THE EUMERALLA FORMATION:

SEDIMENTATION, AND POTENTIAL RESERVOIR DEVELOPMENT,

OTWAY BASIN, SOUTH AUSTRALIA

EAMONN THOMAS MONTAGUE

B. App. Sci. (R.M.I.T.)

This thesis is submitted as partial fulfillment for the Honours Degree of Bachelor of Science in Petroleum Geology and Geophysics, University of Adelaide.

November 1989

ABSTRACT

The Eumeralla Formation is a sequence of non-marine shales, silty sandstones and minor volcanogenic sandstones, deposited in the rift setting of the Otway Basin. The Eumeralla Formation had been regarded as a regional seal until gas flows were reported in the Eumeralla Formation from the Katnook wells. The main aim of this thesis is to develop a depositional model to predict the occurrences of reservoir sands and the diagenetic controls on reservoir development.

Subdivision of the Eumeralla Formation was carried out using wireline log character and palynology. Facies for the subdivisions were interpreted from sedimentological analysis of core.

A meandering fluvial environment with associated backswamp sub-environments were overlain by sediments deposited in a floodplain setting. Subsidence resulted in deepening water levels and the formation of an extensive shallow lacustrine environment. A eustatic rise in sea level and rapid subsidence formed a series of relatively deep water lakes which were subjected to marine influence at the close of deposition of the Eumeralla Formation.

The best reservoir sands develop in the fluvial and deep water lake environments. Diagenetic studies indicate that these sands develop best over structural highs where compaction is minimal.

Intraformational seals are abundant, resulting in migration problems.

The sands in the Eumeralla Formation are 'hot', and consequently have a bland GR log signature. The SP log combined with the caliper log are the best tools for defining sand bodies in the Eumeralla Formation.

ACKNOWLEDGEMENTS

I have to acknowledge the help and advice of many people who have made the preparation of this thesis possible.

The staff at SAGASCO Resources, especially Robb Willink, Doug Coelho, Doug Roberts and Lynton Spencer. And a very special thanks to Julie Hurrell (for the typing of this thesis), Pauline Oldham, Vicki Dutkiewicz, Chris Kay and Brenton Wells from drafting; without whose help this thesis would remain only an idea.

Many thanks go to the staff at the National Centre, and Adelaide University, especially to Nick Lemon for daring to supervise my project, which required a great deal of skill and patience. I'd also like to thank Bill Stuart for his efficient running of the National Centre and hope future students receive the same high standard of training.

A special thanks go to my fellow honours students for their help and comradeship throughout the year especially Baldy (for his ideas), Bruce, Coxy, Lyndon, Chris and Sandy for amusement value.

I want to thank my parents and my brother for actively encouraging me to pursue further study and for the moral and financial support over the years. Thanks!

CONTENTS

CONTENTS - Cont'd

APPENDICES

FIGURES

FIGURES - Cont'd

TABLES

1.1 Introduction

The Early Cretaceous Eumeralla Formation is a sequence of non-marine shales, silty sandstones and minor lithic sandstones, deposited in the rift setting of the Otway Basin. The Otway Basin is a Jurassic to Tertiary rift-passive margin style basin, located both onshore and offshore along the coastline of southwest Victoria and southeast South Australia (Fig 1). This study is restricted to the area around the Penola Trough, located in the western end of the basin, along the northern margin (Fig 2).

This thesis studies the depositional and reservoir characteristics of the Eumeralla Formation. The Eumeralla Formation has been recognised by numerous authors to be deposited in fluvial and lacustrine settings (Gravestock et al., 1986, Williamson et al., 1987, Heggarty et al., 1988, Williamson et al., 1989, SAGASCO Resources, 1989). The Eumeralla Formation had been regarded as a regional seal, until Katnook 1, drilled in 1987, intersected gas sands, indicating the existence of reservoirs within the formation.

SAGASCO Resources initiated and supported the project. Their interests involved the definition of the rift setting and analysis of the sediments in that setting.

Emphasis is placed on definition of subsurface facies within the formation and the subsequent locations of reservoir development.

The data available for the project consisted of wireline log suites, core data, and seismic profiles. The wireline logs are used for correlations between wells. The SP, caliper, gamma ray and sonic tools were all used for correlation, but the gamma ray was unable to define sand bodies. Core data were used for facies analysis, and seismic data for observing the regional character of the Eumeralla Formation.

Correlations between wells were made difficult by the lack of definition shown by the log suites. This problem was overcome by detailed work, matching logs to the existing core (see Appendix 3).

Consequently, subdivision of the Eumeralla Formation was carried out by assigning facies to core and correlations between holes along sections across the Penola Trough based on log and seismic character.

Twenty four samples were collected for transmitted light microscopy, X-ray diffraction, and some scanning electron microscopy to determine diagenetic factors affecting reservoir quality.

1.2 Exploration History

The first petroleum exploration well to be drilled in the Otway basin was Bore A, near Kingston, South Australia in 1892 (Sprigg, 1985). Over 100 deep wells have been drilled in the Otway Basin, both onshore and offshore. A summary of significant discovery wells is listed below (from Laing et al., 1989):

Table 1

LOCATION	YEAR	WELLNAME	T.D.	BOTTOMED IN	SHOWS
1	1941	Nelson Bore (Glenelg 1)	2226	Paaratte	
2	1959	Port Campbell-1	1819	Waarre	Waarre
3	1962	Pretty Hill 1	1962	Otway	
4	1964	Port Campbell-4	2598	Otway	Otway
5	1965	Casterton 1	2495	Basement	Otway
6	1967	Pecten-1A	2851	Otway	Waarre
7	1967	Caroline-1	3372	Otway	Waarre
8	1968	Garvoc 1	1535	Basement	Otway
9	1968	Woolsthorpe 1	1972	Casterton	Otway
10	1969	Hawkesdale 1	1774	Basement	Otway
11	1974	Ross Creek 1	3659	Otway	
12	1979	North Paaratte-1	1545	Otway	Waarre
13	1980	North Paaratte-3	1603	Otway	Waarre
14	1981	North Paaratte-2	1516	Otway	Waarre
15	1981	Grumby-1	1811	Otway	Waarre
16	1981	Wallaby Creek-1	1763	Otway	Waarre
17	1982	Curdie-1	2600	Otway	Pebble Point
18	1982	Braeside-1	2300	Otway	Eumeralla
19	1983	Greenbanks-1	1226	Basement	Eumeralla
20	1983	Lindon-1	3011	Otway	Pebble Point
21	1984	Stoneyford-1	1205	Basement	Eumeralla
22	1985	Fahley-1	3211	Waarre	Pebble Point
23	1985	Greenslopes 1	2609	Casterton	
24	1986	Normanby-1	3308	Waarre	Waarre
25	1986	Najaba-1A	3412	Otway	Waarre
26	1986	Westgate-1A	1918 (MD)	Otway	Waarre
27	1987	Wilson-1	1317	Paaratte	Pebble Point
28	1987	Tirrengowa-1	1273	Basement	Pretty Hill
29	1987	Windermere-1	1052	Otway	Eumeralla
30	1988	Katnook-1	2520	Otway	Eumeralla
31	1988	Iona-1	1490	Otway	Waarre
32	1989	Katnook 2	NA	NA	Eumeralla Pretty Hill

GAS SHOWS
OIL SHOWS
GAS WELL
WEAK OIL SHOW
GAS WELL WITH OIL SHOWS
WEAK GAS SHOW
WEAK OIL AND GAS SHOW

(see Appendix 5 for well localities)

Ladbroke Grove 1 was drilled in mid-1989 on a nearby structure to the Katnook discoveries. Strong gas flows and condensate were recorded (Mineral Industry Quarterly, SA, 1989). Drilling commenced in November, 1989 on Laira 1, on an adjacent structure to Katnook.

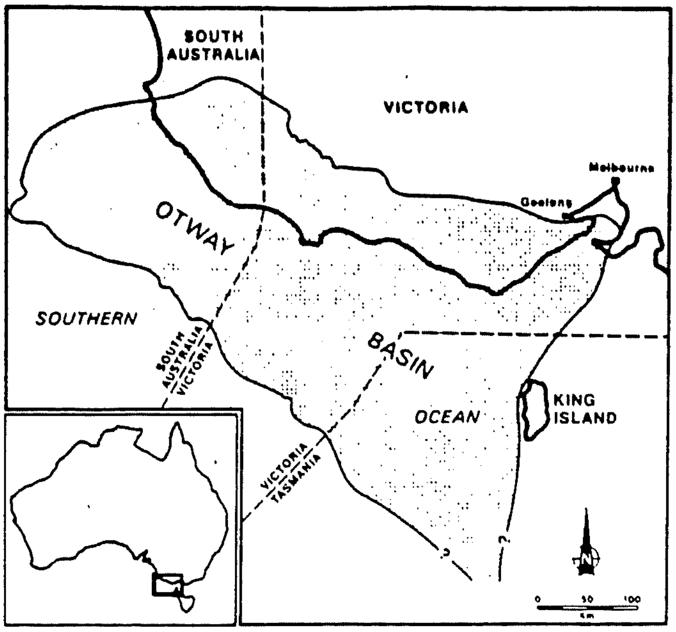


Figure 1 — Locality map of Otway Basin.

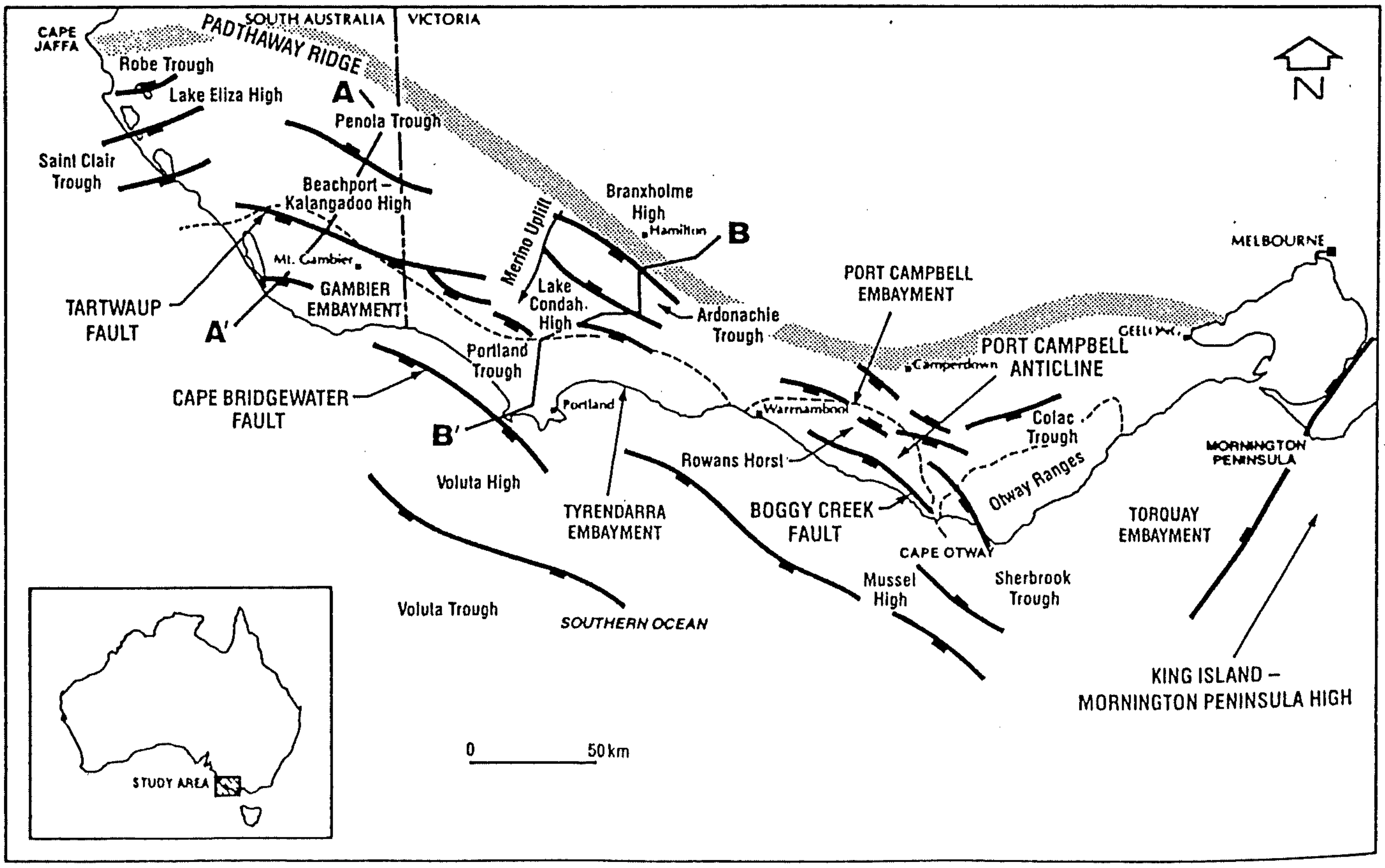


Figure 2. Tectonic elements of the Otway Basin.

(from Laing, et al., 1989)

2.0 REGIONAL GEOLOGY

The Otway Basin was initiated in the Late Jurassic, in response to the rifting between Australia and Antarctica. The basin trends NW-SE and straddles approximately 500 km of the coastline in Victoria and South Australia (Williamson et al., 1989). The Otway Basin covers an area of approximately 150 000 km^2, and is bounded to the east by the sub-cropping King Island - Mornington Peninsula Basement High, and to the northwest by the Padthaway Ridge (Fig 2). The remainder of the northern boundary is generally considered to be the Lower Cretaceous-Tertiary subcrop line. The southern margin is marked by the continental shelf margin (Laing et al., 1989).

2.1 Structure and Tectonic Setting

The rifting that formed the Otway Basin began around 140 Ma, and created an intracratonic basin that filled with Late Jurassic and Early Cretaceous sediments. Rifting in the Otway Basin occurred in two distinct stages. The first stage ended in the Late Neocomian (110-120 Ma) (Williamson et al., 1989 (a) & (b)) and the second stage ceased upon breakup, at the end of the Early Cretaceous (96 Ma) (Veevers, 1988 (b)). Post-rift development of the Otway was a period of much slower subsidence, and tectonic quiescence (Heggarty et al., 1988).

The most recent theories on the mechanisms for rifting suggest the rift formed by lithospheric extension and detachment (Fig 3) (Etheridge et al., 1983, Megalla, 1986 and Heggarty et al., 1988). This is supported by the fault geometries of the first rift stage which are listric and detach within basement.

These faults formed a series of E-W to ENE-WSW trending grabens and half grabens, with an associated SSE transfer direction. The second stage faults trend SE-NW and reflect the final rift trends of the Otway Basin. Both rift stages occurred during a period of rapid subsidence (50m/Ma) (Fig 4) (Heggarty et al., 1988). Williamson et al., (1989b) noted that second stage rifting was most intense towards the eventual oceanic edge of the continental plate, and that the first stage rifts had their most intense expression shoreward. The conclusion of the first stage was accompanied by uplift and erosion suggested by an angular unconformity between the sediments of the two rift stages(App.2).The faults of the first stage have undergone little reactivation during the later rift history and as a consequence have been strongly overprinted (Williamson et al., 1989 (a)).

Rifting was terminated during the mid-Cretaceous breakup between Australia and Antarctica and accompanied by a period of block faulting, differential uplift, and slight to considerable erosion. The Otway Basin became divided

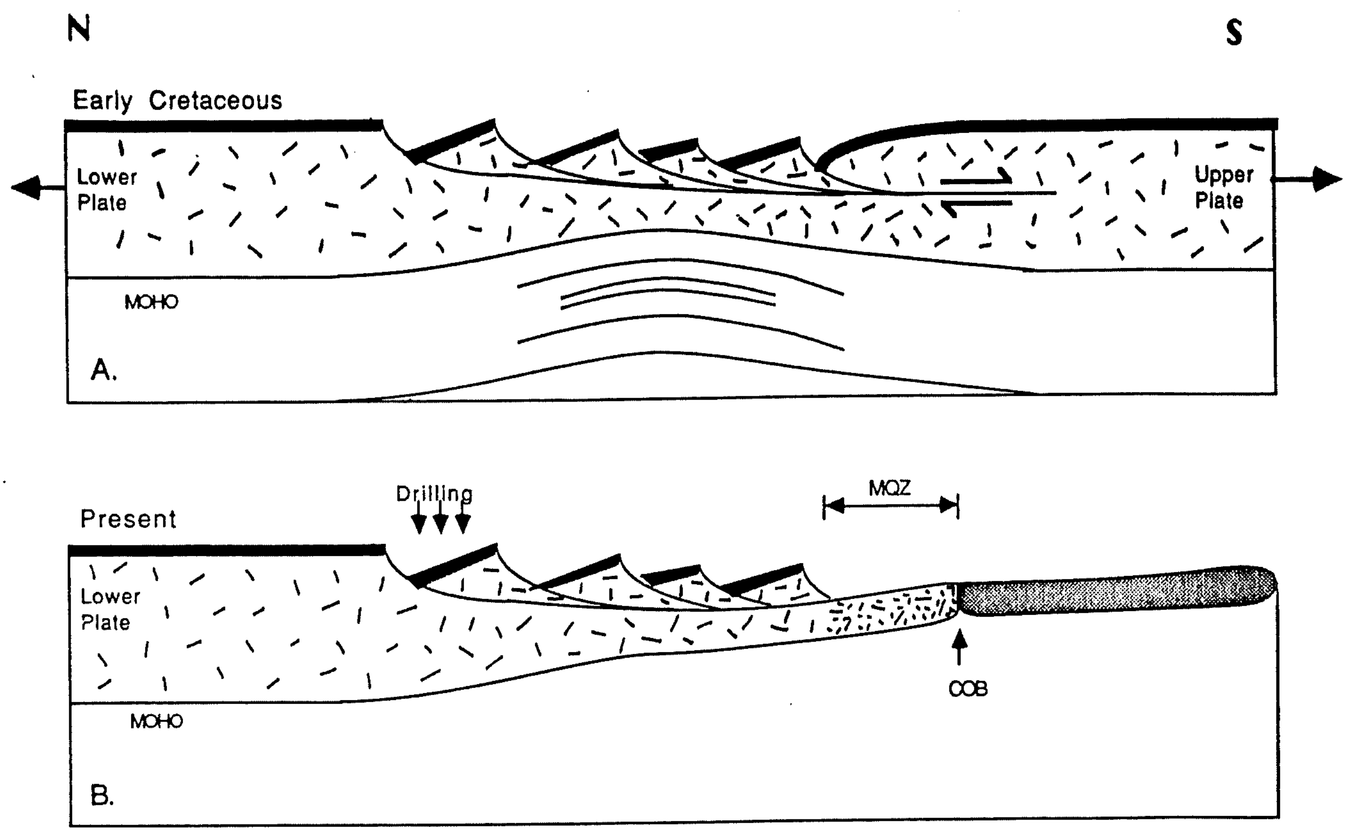


Figure 3. Detachment model for extension.

