57
43 23
39 49
37 11
38 5

FIGURE 22.3

# CHAPTER 6 DEPOSITIONAL AND STRUCTURAL HISTORY

## 6.1 Introduction

In the Tirrawarra Field, the Patchawarra Formation ranges in thickness from 1112 feet in Tirrawarra 11 to 721 feet in Tirrawarra 13 (Figure 23.1). This has been deposited over a total time span of about 10 million years (Figure 3). Thus the net sedimentation rate is extremely low, being only 0.1 feet per thousand years in Tirrawarra 11, where the greatest accumulation occurs. It is apparent though, by recognition of sedimentary facies and structures observed in the core, that sedimentation rates were at times several orders faster than this. Such facies and structures include massive conglomerates and upward-fining (point bar) sequences.

Why then is there an apparent anomaly between estimated net sedimentation rates taken for the Patchawarra Formation as a whole, and rates for small samples of the Patchawarra Formation as estimated in core? This enigma is not unique to the Patchawarra Formation and has been discussed by Beloussov (1962) who pointed out that the distribution patterns of sediments in the geologic column are at variance with the distribution patterns of recent sediments. For example in recent sediments, the thickness of sedimentary accumulations is dependent on facies, but in ancient sediments the thicknesses are independent of facies. Beloussov stated that by far the most common types of continental facies in the geologic section are those from coastal alluvial plains, which are only slightly

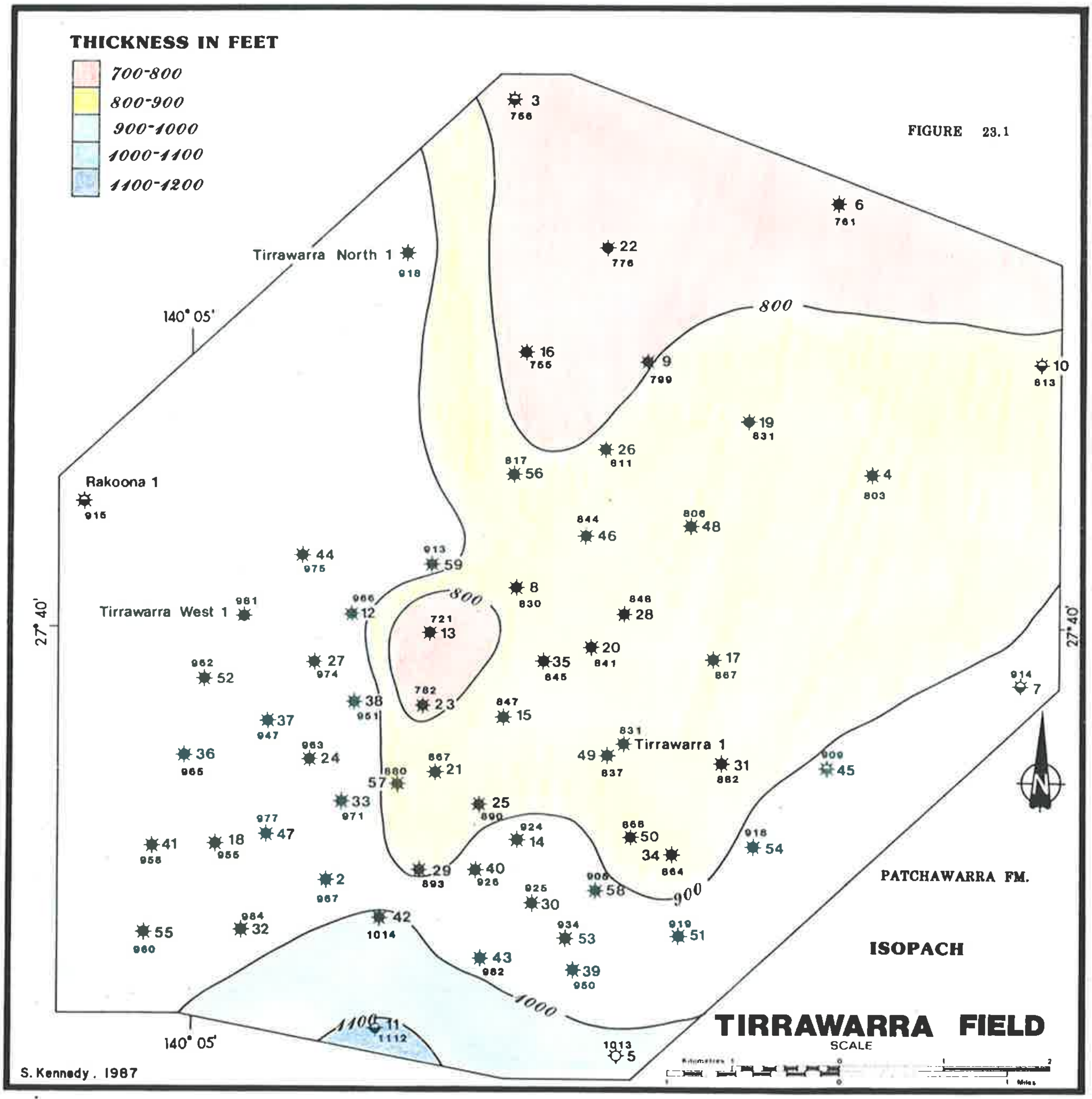

THICKNESS IN FEET
700-800
800-900
900-1000
1000-1100
1100-1200
FIGURE 23.1
3
766
6
761
22
776
Tirrawarra North 1
918
800
140° 05'
16
755
9
799
10
813
19
831
26
811
56
817
4
803
Rakoona 1
915
46
844
48
806
44
975
59
913
8
830
800
Tirrawarra West 1
981
12
966
13
721
28
846
27° 40'
27° 40'
20
841
35
845
17
867
52
962
27
974
38
951
23
782
15
847
7
914
37
947
Tirrawarra 1
831
36
965
24
963
21
867
49
837
31
862
45
909
57
880
33
971
25
890
14
924
50
868
34
864
54
918
41
958
18
955
47
977
2
967
29
893
40
926
30
925
58
906
900
PATCHAWARRA FM.
55
960
32
984
42
1014
53
934
51
919
ISOPACH
43
982
39
950
1000
1100
11
1112
TIRRAWARRA FIELD
SCALE
1013
5
140° 05'
S. Kennedy . 1987
N

FIGURE 23.1

elevated above sea level. This could well be the environmental scenario during Patchawarra time except that an inland sea was possibly the local base level. In these areas of low relief very gentle gradients exist. Stuart (1976), in discussing the sedimentology of the Toolachee Formation, which was laid down in a broadly similar environment to the Patchawarra Formation, stated that gradients probably did not exceed one degree during deposition. In such conditions of low relief, with streams (not necessarily individual streams) acting over a long period of time, the sediments deposited are going to be eroded, transported and re-deposited over and over again.

Beloussov (1962) discussed ancient deltaic sediments on the western slopes of the Urals. Initially many streams flowed across the coastal plain, leaving sediments in a comparitively small area, but channels migrated across the plain redistributing sediments over a large area. "Initially the sedimentary material was deposited unevenly, and the distribution of its facies was irregular; the coarse and fine materials had not been completely sorted, and because of the temporary positions of the channels, were piled in heaps and sinuous bands. But as their channels were displaced, the rivers rewashed their own deposits again and again, correcting the local irregularities in the distribution of clastic material. Such rewashing was promoted by oscillatory crustal movements, displacing the boundary of erosion and transforming the same region into a zone of redistribution and vice versa. As a result, regular distribution of material was achieved in wide zones containing sediments of decreasing grain sizes in accordance with the distance from the boundary of erosion. The accumulation of large thicknesses is only possible during the subsidence of the crust. As a result of this subsidence, redistributed sediments with an averaged and simplified distribution of facies will be fixed in the geologic section, after being covered by more recent sediments." (Beloussov, 1962 p. 250-251). This worker's ideas are summarised by his distinction between two phenomena. " (1) Deposition :- an initial phenomenon of short duration.

(11) Accumulation :- a prolonged phenomenon fixing the sedimentary material in the geologic section." (Beloussov, 1962 p. 267).

It is now relevant to examine the distribution patterns of Patchawarra Formation sediments (and to a lesser extent, Tirrawarra Sandstone) in the Tirrawarra Field, and the relationship of these patterns to the structure of the field. Figure 29 (Enclosure) incorporates other figures describing the structure, thickness, sand thickness, sand percentage and porosities of the different Facies Associations. This figure should be referred to in the following discussion.

## 6.2 Tirrawarra Sandstone

Eustatic water levels were probably relatively low. The structure contour map of Top Tirrawarra Sandstone (Figure 24.1) indicates that the dome structure is centred around Tirrawarra 13. This area in Tirrawarra Sandstone times was probably slightly higher than the surrounding areas when braided or meandering streams were sweeping back

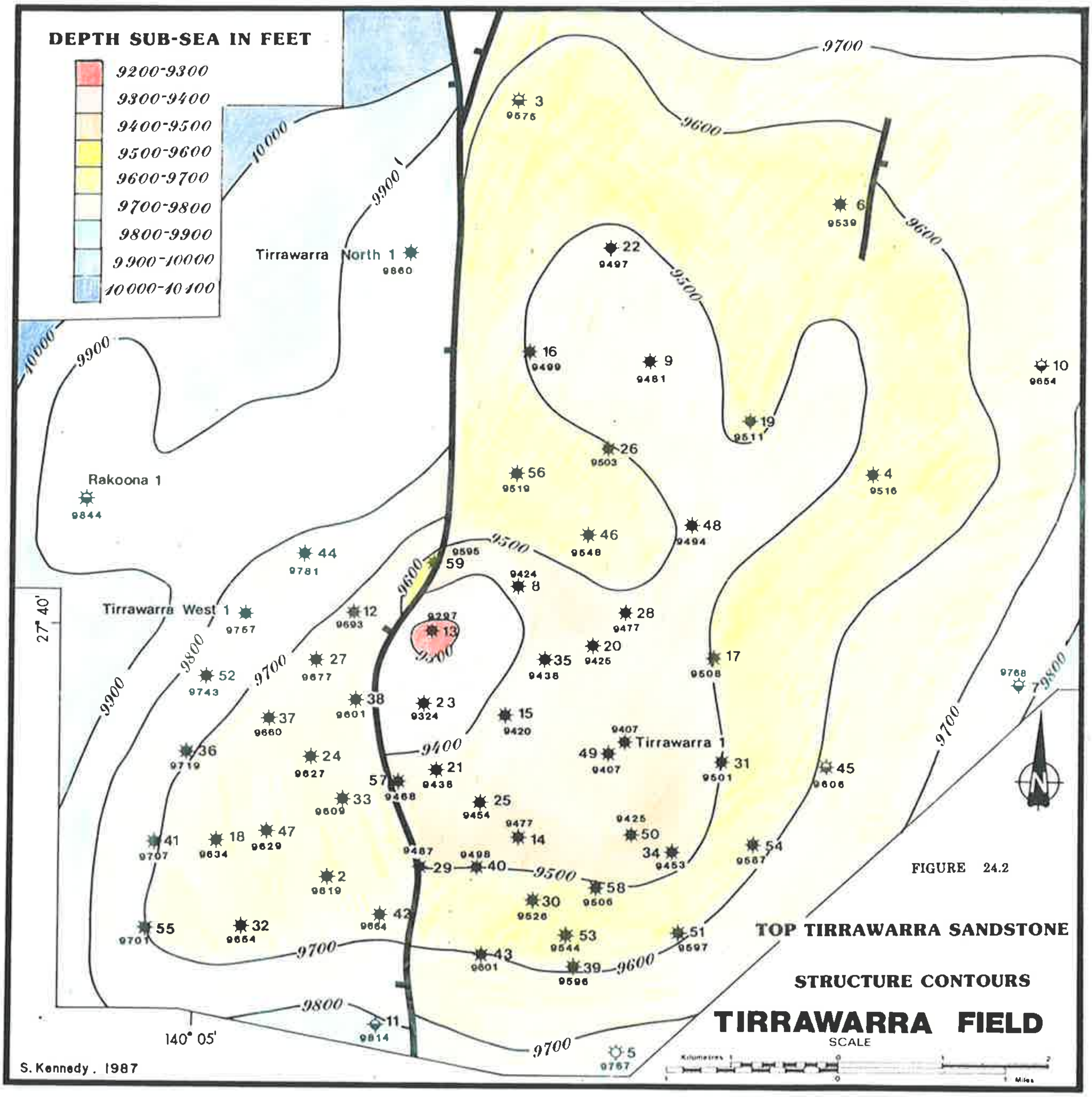

DEPTH SUB-SEA IN FEET
9200-9300
9300-9400
9400-9500
9500-9600
9600-9700
9700-9800
9800-9900
9900-10000
10000-10100
TOP TIRRAWARRA SANDSTONE
STRUCTURE CONTOURS
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
FIGURE 24.2
S. Kennedy. 1987
27° 40'
140° 05'
Tirrawarra North 1
9860
Rakoona 1
9844
Tirrawarra West 1
9757
Tirrawarra 1
9407
3 9575
6 9539
22 9497
16 9499
9 9481
10 9654
19 9511
26 9503
56 9519
4 9516
46 9548
48 9494
44 9781
59 9595
8 9424
12 9693
13 9297
28 9477
20 9425
35 9438
17 9508
27 9677
52 9743
7 9768
38 9601
23 9324
15 9420
37 9660
36 9719
24 9627
49 9407
31 9501
45 9606
57 9488
21 9438
33 9609
25 9454
14 9477
50 9425
34 9453
54 9587
41 9707
18 9634
47 9629
29 9487
40 9498
58 9506
2 9619
30 9526
42 9664
55 9701
32 9654
53 9544
51 9597
43 9601
39 9596
11 9814
5 9767
9300
9400
9500
9600
9700
9800
9900
10000

FIGURE 24.1

and forth, depositing and reworking their loads. Thus one would expect more erosion and/or non deposition in the Tirrawarra 13 vicinity than in the surrounding areas which were subsiding at a slightly faster rate. This is confirmed by the fact that the Tirrawarra Sandstone has a field minimum thickness of 65 feet in Tirrawarra 13 (Figure 26).

A major normal fault has displaced the Tirrawarra Sandstone and may have been at least episodically active during the deposition of this unit. It is shown on the map of Top Tirrawarra Sandstone Structure Contours (Figure 24.1). The fault is inferred both from seismic and well interpretation and its extension has been traced at least 30 kilometres north north-east of Tirrawarra Field (Figure 25, after Delhi ). The fault has a throw of about 100 feet at the southern end of the field and 150 feet in the north. The western block has been downthrown. The eastern block includes the top of the dome which is centred on Tirrawarra 13. Intermittant vertical movement along this fault plane during this time may at least partly explain the distribution of Tirrawarra Sandstone.

In places there has been a greater accumulation of Tirrawarra Sandstone, immediately west of the fault line than to the east (Figure 26). For example Tirrawarra 12 has 31 feet more of Tirrawarra Sandstone than does Tirrawarra 13, less than one kilometre away on the upthrown block. Tirrawarra 38, west of the fault, has a thickness of 21 feet greater than its nearest neighbour on the upthrown block, Tirrawarra 23, 600 metres to the east. Tirrawarra

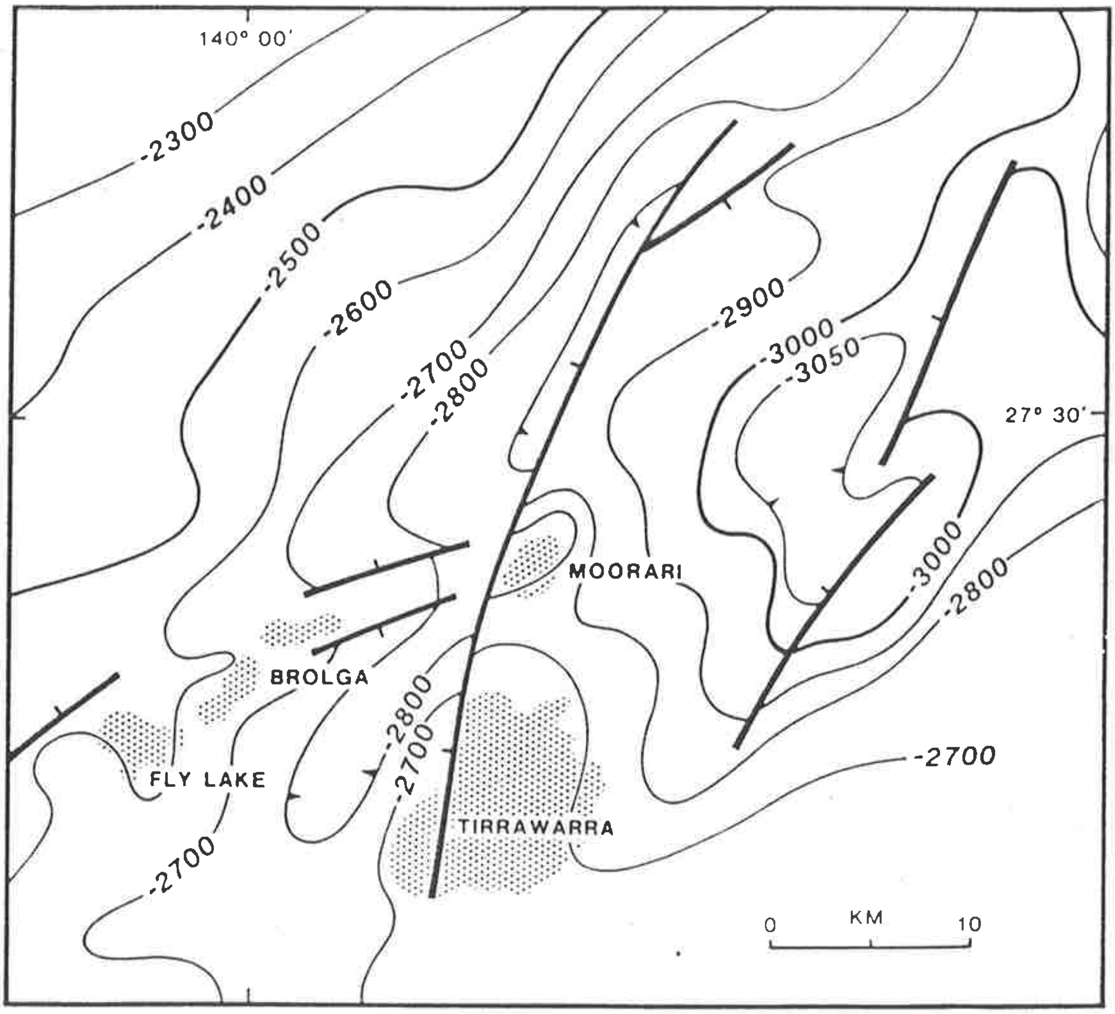


FIGURE 25 Sub Regional Map

Top Patchawarra Structure (after Delhi)

( Contour Interval 100 metres )

▨ Limit of field

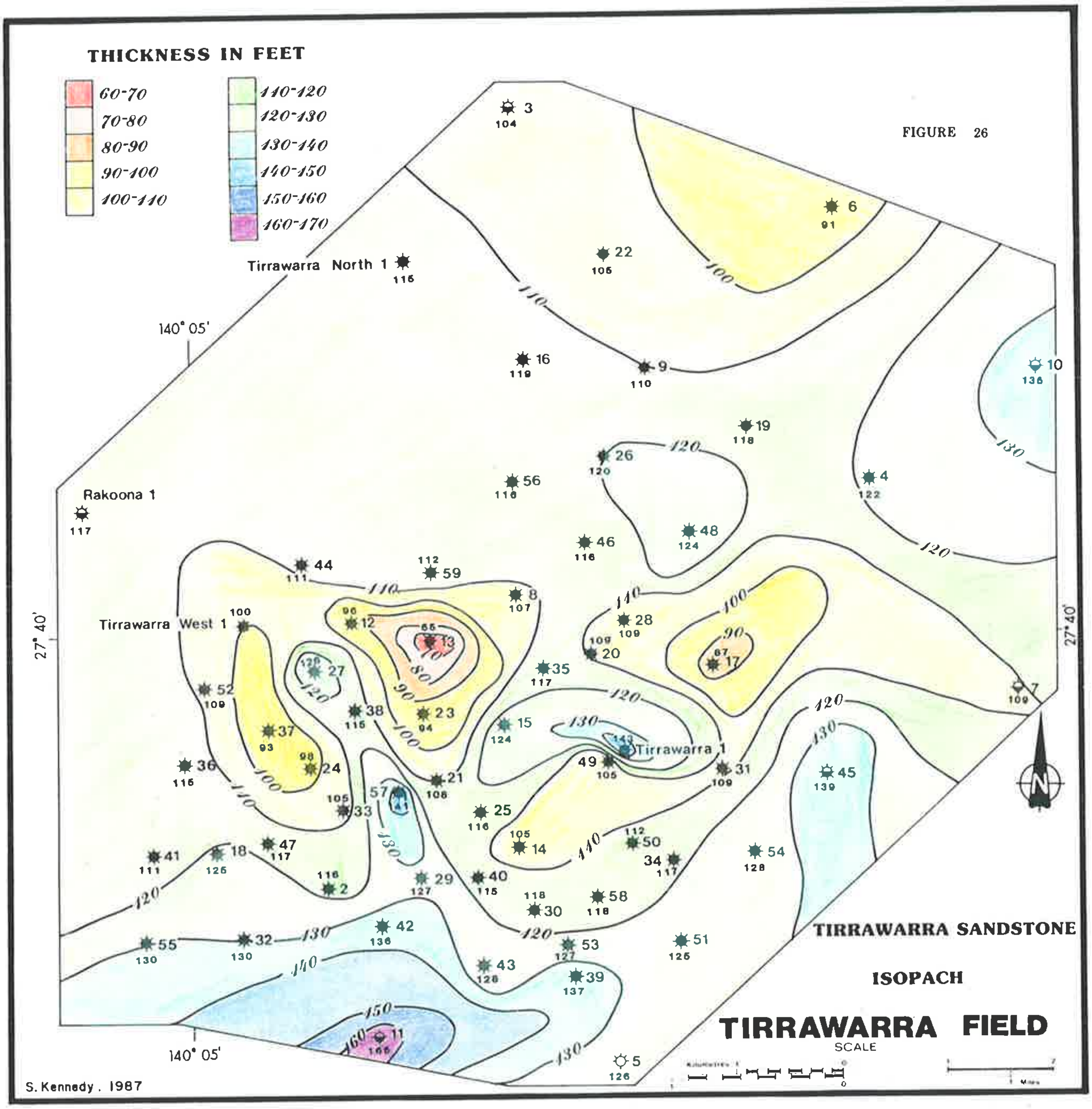

THICKNESS IN FEET
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140
140-150
150-160
160-170
FIGURE 26
TIRRAWARRA SANDSTONE
ISOPACH
TIRRAWARRA FIELD
SCALE
S. Kennedy . 1987
140° 05'
27° 40'
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
3 104
6 91
22 105
16 119
9 110
10 136
19 118
26 120
4 122
56 118
48 124
46 116
44 111
59 112
8 107
28 109
20 109
12 96
13 65
17 87
35 117
27 126
38 115
23 94
52 109
37 93
24 98
15 124
143
49 105
31 109
45 139
36 116
21 108
57 141
33 105
25 116
14 105
50 112
34 117
54 128
41 111
18 125
47 117
2 116
29 127
40 115
30 118
58 118
55 130
32 130
42 136
53 127
51 125
43 128
39 137
11 166
5 126
7 109
60
70
80
90
100
110
120
130
140
150
160

FIGURE 26

Sandstone, the second highest accumulation for the field. These figures suggest that the fault was active during deposition and that streams shed their load to form a wedge shaped deposit on the downthrown block in the manner described by Rust and Koster (1979). The irregular pattern in other parts of the field can be explained by erosion, reworking and redeposition during the one to three million years of accumulation.

## 6.3 Facies Associations 1A and 1B.

Eustatic water levels had risen during early Patchawarra times. The areas around Tirrawarra 13 continued to subside faster than this centre as indicated by the distribution of thick channel sands, of Facies Association 1A (Figure 18) around the flanks.

Subsidence was slower in the Tirrawarra 13 area, in comparison to the surrounding area during deposition of Facies Association 1B, as may be seen from Figure 19.1, Facies Association 1A and 1B Isopach. The main north-south fault was still active in early Patchawarra times, although its influence was reduced in the southern part of the field. North of Tirrawarra 57 thicker accumulations of combined Facies Associations 1A and 1B occur on the downthrown block compared with the upthrown block, thus structural growth is occurring. It is observed here that the field minimum of 241 feet occurs in Tirrawarra 13, whereas Tirrawarra 12, less than a kilometre to the west, has 403 feet of Facies Associations 1A and 1B.

The distribution of sand percentage (Figure 19.2) and total sand isopach (Figure 19.3) appears to be at least partly influenced by structure. There is a low sand percentage on the downthrown fault block, compared with the upthrown block (north from Tirrawarra 38). This is likely due to the winnowing out of the fines onto the low ground to the west leaving a relatively high sand percentage on the high block.

However an anomalously high sand percentage and sand isopach for Facies Associations 1A and 1B combined, occurs in both Tirrawarra West 1 and Rakoona 1 on the western extremity of the field. These sands may be delta front or shore line sands. Examination of the WNW-ESE cross section (Figure 17.2, also Enclosure), shows gamma log patterns which indicate there are two thick sandstones in Rakoona 1, centred on 9610 feet and 9735 feet. These have no correlates in Tirrawarra 12 or in other wells further east on the cross section. These two sands have a "blocky" gamma log pattern, quite unlike the upward-fining pattern shown further east in this Facies Association. Thus it is possible there were shorelines in the western part of the field at this time.

## 6.4 Facies Association 2A

It is observed from the isopach map of Facies Association 2A (Figure 20.1) that deposition is greatest at the southern end of the field with 245 feet in Tirrawarra 11, and least in the north with 129 feet in Tirrawarra 6.

There is also a major depocentre, aligned north-south and coinciding with the downthrown block immediately west of the fault line. This implies that the fault was reactivated for much of its length, at least up until the commencement of deposition of the Patchawarra Coal and structural growth occurred in this trough.

There appears to be no relationship between isopachs on the one hand (Figure 20.1) and total sand isopachs (Figure 20.3) and sand percentage (Figure 20.2) on the other. Looking at the field as a whole (Figure 20.1) the thicker occurrences of Facies Association 2A in the south may suggest greater subsidence there compared with the north, although the proximity of source material may be a factor.

Most sand was probably deposited from meandering streams during this time, as indicated by upward-fining gamma log patterns. However some of the lowermost sands of Facies Association 2A have blocky or upward coarsening patterns, implying a shoreline or delta front environment of deposition. An example is in Tirrawarra 48, centred on 9260 feet (Figure 17.1, also Enclosure). This would suggest that eustatic water levels were still relatively high but falling in early Facies Association 2A time.

The distribution pattern of the Patchawarra Coal, which forms the top part of Facies Association 2A, deserves separate consideration. Flores (1983) has estimated a peat accumulation rate of 0.5 feet/ century (0.15 m /century) for the Palaeocene temperate climate coals of the Powder River Basin. This rate could be considered for the Permian Patchawarra Formation coals which were also deposited in a cool climate (Frakes, 1979). Peat, on alteration to coal, compacts to about 20 per cent of its volume (Hills, 1963). The average thickness of the Patchawarra coal in the Tirrawarra Field is 50 feet and, using the above figures, a deposition time of 50 000 years is estimated. This is only a small fraction of the 10 million years of accumulation for the whole of the Patchawarra Formation.

Despite this short time of Patchawarra Coal accumulation there is evidence that structural growth has occurred. On examining the Patchawarra Coal isopachs (Figure 27) a clear pattern emerges. There is a thinning in the Patchawarra Coal from southwest to northeast. This implies that the rate of subsidence was higher in the southwest than in the northeast but not so high for the area to be inundated with fine clastic sediment at this time. It is noted that only 31 feet of Patchawarra Coal accumulated at Tirrawarra 13, and this is markedly thinner than in surrounding wells. Once again this implies a slower rate of subsidence in the Tirrawarra 13 area.

By this time the north-south fault was active only in the northern one third of the field, but a throw of about 150 feet is apparent (Figure 24.2). This confined late stage activity probably accounts for the greater thickness of Patchawarra Coal on the downthrown block compared with the thickness in neighbouring wells to the east.

## 6.5 Facies Association 2B

Eustatic water levels were relatively low during deposition of this unit. Of all the Facies Associations this unit best shows the development of point-bar sands, and there is a demonstratable relationship between structure, unit thickness and sand percentage.

The isopach map (Figure 21.1) indicates that Facies Association 2B thins in a northeasterly direction, but the pattern is more complex than for other Facies Associations

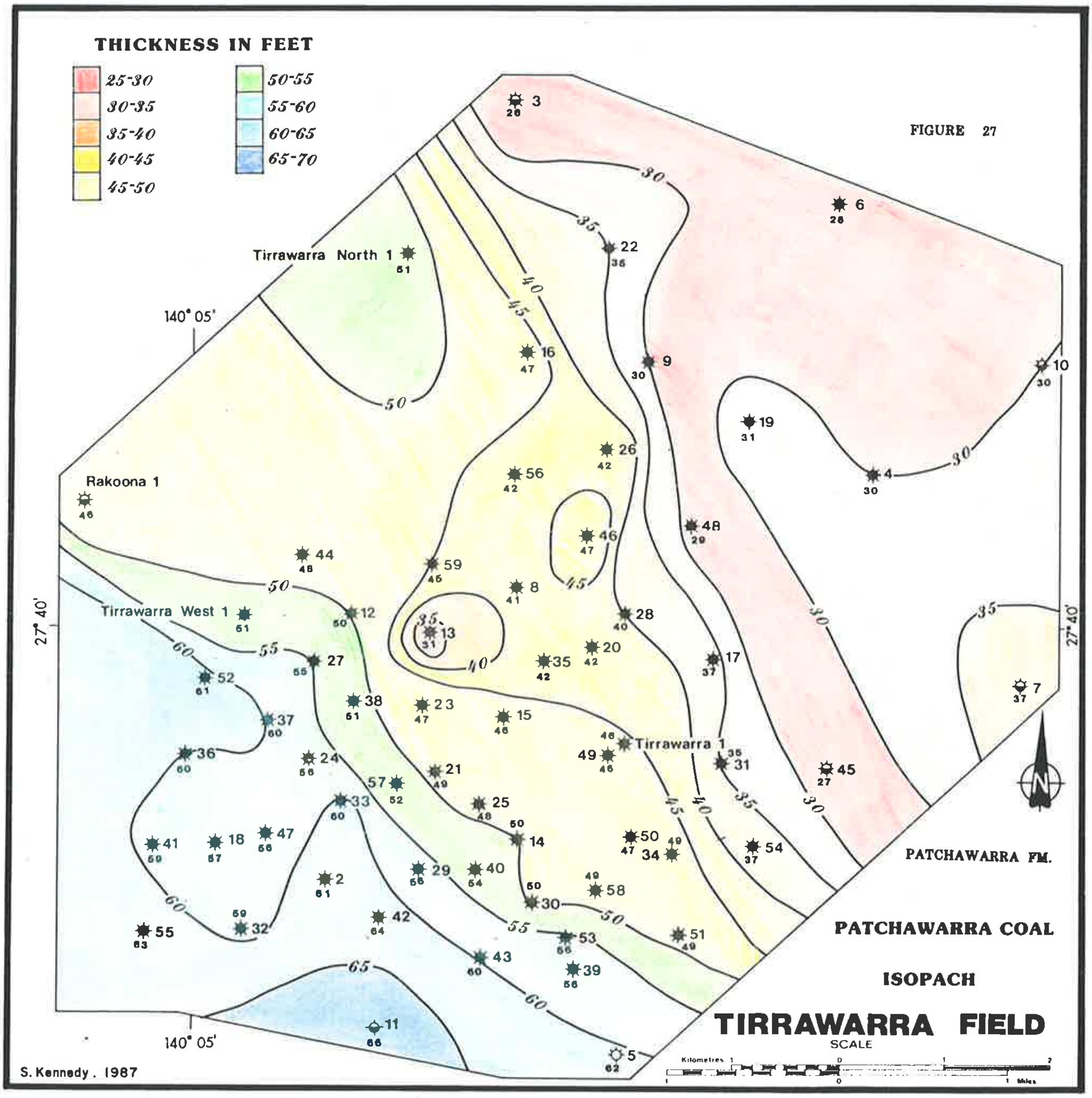

THICKNESS IN FEET
25-30
30-35
35-40
40-45
45-50
50-55
55-60
60-65
65-70
FIGURE 27
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
140° 05'
27° 40'
25
30
35
40
45
50
55
60
65
PATCHAWARRA FM.
PATCHAWARRA COAL
ISOPACH
TIRRAWARRA FIELD
SCALE
Kilometres 1
0
1
2
1
0
1 Miles
S. Kennedy . 1987