(from Heggarty et al., 1988)

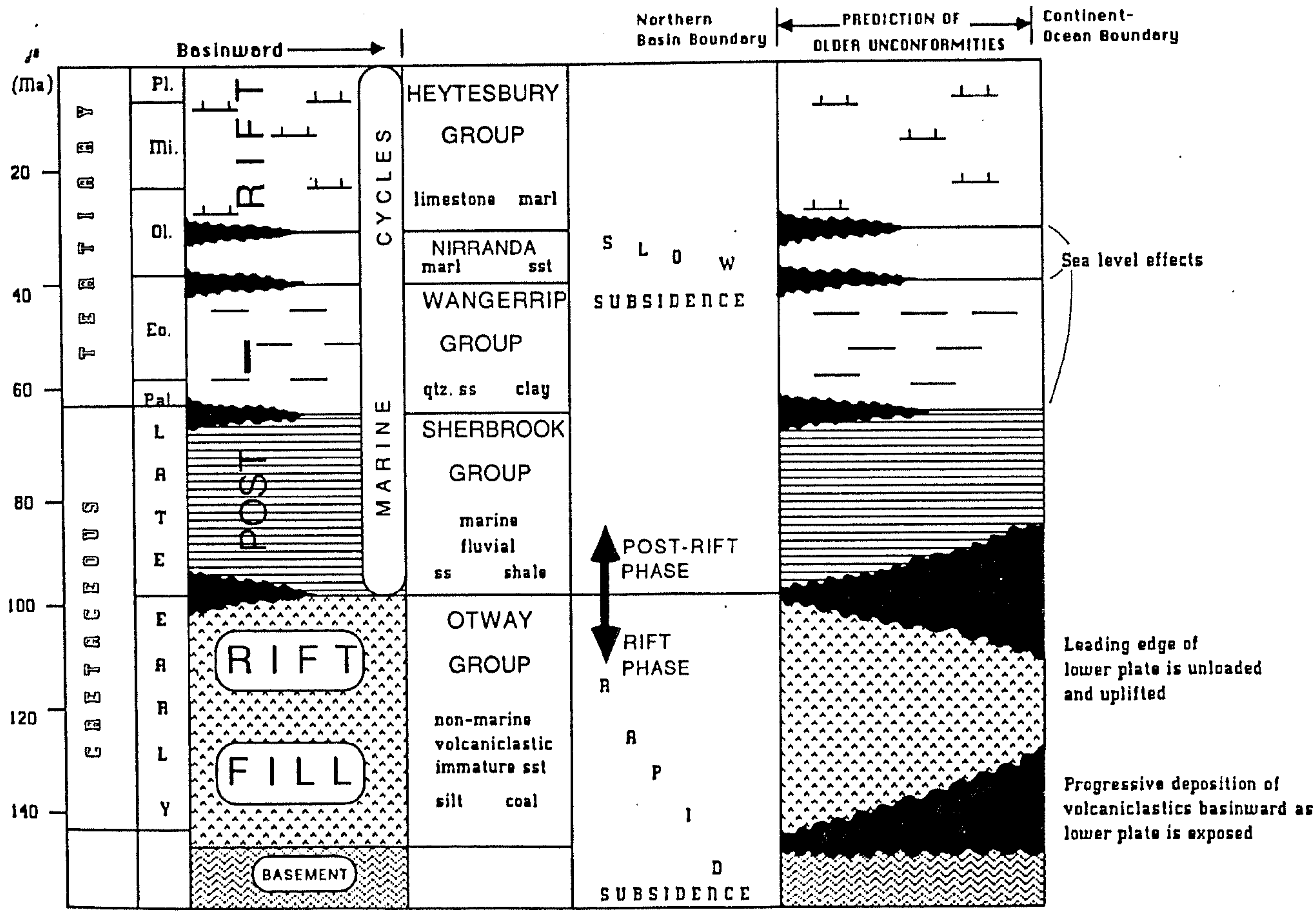


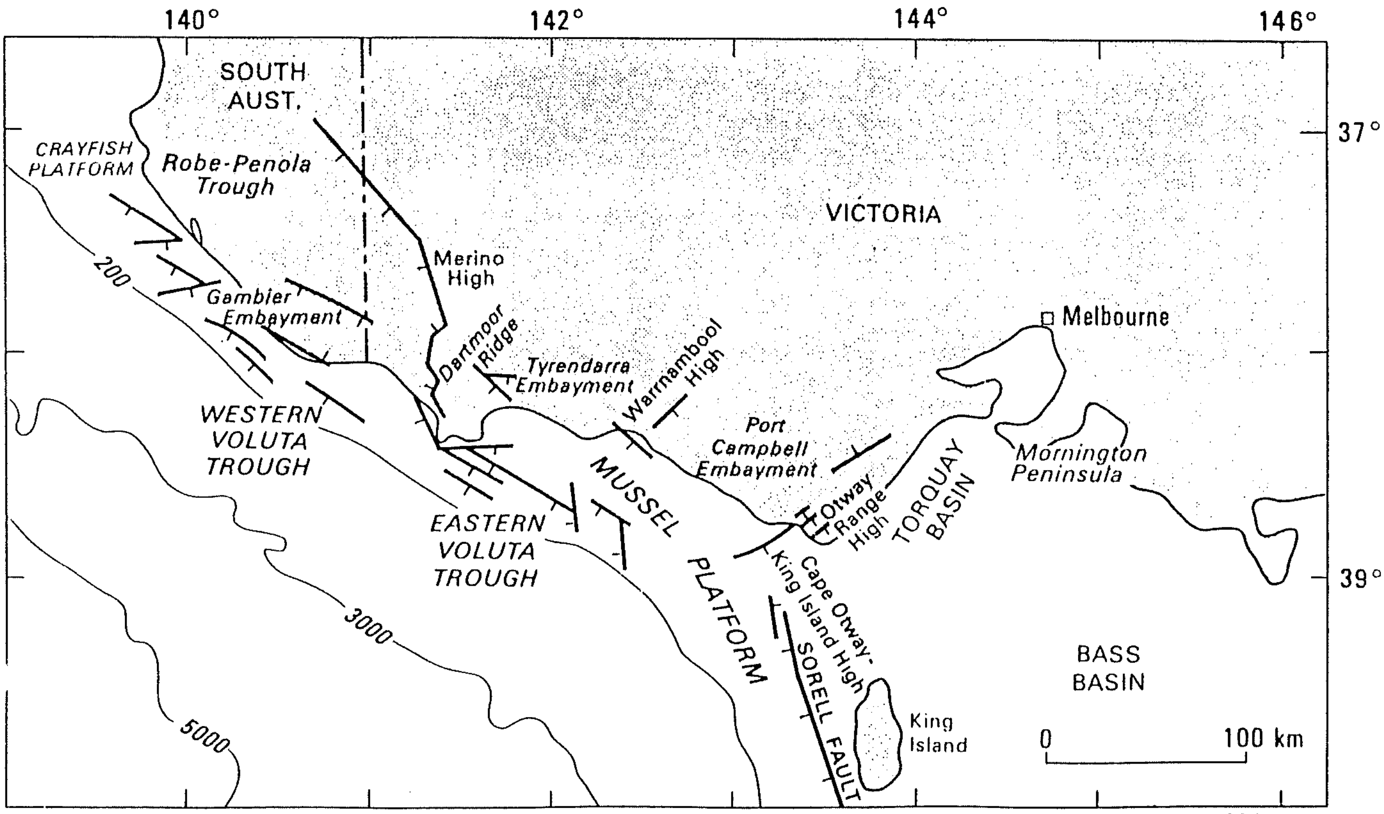
Figure 4. Otway Basin evolution schematic.

(from Heggarty et al., 1988)

into several NW-SE trending sub-basins. The Otway Ranges High and the Cape Otway - King Island High became prominent structural and topographic features, dividing the basin into two distinct sedimentary provinces (Fig 5) (Williamson et al., 1987). Subsidence during the post-rift stage is modelled as cooling and contraction of extended continental lithosphere and is much slower than the rift stages (Fig 4) Heggarty et al., 1988).

Figure 5

(Williamson et al., 1987)



2.2 Depositional History of the Otway Basin

The depositional history of the Otway Basin can be subdivided into 2 phases; a period of rapid subsidence during rifting, and slow subsidence following breakup with sea floor spreading (Fig 4) (Heggarty et al., 1988).

Rift sedimentation consists of volcaniclastic sediments of the Late Jurassic Casterton Volcanics and overlying Lower Cretaceous Otway Group (Fig 6). The rift sediments are typically 3000-4000m thick and overlie a basement of Palaeozoic low grade metamorphics and sediments of the Tasman Orogenic Belt (Heggarty et al., 1988 and Yu, 1988). The Casterton Volcanics have been defined by Gravestock et al. (1986) as a sequence of "interbedded carbonaceous shale and minor feldspathic sandstone and siltstone characterised by interbedded olivine basalt and volcaniclastics". The Otway Group has been subdivided into two formations, the basal Crayfish Formation and the overlying Eumeralla Formation (Fig 6). The Crayfish Formation consists mainly of quartzose sandstones deposited in a high-energy, westward flowing fluvial environment (Gravestock et al., (1986) and Laing et al., (1989)). The Geltwood Beach Formation is a shaley, western lateral equivalent of the Crayfish Formation (O'Brien, 1987). The Eumeralla Formation is a sequence of shales, lithic siltstones and volcanogenic sandstones and thin coals deposited in fluviatile and lacustrine settings, during a period of active volcanism (Williamson et al., 1987). More detailed descriptions of the Eumeralla Formation are presented throughout this thesis.

Following breakup between Australia and Antarctica, deltaic sediments of the Sherbrook Group and Wangerrip Group were deposited along the passive margin of the Otway Basin. The Sherbrook Group is a transgressive deltaic sequence resulting from a eustatic rise in sea level. The Waarre Formation, the basal transgressive sand of the Sherbrook Group, consists of fine to very coarse grained carbonaceous quartz sandstones, siltstones, mudstones, and coaly horizons. Continued transgression and subsidence resulted in the deposition of the paralic to marine Flaxmans Formation and Nullawarre Greensand and eventually the pro-delta muds of the Belfast Formation. Marine regression in the Late Cretaceous was accompanied by sediments from the prograding deltaic Paaratte Formation, and the continental coastal plain deposits of the Curdies Formation and Timboon Sand. Sedimentation in the Tertiary, Wangerrip Group began with a marine transgression, and deposited the deltaic sandy Pebble Point Formation; a sequence of pebbly and oolitic sandstone. Pro-delta muds of the Pember Mudstone indicated continued transgression until the Early Eocene (Williamson et al., 1987).

Marine regression occurred through the Early Eocene, depositing the Middle to Late Eocene Nirranda Group unconformably over the Wangerrip Group. The Nirranda Group sediments are in turn unconformably overlain by the thick marine carbonates of the Late Oligocene and Miocene Heytesbury Group. Deposition in the Otway Basin generally ceased following the Late Miocene to Quaternary uplift and folding.

GENERALISED TECTONO-STRATIGRAPHIC EVENT DIAGRAM (JURASSIC - CAINZOIC) OF THE WESTERN OTWAY BASIN

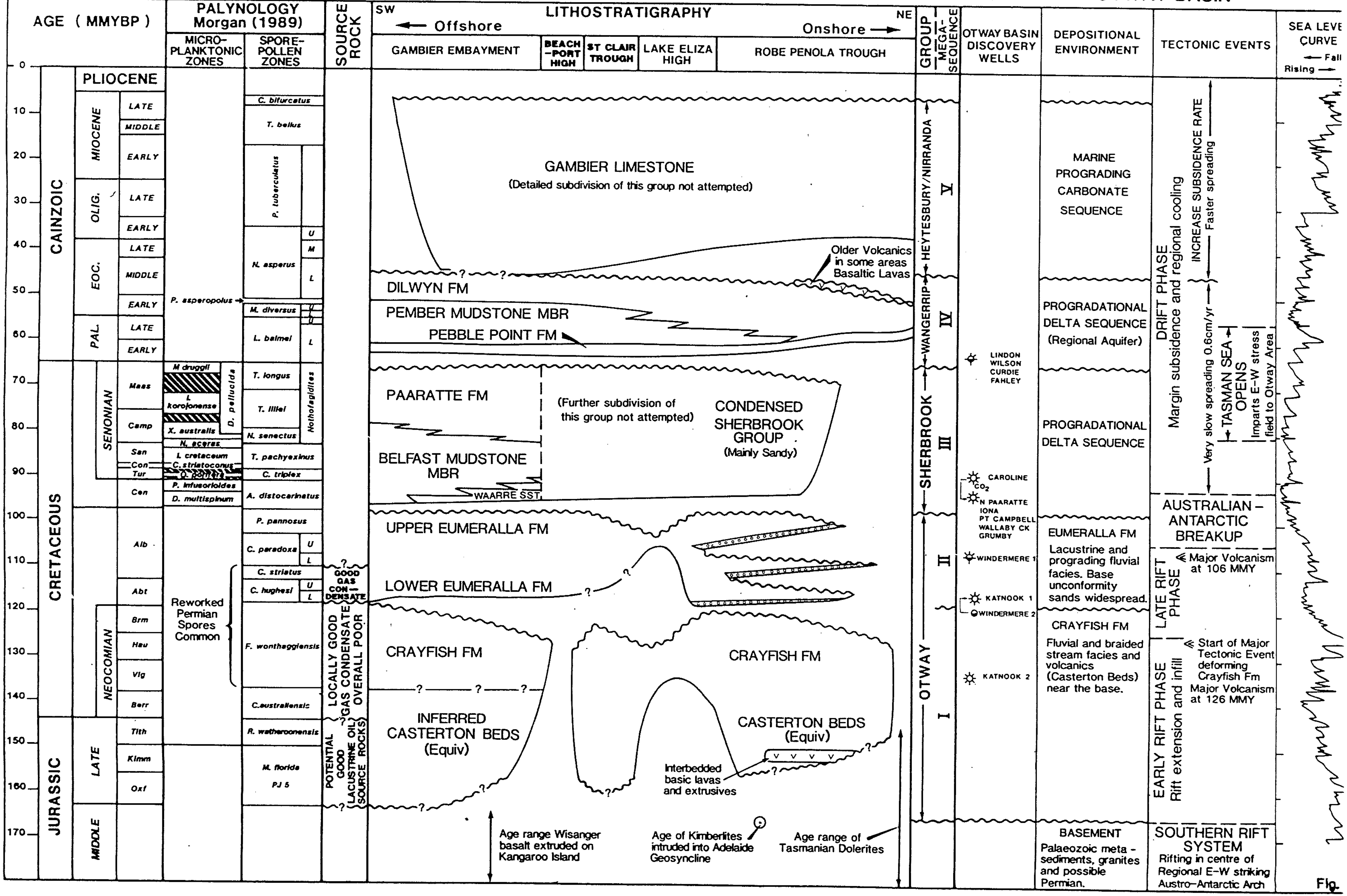


Figure 6 SAGASCO Resources, 1989.

3.0 SUBSURFACE FACIES OF THE EUMERALLA FORMATION

3.1 Wireline Log Subdivision of the Eumeralla Formation

The Eumeralla Formation has been subdivided into five units, based on wireline log character and palynology. The units are referred to as Units I, II, III, IV and V (from the top to the basal unit). Figure 7 shows the proposed subdivisions.

3.1.1 Unit I

Unit I is characterised on the logs by a very bland SP response, and is generally associated with the P. pannosus palynological subzone (Morgan, 1987). Core within this unit shows the lithologies are dominated by mudstones and siltstones, with minor fine grained lithic sandstone. The siltstones are planar and ripple cross laminated, and show slump structures and minor hummocky cross stratification (Appendix 4). The mudstones are grey to green-grey in colour and are generally massive, with some lamination and bioturbation. Coaly leaf detritus is abundant.

3.1.2 Unit II

Unit II is the thickest unit in the Eumeralla Formation, and consists of numerous sand bodies (generally 10-15m and up to 25m thick) interbedded with silts and mudstones.