FIGURE 27

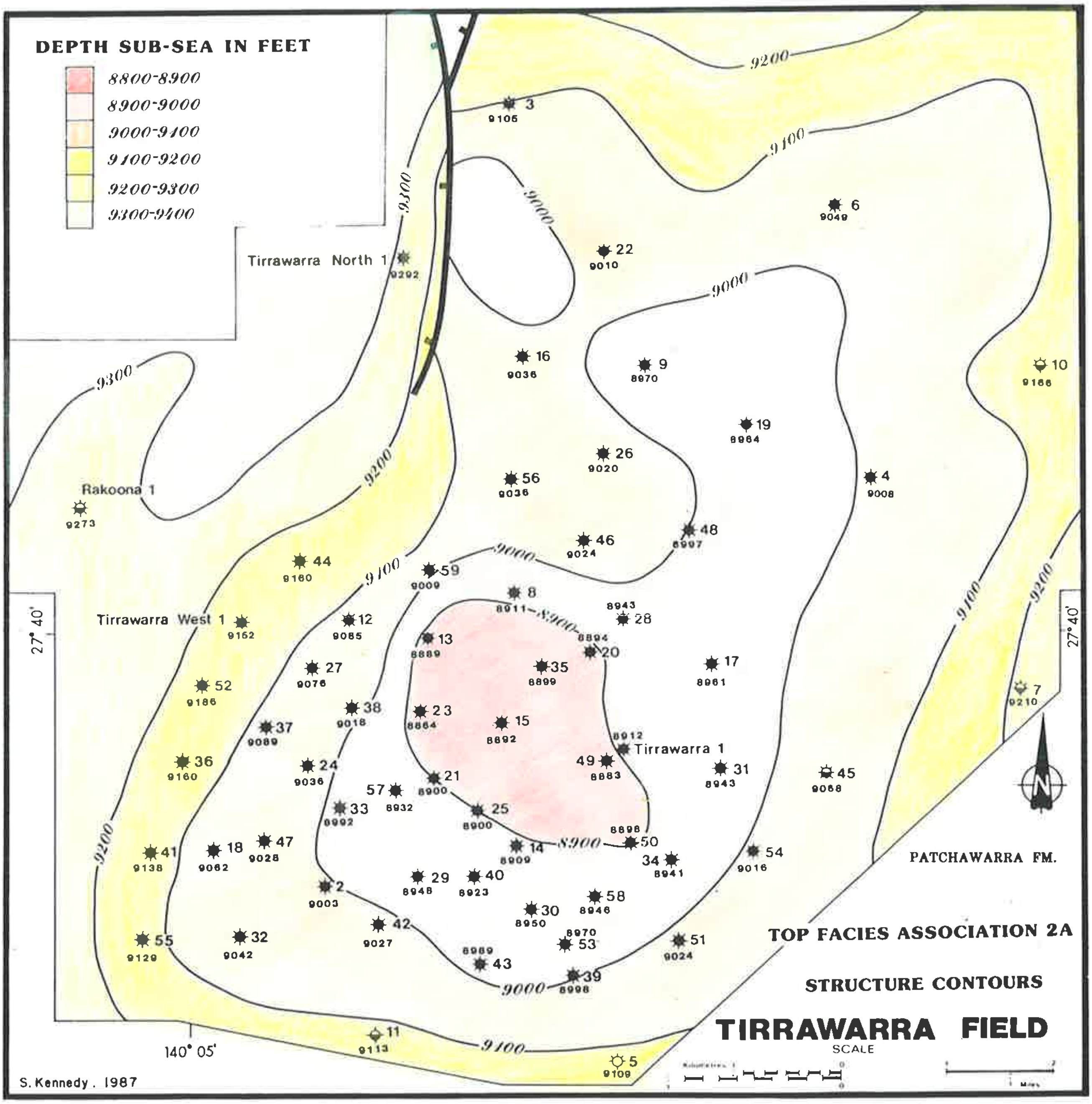

DEPTH SUB-SEA IN FEET
8800-8900
8900-9000
9000-9100
9100-9200
9200-9300
9300-9400
9200
9100
9000
9300
8900
3 9106
6 9049
22 9010
Tirrawarra North 1 9292
16 9036
9 8970
10 9166
19 8964
26 9020
4 9008
56 9036
Rakoona 1 9273
46 9024
48 8997
44 9160
59 9009
8 8911
8943 28
Tirrawarra West 1 9162
12 9085
13 8889
8894 20
17 8961
27 9076
35 8899
52 9186
7 9210
38 9018
23 8864
15 8892
37 9089
8912 Tirrawarra 1
49 8883
31 8943
45 9068
36 9160
24 9036
57 8932
21 8900
33 8992
25 8900
8898 50
41 9138
18 9062
47 9028
14 8909
34 8941
54 9016
29 8948
40 8923
2 9003
58 8946
30 8950
55 9129
32 9042
42 9027
8970 53
51 9024
8989 43
39 8998
11 9113
5 9109
27° 40'
140° 05'
N
PATCHAWARRA FM.
TOP FACIES ASSOCIATION 2A
STRUCTURE CONTOURS
TIRRAWARRA FIELD
SCALE
Miles
S. Kennedy. 1987

FIGURE 24.2

or the Patchawarra Coal. Sediments on the crest of the structure bifurcate towards the south. One thick trend branches out to the west to include the area of Tirrawarra West 1 and Tirrawarra 52 and 36. The other region of thick sediments extends to the southern extremity of the field, to reach a field maximum of 230 feet in Tirrawarra 11.

There is also a region of thick sediments around Tirrawarra North 1 on the northwest flank of the Tirrawarra anticline. This area is on the downthrown block of the north striking fault, still active at the end of Facies Association 2A time (Figure 24.2). Thus the same pattern is observed in this northwest corner of the field for Facies Association 2B as for the Patchawarra Coal, and it indicates that there was continued if episodic movement on the fault. Sediments of Facies Association 2B were shed westward onto the downthrown block from the high ground to the east.

Facies Association 2B exhibits a thinning from southwest to northeast (Figures 17.1 and 21.1) and this implies that the major depocentre was in the southwest. Sandstone percentages (Figure 21.2) and total sandstone isopachs (Figure 21.3) exhibit some interesting trends. An arcuate region of high sandstone percentage and thickness, with a northeast to southwest strike, passes through Tirrawarra 13. This area reflects multistorey stacking of point-bars, the tops of which have been eroded. It will be recalled that the Tirrawarra 13 area was the highest point of the anticline during deposition of the Tirrawarra Sandstone, Facies Association 1A/1B and Patchawarra Coal. It is likely then, for at least part of Facies Association 2B time, Tirrawarra 13 area formed the top of the structure. It is proposed that this area was subsiding slightly more slowly than its surrounds. Streams flowing across the area deposited sands haphazardly over a short period of time, but then reworked them, eroded their finer grained tops and transported these fines to the more rapidly subsiding parts of the basin in the manner described by Beloussov (1962). Thus a concentration of stacked sands is left on the high spots. It is possible to correlate, using gamma log signatures, the stacked sands of Tirrawarra 13 with individual point bar deposits in wells to the southeast and northwest (Figure 17.2 ). There is a definite thinning and separation of these point bar deposits on the flanks of the field.

There is an exception, however, in the Tirrawarra 10, 7 and 45 area on the eastern flank of the anticline. High sand percentages from Facies Association 2B may indicate a preferential channel path from the Moorari area which is north of Tirrawarra Field. Channels may have bypassed the anticline, which would have been a high point in the landscape.

More rapidly subsiding areas such as Tirrawarra North 1 (the downthrown block) and the southwest corner of the field have low sand percentages, as would be expected when mainly the winnowed out fines have been transported.

## 6.6 Facies Association 3

Eustatic water levels were rising again during this time. This Facies Association also thins from southwest to northeast (Figures 17.1 and 22.1), and this implies greater subsidence in the southwest. The isopach map (Figure 22.1) indicates two distinct areas of sediment thickening, one centred on Tirrawarra 41 in the southwest, the other in the Tirrawarra 5 area in the extreme south. It is not known whether the north-south fault was still active at the beginning of Facies Association 3 time, as the top of the coal band which defines the base of this unit is not resolvable by seismic means. However the Top Facies Association 3 (i.e. Top Patchawarra Formation ) Structure Map (Figure 24.3) incorporates seismic and well data and it indicates the fault was inactive by the end of Patchawarra Formation time. Sand percentages and thicknesses (Figures 22.2 and 22.3) are generally low and do not appear to be related to variations in the unit thickness across the field. Upward-fining sequences, as indicated by gamma log patterns in the two cross sections (Figures 17.1 and 17.2) suggest that deposition from meandering streams was still important at that time. However thick sands with blocky gamma log patterns account for the high sand percentages in Tirrawarra West 1 and Tirrawarra 27. These sands are probably shore line sands.

## 6.7 The entire Patchawarra Formation

A comparison of the three structure maps (Figures 24.1, 24.2, 24.3) shows that structural growth has occurred around the flanks of the Tirrawarra anticline, particularly the northern and western flanks. Structural growth of the southwestern flank is less obvious. This area is closer to the major depocentre and has received relatively more fine sediment, which has been winnowed out from farther north-

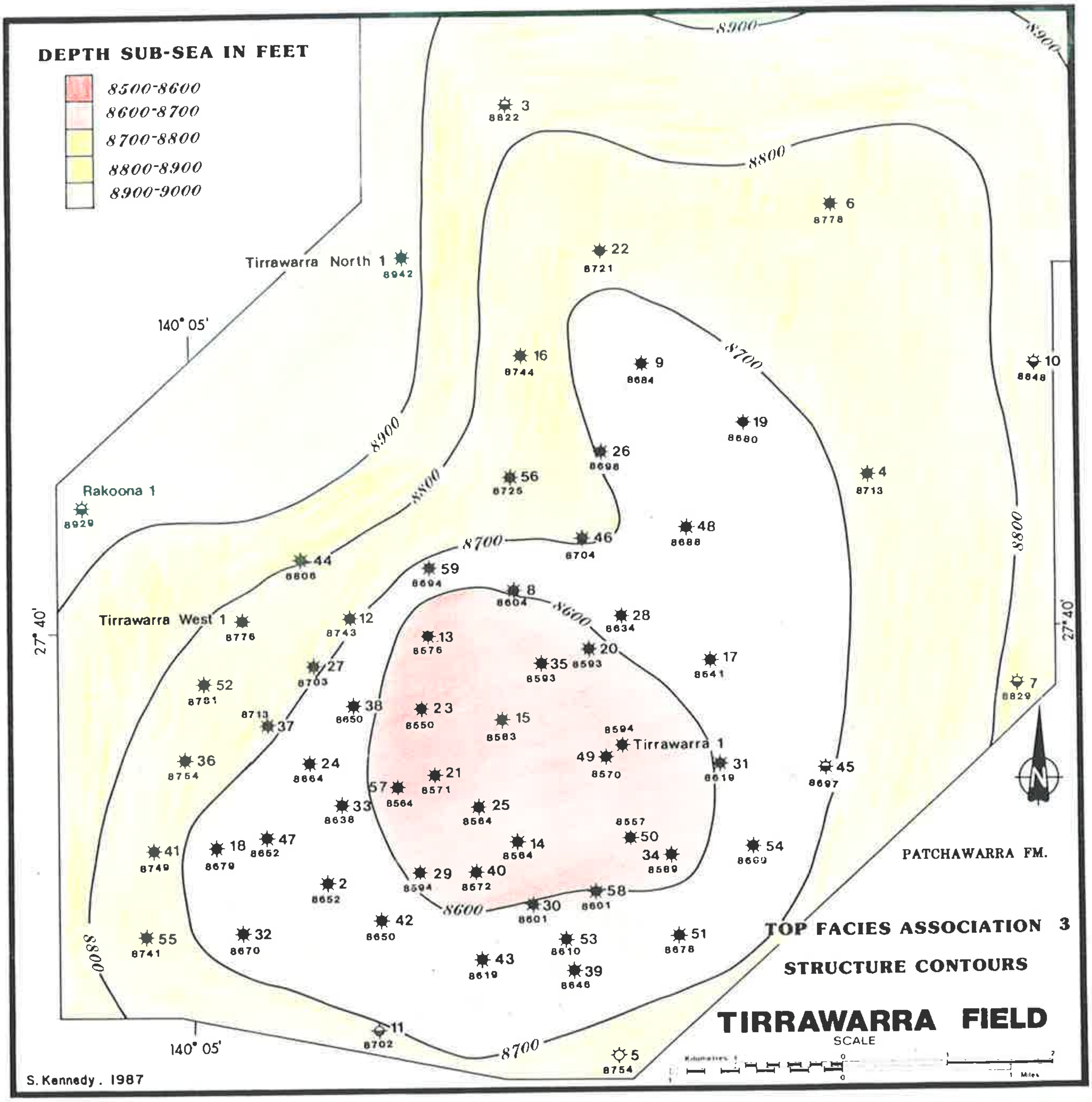

DEPTH SUB-SEA IN FEET
8500-8600
8600-8700
8700-8800
8800-8900
8900-9000
8900
8800
8700
8600
3 8822
6 8778
22 8721
Tirrawarra North 1 8942
140° 05'
16 8744
9 8684
10 8648
19 8680
26 8698
56 8725
4 8713
Rakoona 1 8929
48 8688
46 8704
44 8806
59 8694
8 8604
28 8634
Tirrawarra West 1 8776
12 8743
13 8576
20 8593
17 8641
27 8703
35 8593
7 8829
52 8781
38 8650
23 8650
15 8583
37 8713
8594 Tirrawarra 1
36 8754
24 8664
49 8570
31 8619
45 8697
57 8564
21 8571
33 8638
25 8564
41 8749
18 8679
47 8652
14 8564
50 8557
34 8589
54 8669
2 8652
29 8594
40 8672
58 8601
30 8601
55 8741
32 8670
42 8650
53 8610
51 8678
43 8619
39 8646
11 8702
5 8754
27° 40'
N
PATCHAWARRA FM.
TOP FACIES ASSOCIATION 3
STRUCTURE CONTOURS
TIRRAWARRA FIELD
SCALE
Kilometres 1 0 1 2
Miles 1 0 1
S. Kennedy. 1987

FIGURE 24.3

east. Hills (1963) states that muds buried to a depth of 8000 feet (the depth of the Patchawarra Formation) may compact to 25 per cent of their original volume, but sands obviously do not compact as much. Thus original structural growth on the south west flank of the Tirrawarra anticline may have been masked by the effects of differential compaction.

From the isopach map (Figure 23.1) it may be observed that the Patchawarra Formation decreases in thickness from southwest to northeast . This implies that subsidence was occurring at a slightly faster rate in the southwest during the 10 million years in which these sediments accumulated. This can be explained by the hypothesis of Beloussov (1963) that greater subsidence causes greater accumulation.

The Patchawarra Formation is actually thinnest at Tirrawarra 13, the vicinity of which must have been subsiding slowest during this 10 million year interval. A similar pattern is observed in the diagram of Total Coal Isopachs (Figure 23.2). There is a general thinning from southwest to northeast, but in Tirrawarra 13 there is less gross coal than anywhere else in the field. Once again a direct relationship between subsidence and accumulation rate is implied. As previously stated, subsidence rates would generally have been very slow during this 10 million year interval, and it is considered that these rates would not have been fast enough for clastic sediments to inundate coals in one part of the basin, but not in another. Gross sand values (Figure 23.3) and sand percentage values (Figure 23.4) do not appear to be related to Patchawarra

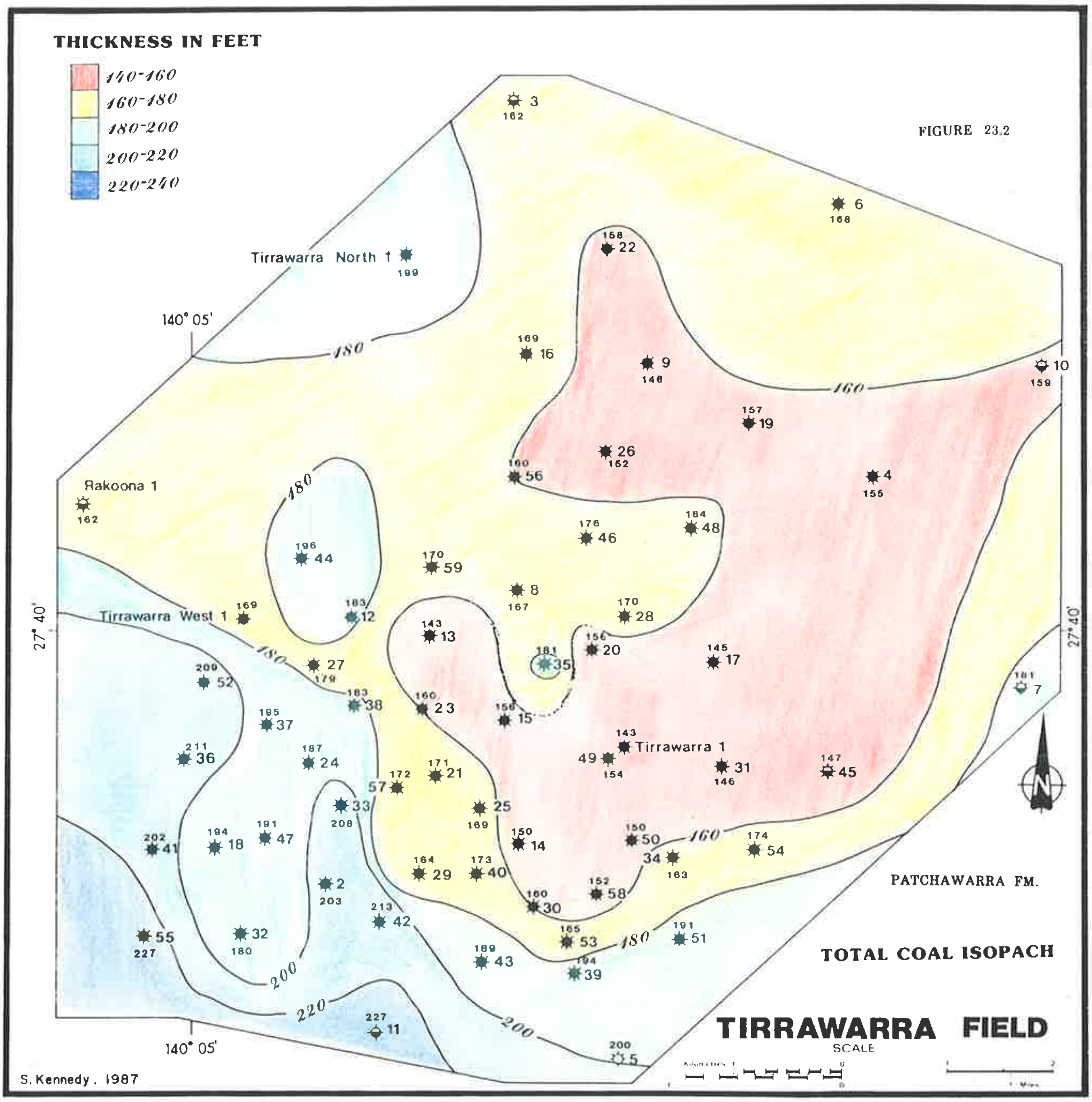

THICKNESS IN FEET
🟥 140-160
🟨 160-180
180-200
200-220
220-240
FIGURE 23.2
3
162
6
168
Tirrawarra North 1
199
140° 05'
180
169
16
158
22
9
146
10
159
160
157
19
26
152
4
155
Rakoona 1
162
180
160
56
176
46
164
48
196
44
170
59
8
167
27° 40'
Tirrawarra West 1
169
183
12
180
170
28
143
13
181
35
156
20
145
17
27
179
209
52
183
38
160
23
156
15
181
7
195
37
143
Tirrawarra 1
211
36
187
24
49
154
31
146
147
45
172
57
171
21
33
208
25
169
202
41
194
18
191
47
150
14
150
50
160
174
54
34
163
2
203
164
29
173
40
152
58
PATCHAWARRA FM.
160
30
213
42
165
53
180
191
51
55
227
32
180
189
43
194
39
TOTAL COAL ISOPACH
200
220
227
11
200
140° 05'
200
5
TIRRAWARRA FIELD
SCALE
Kilometres 1
0
1
2
1 Miles
S. Kennedy . 1987

FIGURE 23.2

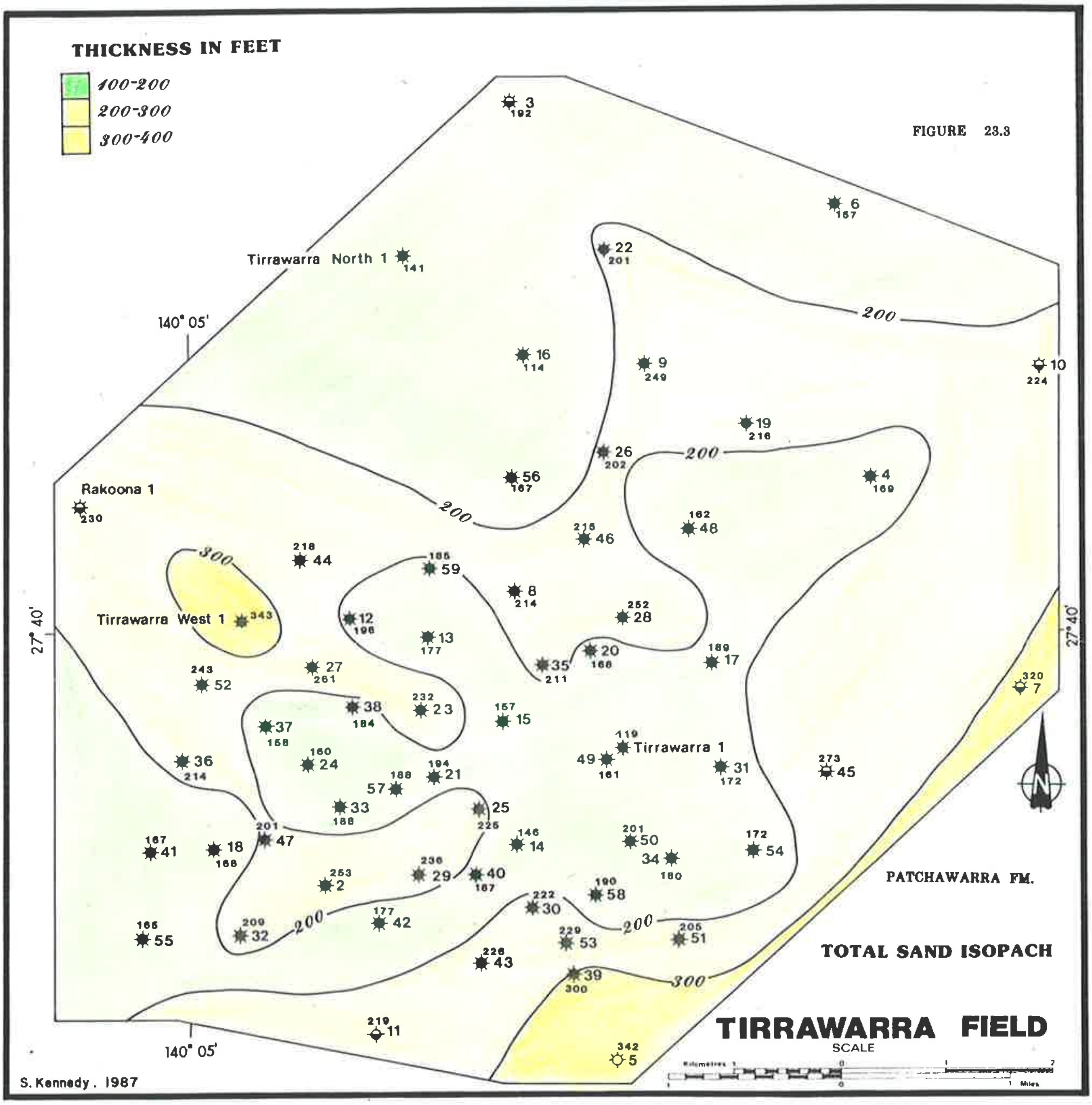

THICKNESS IN FEET
100-200
200-300
300-400
FIGURE 23.3
3 192
6 157
Tirrawarra North 1 141
22 201
200
140° 05'
16 114
9 249
10 224
19 216
26 202
56 167
4 169
Rakoona 1 230
200
162 48
216 46
300
218 44
185 59
8 214
Tirrawarra West 1 343
12 196
13 177
252 28
27°40'
27°40'
27 261
35 211
20 166
169 17
243 52
320 7
38 184
232 23
157 15
37 158
119 Tirrawarra 1
49 161
31 172
273 45
36 214
160 24
188 57
194 21
33 188
25 225
N
201 47
167 41
18 166
146 14
201 50
34 180
172 54
PATCHAWARRA FM.
253 2
236 29
40 167
190 58
222 30
200
209 32
177 42
200
166 55
229 53
205 51
TOTAL SAND ISOPACH
226 43
39 300
300
219 11
TIRRAWARRA FIELD
SCALE
140° 05'
342 5
Kilometres 1 0 1 2
1 0 1 Miles
S. Kennedy. 1987

FIGURE 23.3

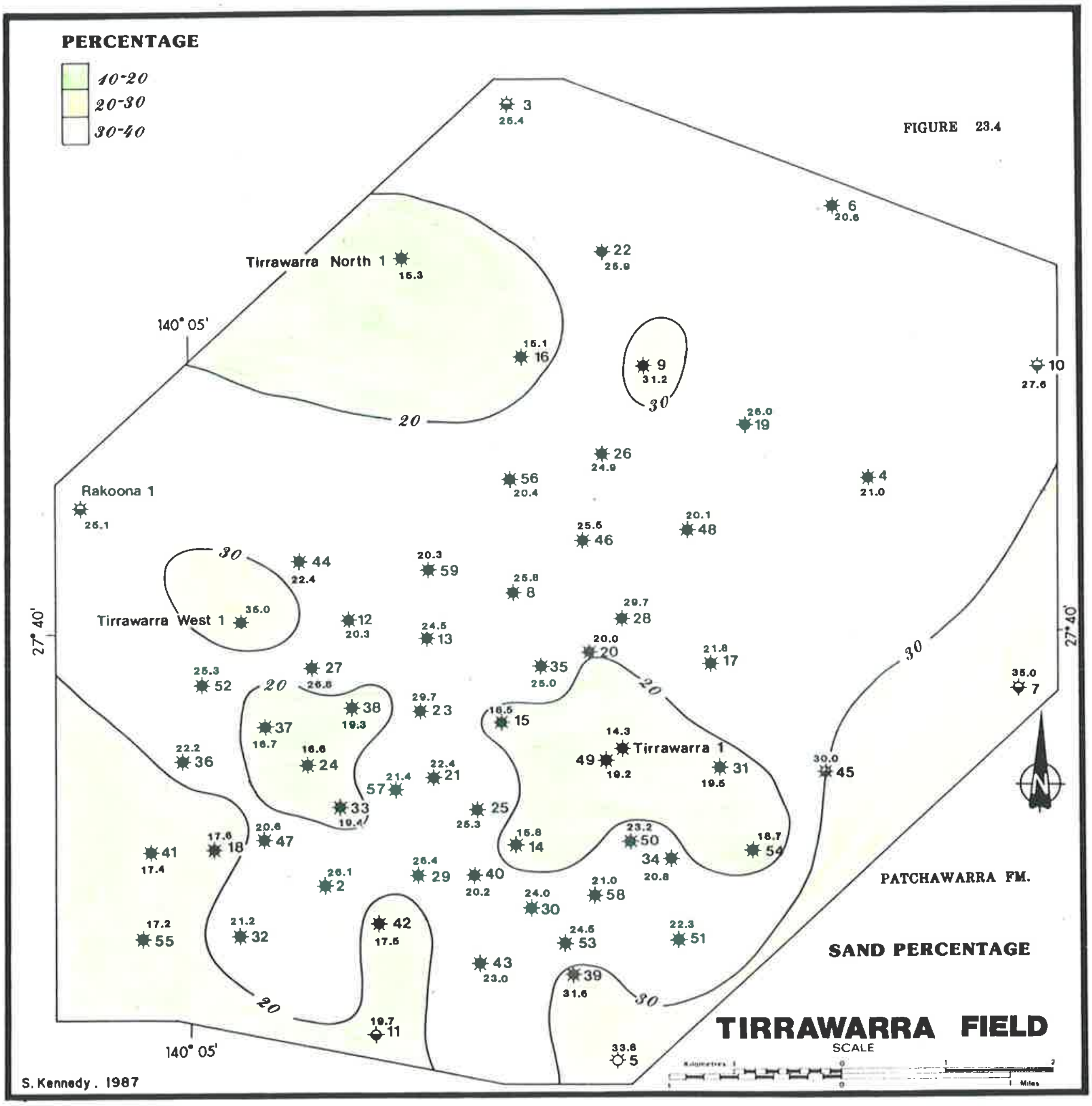

PERCENTAGE
10-20
20-30
30-40
FIGURE 23.4
TIRRAWARRA FIELD
SAND PERCENTAGE
PATCHAWARRA FM.
SCALE
Kilometres
Miles
140° 05'
27° 40'
Tirrawarra North 1
15.3
Tirrawarra West 1
35.0
Rakoona 1
25.1
Tirrawarra 1
14.3
3
25.4
6
20.6
22
25.9
16
15.1
9
31.2
10
27.6
19
26.0
26
24.9
56
20.4
4
21.0
48
20.1
46
25.5
44
22.4
59
20.3
8
25.8
28
29.7
12
20.3
13
24.5
20
20.0
17
21.8
35
25.0
52
25.3
27
26.8
7
35.0
38
19.3
23
29.7
15
16.5
37
16.7
24
16.6
49
19.2
31
19.5
36
22.2
21
22.4
57
21.4
45
30.0
33
19.4
25
25.3
47
20.6
18
17.6
41
17.4
14
15.8
50
23.2
54
16.7
34
20.8
2
26.1
29
26.4
40
20.2
58
21.0
30
24.0
42
17.5
55
17.2
32
21.2
53
24.5
51
22.3
43
23.0
39
31.6
11
19.7
5
33.8
20
30
S. Kennedy. 1987

FIGURE 23.4

Formation thickness. It must be remembered however that different types of sand are included in these maps ; point bar sands, crevasse splay sands and shore line sands. Therefore one could not expect a significant gross winnowing effect as in Facies Association 2B where mainly point bar sands were deposited.

# CHAPTER 7 POROSITY TRENDS

SANTOS workers have calculated the porosity of the Patchawarra Formation at 2.0 foot intervals using measurements obtained from down hole geophysical instruments. Average porosity figures have been obtained for the sandstones intersected in each well, for the two main gas producing units- Facies Associations 2A and 2B. Percentage porosity figures were computer generated, sandstones being defined as sediments producing a gamma reading of less than 100 A.P.I. units and a sonic count of less than 90 microseconds per foot.

The equation used to calculate porosity is :-

$$\text{Porosity} = \frac{DT - 55.5}{0.61GR + 124.0}$$

Where DT = Sonic Reading in Microseconds per foot

and GR = Gamma Ray reading in A.P.I. units.

It is known as the Overton Equation and is derived from emperical measurements of, and correlation with, core from Tirrawarra Field and Fly Lake / Brolga Field.

Porosity maps have been constructed for Facies Associations 2A and 2B. These maps (Figures 28.1 and 28.2) are also incorporated in Figure 29 (Enclosure) in order to compare them with structure and sandstone percentage.

Mean porosity of sandstones in Facies Association 2A (Figure 28.1) ranges from 6.9 per cent in Tirrawarra 10 on the northeast flank of the anticline to 13.5 per cent on

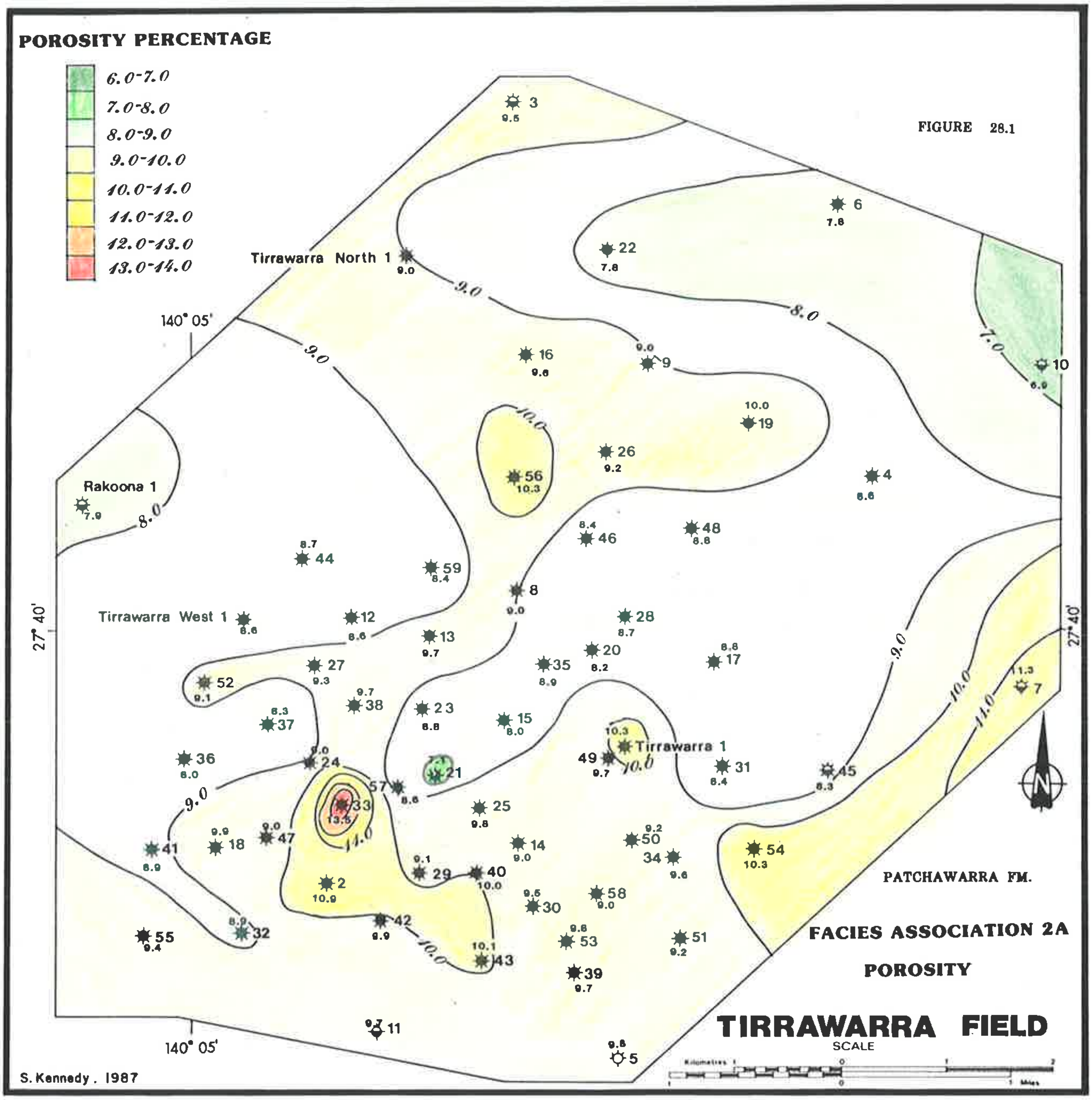

POROSITY PERCENTAGE
6.0-7.0
7.0-8.0
8.0-9.0
9.0-10.0
10.0-11.0
11.0-12.0
12.0-13.0
13.0-14.0
FIGURE 28.1
Tirrawarra North 1
Rakoona 1
Tirrawarra West 1
Tirrawarra 1
140° 05'
27° 40'
PATCHAWARRA FM.
FACIES ASSOCIATION 2A
POROSITY
TIRRAWARRA FIELD
SCALE
Kilometres
Miles
N
S. Kennedy . 1987

FIGURE 28.1

the southwest nose of the anticline. Most porosities however are in the range 8-10 per cent. The 9 per cent contour approximately parallels the northeast-southwest trend of the field. The value for Tirrawarra 33 is clearly anomalous but no core is available to investigate this porosity of 13.5 per cent.