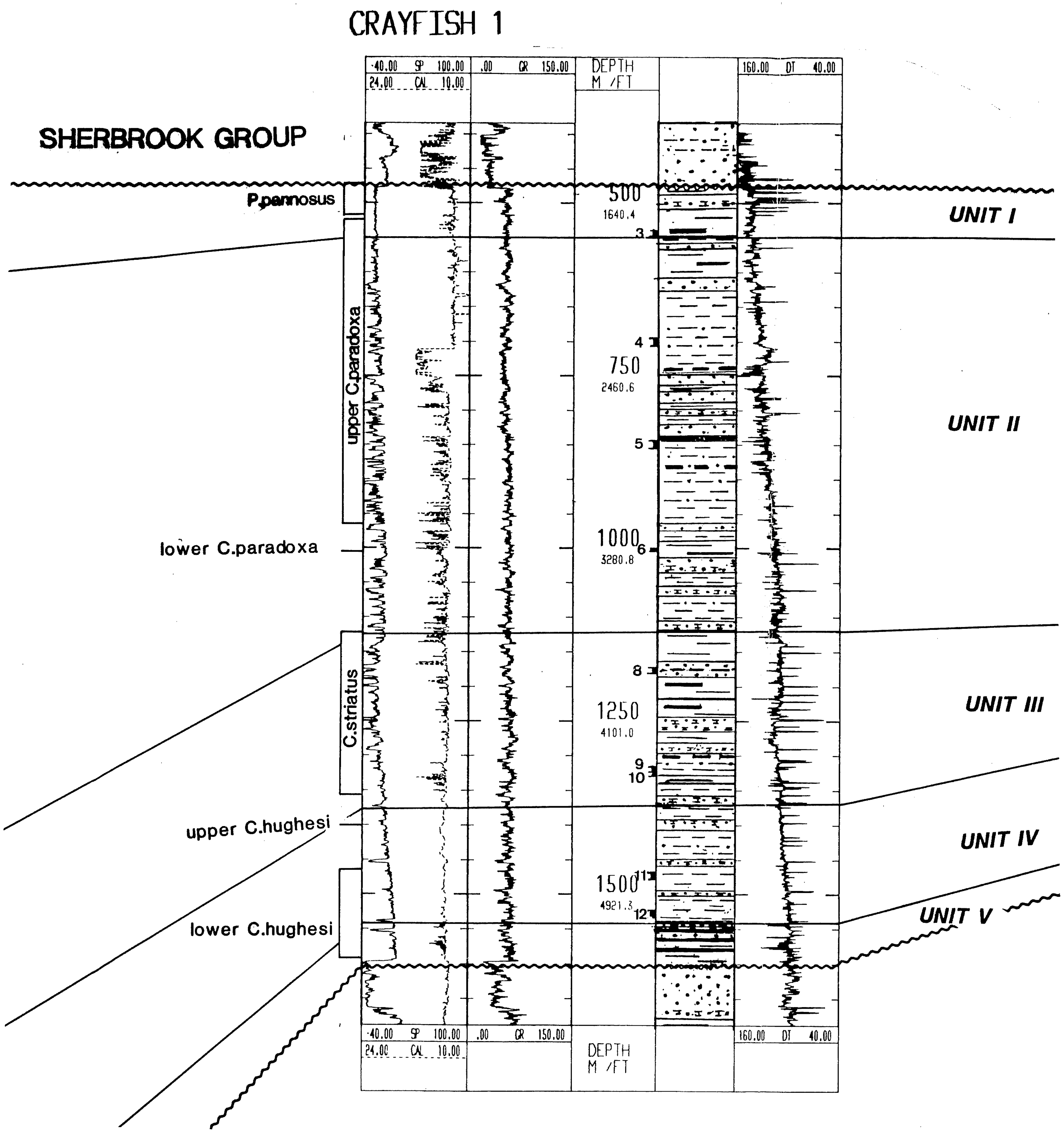


Figure 7. Proposed Eumeralla Formation subdivisions

Prominent negative SP deflections clearly illustrate the sandy nature of the unit which consists of fining and coarsening upward sands, in an overall coarsening upwards sequence. The gamma ray and sonic tools are generally lacking in character, however fast sonic spikes corresponding to calcium carbonate cemented stringer sands are commonly found (at the bottom of the unit) towards the edge of the basin. This sandy unit is associated with the *C. paradoxa* palynological subzone.

The sands vary from fine to medium grained, are green, well sorted, with generally angular grains. Sedimentary structures include mud rip-up clasts, scours, flame structures and climbing and planar cross laminations. Coaly detritus is common, particularly in the silts and muds.

3.1.3 Unit III

This unit is indicated by the SP log to be siltier than the overlying Unit II. The SP log shows fining upwards and minor intervals of coarsening upwards sands in an overall coarsening upwards unit. The sands of Unit III are characterised by a dominance of fast sonic spikes as a result of diagenetic concentrations of calcium carbonate cement (Chapter 6). The isolation of these carbonate cemented stringer sands is more pronounced in the deeper wells. Unit III is associated with the *C. striatus*

The sands are grey-green, fine to very fine grained, and are generally well sorted. The sediments are ripple and planar cross laminated, with climbing ripples, linsen bedding, bioturbation, some wave ripple tops and possible flame structures. The argillaceous sediments are often slumped and contain abundant carbonaceous detritus.

3.1.4 Unit IV

Unit IV is an argillaceous unit, with some minor silty sandstone interbeds present near the edge of the basin. The SP log is generally uniform in character, with some minor negative deflections indicating sand interbeds within the dominant silt and mudstones. Calcium carbonate cemented stringers and coaly detritus appear in the shallower wells. Unit IV is associated with the upper portion of the C. hughesi subzone, and the top of Unit IV is near the base of the Aptian.

The coarser sediments in Unit IV are mostly grey with planar and ripple cross laminations, slumps, linsen bedding, ripples, occasional climbing ripples and allochthonous quartz granules. The mudstones are massive or laminated with minor coal seams and common bioturbation.

3.1.5 Unit V

Unit V, the basal Eumeralla Formation unit, consists of coals interbedded with silt and mudstones, and occasional sand interbeds. The sonic log clearly shows the unit to be organic rich, and negative deflections in the SP log indicate the occasional presence of thin sand bodies (eg Casterton 1). Unit V is generally found at the base of the C. hughesi palynological subzone, and the base of the Aptian.

The silts and sands are all grey due to the organic carbon content, with planar and ripple cross laminations, climbing ripples, linsen bedding, wave ripples and some bioturbation. The mudstones are generally dark grey and massive or laminated, with abundant organic matter. Possible trough cross bedding is present in the sands, and red haematitic hardbands representing possible subaerial exposure occur in the mudstones.

3.1.6 Additional Notes

The following depositional and sedimentological patterns were observed within the Eumeralla Formation:

- the NW-SE faults of the second rift stage are shown by the isopach maps to become dominant in the Middle Albian (Unit II and Unit I)(Figs. 15+16).

SW
A
NE
A'
CHAMA 1A
CRAYFISH 1
NEPTUNE 1
LAKE ELIZA 1
LAKE HAWDON 1
CAMELBACK 1
LUCINDALE 1
SHERBROOK GROUP
CRAYFISH FORMATION
INTRA-EUMERALLA UNCONFORMITY
UNIT I
UNIT II
UNIT III
UNIT IV
UNIT V
P.pannosus
lower C.paradoxa
upper C.paradoxa
C.paradoxa
C.striatus
upper C.hughesi
lower C.hughesi
C.hughesi
DEPTH M /FT
LIMIT OF OTWAY BASIN
S.A.
VIC.
MERINO UPLIFT
100 KM.

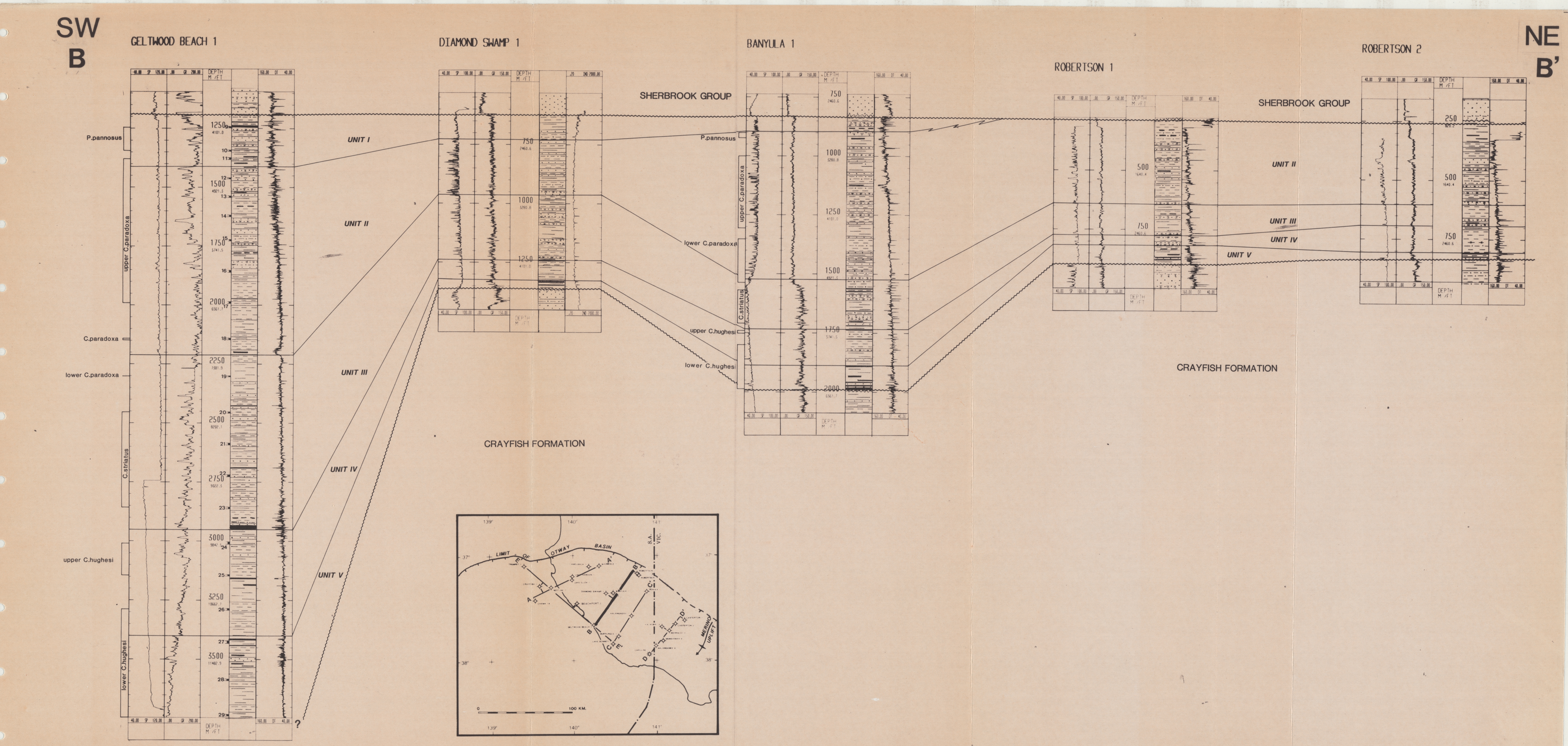

SW
B
NE
B'
GELTWOOD BEACH 1
DIAMOND SWAMP 1
BANYULA 1
ROBERTSON 1
ROBERTSON 2
SHERBROOK GROUP
CRAYFISH FORMATION
UNIT I
UNIT II
UNIT III
UNIT IV
UNIT V
P.pannosus
upper C.paradoxa
C.paradoxa
lower C.paradoxa
C.striatus
upper C.hughesi
lower C.hughesi
DEPTH M /FT
LIMIT OF OTWAY BASIN
S.A.
VIC.
MERINO UPLIFT
100 KM.

FIG.9

SW
C
LAKE BONNEY 1
BURRUNGULE 1
KALANGADOO 1
PENOLA 1
NE
C'
SHERBROOK GROUP
C.triplex
P.pannosus
UNIT I
UNIT II
UNIT III
UNIT IV
UNIT V
upper C.hughesi
lower C.paradoxa
C.striatus
lower C.hughesi
upper C.paradoxa
F. wonthaggiensis
CRAYFISH FORMATION
NO SONIC RUN
DEPTH M /FT
LIMIT OF OTWAY BASIN
MERINO UPLIFT
S.A.
VIC.
100 KM.

FIG.10

SW
D
NE
D'
CAROLINE 1
MALANGANNEE 4
KALADBRO 2
WERRIKOO 2
CASTERTON 2
CASTERTON 1
P.pannosus
SHERBROOK GROUP
EUMERALLA FORMATION OUTCROP
UNIT I
UNIT II
UNIT III
UNIT IV
UNIT V
C.striatus
lower C.hughesi
CRAYFISH FORMATION
DEPTH M /FT
LIMIT OF OTWAY BASIN
S.A.
VIC.
MERINO UPLIFT
100 KM.

FIG.11

NW
E
SE
E'
TRUMPET 1
CRAYFISH 1
NEPTUNE 1
BEACHPORT 1
GELTWOOD BEACH 1
LAKE BONNEY 1
SHERBROOK GROUP
CRAYFISH FORMATION
UNIT I
UNIT II
UNIT III
UNIT IV
UNIT V
P.pannosus
upper C.paradoxa
lower C.paradoxa
C.paradoxa
C.striatus
upper C.hughesi
lower C.hughesi
C.hughesi
DEPTH M/FT
BEACHPORT 1
OTWAY BASIN
01/09/61
OTWAY
BASIN
S.A.
VIC.
MERINO UPLIFT
100 KM.
139°
140°
141°
37°
38°

- the thickening of sand bodies towards the basin edge (see cross sections).
- the dominance of calcium carbonate cemented stringers in the shallow wells (ie towards the basin edge) (see cross sections).
- the grading in colour of the sands from grey to light grey in the bottom two units, to green and grey-green in the upper units.
- the good sorting of the sands, indicating storm reworking.

3.2 Facies Interpretation of Eumeralla Formation Subdivisions

Core data (eg sedimentary structures) combined with the correlations made between the wells and some seismic data, have resulted in the assignment of the following facies to Units I, II, III, IV and V of the Eumeralla Formation.

3.2.1 Unit I

Unit I shows the Late Albian marine influence on the Eumeralla Formation, noted by Frakes et al, (1987). The presence of marine dinoflagellates and rare spiny acritarchs in the P. pannosus palynological subzone (Morgan, 1987) are indicative of brackish environments and possible marine influence. Onlap of this marginal marine unit is observed on seismic (Appendix 2A), lending evidence to the presence of a seaway to the west (Fig 13), (Frakes et al, 1987).

UNIT I	X			X	X		X	X	X	
UNIT II			X	X		X	X	X		X
UNIT III	X	X	X	X	X	X	X	X	X	X
UNIT IV	X	X		X	XX	X	X	X		
UNIT V *T,*C	X			X		X	X	X		

TABLE 2

Assemblages of sedimentary features

X - Present

XX - Abundant

*T- trough cross bedding

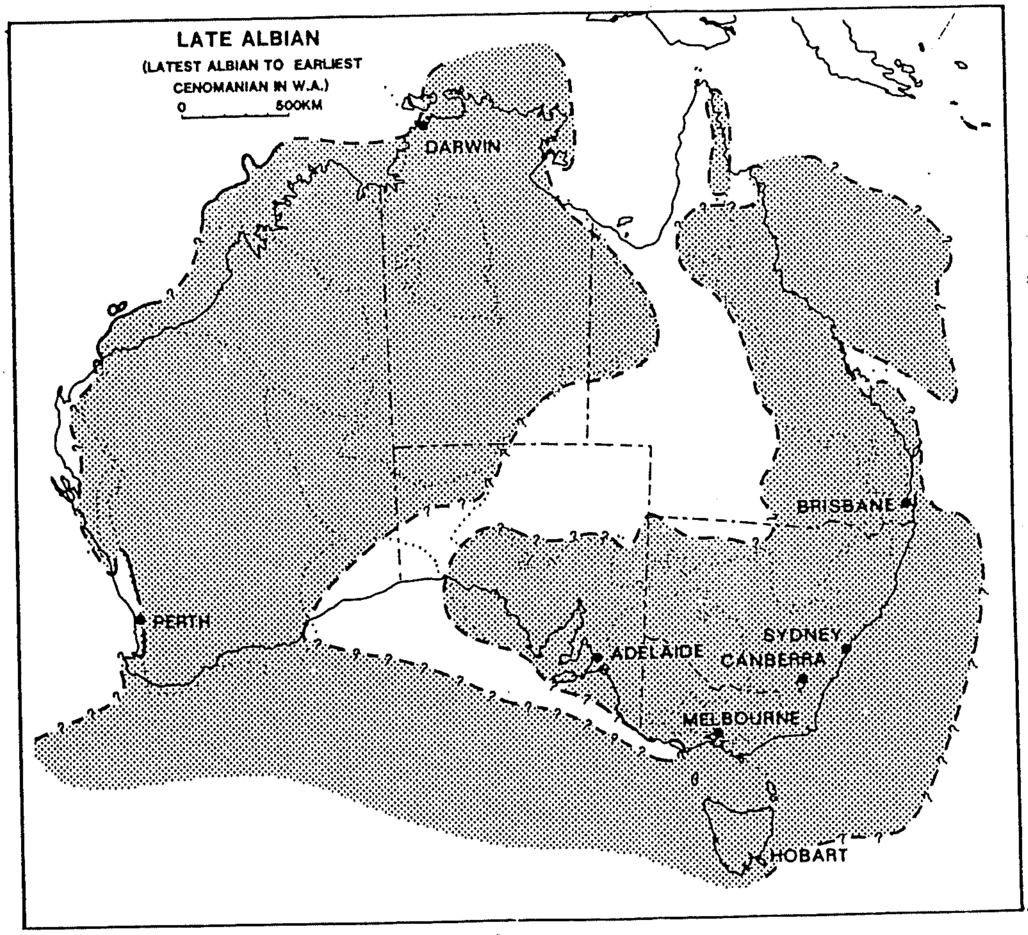
*C- coal rich

- fining upwards

- coarsening upwards

Explanation of symbols in Appendix 3.