There is no direct relationship between sand percentage and porosity or between sand thickness and porosity for this Facies Association. Indeed the relationship is reciprocal in some instances. Thus Tirrawarra 33 with only 9.4 per cent sand (Figure 20.2) has a porosity of 13.5 per cent, and Tirrawarra 7 on the east side of the field has only 5.2 per cent sand but a porosity of 11.3 per cent. On the other hand Tirrawarra 22 in the north of the field has 30.0 per cent sand, but this has a porosity of just 7.8 per cent.

In Facies Association 2B (Figure 28.2) sandstone average porosities are somewhat higher than in the underlying unit, most being in the range 9-11 per cent. The highest value is 12.7 per cent in Tirrawarra 33 and the lowest porosity is 7.4 per cent in Tirrawarra 6 in the north-east of the field. Porosity trends are roughly parallel to the structure with the highest values being at the top of the structure. This may be explained by the winnowing out of fines from the top of the stucture, as previously proposed for this Facies Association. Thus the relatively coarse, well sorted sands from the stacked point bar bases would be expected to have a high porosity.

There is no apparent relationship between porosity per cent and sand percentage in Facies Association 2B. For

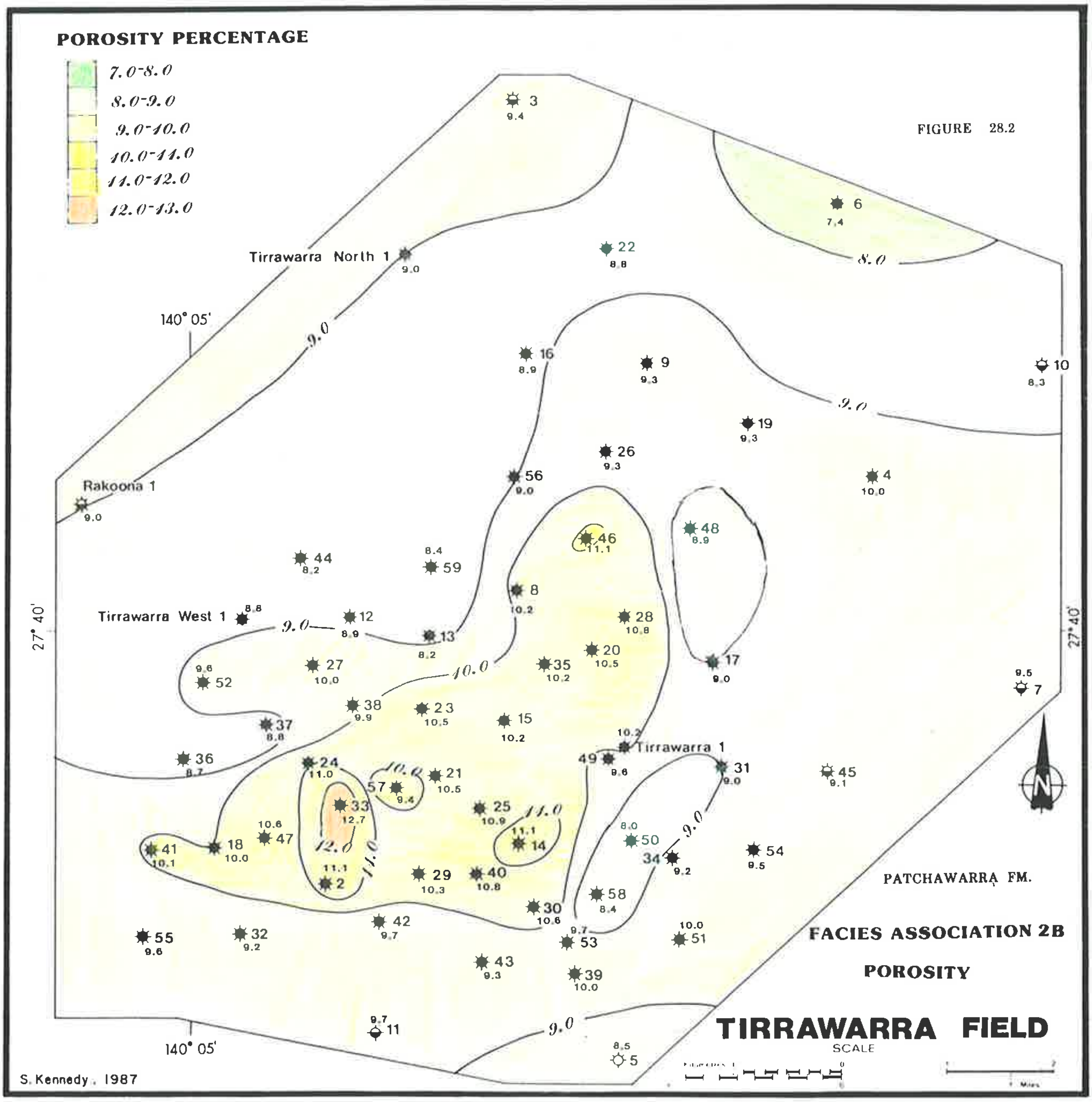

POROSITY PERCENTAGE
7.0-8.0
8.0-9.0
9.0-10.0
10.0-11.0
11.0-12.0
12.0-13.0
FIGURE 28.2
3 9.4
6 7.4
8.0
22 8.8
Tirrawarra North 1 9.0
140° 05'
9.0
16 8.9
9 9.3
10 8.3
9.0
19 9.3
26 9.3
56 9.0
4 10.0
Rakoona 1 9.0
46 11.1
48 8.9
44 8.2
59 8.4
8 10.2
Tirrawarra West 1 8.8
12 8.9
9.0
13 8.2
28 10.8
20 10.5
27° 40'
27° 40'
52 9.6
27 10.0
10.0
35 10.2
17 9.0
7 9.5
38 9.9
23 10.5
15 10.2
37 8.8
36 8.7
24 11.0
10.0
21 10.5
Tirrawarra 1 10.2
49 9.6
31 9.0
45 9.1
57 9.4
33 12.7
25 10.9
11.0
14 11.1
50 8.0
9.0
12.0
11.0
41 10.1
18 10.0
47 10.6
2 11.1
29 10.3
40 10.8
34 9.2
54 9.5
58 8.4
30 10.6
PATCHAWARRA FM.
42 9.7
53 9.7
51 10.0
55 9.6
32 9.2
FACIES ASSOCIATION 2B
POROSITY
43 9.3
39 10.0
11 9.7
9.0
TIRRAWARRA FIELD
SCALE
5 8.5
140° 05'
S. Kennedy, 1987
N

FIGURE 28.2

example, Tirrawarra 45 in the southeast has 61.5 per cent sand (Figure 21.2) but the average porosity is only 9.1 per cent. The gamma log pattern from this well suggests that some of the lower sands from Facies Association 2B, may contain clays which would reduce the porosity.

It is interesting to note that the highest porosity in Facies Association 2B occurs in Tirrawarra 33 which also contains sandstones with the highest porosity in Facies Association 2A. It is possible that there is a confined structural influence on sandstone porosity in this small area.

To summarise sandstone porosity trends in the Tirrawarra Field the following points may be made.

(1) Porosity trends parallel the structure.

(11) Porosity percentages are higher in Facies Association 2B than in 2A.

(111) No apparent relationship exists between sandstone percentage and porosity percentage.

(1V) High porosity trends may compensate for thin sandstone bands.

(V) Small structures may be influencing porosity.

# CHAPTER 8 SUMMARY AND CONCLUSIONS.

This study of the Patchawarra Formation in the Tirrawarra Field has investigated sedimentological trends as observed in the limited core available, and as interpreted from geophysical logs. The Patchawarra Formation has been subdivided into Facies Associations, each with characteristic assemblages of facies. Matching of core with geophysical logs has enabled sandstones, coal and mudrocks to be identified with confidence in wells where no core has been taken.

Isopach, sand percentage and total sand isopach maps have been constructed for each Facies Association. Selected coal isopach maps have been drawn. Structure maps have been drafted from well and seismic data. By an integrated analysis of these maps it has been possible to determine the depositional and structural history of this area during the time of Patchawarra deposition in the Early Permian.

Sandstone porosities have been determined for the two gas-rich Facies Associations and are shown to be influenced by depositional and structural trends.

Several conclusions may be drawn from this research. Core investigation has supported the hypotheses of earlier workers that the Patchawarra Formation was deposited in an environment ranging from lake, through shoreline and lower delta plain to upper delta plain. There has however been considerable reworking of material, particularly sands, as one would expect with the accumulation of less than 1200 feet of sediment over about 10 million years. This has lead to the formation of stacked sand bodies, particularly at the high point of the structure. Fine sediment has been carried down from the north towards the main depocentre, which, from isopach investigation of Facies Associations and coals, appears to be towards the southwest. The depositional slope, which was probably very gentle, must have been down from the northeast towards the southwest. This interpretation is in disagreement with that of Thornton (1979) who stated that the Murteree Sea invaded from the east at the end of Patchawarra time. The position of Tirrawarra Field in the Patchawarra Trough, however, may be responsible for this southwest depocentre.

Faulting has also influenced depositional patterns from Tirrawarra Sandstone time at least up to the commencement of Facies Association 3 time. A depositional centre on the western or downthrown block of the main north-south fault was episodically present.

High sand percentages and sand thicknesses present in the western extremity of the field in Facies Association 1B cannot be explained by fault activity or differential subsidence. Shoreline or delta front sands may account for the greater sand percentage and thickness in this instance, thus the possibility of a lower delta-swamp setting concurrent with shoreline lake environments.

Isolated thick sands were also deposited much later, during Facies Association 2B time, but on the eastern flank of the field. Channels may have brought in sand from the Moorari area, bypassing the anticline.

It has therefore been shown that faulting, differential subsidence, eustatics and sediment dispersal have interacted in a complex fashion to bring about patterns of facies relationships in Tirrawarra Field. But the field cannot be considered in isolation, its position in the Patchawarra Trough must be taken into account. Structural growth has occurred along the north-south fault as demonstrated by Figures 19.1, 20.1, 24.1 and 24.2 (incorporated in Figure 29). Figure 25 indicates that this fault extends north-northeast from Tirrawarra Field, past the western flank of Moorari Field. Fault-dependent anticlines in other parts of the Patchawarra Trough may also be influenced by the structural growth factor. Structural growth on the northern and western flanks of the Tirrawarra anticline is indicated by a comparison of Figures 24.1, 24.2 and 24.3. In other portions of the Patchawarra Trough there may be overall greater rates of subsidence and consequently more sediment input along its main depositional axis compared with at least the area of its northern flanks. A future line of research should be to investigate the influence of faults and differential subsidence on sediment patterns in other parts of the Patchawarra Trough.

Sandstone porosity, while being influenced to some extent by structure, is not directly affected by sandstone percentage. Quite high porosities may occur in low sandstone percentage areas. It is suggested from this study that there may be thick sands of reservoir potential down flank from the anticline on the western side in Facies Association 1B and on the eastern side in Facies Association 2B. While structure is not favourable in these two areas, stratigraphic traps cannot be ruled out. Even thin sandstone layers down flank, which are more likely to form stratigraphic traps, may possess promising porosities, and are thus attractive exploration targets.

## TABLE 1

TIRRAWARRA FIELD :- PATCHAWARRA FORMATION, GAMMA RAY VALUES AT SHALE-SAND BOUNDARIES DETERMINED FROM CORE & GAMMA LOG EVALUATION.

| WELL NO. | CORE DEPTH feet | NATURE OF BOUNDARY | GAMMA LOG DEPTH-feet | GAMMA RAY VALUE A.P.I. UNITS |
|---|---|---|---|---|
| TIRRA. 2 | 9050 | sharp | 9059 | 119 |
| " | 9054 | gradational | 9063 | 92 |
| " | 9077 | " | 9086 | 114 |
| " | 9081 | " | 9090 | 74 |
| " | 9084 | " | 9093 | 97 |
| " | 9184 | " | 9193 | 65 |
| " | 9613 | sharp | 9622 | 70 |
| " | 9619 | " | 9628 | 94 |
| " | 9622 | gradational | 9631 | 122 |
| " | 9627 | " | 9636 | 70 |
| " | 9658 | " | 9667 | 110 |
| " | 9659 | " | 9668 | 122 |
| " | 9679 | " | 9688 | 110 |
| " | 9681 | " | 9690 | 96 |
| " | 9702 | " | 9711 | 137 |
| " | 9704 | " | 9713 | 80 |
| " | 9719 | " | 9728 | 101 |
| " | 9722 | " | 9731 | 108 |
| TIRRA. 3 | 9194 | sharp | 9191 | 99 |
| " | 9212 | " | 9209 | 69 |
| " | 9214 | gradational | 9211 | 68 |
| " | 9215 | " | 9212 | 66 |
| " | 9226 | sharp | 9223 | 58 |
| " | 9237 | gradational | 9234 | 67 |
| " | 9284 | sharp | 9282 | 120 |
| " | 9286 | gradational | 9284 | 78 |
| " | 9288 | sharp | 9286 | 116 |
| " | 9289 | gradational | 9289 | 104 |
| " | 9299 | sharp | 9297 | 129 |
| TIRRA. 4 | 8843 | gradational | 8870 | 149 |
| " | 8846 | sharp | 8873 | 80 |
| " | 8854 | " | 8881 | 131 |
| " | 8855 | gradational | 8882 | 95 |
| " | 9013 | " | 9050 | 107 |
| TIRRA. 5 | 8961 | sharp | 8954 | 101 |
| " | 8978 | " | 8970 | 98 |
| " | 8984 | gradational | 8976 | 133 |
| " | 8986 | sharp | 8978 | 90 |
| " | 8989 | gradational | 8981 | 123 |
| " | 9134 | " | 9130 | 83 |
| " | 9148 | sharp | 9144 | 118 |
| " | 9153 | " | 9149 | 102 |
| " | 9156 | " | 9152 | 117 |
| " | 9161 | " | 9157 | 113 |
| " | 9164 | gradational | 9160 | 101 |
| " | 9167 | sharp | 9163 | 83 |
| " | 9171 | gradational | 9167 | 81 |

## TABLE 1 (continued)

### TIRRAWARRA FIELD :- PATCHAWARRA FORMATION, GAMMA RAY VALUES AT SHALE-SAND BOUNDARIES DETERMINED FROM CORE & GAMMA LOG EVALUATION.

| WELL NO. | CORE DEPTH feet | NATURE OF BOUNDARY | GAMMA LOG DEPTH-feet | GAMMA RAY VALUE A.P.I. UNITS |
|---|---|---|---|---|
| TIRRA. 5 | 9182 | gradational | 9178 | 93 |
| " | 9186 | sharp | 9182 | 97 |
| " | 9202 | " | 9197 | 62 |
| " | 9211 | " | 9206 | 96 |
| " | 9219 | " | 9214 | 67 |
| " | 9242 | " | 9237 | 63 |
| " | 9363 | " | 9359 | 101 |
| " | 9370 | gradational | 9366 | 108 |
| " | 9400 | sharp | 9395 | 75 |
| " | 9404 | gradational | 9399 | 88 |
| " | 9873 | sharp | 9867 | 96 |
| " | 9879 | gradational | 9873 | 125 |
| " | 9881 | sharp | 9875 | 117 |
| " | 9892 | " | 9886 | 127 |
| " | 9895 | gradational | 9889 | 81 |
| " | 9897 | " | 9891 | 78 |
| " | 9900 | sharp | 9894 | 80 |
| " | 9902 | " | 9896 | 106 |
| TIRRA. 11 | 9919 | " | 9913 | 88 |
| " | 9922 | gradational | 9916 | 124 |
| " | 9930 | " | 9924 | 128 |
| " | 9935 | " | 9929 | 120 |
| " | 9937 | sharp | 9931 | 103 |
| " | 9940 | " | 9934 | 38 |
| " | 9948 | gradational | 9942 | 97 |
| TIRRA. 12 | 9108 | " | 9120 | 79 |
| " | 9109 | " | 9121 | 121 |
| " | 9111 | " | 9123 | 161 |
| " | 9112 | " | 9124 | 132 |
| " | 9113 | " | 9125 | 129 |
| " | 9114 | " | 9126 | 111 |
| " | 9132 | " | 9144 | 117 |
| " | 9134 | sharp | 9146 | 130 |
| " | 9832 | " | 9846 | 47 |
| " | 9839 | " | 9853 | 86 |
| " | 9845 | " | 9859 | 109 |
| TIRRA. 13 | 8978 | " | 8977 | 77 |
| " | 9008 | " | 9007 | 85 |
| TIRRA. 16 | 9117 | " | 9125 | 127 |
| " | 9135 | sharp | 9133 | 47 |
| " | 9137 | gradational | 9135 | 40 |
| " | 9144 | sharp | 9152 | 71 |
| " | 9150 | gradational | 9158 | 231 |
| " | 9159 | " | 9167 | 82 |
| TIRRA. 17 | 9641 | sharp | 9647 | 105 |
| TIRRA. 19 | 9067 | " | 9069 | 51 |
| " | 9069 | " | 9070 | 85 |
| " | 9071 | " | 9073 | 100 |
| " | 9075 | gradational | 9077 | 101 |

## TABLE 1 (continued)

TIRRAWARRA FIELD :- PATCHAWARRA FORMATION, GAMMA RAY VALUES AT SHALE-SAND BOUNDARIES DETERMINED FROM CORE & GAMMA LOG EVALUATION.

| WELL NO. | CORE DEPTH feet | NATURE OF BOUNDARY | GAMMA LOG DEPTH-feet | GAMMA RAY VALUE A.P.I. UNITS |
|---|---|---|---|---|
| TIRRA. 19 | 9093 | sharp | 9095 | 96 |
| " | 9095 | gradational | 9097 | 121 |
| " | 9099 | sharp | 9101 | 92 |
| " | 9102 | gradational | 9104 | 97 |
| TIRRA. 28 | 9019 | sharp | 9029 | 61 |
| " | 9027 | gradational | 9037 | 108 |
| " | 9031 | sharp | 9041 | 89 |
| " | 9034 | gradational | 9044 | 96 |
| TIRRA. 32 | 9714 | " | 9724 | 94 |
| " | 9715 | sharp | 9725 | 104 |
| " | 9743 | " | 9753 | 129 |
| " | 9746 | " | 9757 | 156 |
| " | 9747 | " | 9758 | 139 |
| " | 9753 | " | 9764 | 104 |
| " | 9755 | " | 9766 | 132 |

# TABLE 2

TIRRAWARRA FIELD :- PATCHAWARRA FORMATION, SONIC VALUES AT SHALE-COAL AND MUD-COAL BOUNDARIES DETERMINED FROM CORE AND SONIC LOG EVALUATION.

| WELL NO. | CORE DEPTH feet | NATURE OF BOUNDARY | SONIC LOG DEPTH feet | SONIC LOG VALUE microseconds per foot |
|---|---|---|---|---|
| 1 | 9025 | sand-coal | 9037 | 71 |
| 2 | 9046 | coal-sand | 9055 | 113 |
| " | 9062 | sand-coal | 9071 | 78 |
| " | 9066 | coal-carbonaceous shale | 9076 | 88 |
| " | 9182 | coal-mud | 9191 | 98 |
| " | 9220 | intraform. conglom.-coal | 9228 | 94 |
| " | 9222 | coal-carbonaceous shale | 9231 | 115 |
| " | 9629 | sand-coal | 9638 | 68 |
| " | 9630 | coal-shale | 9639 | 67 |
| " | 9646 | shale-coal | 9654 | 111 |
| " | 9648 | coal-shale | 9657 | 101 |
| " | 9666 | carbonaceous shale-coal | 9676 | 100 |
| " | 9668 | coal-shale | 9678 | 99 |
| " | 9676 | shale-coal | 9685 | 74 |
| " | 9677 | coal-shale | 9686 | 86 |
| " | 9684 | shale-coal | 9694 | 94 |
| " | 9687 | coal-shale | 9697 | 99 |
| " | 9696 | shale-coal | 9705 | 76 |
| " | 9698 | coal-shale | 9708 | 84 |
| " | 9707 | shale-coal | 9716 | 96 |
| " | 9708 | coal-shale | 9717 | 96 |
| " | 9725 | shale-coal | 9735 | 109 |
| 3 | 9199 | sand-coal | 9196 | 89 |
| " | 9202 | coal-shale | 9199 | 115 |
| " | 9239 | shale-coal | 9236 | 90 |
| " | 9291 | shale-coal | 9289 | 80 |
| " | 9293 | coal-carbonaceous shale | 9291 | 125 |
| " | 9306 | sand-coal | 9304 | 72 |
| 4 | 9010 | coal-carbonaceous shale | 9046 | 99 |
| " | 9021 | carbonaceous shale-coal | 9057 | 158 |
| " | 9030 | coal-intraform. conglom. | 9067 | 64 |
| 5 | 9112 | carbonaceous shale-coal | 9108 | 110 |
| " | 9114 | coal-carbonaceous shale | 9110 | 88 |
| " | 9116 | carbonaceous shale-coal | 9112 | 138 |
| " | 9131 | coal-shale | 9127 | 91 |
| " | 9187 | shale-coal | 9183 | 139 |
| " | 9189 | coal-shale | 9185 | 137 |
| " | 9196 | sandy shale-coal | 9192 | 135 |
| " | 9200 | coal-shale | 9196 | 105 |
| " | 9212 | shale-coal | 9207 | 74 |
| " | 9218 | coal-shale | 9213 | 96 |
| " | 9249 | sandy shale-coal | 9244 | 76 |
| " | 9311 | coal-sandy shale | 9307 | 95 |

## TABLE 2 (continued)

TIRRAWARRA FIELD :- PATCHAWARRA FORMATION, SONIC VALUES AT SHALE-COAL AND MUD-COAL BOUNDARIES DETERMINED FROM CORE AND SONIC LOG EVALUATION.

| WELL NO. | CORE DEPTH feet | NATURE OF BOUNDARY | SONIC LOG DEPTH feet | SONIC LOG VALUE microseconds per foot |
|---|---|---|---|---|
| 5 | 9409 | sand-coal | 9404 | 73 |
| " | 9428 | coal-shale | 9423 | 135 |
| " | 9430 | shale-coal | 9424 | 139 |
| " | 9432 | coal-shale | 9426 | 104 |
| " | 9435 | shale-coal | 9430 | 70 |
| " | 9436 | coal-sandy shale | 9431 | 70 |
| " | 9883 | shale-coal | 9877 | 88 |
| " | 9888 | coal-shale | 9882 | 66 |
| 11 | 9905 | sand-coal | 9899 | 123 |
| " | 9908 | coal-sand | 9902 | 115 |
| " | 9912 | sand-coal | 9906 | 70 |
| " | 9914 | coal-shale | 9908 | 103 |
| " | 9923 | shale-coal | 9917 | 70 |
| " | 9925 | coal-shale | 9919 | 99 |
| " | 9931 | shale-coal | 9925 | 78 |
| " | 9932 | coal-shale | 9926 | 67 |
| 12 | 9129 | sand-coal | 9142 | 85 |
| " | 9130 | coal-carbonaceous shale | 9143 | 109 |
| " | 9143 | sand-coal | 9155 | 85 |
| " | 9144 | coal-sand | 9156 | 121 |
| " | 9824 | coal-carbonaceous shale | 9837 | 73 |
| 13 | 8993 | sand-coal | 8991 | 96 |
| " | 8995 | coal-sand | 8993 | 184 |
| 16 | 9108 | sand-coal | 9116 | 83 |
| " | 9111 | coal-carbonaceous shale | 9119 | 124 |
| 28 | 9019 | conglomerate-coal | 9029 | 77 |
| " | 9020 | coal-shale | 9030 | 81 |
| 32 | 9709 | shale-coal | 9719 | 73 |
| " | 9710 | coal-shale | 9720 | 77 |
| " | 9717 | shale-coal | 9727 | 68 |
| " | 9719 | coal-shale | 9729 | 111 |
| " | 9738 | shale-coal | 9748 | 76 |
| " | 9740 | coal-shale | 9750 | 99 |
| " | 9741 | shale-coal | 9751 | 80 |
| " | 9742 | coal-shale | 9752 | 74 |
| " | 9756 | sand-coal | 9766 | 72 |
| " | 9760 | coal-sand | 9771 | 95 |

## TABLE 3 CORE-LOG INVESTIGATION TIRRAWARRA FIELD

## PATCHAWARRA FM. FACIES PROPORTIONS IN FACIES ASSOCIATIONS

| STATE AND CODE / ASSOCIATION | | Coal C | Massive & Bio-turbated Mudrock Fm | Flat Laminated Mudrock Fl | Wave Rippled Mudrock Fw | Hetero-lithic Interbeds Hi | Wave Rippled Sandstone Sw | Massive Sandstone Sm | Trough Cross Bedded Sandstone St | Planar Cross Bedded Sandstone Sp | Massive Conglom-erate Gm | Chaotic Conglom-erate Gc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **3** | Feet | - | 26 | 6 | 8 | 3 | 3 | 8 | - | 3 | - | - |
| | % | - | 45.6 | 10.5 | 14.0 | 5.3 | 5.3 | 14.0 | - | 5.3 | - | - |
| **2B** | Feet | 56 | 23 | 74 | 17 | 18 | 88 | 160 | 8 | 39 | 4 | 19 |
| | % | 11.1 | 4.6 | 14.6 | 3.4 | 3.6 | 17.4 | 31.5 | 1.6 | 7.7 | 0.8 | 3.7 |
| **2A** | Feet | 145 | 24 | 21 | 2 | 15 | 27 | 77 | 5 | 13 | 3 | 5 |
| | % | 43.0 | 7.1 | 6.2 | 0.6 | 4.5 | 8.0 | 22.8 | 1.5 | 3.9 | 0.9 | 1.5 |
| **1B** | Feet | 32 | 99 | 10 | 22 | 34 | 38 | 15 | 1 | 2 | - | - |
| | % | 12.7 | 39.1 | 4.0 | 8.7 | 13.4 | 15.0 | 5.9 | 0.4 | 0.8 | - | - |
| **1A** | Feet | 4 | 23 | 2 | - | - | - | 17 | - | - | - | - |
| | % | 8.7 | 50.0 | 4.4 | - | - | - | 36.9 | - | - | - | - |

# TABLE 4

TIRRAWARRA FIELD :- PATCHAWARRA FORMATION ISOPACH VALUES. READINGS IN FEET.

| WELL NO | FACIES ASSOC. 3 | FACIES ASSOC. 2B | FACIES ASSOC. 2A | FACIES ASSOC. 1A & 1B |
|---|---|---|---|---|
| TIRR. 1 | 162 | 156 | 172 | 341 |
| " 2 | 182 | 168 | 208 | 408 |
| " 3 | 139 | 147 | 155 | 315 |
| " 4 | 169 | 132 | 156 | 346 |
| " 5 | 209 | 152 | 220 | 432 |
| " 6 | 134 | 142 | 129 | 356 |
| " 7 | 191 | 190 | 155 | 378 |
| " 8 | 144 | 163 | 166 | 357 |
| " 9 | 140 | 159 | 171 | 329 |
| " 10 | 164 | 154 | 141 | 354 |
| " 11 | 181 | 230 | 245 | 456 |
| " 12 | 170 | 172 | 221 | 403 |
| " 13 | 149 | 164 | 167 | 241 |
| " 14 | 162 | 183 | 185 | 393 |
| " 15 | 153 | 156 | 172 | 366 |
| " 16 | 142 | 150 | 143 | 320 |
| " 17 | 179 | 141 | 189 | 358 |
| " 18 | 215 | 168 | 207 | 365 |
| " 19 | 143 | 141 | 185 | 362 |
| " 20 | 154 | 147 | 169 | 371 |
| " 21 | 162 | 167 | 183 | 355 |
| " 22 | 143 | 146 | 166 | 321 |
| " 23 | 156 | 158 | 157 | 311 |
| " 24 | 192 | 180 | 208 | 383 |
| " 25 | 166 | 170 | 167 | 387 |
| " 26 | 143 | 179 | 139 | 350 |
| " 27 | 178 | 195 | 219 | 382 |
| " 28 | 155 | 154 | 166 | 383 |
| " 29 | 175 | 179 | 167 | 372 |
| " 30 | 176 | 173 | 199 | 377 |
| " 31 | 186 | 138 | 179 | 379 |
| " 32 | 188 | 184 | 205 | 407 |
| " 33 | 176 | 178 | 213 | 404 |
| " 34 | 185 | 167 | 152 | 360 |
| " 35 | 153 | 154 | 177 | 361 |
| " 36 | 212 | 194 | 180 | 379 |
| " 37 | 189 | 187 | 177 | 394 |
| " 38 | 170 | 198 | 208 | 375 |
| " 39 | 195 | 157 | 196 | 402 |
| " 40 | 170 | 181 | 198 | 377 |
| " 41 | 225 | 164 | 162 | 407 |
| " 42 | 184 | 193 | 235 | 402 |
| " 43 | 182 | 188 | 218 | 394 |
| " 44 | 172 | 181 | 245 | 377 |
| " 45 | 190 | 182 | 170 | 367 |
| " 46 | 150 | 170 | 156 | 368 |
| " 47 | 220 | 156 | 212 | 389 |
| " 48 | 144 | 165 | 160 | 337 |

## TABLE 4 (continued)

### TIRRAWARRA FIELD :- PATCHAWARRA FORMATION ISOPACH VALUES.READINGS IN FEET.

| WELL NO | FACIES ASSOC. 3 | FACIES ASSOC. 2B | FACIES ASSOC. 2A | FACIES ASSOC. 1A & 1B |
|---|---|---|---|---|
| TIRR. 49 | 171 | 142 | 170 | 355 |
| " 50 | 175 | 166 | 143 | 385 |
| " 51 | 199 | 147 | 179 | 394 |
| " 52 | 204 | 201 | 184 | 374 |
| " 53 | 185 | 175 | 200 | 374 |
| " 54 | 183 | 164 | 183 | 388 |
| " 55 | 226 | 159 | 217 | 360 |
| " 56 | 145 | 166 | 152 | 348 |
| " 57 | 168 | 181 | 195 | 336 |
| " 58 | 180 | 164 | 189 | 371 |
| " 59 | 165 | 149 | 220 | 379 |
| TIR.N. 1 | 163 | 187 | 196 | 372 |
| TIR.W. 1 | 200 | 183 | 213 | 385 |
| RAKOONA 1 | 188 | 156 | 182 | 389 |

# TABLE 5

TIRRAWARRA FIELD :- PATCHAWARRA FORMATION
FACIES ASSOCIATIONS, SAND THICKNESSES AND SAND PERCENTAGES.

| WELL NO. | FACIES ASSOCIATION 3 | | FACIES ASSOCIATION 2B | | FACIES ASSOCIATION 2A | |
|---|---|---|---|---|---|---|
| | THICK. (feet) | % | THICK. (feet) | % | THICK. (feet) | % |
| TIRR. 1 | 20 | 12.3 | 42 | 26.9 | 29 | 16.9 |
| " 2 | 35 | 19.2 | 73 | 43.5 | 49 | 23.6 |
| " 3 | 22 | 15.8 | 72 | 49.0 | 28 | 18.1 |
| " 4 | 28 | 16.6 | 51 | 38.6 | 35 | 22.4 |
| " 5 | 38 | 18.2 | 76 | 50.0 | 88 | 40.0 |
| " 6 | 16 | 11.9 | 46 | 32.4 | 15 | 11.6 |
| " 7 | 69 | 36.1 | 114 | 60.0 | 8 | 5.2 |
| " 8 | 21 | 14.6 | 86 | 52.8 | 21 | 12.7 |
| " 9 | 21 | 15.0 | 80 | 50.3 | 54 | 31.6 |
| " 10 | 25 | 15.2 | 77 | 50.0 | 10 | 7.1 |
| " 11 | 37 | 20.4 | 43 | 18.7 | 34 | 13.9 |
| " 12 | 20 | 11.8 | 72 | 41.9 | 32 | 14.5 |
| " 13 | 39 | 26.2 | 87 | 53.0 | 13 | 7.8 |
| " 14 | 12 | 7.4 | 52 | 28.4 | 24 | 13.0 |
| " 15 | 6 | 3.9 | 41 | 26.3 | 15 | 8.7 |
| " 16 | 10 | 7.0 | 41 | 27.3 | 7 | 4.9 |
| " 17 | 35 | 19.6 | 31 | 22.0 | 73 | 38.6 |
| " 18 | 29 | 13.5 | 36 | 21.4 | 22 | 10.6 |
| " 19 | 17 | 11.9 | 65 | 46.1 | 46 | 24.9 |
| " 20 | 34 | 22.1 | 49 | 33.3 | 37 | 21.9 |
| " 21 | 36 | 22.2 | 67 | 40.1 | 14 | 7.6 |
| " 22 | 30 | 21.0 | 55 | 37.7 | 51 | 30.7 |
| " 23 | 46 | 29.5 | 62 | 39.2 | 27 | 17.2 |
| " 24 | 12 | 6.3 | 64 | 35.6 | 26 | 12.5 |
| " 25 | 29 | 17.5 | 51 | 30.0 | 23 | 13.8 |
| " 26 | 19 | 13.3 | 88 | 49.2 | 9 | 6.5 |
| " 27 | 55 | 30.9 | 102 | 52.3 | 29 | 13.2 |
| " 28 | 39 | 25.2 | 70 | 45.6 | 42 | 25.3 |
| " 29 | 55 | 31.4 | 68 | 38.0 | 28 | 16.8 |
| " 30 | 42 | 23.9 | 59 | 34.1 | 45 | 22.6 |
| " 31 | 40 | 21.5 | 47 | 34.1 | 28 | 15.6 |
| " 32 | 23 | 12.2 | 56 | 30.4 | 40 | 19.5 |
| " 33 | 12 | 6.8 | 56 | 31.5 | 20 | 9.4 |
| " 34 | 51 | 27.6 | 54 | 32.3 | 25 | 16.4 |
| " 35 | 45 | 29.4 | 65 | 42.2 | 30 | 16.9 |
| " 36 | 30 | 14.2 | 76 | 39.2 | 18 | 10.0 |
| " 37 | 17 | 9.0 | 56 | 29.9 | 12 | 6.8 |
| " 38 | 22 | 12.9 | 73 | 36.9 | 23 | 11.1 |
| " 39 | 49 | 25.1 | 34 | 21.7 | 68 | 34.7 |
| " 40 | 42 | 24.7 | 38 | 21.0 | 35 | 17.7 |
| " 41 | 29 | 12.9 | 55 | 33.5 | 11 | 6.8 |
| " 42 | 40 | 21.7 | 49 | 25.4 | 39 | 16.6 |
| " 43 | 23 | 12.6 | 80 | 42.6 | 51 | 23.4 |
| " 44 | 31 | 18.0 | 56 | 30.9 | 59 | 24.1 |
| " 45 | 44 | 23.2 | 112 | 61.5 | 31 | 18.2 |
| " 46 | 25 | 16.7 | 85 | 50.0 | 13 | 8.3 |