Figure 13 (Frakes et al.,1987.)



The marine influence appears to be distal; based on the paucity of marine indicators, and the fine grain size of the sediments. Hummocky cross stratification indicates that wind and storm events influenced sedimentation (Haines, 1988). Ripple cross lamination indicates wave activity and possible tidal influence. The favoured environment of deposition is distal estuarine, with lacustrine/fluvial influence.

Figure 15 is the isopach map of Unit I. The limit of marine influence is interpreted to be the Unit I zero edge.

However, the absence of these sediments on highs could be due to erosion during the uplift associated with breakup.

3.2.2 Unit II

Unit II is thought to have been deposited in a lacustrine environment with significant water depths. Palynology indicates a non-marine environment, perhaps with very minor marine influence at the top (Morgan, 1987). The fining upwards sands, associated with scours and mud rip-up clasts, probably imply deposition by turbidite currents generated by storm events. The coarsening upwards sands are indicators of reworking during large storm events without transport.

The depth of this lacustrine setting is restricted to the depth of the big storm wave base, which may be in the order of 15-20m (N Lemon, pers comm). However, Australia was in high latitudes in the Cretaceous (Frakes et al., 1988) and could have exposed the developing southern margin to very large storm events and consequently a much deeper storm wave base. It can be concluded that the water depths of Unit II could be anywhere between 20 and 40m depending on the strength of storm activity. The absence of a large thickness of pelagic sediment (indicated by laminated muds), and the frequency of the sand interbeds suggest the lacustrine setting was not overly deep.

Unit II thickens offshore, thins over highs (Fig 16), with depocentres in NW-SE trending troughs, and onlaps onto basement at the edge of the basin (Appendix 2C). The sands near the basin edge are thicker and have a blocky SP signature. The sands become thinner basinward and develop the fining and coarsening upwards packages, which are both present in the shallower wells. The fining upwards packages appear to dominate in the deeper wells, indicating a reduction in the influence of storm activity. The thinning of the sand packages and the reduction of storm influence, is evidence that the waters of the lacustrine systems are deepening towards the depocentre. It is probable that a deep water lacustrine setting is present at the basin centre.

3.2.3 Unit III

The abundance of early, diagenetic carbonate cementation in lacustrine sediments has been thought by several authors to indicate deposition in relatively shallow water (Kelts et al., 1978, Allen et al., 1986, Gore, 1988). The sedimentary structures (ripples, linsen bedding etc) and the presence of coarse allochthonous material (quartz granules) indicates that wave activity dominated sediment distribution. The deposition model proposed for Unit III is a fairly shallow (5-10m) lacustrine environment, influenced strongly by wave and storm activity.

The sands in Unit III increase in thickness, and have minor coarsening upwards packages present towards the basin depocentre. The thickening of the unit in this direction (Fig 17) and the presence of deeper water facies indicates increased water depths towards the basin centre.

3.2.4 Unit IV

The dominantly argillaceous sediments of Unit IV are interpreted to have been deposited in a shallower flood-plain environment. The abundance of laminated and massive mudstones suggests a quiet environment. Biological activity is high, with bioturbation and organic matter present in large quantities. The silts and sands show many features which indicate deposition by either wind or wave activity. Water levels could not have exceeded more than 1 or 2 metres, but there is no evidence of subaerial exposure.

Unit IV is generally very uniform in thickness. It thins only marginally over the highs, but increases in thickness offshore (Fig 18).

3.2.5 Unit V

The base of the Eumeralla Formation (Unit V) is interpreted by several authors to be a low gradient, poorly drained, fluvial palaeoenvironment with high sinuosity streams, and wide floodplains with lacustrine and backswamp environments (Gravestock et al, 1986, Struckmeyer and Felton, 1988, and Struckmeyer, 1988). The presence of trough cross bedding supports the fluvially dominated environmental interpretation. The abundant coals in this unit were derived from stream fringing ferns and ginkgos (Struckmeyer, 1988), and probably deposited in a backswamp environment. Vitrinite macerals present in these coals (K.Serafini, pers comm) indicate the organic matter was only transported a short distance, and mostly preserved in an anoxic backswamp environment.

Unit V thickens away from the basin edge, and thins over the highs (Fig 19). It is possible a significant thickness of coal-bearing source rocks could be developed near the Otway Basin depocentre.

3.3 Seismic Character and Facies

Four seismic sections have been used to observe features within the Eumeralla Formation (Appendix 2), and one of these sections was used to delineate seismic facies (Appendix 2D).

Line OHK85-23 shows two important features; onlap of Unit I onto Unit II, and an intra-Eumeralla Formation unconformity. The onlap represents the sediments of the Late

Albian marine incursion (Unit I) deposited unconformably onto Unit II. The 2D seismic line shows a westerly component of onlap.

The intra-Eumeralla Formation unconformity is evidence of fault movement during deposition, although this is minor compared to overall subsidence. The unconformity is also evident in Lake Eliza 1 as a shift in the base line of the SP log.

Progradation of the Eumeralla Formation on Line OHK85-04, near the basin edge, is indicative of deltaic sedimentation from the north-northwest margin of the basin (Appendix 2B).

Seismic Line OHK85-03, (Appendix 2C) shows the edge of the Otway Basin, with the Eumeralla Formation extending further than the Crayfish Formation onlap edge.

Subdivision of the Eumeralla Formation by wireline logs has been transposed to seismic line OHK85-25 by the use of synthetic seismograms, allowing delineation of seismic facies in the formation. The coaly Unit V shows up as strong peak reflections, Unit IV is generally bland with thin, discontinuous reflectors and Unit III is present as strong trough reflectors due to the presence of the 'fast' calcite cemented stringer sands. The interbedded sands and shales of Unit II, with consequent high reflection coefficients, result in relatively strong, continuous reflections. However, the overlying Unit I consists of very discontinuous and hummocky reflectors, and is seen to onlap onto Unit II.

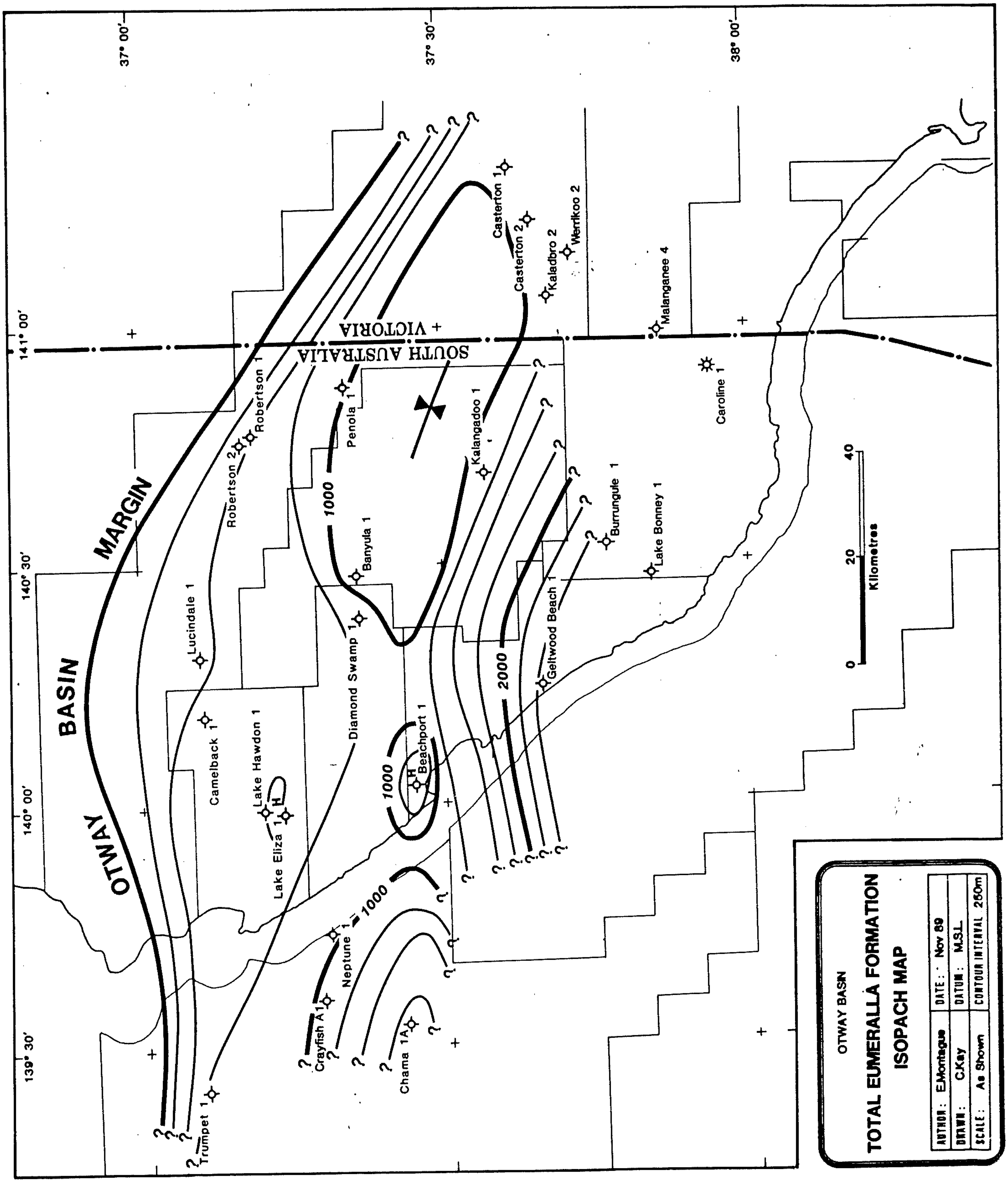

OTWAY BASIN
TOTAL EUMERALLA FORMATION
ISOPACH MAP
AUTHOR: E.Montague
DRAWN: C.Kay
SCALE: As Shown
DATE: Nov 89
DATUM: M.S.L.
CONTOUR INTERVAL 250m
OTWAY BASIN MARGIN
VICTORIA
SOUTH AUSTRALIA
37° 00'
37° 30'
38° 00'
139° 30'
140° 00'
140° 30'
141° 00'
0
20
40
Kilometres
1000
2000
Casterton 1
Casterton 2
Kaladbro 2
Werrikoo 2
Malanganee 4
Caroline 1
Penola 1
Kalangadoo 1
Burrungule 1
Lake Bonney 1
Banyula 1
Geltwood Beach 1
Robertson 1
Robertson 2
Robertson 1
Lucindale 1
Diamond Swamp 1
Camelback 1
Lake Hawdon 1
Lake Eliza 1
Beachport 1
Neptune 1
Crayfish A1
Chama 1A
Trumpet 1

Figure 14.

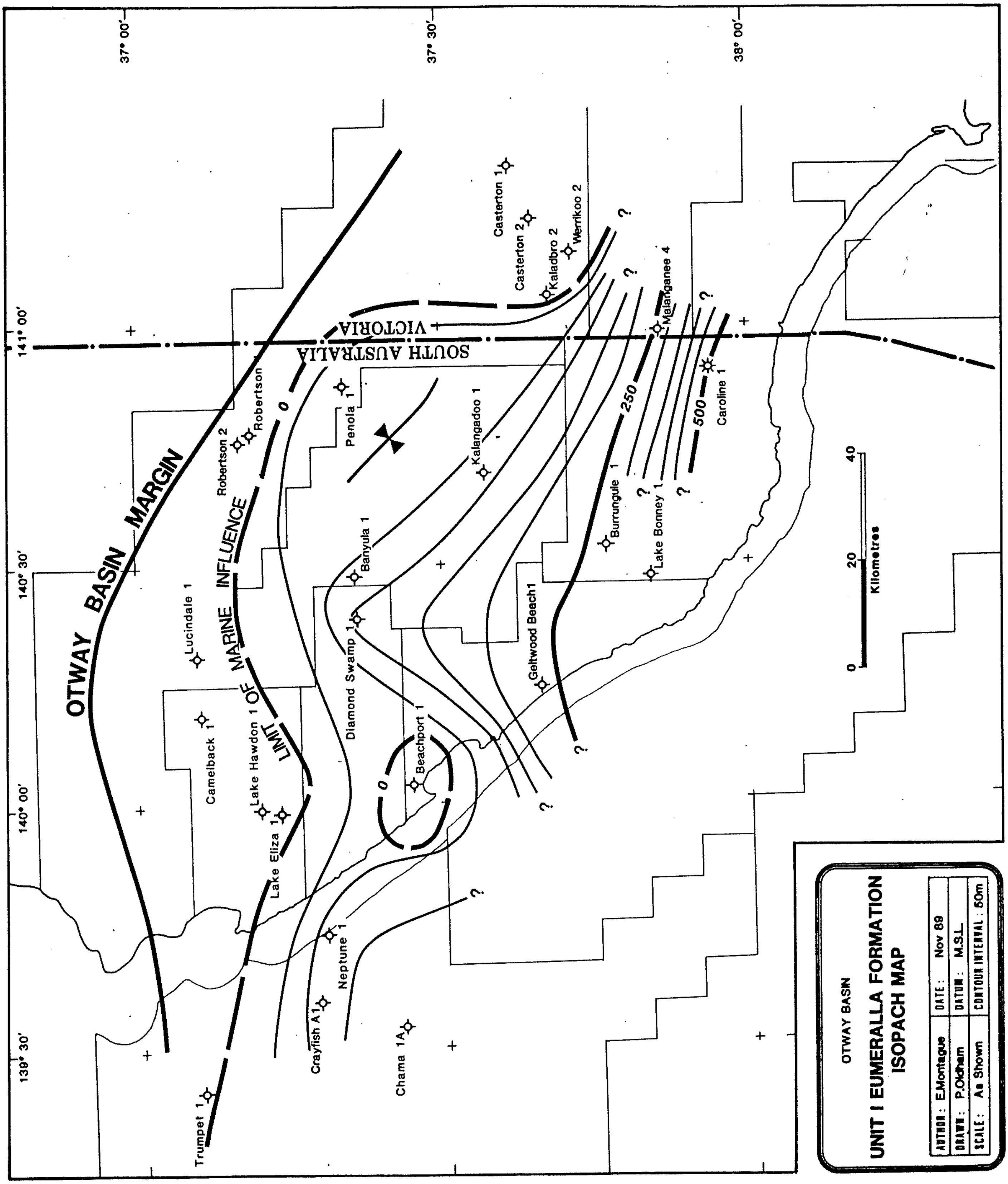

OTWAY BASIN
UNIT I EUMERALLA FORMATION
ISOPACH MAP
AUTHOR: E.Montague
DRAWN: P.Oldham
SCALE: As Shown
DATE: Nov 89
DATUM: M.S.L.
CONTOUR INTERVAL: 50m
OTWAY BASIN MARGIN
LIMIT OF MARINE INFLUENCE
SOUTH AUSTRALIA
VICTORIA
Kilometres
0
20
40
37° 00'
37° 30'
38° 00'
139° 30'
140° 00'
140° 30'
141° 00'
0
250
500
Trumpet 1
Lake Eliza 1
Lake Hawdon 1
Camelback 1
Lucindale 1
Robertson 2
Robertson
Penola 1
Banyula 1
Diamond Swamp 1
Beachport 1
Crayfish A1
Neptune 1
Chama 1A
Kalangadoo 1
Geltwood Beach1
Burrungule 1
Lake Bonney 1
Caroline 1
Malanganee 4
Kaladbro 2
Werrikoo 2
Casterton 2
Casterton 1

Figure 15.