## TABLE 5 (continued)

### TIRRAWARRA FIELD :- PATCHAWARRA FORMATION
### FACIES ASSOCIATIONS, SAND THICKNESSES AND SAND PERCENTAGES.

| WELL NO. | FACIES ASSOCIATION 3 | | FACIES ASSOCIATION 2B | | FACIES ASSOCIATION 2A | |
|---|---|---|---|---|---|---|
| | THICK. (feet) | % | THICK. (feet) | % | THICK. (feet) | % |
| TIRR. 47 | 32 | 14.6 | 76 | 48.7 | 19 | 9.0 |
| " 48 | 17 | 11.8 | 58 | 35.2 | 38 | 23.8 |
| " 49 | 35 | 20.5 | 36 | 25.4 | 27 | 15.9 |
| " 50 | 54 | 30.9 | 49 | 29.5 | 5 | 3.5 |
| " 51 | 57 | 28.6 | 42 | 28.6 | 42 | 23.5 |
| " 52 | 54 | 26.5 | 96 | 47.8 | 11 | 6.0 |
| " 53 | 40 | 21.6 | 61 | 34.9 | 61 | 30.5 |
| " 54 | 37 | 20.2 | 53 | 32.3 | 35 | 19.1 |
| " 55 | 56 | 24.8 | 31 | 19.5 | 28 | 12.9 |
| " 56 | 15 | 10.3 | 71 | 42.8 | 4 | 2.6 |
| " 57 | 30 | 17.9 | 66 | 36.5 | 25 | 12.8 |
| " 58 | 34 | 18.9 | 59 | 36.0 | 48 | 25.9 |
| " 59 | 22 | 13.3 | 58 | 38.9 | 44 | 20.0 |
| TIR. N 1 | 15 | 9.2 | 42 | 22.5 | 34 | 17.3 |
| TIR. W 1 | 80 | 40.0 | 85 | 46.4 | 43 | 20.2 |
| RAK. 1 | 26 | 13.8 | 43 | 27.6 | 29 | 15.9 |

## TABLE 6

TIRRAWARRA FIELD :- PATCHAWARRA COAL ISOPACH VALUES.
THICKNESS IN FEET

| WELL NUMBER | THICKNESS |
|---|---|
| TIRR. 1 | 46 |
| " 2 | 61 |
| " 3 | 26 |
| " 4 | 30 |
| " 5 | 62 |
| " 6 | 28 |
| " 7 | 37 |
| " 8 | 41 |
| " 9 | 30 |
| " 10 | 30 |
| " 11 | 66 |
| " 12 | 50 |
| " 13 | 31 |
| " 14 | 50 |
| " 15 | 46 |
| " 16 | 47 |
| " 17 | 37 |
| " 18 | 57 |
| " 19 | 31 |
| " 20 | 42 |
| " 21 | 49 |
| " 22 | 35 |
| " 23 | 47 |
| " 24 | 56 |
| " 25 | 48 |
| " 26 | 42 |
| " 27 | 55 |
| " 28 | 40 |
| " 29 | 56 |
| " 30 | 50 |
| " 31 | 35 |
| TIRR. 32 | 59 |
| " 33 | 60 |
| " 34 | 49 |
| " 35 | 42 |
| " 36 | 60 |
| " 37 | 60 |
| " 38 | 51 |
| " 39 | 56 |
| " 40 | 54 |
| " 41 | 59 |
| " 42 | 64 |
| " 43 | 60 |
| " 44 | 48 |
| " 45 | 27 |
| " 46 | 47 |
| " 47 | 46 |
| " 48 | 29 |
| " 49 | 46 |
| " 50 | 47 |
| " 51 | 49 |
| " 52 | 61 |
| " 53 | 56 |
| " 54 | 37 |
| " 55 | 63 |
| " 56 | 42 |
| " 57 | 52 |
| " 58 | 49 |
| " 59 | 45 |
| TIRR. N. 1 | 51 |
| TIRR. W. 1 | 51 |
| RAKOONA 1 | 46 |

## TABLE 7

TIRRAWARRA FIELD :- TIRRAWARRA SANDSTONE ISOPACH VALUES.
THICKNESSES IN FEET.

| WELL NUMBER | THICKNESS | WELL NUMBER | THICKNESS |
|---|---|---|---|
| TIRR. 1 | 143 | TIRR. 32 | 130 |
| " 2 | 116 | " 33 | 105 |
| " 3 | 104 | " 34 | 117 |
| " 4 | 122 | " 35 | 117 |
| " 5 | 126 | " 36 | 115 |
| " 6 | 91 | " 37 | 93 |
| " 7 | 109 | " 38 | 115 |
| " 8 | 107 | " 39 | 137 |
| " 9 | 110 | " 40 | 115 |
| " 10 | 135 | " 41 | 111 |
| " 11 | 165 | " 42 | 136 |
| " 12 | 96 | " 43 | 128 |
| " 13 | 65 | " 44 | 111 |
| " 14 | 105 | " 45 | 139 |
| " 15 | 124 | " 46 | 116 |
| " 16 | 119 | " 47 | 117 |
| " 17 | 87 | " 48 | 124 |
| " 18 | 125 | " 49 | 105 |
| " 19 | 118 | " 50 | 112 |
| " 20 | 109 | " 51 | 125 |
| " 21 | 108 | " 52 | 109 |
| " 22 | 105 | " 53 | 127 |
| " 23 | 94 | " 54 | 128 |
| " 24 | 98 | " 55 | 130 |
| " 25 | 116 | " 56 | 116 |
| " 26 | 120 | " 57 | 141 |
| " 27 | 126 | " 58 | 118 |
| " 28 | 109 | " 59 | 112 |
| " 29 | 127 | TIRR. N. 1 | 115 |
| " 30 | 118 | TIRR. W. 1 | 100 |
| " 31 | 109 | RAKOONA 1 | 117 |

## TABLE 8

TIRRAWARRA FIELD :- SUBSEA DEPTHS OF PATCHAWARRA FORMATION AND TIRRAWARRA SANDSTONE HORIZONS. DEPTHS IN FEET.

| WELL NO. | FACIES ASSOC. 3 TOP | FACIES ASSOC. 2B TOP | FACIES ASSOC. 2A TOP | FACIES ASSOC. 1B TOP | TIRRA. SST. TOP | TIRRA. SST. BASE |
|---|---|---|---|---|---|---|
| 1 | 8594 | 8756 | 8912 | 9084 | 9407 | 9549 |
| 2 | 8652 | 8835 | 9003 | 9211 | 9619 | 9735 |
| 3 | 8822 | 8958 | 9105 | 9260 | 9575 | 9679 |
| 4 | 8713 | 8866 | 9008 | 9154 | 9516 | 9638 |
| 5 | 8754 | 8963 | 9109 | 9335 | 9767 | 9893 |
| 6 | 8778 | 8912 | 9049 | 9183 | 9539 | 9630 |
| 7 | 8829 | 9020 | 9210 | 9365 | 9768 | 9880 |
| 8 | 8604 | 8748 | 8911 | 9077 | 9424 | 9531 |
| 9 | 8684 | 8822 | 8981 | 9152 | 9481 | 9592 |
| 10 | 8848 | 9012 | 9166 | 9307 | 9654 | 9786 |
| 11 | 8702 | 8883 | 9113 | 9358 | 9814 | 9979 |
| 12 | 8743 | 8913 | 9085 | 9306 | 9693 | 9805 |
| 13 | 8576 | 8725 | 8889 | 9056 | 9297 | 9362 |
| 14 | 8564 | 8726 | 8909 | 9094 | 9477 | 9582 |
| 15 | 8583 | 8736 | 8892 | 9064 | 9420 | 9544 |
| 16 | 8744 | 8886 | 9036 | 9179 | 9499 | 9618 |
| 17 | 8641 | 8820 | 8961 | 9150 | 9508 | 9595 |
| 18 | 8679 | 8894 | 9062 | 9269 | 9634 | 9759 |
| 19 | 8680 | 8823 | 8964 | 9149 | 9511 | 9629 |
| 20 | 8593 | 8747 | 8894 | 9063 | 9425 | 9534 |
| 21 | 8571 | 8733 | 8900 | 9083 | 9438 | 9546 |
| 22 | 8721 | 8864 | 9010 | 9176 | 9497 | 9602 |
| 23 | 8550 | 8706 | 8864 | 9021 | 9324 | 9426 |
| 24 | 8664 | 8856 | 9036 | 9244 | 9627 | 9725 |
| 25 | 8564 | 8730 | 8900 | 9067 | 9454 | 9570 |
| 26 | 8698 | 8841 | 9020 | 9159 | 9503 | 9629 |
| 27 | 8703 | 8881 | 9076 | 9295 | 9677 | 9803 |
| 28 | 8634 | 8789 | 8943 | 9109 | 9477 | 9586 |
| 29 | 8594 | 8769 | 8948 | 9115 | 9487 | 9616 |
| 30 | 8601 | 8777 | 8950 | 9149 | 9526 | 9644 |
| 31 | 8619 | 8805 | 8943 | 9122 | 9501 | 9610 |
| 32 | 8670 | 8858 | 9042 | 9247 | 9654 | 9784 |
| 33 | 8638 | 8814 | 8992 | 9205 | 9609 | 9714 |
| 34 | 8589 | 8774 | 8941 | 9093 | 9453 | 9570 |
| 35 | 8593 | 8746 | 8899 | 9077 | 9438 | 9555 |
| 36 | 8754 | 8966 | 9160 | 9340 | 9719 | 9834 |
| 37 | 8713 | 8902 | 9089 | 9266 | 9660 | 9753 |
| 38 | 8650 | 8820 | 9018 | 9226 | 9601 | 9716 |
| 39 | 8646 | 8841 | 8998 | 9194 | 9596 | 9733 |
| 40 | 8572 | 8742 | 8923 | 9121 | 9498 | 9613 |
| 41 | 8749 | 8974 | 9138 | 9300 | 9707 | 9817 |
| 42 | 8650 | 8834 | 9027 | 9262 | 9664 | 9797 |
| 43 | 8619 | 8801 | 8989 | 9207 | 9601 | 9727 |
| 44 | 8806 | 8978 | 9160 | 9404 | 9781 | 9893 |
| 45 | 8697 | 8887 | 9068 | 9239 | 9606 | 9745 |
| 46 | 8704 | 8854 | 9024 | 9180 | 9548 | 9664 |

## TABLE 8 (continued)

TIRRAWARRA FIELD :- SUBSEA DEPTHS OF PATCHAWARRA FORMATION AND TIRRAWARRA SANDSTONE HORIZONS. DEPTHS IN FEET.

| WELL NO. | FACIES ASSOC. 3 TOP | FACIES ASSOC. 2B TOP | FACIES ASSOC. 2A TOP | FACIES ASSOC. 1B TOP | TIRRA. SST. TOP | TIRRA. SST. BASE |
|---|---|---|---|---|---|---|
| 47 | 8652 | 8872 | 9028 | 9240 | 9629 | 9746 |
| 48 | 8688 | 8832 | 8997 | 9157 | 9494 | 9618 |
| 49 | 8570 | 8741 | 8883 | 9053 | 9407 | 9512 |
| 50 | 8557 | 8732 | 8898 | 9041 | 9425 | 9537 |
| 51 | 8678 | 8877 | 9024 | 9203 | 9597 | 9722 |
| 52 | 8781 | 8985 | 9186 | 9370 | 9743 | 9852 |
| 53 | 8610 | 8795 | 8970 | 9170 | 9544 | 9671 |
| 54 | 8669 | 8852 | 9016 | 9199 | 9587 | 9715 |
| 55 | 8741 | 8967 | 9129 | 9343 | 9701 | 9831 |
| 56 | 8725 | 8870 | 9036 | 9188 | 9519 | 9635 |
| 57 | 8564 | 8756 | 8932 | 9132 | 9468 | 9609 |
| 58 | 8601 | 8781 | 8946 | 9134 | 9506 | 9624 |
| 59 | 8694 | 8859 | 9009 | 9228 | 9595 | 9707 |
| TN 1 | 8942 | 9105 | 9292 | 9488 | 9860 | 9975 |
| TW 1 | 8776 | 8976 | 9152 | 9372 | 9757 | 9857 |
| RAK 1 | 8929 | 9117 | 9273 | 9413 | 9844 | 9961 |

# TABLE 9

TIRRAWARRA FIELD :- PATCHAWARRA FORMATION ISOPACH, TOTAL SAND ISOPACH, SAND PERCENTAGE AND TOTAL COAL ISOPACH

| WELL NUMBER | PATCH. ISOPACH | TOTAL SAND ISOPACH | SAND PERCENT | TOTAL COAL ISOPACH |
|---|---|---|---|---|
| TIRR. 1 | 831 | 119 | 14.3 | 143 |
| " 2 | 967 | 253 | 26.1 | 203 |
| " 3 | 756 | 192 | 25.4 | 162 |
| " 4 | 803 | 169 | 21.0 | 155 |
| " 5 | 1013 | 342 | 33.8 | 200 |
| " 6 | 761 | 157 | 20.6 | 168 |
| " 7 | 914 | 320 | 35.0 | 181 |
| " 8 | 830 | 214 | 25.8 | 167 |
| " 9 | 799 | 249 | 31.2 | 146 |
| " 10 | 813 | 224 | 27.6 | 159 |
| " 11 | 1112 | 219 | 19.7 | 227 |
| " 12 | 966 | 196 | 20.3 | 183 |
| " 13 | 721 | 177 | 24.5 | 143 |
| " 14 | 924 | 146 | 15.8 | 150 |
| " 15 | 847 | 157 | 18.5 | 156 |
| " 16 | 755 | 114 | 15.1 | 169 |
| " 17 | 867 | 189 | 21.8 | 145 |
| " 18 | 955 | 168 | 17.6 | 194 |
| " 19 | 831 | 216 | 26.0 | 157 |
| " 20 | 841 | 168 | 20.0 | 156 |
| " 21 | 867 | 194 | 22.4 | 171 |
| " 22 | 776 | 201 | 25.9 | 158 |
| " 23 | 782 | 232 | 29.7 | 160 |
| " 24 | 963 | 160 | 16.6 | 187 |
| " 25 | 890 | 225 | 25.3 | 169 |
| " 26 | 811 | 202 | 24.9 | 152 |
| " 27 | 974 | 261 | 26.8 | 179 |
| " 28 | 848 | 252 | 29.7 | 170 |
| " 29 | 893 | 236 | 26.4 | 164 |
| " 30 | 925 | 222 | 24.0 | 160 |
| " 31 | 882 | 172 | 19.5 | 146 |
| " 32 | 984 | 209 | 21.2 | 180 |
| " 33 | 971 | 188 | 19.4 | 208 |
| " 34 | 864 | 180 | 20.8 | 163 |
| " 35 | 845 | 211 | 25.0 | 181 |
| " 36 | 965 | 214 | 22.2 | 211 |
| " 37 | 947 | 158 | 16.7 | 195 |
| " 38 | 951 | 184 | 19.3 | 183 |
| " 39 | 950 | 300 | 31.6 | 194 |
| " 40 | 926 | 187 | 20.2 | 173 |
| " 41 | 958 | 167 | 17.4 | 202 |
| " 42 | 1014 | 177 | 17.5 | 213 |
| " 43 | 982 | 226 | 23.0 | 189 |
| " 44 | 975 | 218 | 22.4 | 196 |
| " 45 | 909 | 273 | 30.0 | 147 |
| " 46 | 844 | 215 | 25.5 | 176 |
| " 47 | 977 | 201 | 20.6 | 191 |

## TABLE 9 (continued)

## TIRRAWARRA FIELD :- PATCHAWARRA FORMATION ISOPACH, TOTAL SAND ISOPACH, SAND PERCENTAGE AND TOTAL COAL ISOPACH

| WELL NUMBER | PATCH. ISOPACH | TOTAL SAND ISOPACH | SAND PERCENT | TOTAL COAL ISOPACH |
|---|---|---|---|---|
| TIRR. 48 | 806 | 162 | 20.1 | 164 |
| " 49 | 837 | 161 | 19.2 | 154 |
| " 50 | 868 | 201 | 23.2 | 150 |
| " 51 | 919 | 205 | 22.3 | 191 |
| " 52 | 962 | 243 | 25.3 | 209 |
| " 53 | 934 | 229 | 24.5 | 165 |
| " 54 | 918 | 172 | 18.7 | 174 |
| " 55 | 960 | 165 | 17.2 | 227 |
| " 56 | 817 | 167 | 20.4 | 160 |
| " 57 | 880 | 188 | 21.4 | 172 |
| " 58 | 905 | 190 | 21.0 | 152 |
| " 59 | 913 | 185 | 20.3 | 170 |
| T.N. 1 | 918 | 141 | 15.3 | 199 |
| T.W. 1 | 981 | 343 | 35.0 | 169 |
| RAK. 1 | 915 | 230 | 25.1 | 162 |