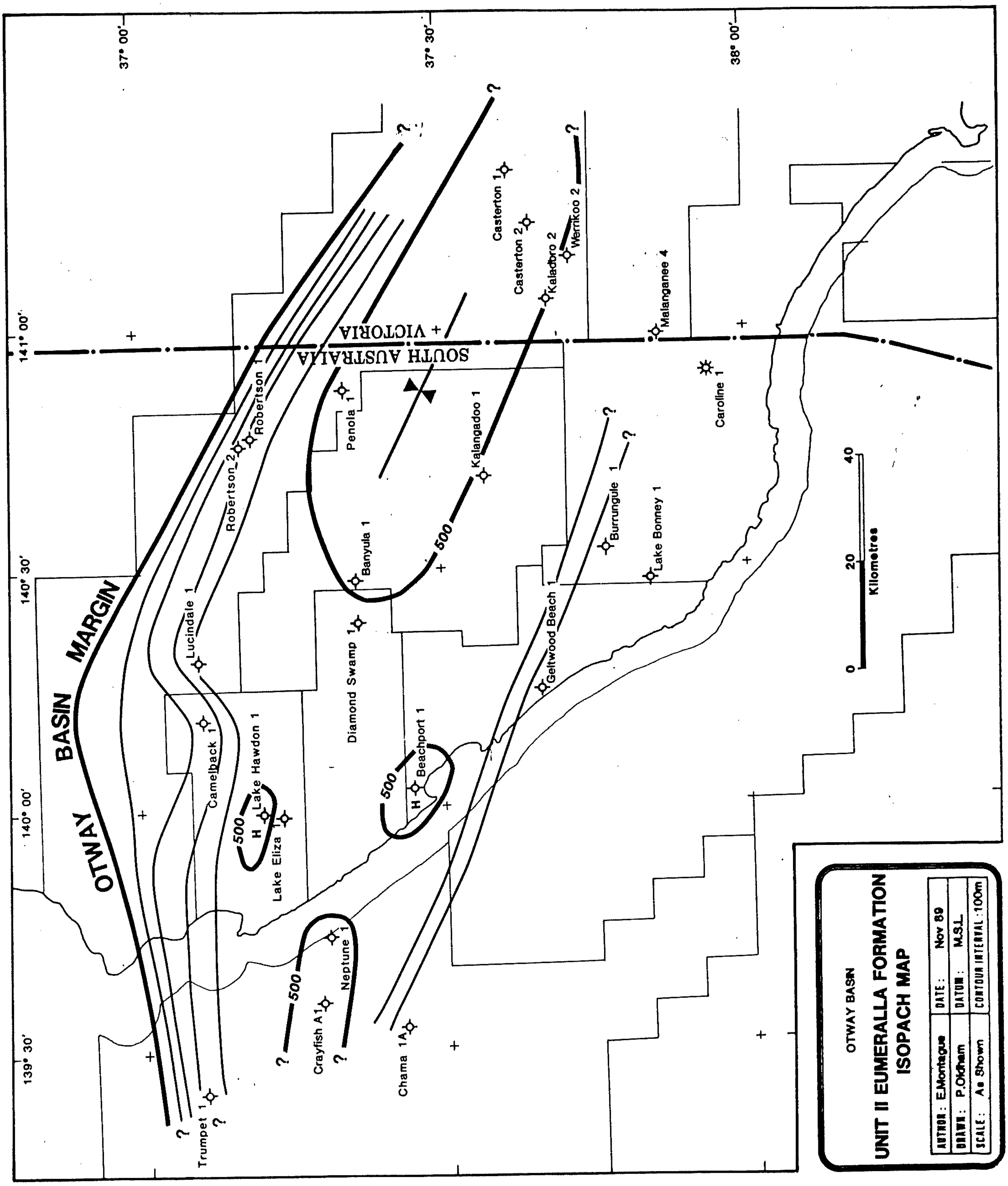
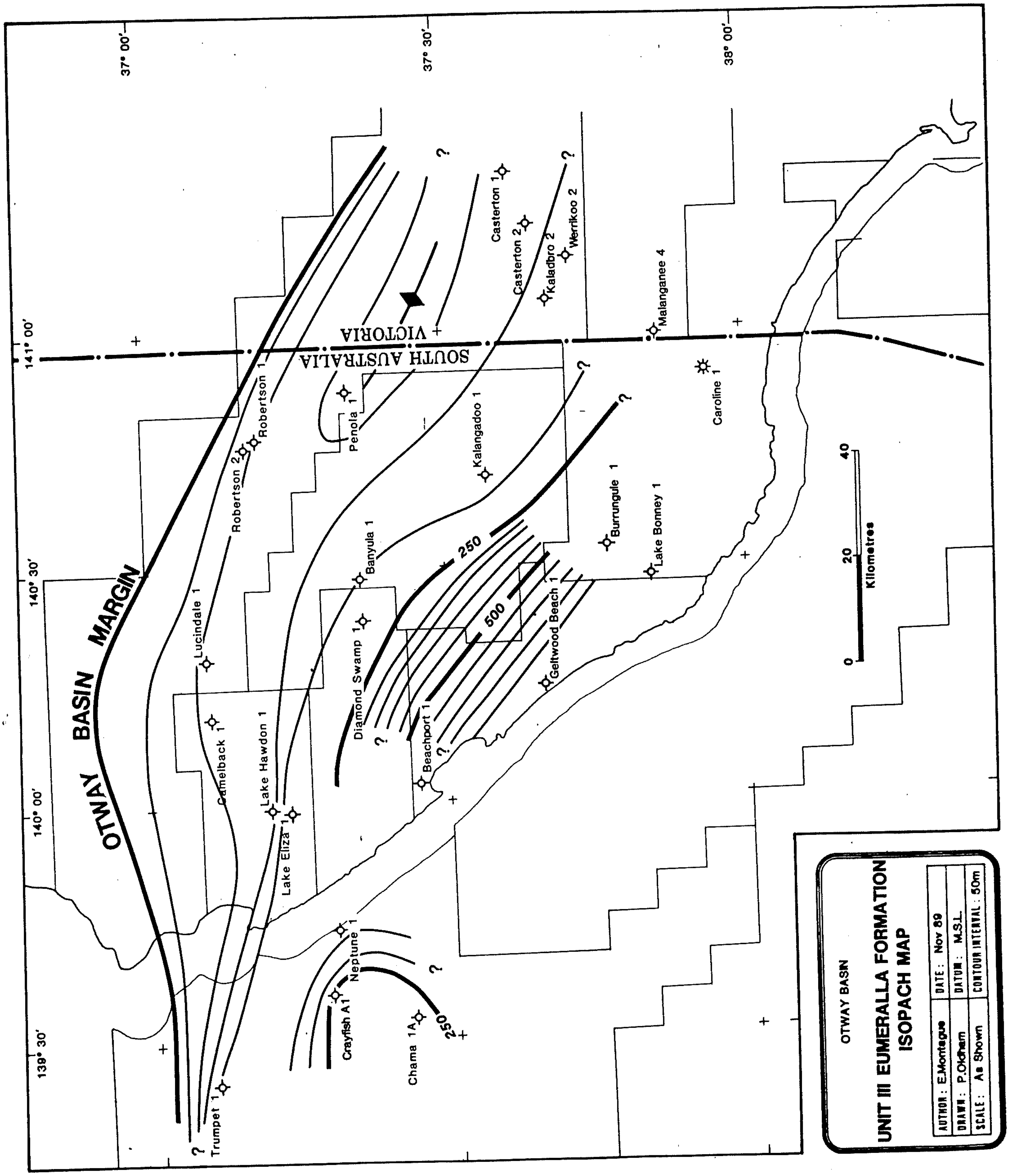

OTWAY BASIN
UNIT II EUMERALLA FORMATION
ISOPACH MAP
AUTHOR: E.Montague
DRAWN: P.Oldham
SCALE: As Shown
DATE: Nov 89
DATUM: M.S.L
CONTOUR INTERVAL: 100m
OTWAY BASIN MARGIN
SOUTH AUSTRALIA
VICTORIA
37° 00'
37° 30'
38° 00'
139° 30'
140° 00'
140° 30'
141° 00'
Kilometres
0
20
40
500
H
Trumpet 1
Camelback 1
Lucindale 1
Robertson 2
Robertson 1
Lake Hawdon 1
Lake Eliza 1
Neptune 1
Crayfish A1
Chama 1A
Beachport 1
Diamond Swamp 1
Banyula 1
Penola 1
Kalangadoo 1
Geltwood Beach 1
Burrungule 1
Lake Bonney 1
Caroline 1
Malanganee 4
Kaladbro 2
Werrikoo 2
Casterton 1
Casterton 2

Figure 16.



OTWAY BASIN
UNIT III EUMERALLA FORMATION
ISOPACH MAP
AUTHOR : E.Montague
DRAWN : P.Oldham
SCALE : As Shown
DATE : Nov 89
DATUM : M.S.L.
CONTOUR INTERVAL : 50m
OTWAY BASIN MARGIN
SOUTH AUSTRALIA
VICTORIA
37° 00'
37° 30'
38° 00'
139° 30'
140° 00'
140° 30'
141° 00'
Kilometres
0
20
40
250
500
Trumpet 1
Lucindale 1
Camelback 1
Lake Hawdon 1
Lake Eliza 1
Robertson 1
Robertson 2
Penola 1
Banyula 1
Diamond Swamp 1
Beachport 1
Geltwood Beach 1
Kalangadoo 1
Burrungule 1
Lake Bonney 1
Caroline 1
Casterton 1
Casterton 2
Kaladbro 2
Werrikoo 2
Malanganee 4
Neptune 1
Crayfish A1
Chama 1A

Figure 17.

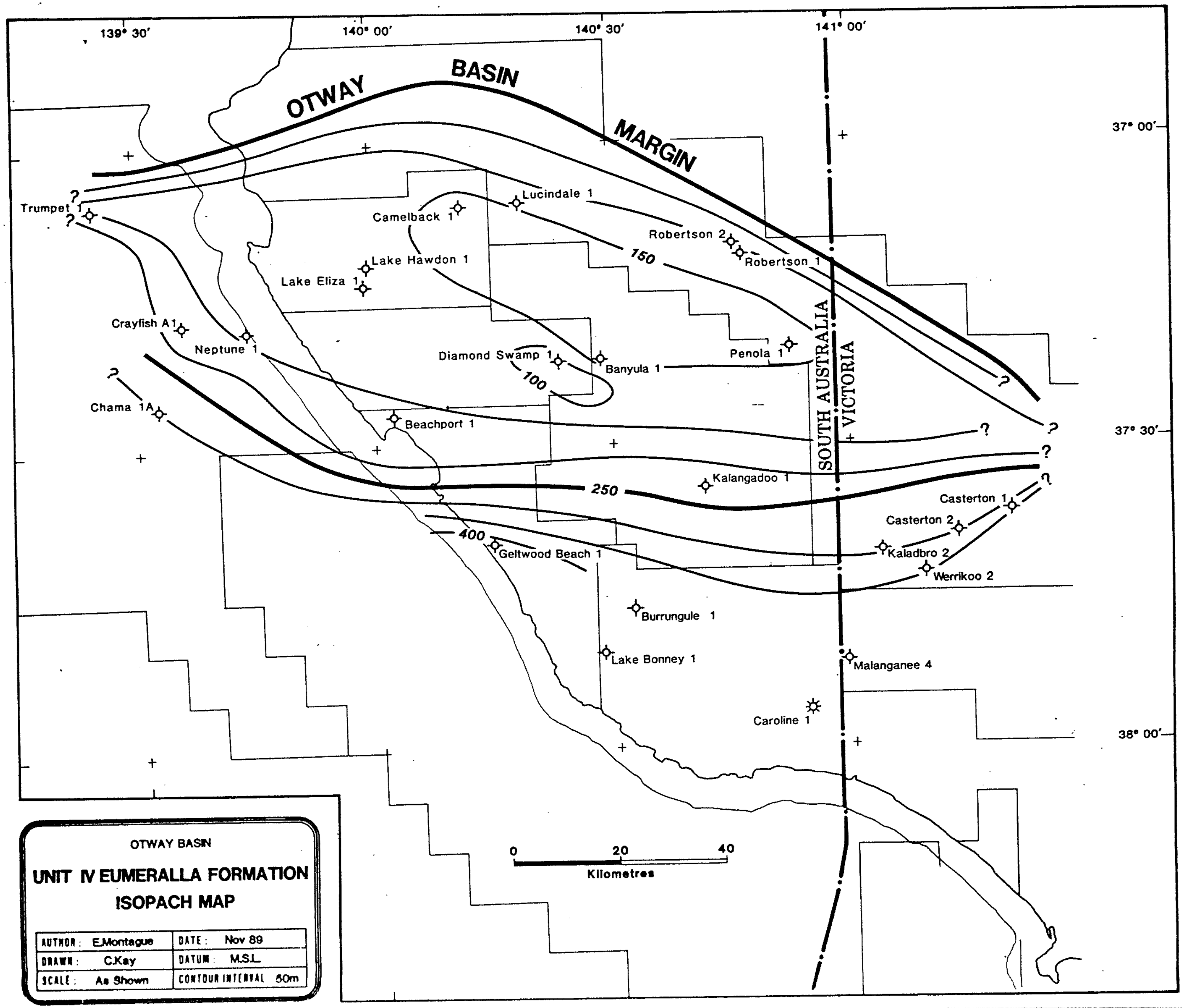

139° 30'
140° 00'
140° 30'
141° 00'
37° 00'
37° 30'
38° 00'
OTWAY BASIN MARGIN
SOUTH AUSTRALIA
VICTORIA
Trumpet 1
Crayfish A1
Neptune 1
Chama 1A
Lake Eliza 1
Lake Hawdon 1
Camelback 1
Lucindale 1
Robertson 2
Robertson 1
Penola 1
Diamond Swamp 1
Banyula 1
Beachport 1
Kalangadoo 1
Geltwood Beach 1
Burrungule 1
Lake Bonney 1
Malanganee 4
Caroline 1
Casterton 1
Casterton 2
Kaladbro 2
Werrikoo 2
100
150
250
400
0
20
40
Kilometres
OTWAY BASIN
UNIT IV EUMERALLA FORMATION
ISOPACH MAP
AUTHOR: E.Montague
DATE: Nov 89
DRAWN: C.Kay
DATUM: M.S.L.
SCALE: As Shown
CONTOUR INTERVAL 50m

Figure 18.

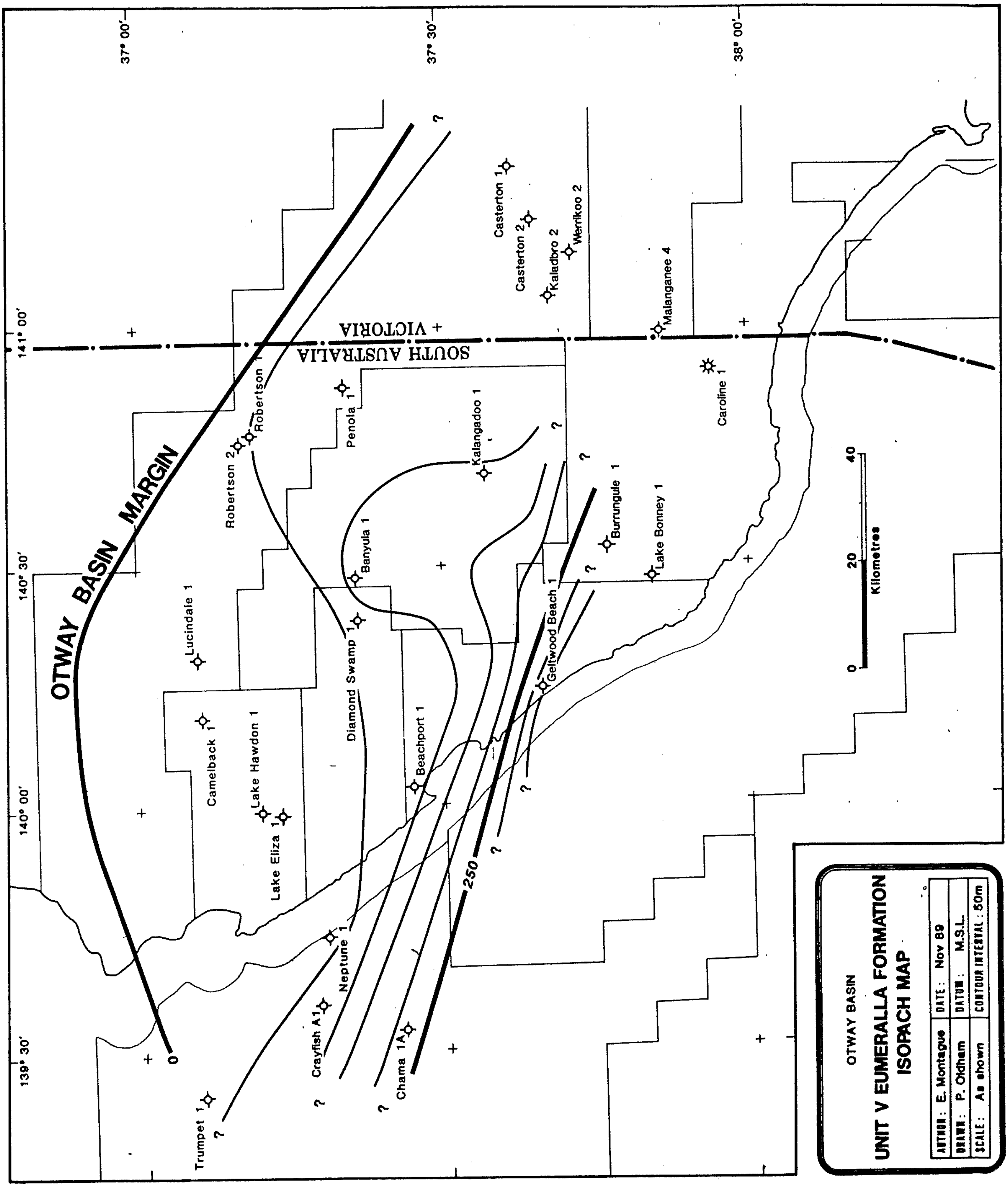

OTWAY BASIN
UNIT V EUMERALLA FORMATION
ISOPACH MAP
AUTHOR : E. Montague
DRAWN : P. Oldham
SCALE : As shown
DATE : Nov 89
DATUM : M.S.L.
CONTOUR INTERVAL : 50m
OTWAY BASIN MARGIN
SOUTH AUSTRALIA
VICTORIA
37° 00'
37° 30'
38° 00'
139° 30'
140° 00'
140° 30'
141° 00'
0
20
40
Kilometres
0
250
Trumpet 1
Crayfish A1
Chama 1A
Neptune 1
Lake Eliza 1
Lake Hawdon 1
Camelback 1
Lucindale 1
Beachport 1
Diamond Swamp 1
Banyula 1
Robertson 2
Robertson 1
Penola 1
Kalangadoo 1
Geltwood Beach 1
Burrungule 1
Lake Bonney 1
Caroline 1
Malanganee 4
Kaladbro 2
Werrikoo 2
Casterton 2
Casterton 1

Figure 19.