## TABLE 10

TIRRAWARRA FIELD, PATCHAWARRA FORMATION.
FACIES ASSOCIATIONS 1A AND 1B COMBINED:-
TOTAL SAND ISOPACH AND SAND PERCENTAGE

| WELL NUMBER | SAND THICKNESS (FEET) | SAND PERCENTAGE |
|---|---|---|
| TIRR. 1 | 28 | 8.2 |
| " 2 | 96 | 23.5 |
| " 3 | 70 | 22.2 |
| " 4 | 55 | 15.9 |
| " 5 | 140 | 32.4 |
| " 6 | 80 | 22.5 |
| " 7 | 129 | 34.1 |
| " 8 | 86 | 24.1 |
| " 9 | 94 | 28.6 |
| " 10 | 112 | 31.6 |
| " 11 | 105 | 23.0 |
| " 12 | 72 | 17.9 |
| " 13 | 38 | 15.8 |
| " 14 | 58 | 14.8 |
| " 15 | 95 | 26.0 |
| " 16 | 56 | 17.5 |
| " 17 | 50 | 14.0 |
| " 18 | 81 | 22.2 |
| " 19 | 88 | 24.3 |
| " 20 | 48 | 12.9 |
| " 21 | 98 | 27.6 |
| " 22 | 65 | 20.2 |
| " 23 | 97 | 31.2 |
| " 24 | 58 | 15.1 |
| " 25 | 122 | 31.5 |
| " 26 | 86 | 24.6 |
| " 27 | 75 | 19.6 |
| " 28 | 101 | 27.1 |
| " 29 | 85 | 22.8 |
| " 30 | 76 | 20.2 |
| " 31 | 57 | 15.0 |
| " 32 | 90 | 22.1 |
| " 33 | 111 | 27.5 |
| " 34 | 50 | 13.9 |
| " 35 | 72 | 19.9 |
| " 36 | 90 | 23.7 |
| " 37 | 73 | 18.5 |
| " 38 | 66 | 17.6 |
| " 39 | 149 | 37.0 |
| " 40 | 72 | 19.1 |
| " 41 | 72 | 17.7 |
| " 42 | 49 | 12.2 |
| " 43 | 72 | 18.3 |
| " 44 | 72 | 19.1 |
| " 45 | 86 | 23.4 |
| " 46 | 92 | 25.0 |
| " 47 | 74 | 19.0 |
| " 48 | 49 | 14.5 |

## TABLE 10 (continued)

### TIRRAWARRA FIELD, PATCHAWARRA FORMATION. FACIES ASSOCIATIONS 1A AND 1B COMBINED:- TOTAL SAND ISOPACH AND SAND PERCENTAGE

| WELL NUMBER | SAND THICKNESS (FEET) | SAND PERCENTAGE |
|---|---|---|
| TIRR. 49 | 63 | 17.7 |
| " 50 | 93 | 24.2 |
| " 51 | 64 | 16.2 |
| " 52 | 82 | 21.9 |
| " 53 | 67 | 17.9 |
| " 54 | 47 | 12.1 |
| " 55 | 50 | 13.9 |
| " 56 | 77 | 22.1 |
| " 57 | 67 | 19.9 |
| " 58 | 49 | 12.9 |
| " 59 | 61 | 16.1 |
| T.N. 1 | 50 | 13.4 |
| T.W. 1 | 135 | 35.1 |
| RAK. 1 | 132 | 33.9 |

## TABLE 11

### TIRRAWARRA FIELD , PATCHAWARRA FORMATION SANDSTONE POROSITY VALUES

| WELL NUMBER | FACIES ASSOCIATION 2B POROSITY PERCENTAGE | FACIES ASSOCIATION 2A POROSITY PERCENTAGE |
|---|---|---|
| TIRR. 1 | 10.2 | 10.3 |
| " 2 | 11.1 | 10.9 |
| " 3 | 9.4 | 9.5 |
| " 4 | 10.0 | 8.6 |
| " 5 | 8.5 | 9.8 |
| " 6 | 7.4 | 7.8 |
| " 7 | 9.5 | 11.3 |
| " 8 | 10.2 | 9.0 |
| " 9 | 9.3 | 9.0 |
| " 10 | 8.3 | 6.9 |
| " 11 | 9.7 | 9.7 |
| " 12 | 8.9 | 8.6 |
| " 13 | 8.2 | 9.7 |
| " 14 | 11.1 | 9.0 |
| " 15 | 10.2 | 8.0 |
| " 16 | 8.9 | 9.6 |
| " 17 | 9.0 | 8.8 |
| " 18 | 10.0 | 9.9 |
| " 19 | 9.3 | 10.0 |
| " 20 | 10.5 | 8.2 |
| " 21 | 10.5 | 7.1 |
| " 22 | 8.8 | 7.8 |
| " 23 | 10.5 | 8.8 |
| " 24 | 11.0 | 9.0 |
| " 25 | 10.9 | 9.8 |
| " 26 | 9.3 | 9.2 |
| " 27 | 10.0 | 9.3 |
| " 28 | 10.8 | 8.7 |
| " 29 | 10.3 | 9.1 |
| " 30 | 10.6 | 9.5 |
| " 31 | 9.0 | 8.4 |
| " 32 | 9.2 | 8.9 |
| " 33 | 12.7 | 13.5 |
| " 34 | 9.2 | 9.6 |
| " 35 | 10.2 | 8.9 |
| " 36 | 8.7 | 8.0 |
| " 37 | 8.8 | 8.3 |
| " 38 | 9.9 | 9.7 |
| " 39 | 10.0 | 9.7 |
| " 40 | 10.8 | 10.0 |
| " 41 | 10.1 | 8.9 |
| " 42 | 9.7 | 9.9 |
| " 43 | 9.3 | 10.1 |
| " 44 | 8.2 | 8.7 |
| " 45 | 9.1 | 8.3 |
| " 46 | 11.1 | 8.4 |
| " 47 | 10.6 | 9.0 |

## TABLE 11 (continued)

TIRRAWARRA FIELD , PATCHAWARRA FORMATION
SANDSTONE POROSITY VALUES

| WELL NUMBER | FACIES ASSOCIATION 2B POROSITY PERCENTAGE | FACIES ASSOCIATION 2A POROSITY PERCENTAGE |
|---|---|---|
| TIRR. 48 | 8.9 | 8.8 |
| " 49 | 9.6 | 9.7 |
| " 50 | 8.0 | 9.2 |
| " 51 | 10.0 | 9.2 |
| " 52 | 9.6 | 9.1 |
| " 53 | 9.7 | 9.8 |
| " 54 | 9.5 | 10.3 |
| " 55 | 9.6 | 9.4 |
| " 56 | 9.0 | 10.3 |
| " 57 | 9.4 | 8.6 |
| " 58 | 8.4 | 9.0 |
| " 59 | 8.4 | 8.4 |
| T.N. 1 | 9.0 | 9.0 |
| T.W. 1 | 8.8 | 8.6 |
| RAK. 1 | 9.0 | 7.9 |

## TABLE 12

### TIRRAWARRA FIELD, PATCHAWARRA FORMATION CORE BOUNDARIES

| WELL NUMBER | CORE NUMBER | TOP (FEET) | BOTTOM (FEET) |
|---|---|---|---|
| TIRR. 1 | 4 | 8997 | 9023 |
| " " | 5 | 9023 | 9058 |
| TIRR. 2 | 1 | 9044 | 9104 |
| " " | 2 | 9180 | 9235 |
| " " | 3 | 9610 | 9670 |
| " " | 4 | 9670 | 9730 |
| TIRR. 3 | 1 | 9188 | 9248 |
| " " | 2 | 9274 | 9324 |
| TIRR. 4 | 1 | 8825 | 8860 |
| " " | 2 | 9008 | 9042 |
| TIRR. 5 | 1 | 8960 | 8990 |
| " " | 2 | 9111 | 9171 |
| " " | 3 | 9171 | 9231 |
| " " | 4 | 9231 | 9291 |
| " " | 5 | 9291 | 9351 |
| " " | 6 | 9351 | 9385 |
| " " | 7 | 9385 | 9445 |
| " " | 8 | 9870 | 9904 |
| TIRR. 11 | 1 | 9900 | 9953 |
| TIRR. 12 | 1 | 9095 | 9135 |
| " " | 2 | 9140 | 9163 |
| " " | 3 | 9823 | 9846 |
| TIRR. 13 | 1 | 8949 | 8955 |
| " " | 2 | 8955 | 8999 |
| " " | 3 | 9005 | 9015 |
| " " | 4 | 9030 | 9036 |
| " " | 5 | 9036 | 9064 |
| TIRR. 16 | 1 | 9106 | 9138 |
| " " | 2 | 9140 | 9161 |
| TIRR. 17 | 1 | 9617 | 9630 |
| " " | 2 | 9630 | 9642 |
| TIRR. 19 | 1 | 9058 | 9085 |
| " " | 2 | 9085 | 9105 |
| TIRR. 28 | 1 | 9014 | 9044 |
| TIRR. 32 | 1 | 9706 | 9731 |
| " " | 2 | 9736 | 9763 |

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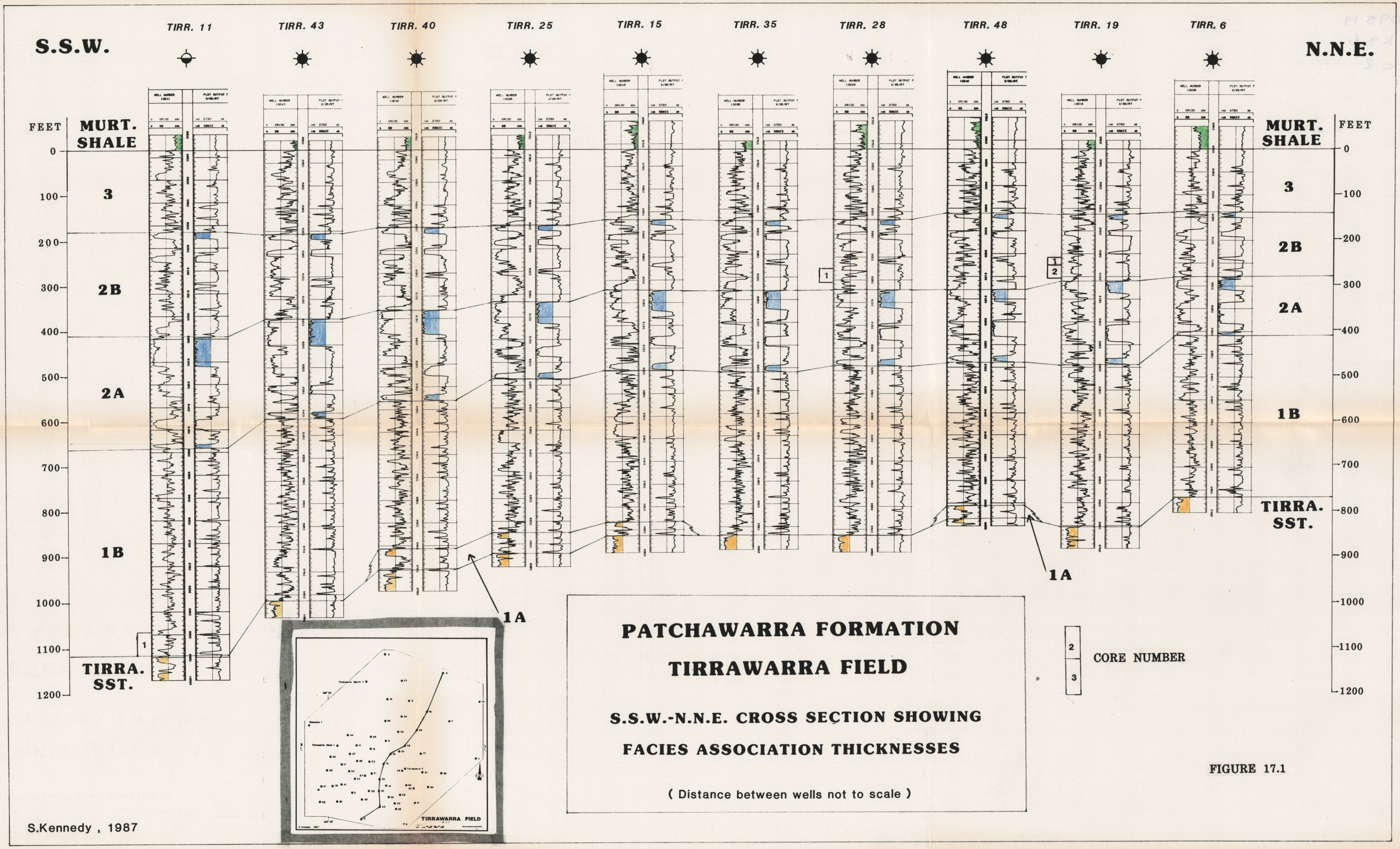
## FIGURE 29
## TIRRAWARRA FIELD

RELATIONSHIP OF FACIES ASSOCIATION THICKNESS,

SAND PERCENTAGE, GROSS SAND

AND POROSITY TO STRUCTURE.

S. KENNEDY, 1987



# PATCHAWARRA FORMATION
# TIRRAWARRA FIELD

## S.S.W.-N.N.E. CROSS SECTION SHOWING FACIES ASSOCIATION THICKNESSES

( Distance between wells not to scale )

FIGURE 17.1

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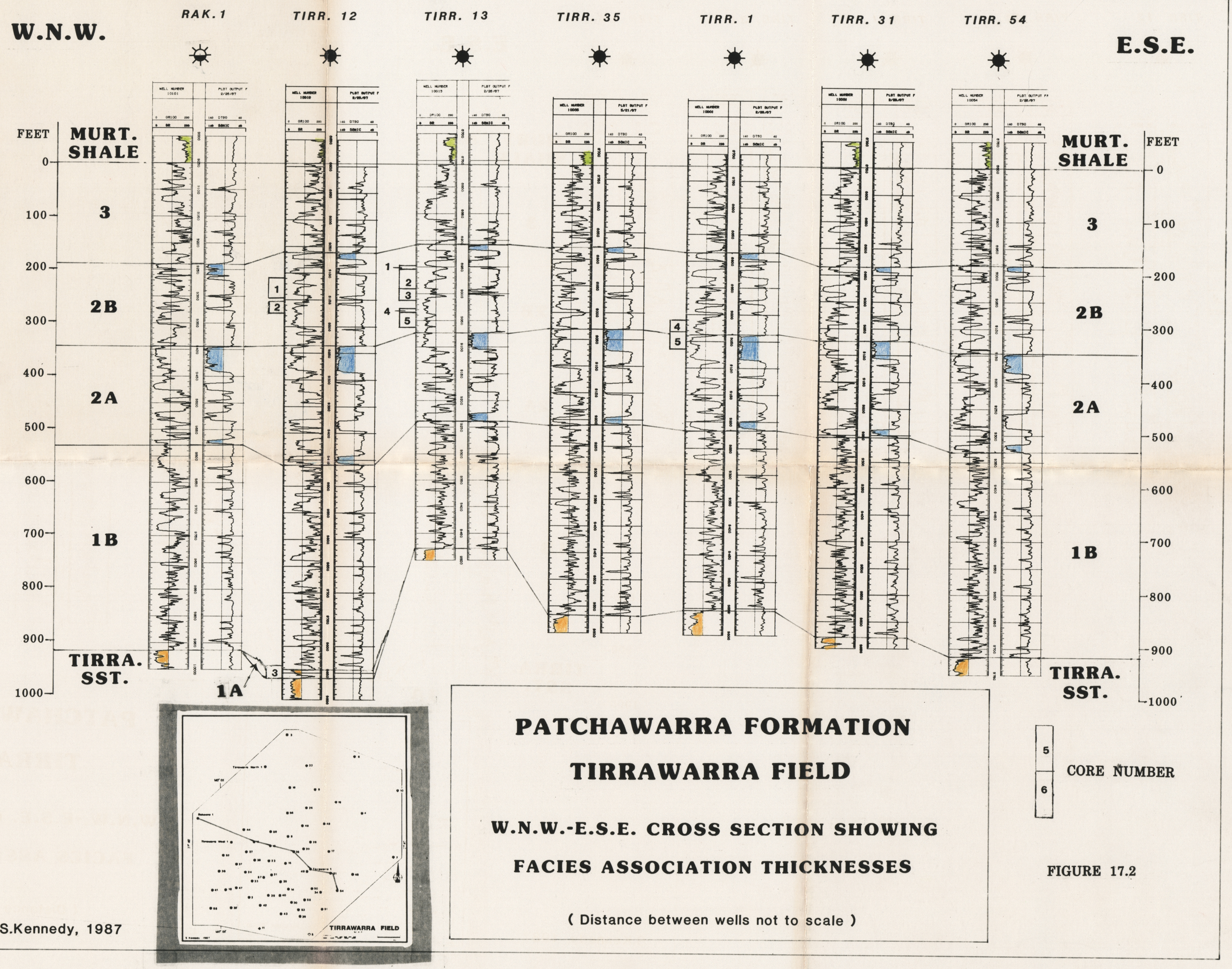

## PATCHAWARRA FORMATION

## TIRRAWARRA FIELD

### W.N.W.-E.S.E. CROSS SECTION SHOWING FACIES ASSOCIATION THICKNESSES

( Distance between wells not to scale )

FIGURE 17.2

S.Kennedy, 1987