4.0 DEPOSITIONAL MODELS

4.1 Sedimentation in Rift Basins

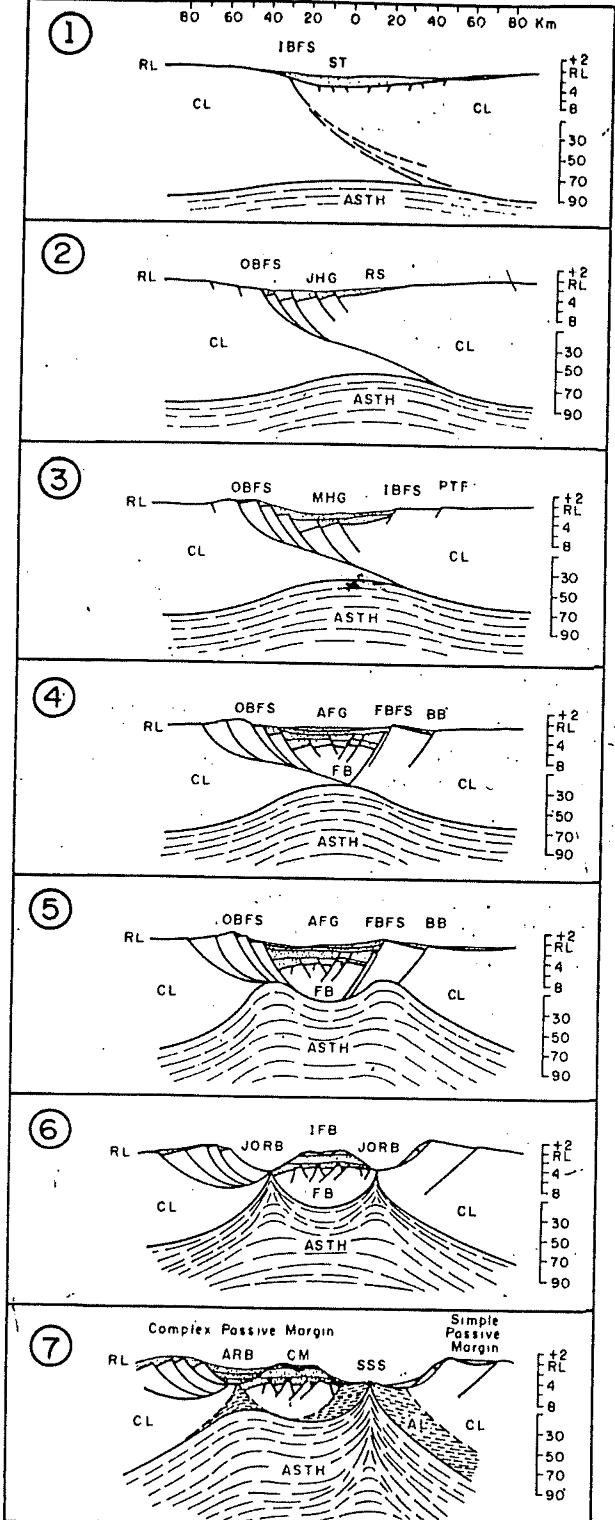
The stratigraphy and sedimentology of rift basins is strongly controlled by the development of basement elements (Gibbs, 1987). Although rift basins differ in architecture (eg basins dominated by ramp and flat fault arrays versus sag basins) they generally follow the same stages of evolution (Scott et al., 1989) (Fig 20). The Eumeralla Formation is equivalent to deposition in stage 4 of rift evolution.

4.2 Depositional Model for the Eumeralla Formation

The deposition of the Eumeralla Formation was mainly structurally controlled, although eustatics played an important role in the deposition of the upper sections of the Eumeralla Formation.

The change in rift direction in the Late Neocomian resulted in uplift and a change in fault direction from E-W to NW-SE (Williamson et al., 1989(a)). The westward flowing fluvial system of the Crayfish Formation (Gravestock et al., 1986) (Fig 21) was cut by the new generation of faults. Drainage in Unit V continued along the Crayfish Formation river channels as high sinuosity meandering streams. Subsidence due to rifting had associated fault movement, and resulted

POSSIBLE STAGES IN THE EVOLUTION OF RIFTS



STAGE 1 : STRETCH TROUGH

Initial stretching and thinning of CL, creating relatively broad surface depression. Uppermost crust may shatter, but fault throws generally below resolution level of seismics. Typical amount of subsidence is 1.0 to 1.5 km. Sediment infill dominated by fluvial or eolian sands showing much reworking. System will appear transgressive with variable and complicated input pattern.

STAGE 2 : JUVENILE HALF GRABEN (JHG)

Development of asymmetric graben composed of fault blocks that tilt mainly in the same direction. OBFS divides region of shoulder uplift from region of continued subsidence, but actual subsidence more or less equally distributed among faults that define tilted blocks. Typical number of active blocks range from 3 to 6, with typical width of 10 km. Region of active subsidence generally narrower than width of ST. Stratigraphy controlled by wedge-block style of deposition of fluvial clastics, which can enter from either side of half graben. Sediment lithology dependent on position within wedge-block and distance from source. An angular unconformity often divides Stage 1 and Stage 2, suggesting that onset of block-rotation is relatively abrupt. Onset of Stage 2 probably relates to creation of a detachment zone through CL.

STAGE 3 : MATURE HALF GRABEN (MHG)

Development of strongly asymmetric graben with most of subsidence taken up along OBFS. Continued uplift and rotation of shoulder usually creates back-tilted rift mountains, resulting in cessation of significant sediment input from steep side of half graben. Motions along internal faults slow or cease but overall rate of subsidence may increase. Subsidence generally outpaces sedimentation, except where axial deltas occur. With switch from distributed to localized master-fault systems, wedge-block style of deposition gives way to construction of broad fans originating from ramping side of half graben.

STAGE 4 : FACING HALF GRABEN (FBFS)

Activation of FBFS concurrent with retardation or cessation of subsidence along OBFS. Geometry eventually produces apparent full graben with axial high, or 'hinge zone'. Central region may become a free block. Back-tilted rift mountains can develop on both sides of the basin, which results in cutting off of fluvial sediment supply and creation deep, sediment starved lakes. Onset of FBFS activity usually marked by angular unconformity and creation of a new generation of faults. Sedimentation dominated by biogenic rain and local border fault fanglomerates.

STAGE 5 : BIFURCATION OF RISING PLUME

Alternation in boundary fault activity between FBFS and OBFS, possibly several times. Alternations appear to be relatively sudden, resulting in creation of angular unconformities. Abandoned site of AFG may be uplifted and eroded, sometimes extensively. Overall pattern is a teeter-totter, albeit with a complicated and spatially changing hinge line. Most shallow processes explicable in terms response of FB to rising ASTH. If ASTH rises along major detachments, plumes may split into eddies. Depositional patterns during this stage mainly a continuation of previous stage.

STAGE 6 : JUVENILE OCEANIC RIFT BASIN (JORB)

Development of one or more JORB. Drawing shows situation of simultaneously active JORB separated by FB. Central block can become completely isolated if bounded by transforms in other plane. IFB probably uplifted relative to level in Stage 4, resulting in redeformation of block and erosion and reworking of sediment pile on top of FB.

STAGE 7 : SUCCESSFUL SPREADING SYSTEM (SSS)

Continued opening of one JORB and eventual abandonment of other(s). Abandonment can occur at any time from Stage 4 onward. Situation depicted shows small ARB, but features can be large, thickly sedimented basins underlain by broad zone of AL. Mechanically, FB becomes attached to one plate but geophysically and petrologically it will appear as a continental "marshmallow" riddled with rift-type structures. If both JORB remain active for lengthy period, IFB may become a microcontinent.

AFG = Apparent Full Graben
AL = Accreted Lithosphere
ARB = Abandoned Rift Basin
ASTH = Asthenosphere
BB = Back Basin
CL = Continental Lithosphere
CM = Continental "Marshmallow"
FB = Free Block
FBFS = Facing Border Fault System
IBFS = Incipient Border Fault System
IFB = Isolated Free Block
JHG = Juvenile Half Graben
JORB = Juvenile Oceanic Rift Basin
MHG = Mature Half Graben
OBFS = Original Border Fault System
PTF = Platform
RL = Reference Level
RS = Ramping side of Half Graben
SSS = Successful Spreading System
ST = Stretch Trough

Figure 20. Stages of rift evolution.

(from Scott and Rosendahl, 1989)

in ponding of the streams against the footwalls of the NW-SE faults (Fig 22). The ponding of these streams produced backswamp/shallow lacustrine sub-environments where most organic matter in Unit V accumulated.

Continued subsidence in the Late Aptian resulted in shallow flooding of most of the onshore basin (perhaps to a depth of approximately 1-2 metres) and the establishment of a basinwide floodplain (Unit IV). Assuming the relief of the fault scarps were less pronounced before the mid-Albian fault activation, it would then have been possible to cover most of the basin (apart from the scarps on the upthrown blocks) in shallow water. Many ancient basins at this stage of evolution develop playas, however Australia's high palaeolatitudes (65°-70°) in the mid-Jurassic to mid-Cretaceous (Frakes et al., 1988) probably generated a cool temperate climate with seasonal periglacial (and perhaps glacial) conditions, allowing little or no evaporation.

The Eumeralla Formation was primarily lacustrine during the Albian. The deposition of Unit III in a shallow lacustrine environment is the result of continued subsidence and drainage into the basin. The sequence coarsens upwards implying the progradation of lacustrine deltas (Frostick et al., 1986) (Fig 23), and indicating sedimentation rates to be roughly keeping pace with subsidence (50m/Ma, from Heggarty et al., 1988).

Unit II is dated at the early Albian (105 Ma) from the palynology of (Morgan, 1987) (Fig 26), and was deposited in a relatively deep lacustrine basin as a result of the early Albian major eustatic sea level rise (Haq et al., 1987) and increased subsidence associated with mid-Albian fault activation. Eustatic sea level rises can significantly affect lake water levels, eg Katz et al., (1989) observed lake water-level fluctuations of 600m or more in as little as 20,000 years. Unit II appears to have been deposited in water levels of between 20 and 40 metres, but lake levels were sufficiently deep enough to deposit storm generated lacustrine turbidites (Fig 24). Sand deposition may also occur from interflows along thermal stratification layers (Allen and Collinson, 1986) (Fig 25). Unit II coarsens upwards, implying rapid sedimentation rates (compensating for eustacy and subsidence), with lacustrine deltas filling the basin (Fig 24).

Sea levels continued to rise in the late Albian (Fig 26) and, with continued rapid subsidence prior to breakup, opened a seaway from the west along the southern margin of Australia (Fig 13), resulting in a marine influence on deposition (Unit I). This marine influence, is interpreted to be distal estuarine, with possible macrotidal influences. Onlap of Unit I onto Unit II is observed on seismic lines OHK85-23 and OHK85-25 (Appendix 2A and 2D).

Sharp fast sonic spikes are observed at the top of the Eumeralla Formation, and are probably a result of diagenetic precipitates related to the hiatus in deposition upon breakup.

The SAGASCO subdivision of the Eumeralla into upper and lower units near the Aptian/Albian boundary (Fig 6) was used in figure 26. From the discussion above, this places the Lower Eumeralla in a dominantly fluvial environment and the Upper Eumeralla in a dominantly lacustrine environment.

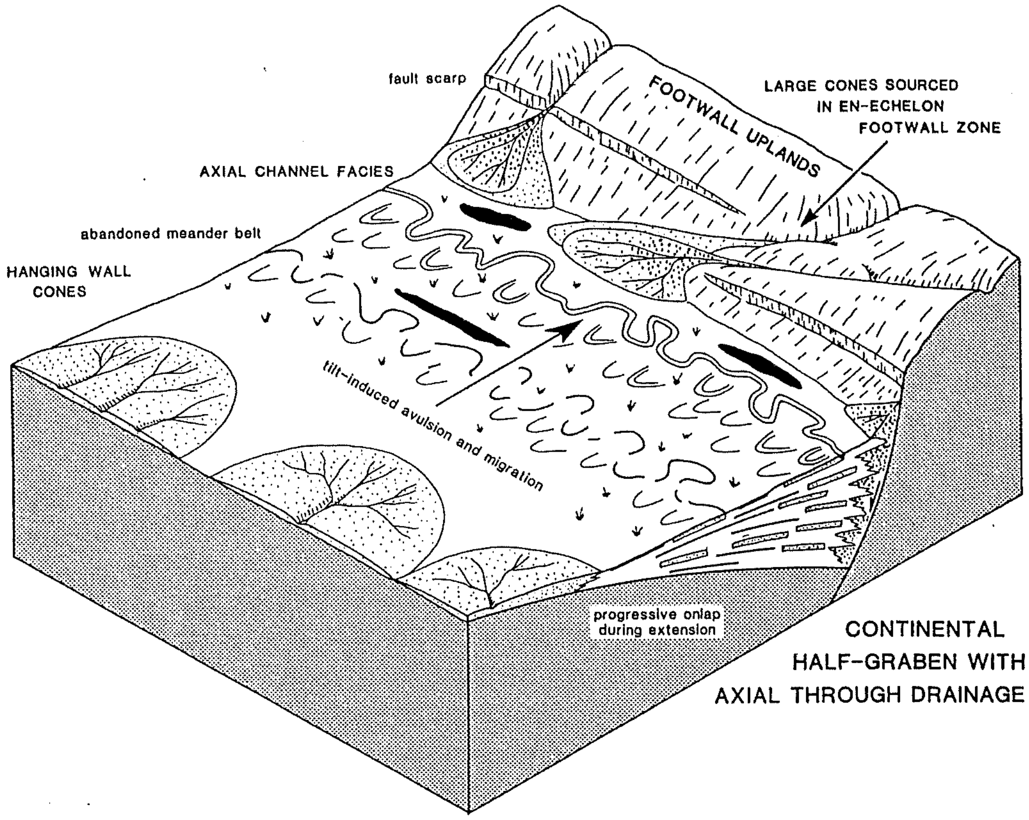


Figure 21.

(from Leeder and Gawthorpe, 1987)

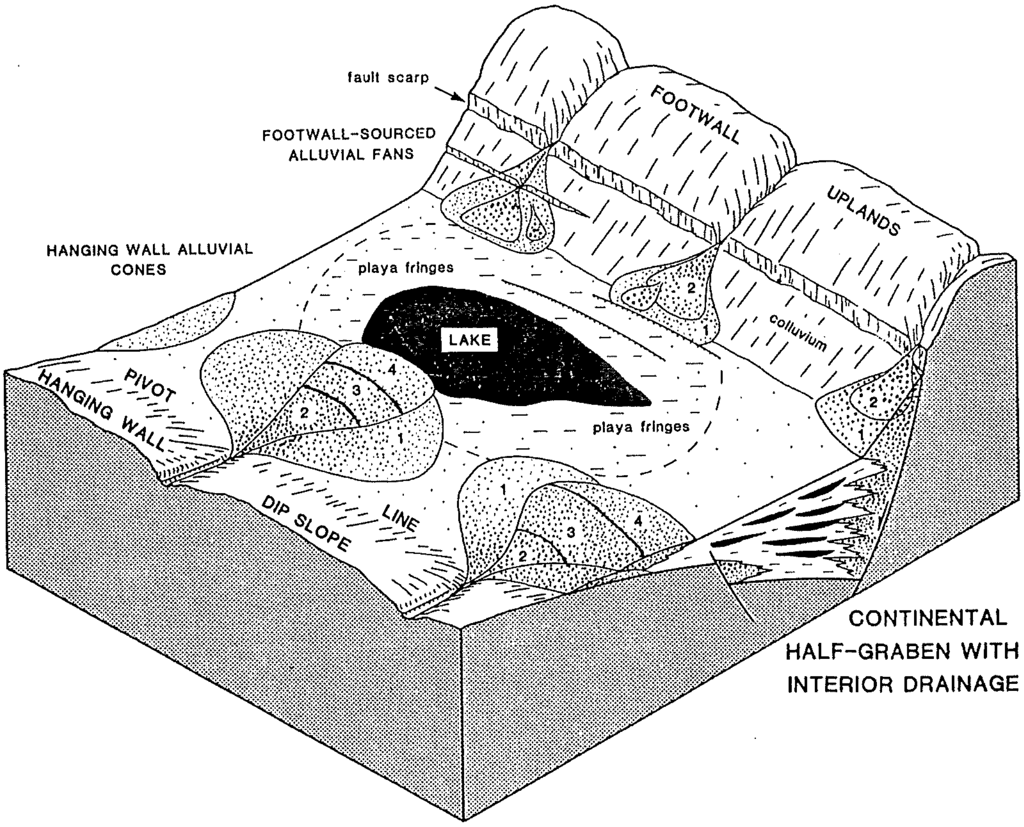


Figure 22.

(from Leeder and Gawthorpe, 1987)

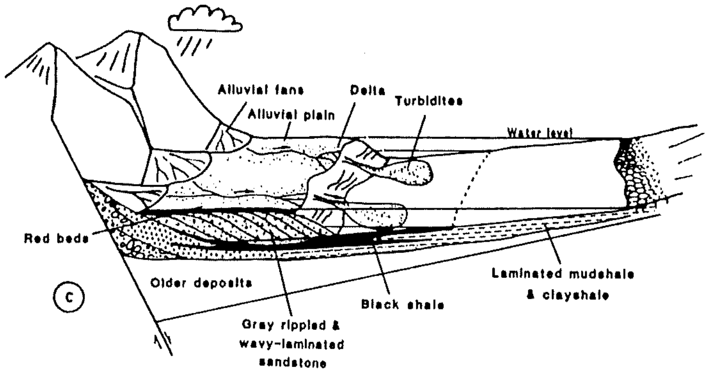


Figure 23.

(modified from Gore, 1987)

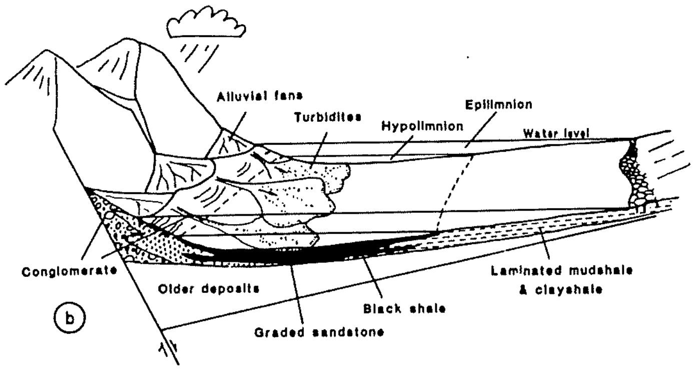


Figure 24.

(modified from Gore, 1987)

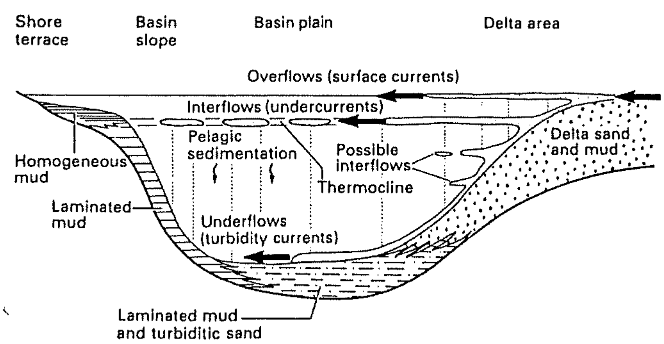
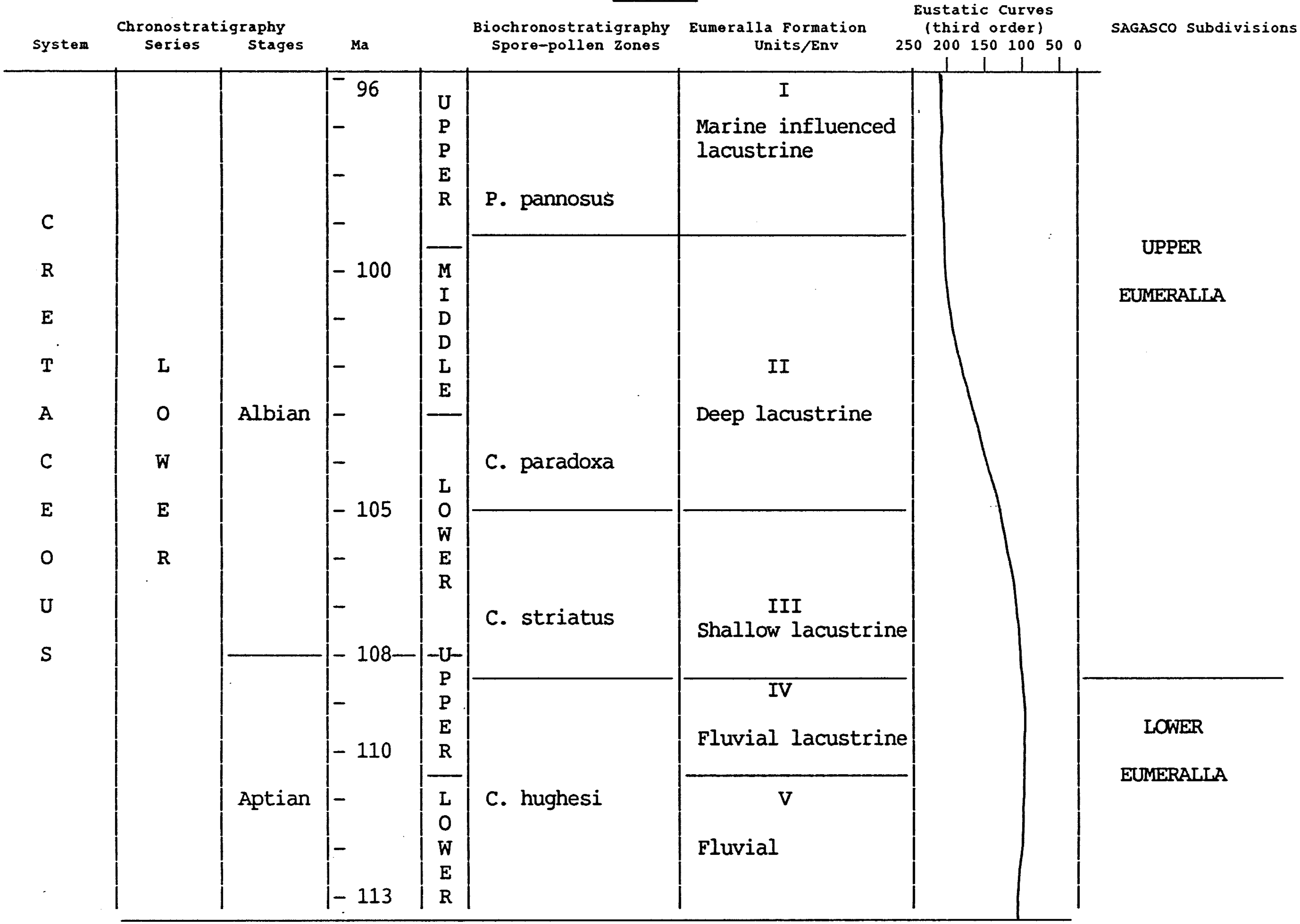


Figure 25.

(from Allen and Collinson, 1986)

JMH8911016

Figure 26



(modified from Haq et al, 1987 and Helby et al, 1987)

5.0 PETROPHYSICS OF THE EUMERALLA FORMATION

Petrophysical interpretations of the Eumeralla Formation were made difficult by:

- the poor GR response of the sands;
- variable vintages of the log runs; and
- the use of low resolution tools in the older wells (eg SN, LN logs).

To overcome these problems, detailed matching of the core with the wireline logs was used to determine the log responses of the lithologies (Appendix 3). The results are discussed below, and are summarised in Figure 27.

The sandstones of the Eumeralla Formation have very poor GR log responses and are considered to be 'hot', due to the presence of weathered potassium feldspars. However, in the calcite cemented sandstones the GR log response is better because the feldspars are unaltered (eg Kalangadoo 1, 1207m). Alteration of the feldspars often attracts more potassium (N Lemon, pers comm), and results in increasing the radioactivity of the sands.

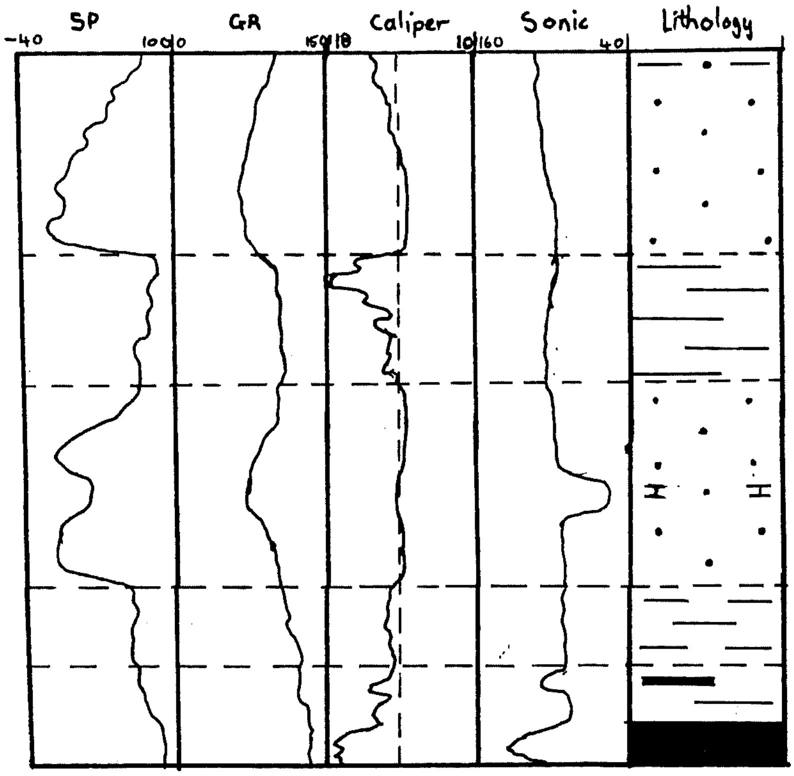
The SP log and the caliper log are the most sensitive to Eumeralla Formation lithologies. However, the SP log cannot delineate between clean sands and kaolinite cemented sands, although the effective porosities between the two sands differ considerably (Plates 1F and 2D). Significant amounts of microporosity can develop between kaolinite booklets giving an over estimation of effective porosity (J Schulz-Rojhan, pers comm), (Plate 2F) resulting in an SP log signature similar to that of a clean sand (eg Crayfish 1, 1175.3m)

The caliper log may differentiate between kaolinite cemented and clean sands; mudcake should be better developed on the clean sands. However, the calcite pore filling cement, present in Eumeralla Formation sandstones has no microporosity (or permeability), and consequently a subdued SP log reading (eg Crayfish 1, 1172m), and very fast transit times.

Siltstones and mudstones may be defined by assigning arbitrary SP cut-off values (determined by matching core to the wireline logs), which vary from well to well. Both argillaceous sediments have similar GR readings, but the mudstones tend to cave more than the siltstones (eg Crayfish 1, 537m)

Organic rich sediments, and coals are characterised by slow transit times and caving. The coals of the Eumeralla Formation are generally 'hot' (eg Kalangadoo 1, 1343m), possibly due to precipitation from uranium rich fluids on contact with organic matter (N Lemon, pers comm).

IDEALISED PETROPHYSICAL RESPONSES



Fining upwards sandstone.

Clean/kaolinitic sandstone

Mudstone

Clean sandstone.

Calcite cemented sandstone

Siltstone

Organic rich mudstone.

Coal beds.

Lithology key in Appendix 3.

Figure 27.

6.0 DIAGENESIS OF THE EUMERALLA FORMATION

6.1 Petrology and XRD Analysis

Core samples were collected and studied in thin sections, and by XRD and SEM. From thin section studies, the mineralogy and the paragenetic sequences of the Eumeralla Formation sandstones were determined. XRD indicated any variations in bulk mineralogy, and SEM was used to refine and verify the paragenetic sequence.

XRD traces indicate the presence of two distinct mineralogical groups (Figs 28 and 29):

1. Lower Eumeralla (Units IV, V)
2. Upper Eumeralla (Units I-III)

1. Lower Eumeralla

From thin section and hand specimen analysis, the Lower Eumeralla sandstones are generally grey, fine grained, well sorted, quartzose litharenites, with sub-angular to sub-rounded grains indicating moderate chemical and textu maturity (Plate 1A). The mineralogy is dominated by quartz and volcanic lithic fragments, with plagioclase, orthoclase, chlorite and biotite.

2. Upper Eumeralla

XRD analysis on the Upper Eumeralla sandstones identified significant increases in plagioclase, chlorite, biotite and illite (Fig 29). Thin section and hand specimen descriptions showed the Upper Eumeralla sandstones to be grey-green in colour, with abundant volcanic lithic fragments (up to 40%). The sandstones are fine to medium grained, and moderately sorted, with angular to sub-angular grains implying textural and chemical immaturity. The mineralogy is clearly dominated by lithic fragments, with quartz, plagioclase, orthoclase, illite, biotite, chlorite and muscovite. The illite is an alteration product of orthoclase.

The green colour present in the Upper Eumeralla sandstones is due to the increase in chlorite and the reduction in organic carbon content. These sandstones have a trimodal lithic component (Plate 1B), consisting of relatively fresh basic volcanic, weathered acid igneous and sedimentary rock (siltstone) fragments. Basic volcanics are less stable than acidic and probably have a local source while the acidics may have come from an older, distal source, possibly the Padthaway Ridge (Fig 2) (N Lemon pers comm). The fresh basic volcanics are probably derived from rift volcanics which are believed to have been extruded during the deposition of the Eumeralla (Williamson et al., 1987).

6.2 Diagenetic History and Effects on Porosity

Diagenetic cementation of the Eumeralla Formation sandstones is the most important factor in the destruction of primary intergranular porosity. Generally there are only two cement types; calcite, and randomly distributed kaolinite cement.

The calcite cement is generally restricted to Unit III in the deeper wells, with a wider distribution in shallower wells. The calcite cement is observed in thin section to precede the introduction of the kaolinite cement (Plate 1C).

The calcite cement developed in two stages; an early pore lining stage, followed by a pore filling stage (Plate 1D and 1E). The pore filling cement is an iron rich sparry calcite, which precipitated early, as indicated by the floating grains (Plate 1E). Although the calcite cement has corroded the edges of the framework grains, no secondary porosity has developed from subsequent dissolution of the cement.

The kaolinite cement is present as grain coating and pore filling stages (Plate 2F), and is indicated to be early, as the grains are floating in the cement. Some microporosity was noted in the pore filling kaolinite cement.

Plate 2A shows the relationship of sandstone porosity (primary and secondary) to areas of cement. The cemented grains have resisted compaction, but the non-cemented grains are moderately compacted, exhibiting tangential, straight line and slightly sutured contacts (Plate 2A). However, these compacted grains have reasonable porosity, due to the enhancement of the remaining primary intergranular porosity by the dissolution of acid igneous framework grains (Plates 2B and 2D). Layers of mud rip-up clasts exhibit the same characteristics (Plate 2C). Although the lithic (dominantly siltstone) layers are larger in grain size, their pores are filled with matrix, and resist compaction. The 'clean' area shows compaction, but has good porosity due to the enhancement of the primary porosity by dissolution.

In conclusion, the secondary porosity in the Eumeralla Formation sandstones has probably developed from fluid expulsion during compaction dissolving the already partially weathered acid igneous fragments. The secondary porosity plays a very important role in the development of reservoir quality sandstones. Although the expulsion of corrosive fluids during compaction is probably the mechanism for porosity enhancement, it is important not to have overcompaction which destroys most of the primary porosity. The best reservoir sands develop on the structural highs, where minimal compaction has taken place, but fluids escaping from deeper in the basin have dissolved some of the framework grains, and primary intergranular porosity is still partially preserved (Plate 2D).

The paragenetic sequence of the Eumeralla Formation sandstones can be summarised as:

1. pore lining calcite cement (not present on all grains). The pore lining cement may be obscured by corrosion of framework grains rims by pore filling cement.

2. iron rich pore filling calcite cement.

3. pore lining kaolinite cement.

4. pore filling kaolinite cement.

5. compaction of non-cemented grains, and the dissolution of weathered rock fragments (particularly acid igneous fragments).

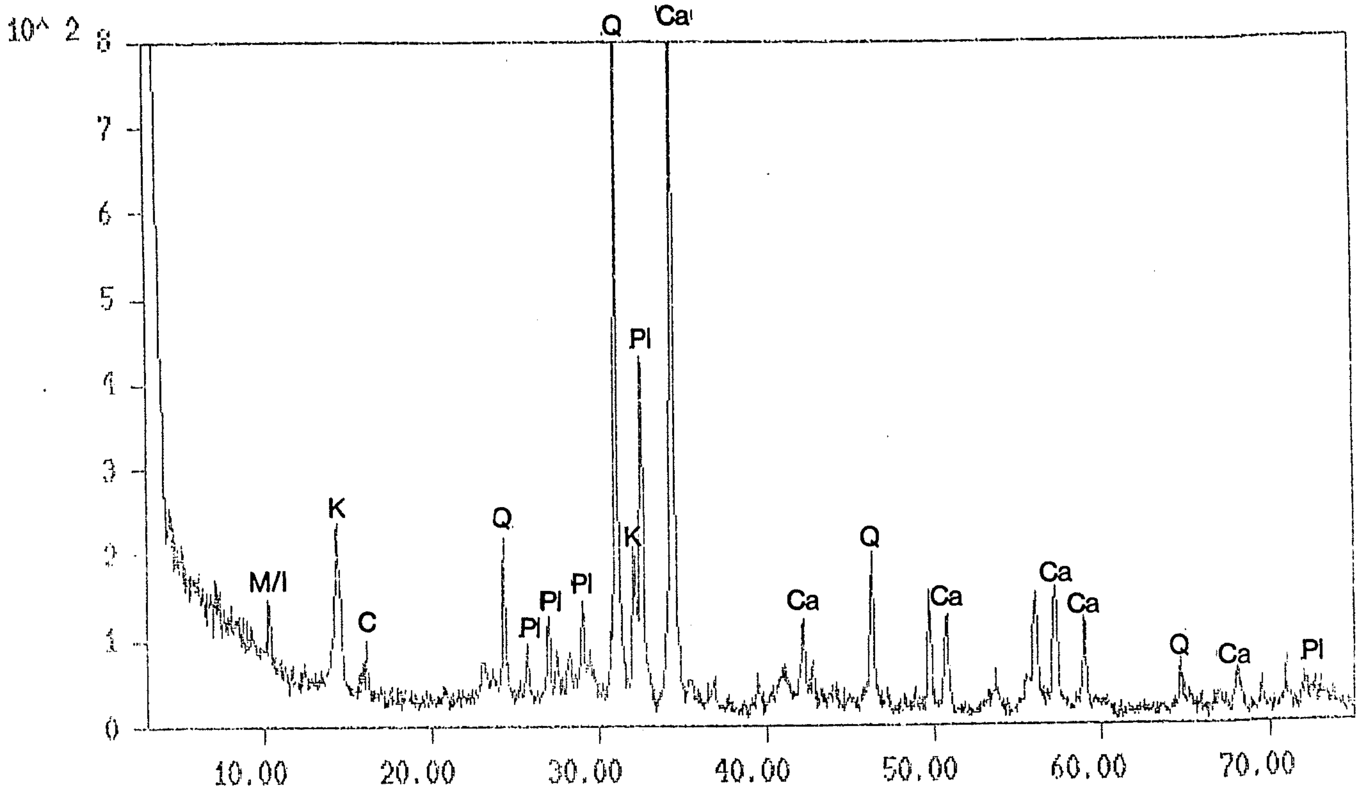

10^ 2
0
1
2
3
4
5
6
7
8
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Q
Ca
Pl
K
M/I
C
Q
Pl
Pl
Pl
K
Q
Ca
Ca
Ca
Ca
Q
Ca
Pl

Fig. 28

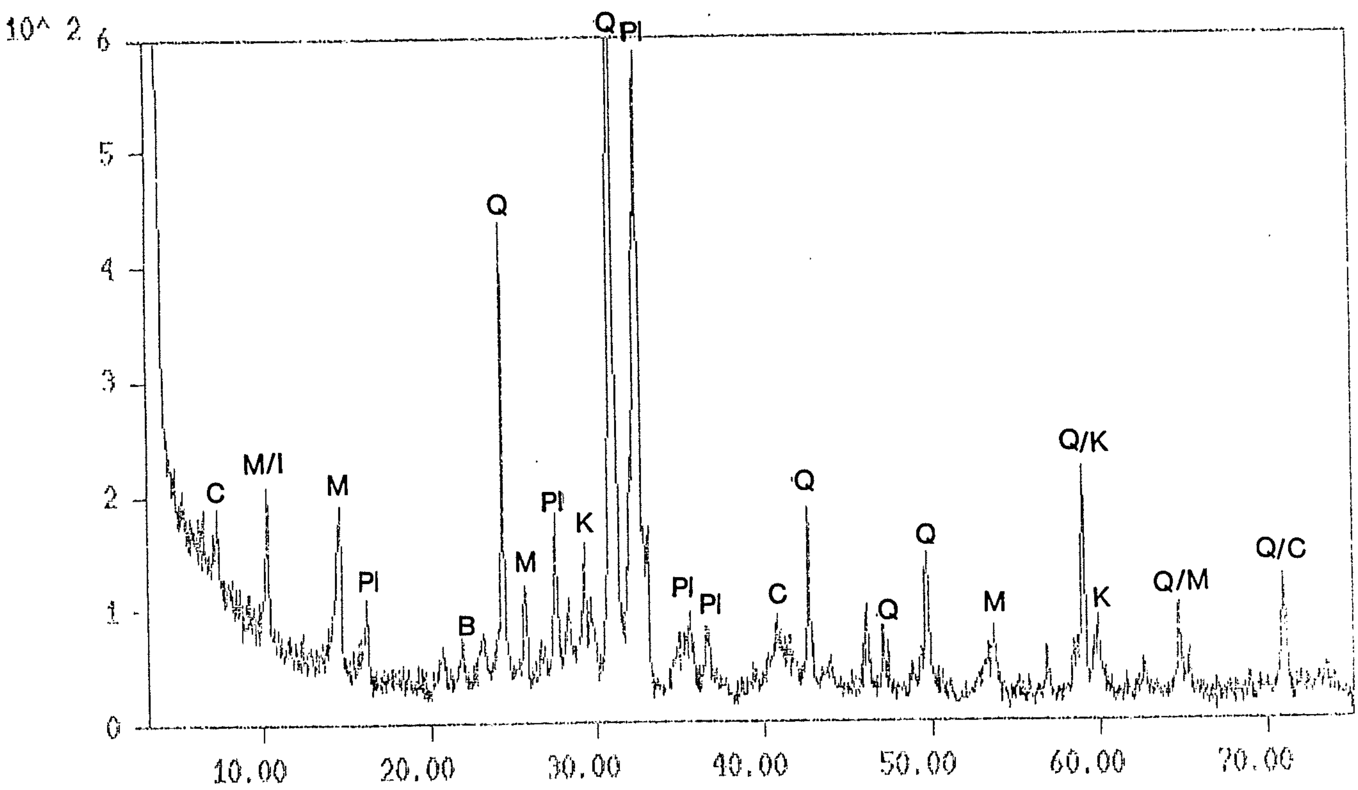

10^ 2
0
1
2
3
4
5
6
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Q
Pl
Q
C
M/I
M
Pl
B
M
Pl
K
Pl
Pl
C
Q
Q
Q
M
Q/K
K
Q/M
Q/C

Fig. 29

PLATE 1

1A)	Kalangadoo 1	5629′	(PPL)	Unit IV
1B)	Geltwood Beach 1	Core 12	(PPL)	Unit II
1C)	Kalangadoo 1	5629′	(XPL)	Unit IV
1D)	Crayfish 1	3849′	(XPL)	Unit III
1E)	Penola 1	Core 11B	(PPL)	Unit II
1F)	Crayfish 1	3853′	(XPL)	Unit III

Q - quartz grains

BV - basic volcanic fragments

S - sedimentary rock fragments

AI - acid igneous rock fragments

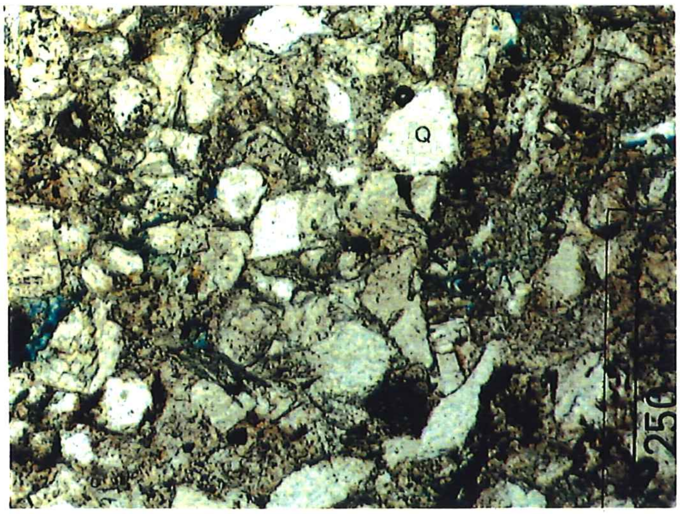
C - calcite cement

P - plagioclase

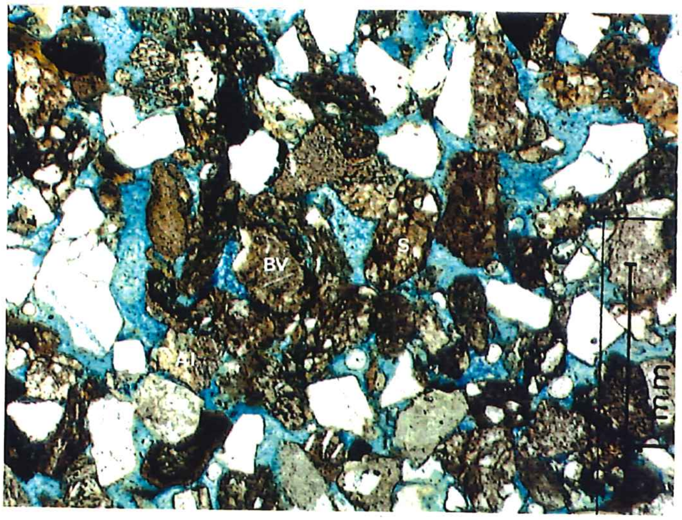
K - kaolinite cement

C1 - pore lining calcite

C2 - pore filling calcite



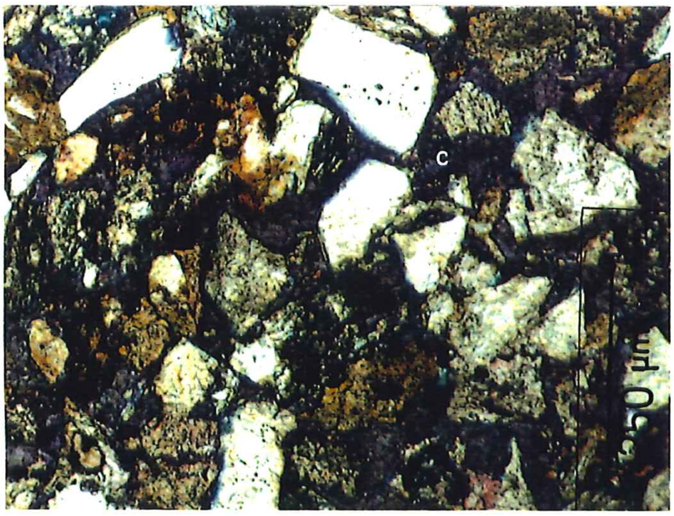
1A



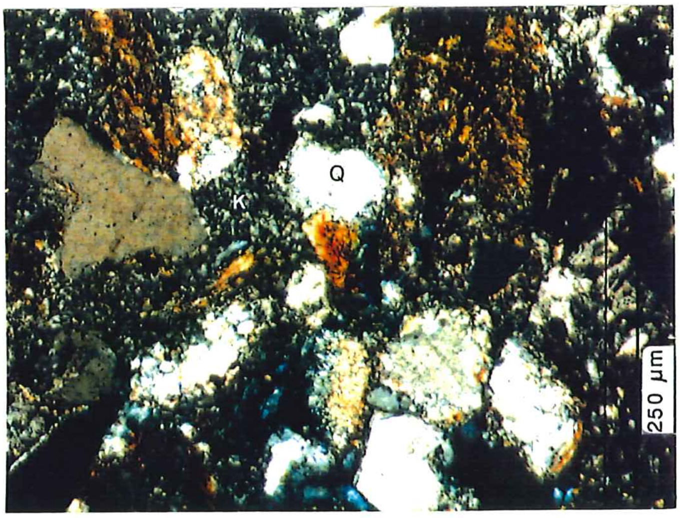
1B

1C

1D



1E



1F

Plate 1

PLATE 2

2A) Geltwood Beach	Core 13	(PPL)	Unit II
2B) Crayfish 1	3855′	(PPL)	Unit III
2C) Penola 1	Core 7	(PPL)	Unit II
2D) Beachport 1	2292′	(PPL)	Unit II
2E) Crayfish 1	3849′	(SEM)	Unit III
2F) Crayfish 1	3855′	(SEM)	Unit III

Q - quartz grains

M - matrix

P - primary porosity

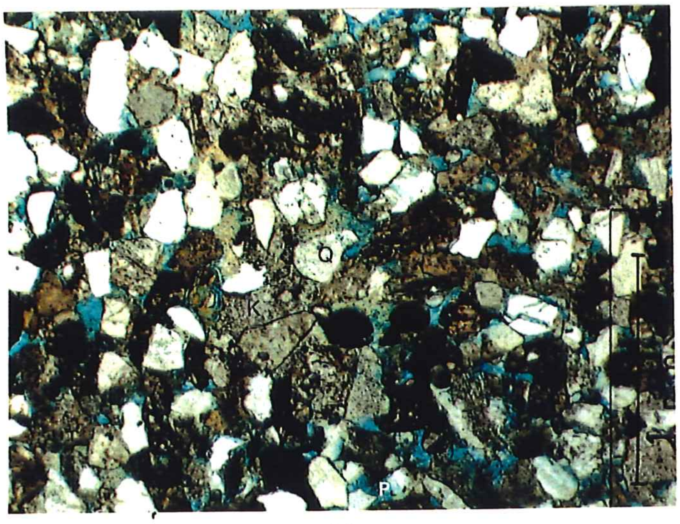
S - secondary porosity

C1 - pore lining calcite cement

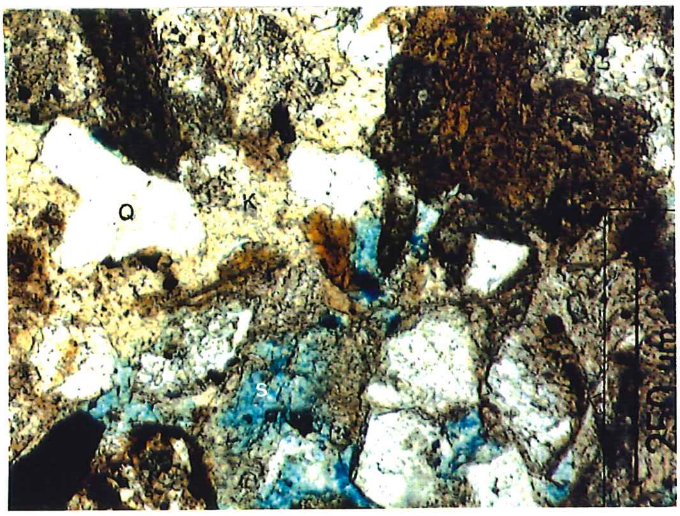
C2 - pore filling calcite cement

K1 - pore lining kaolinite cement

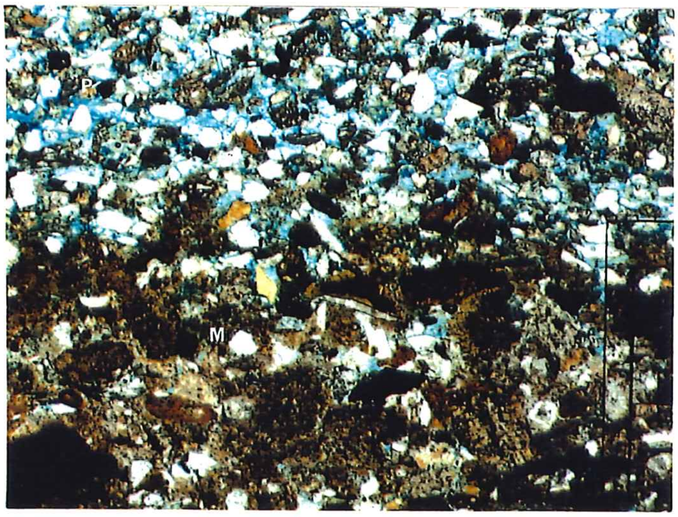
K2 - pore lining kaolinite cement



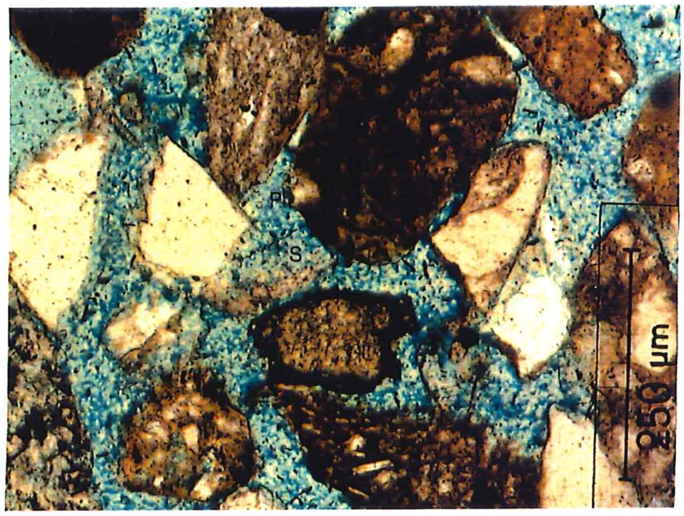
2A



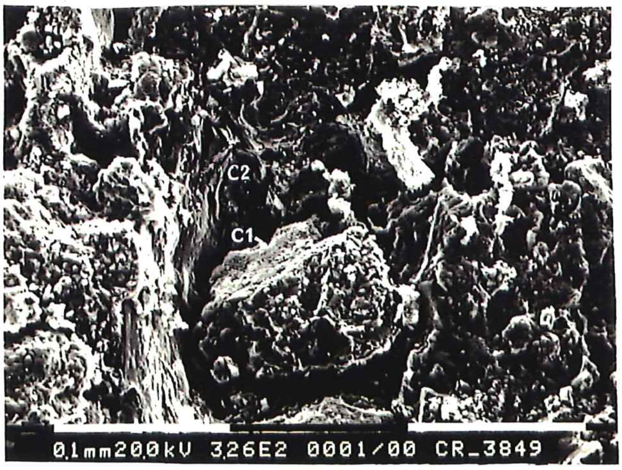
2B



2C



2D



2E

2F

Plate 2

7.0 POTENTIAL RESERVOIR DISTRIBUTION WITHIN THE EUMERALLA FORMATION

7.1 Reservoir Distribution

Reservoir sands in the Eumeralla Formation are developed in four environments:

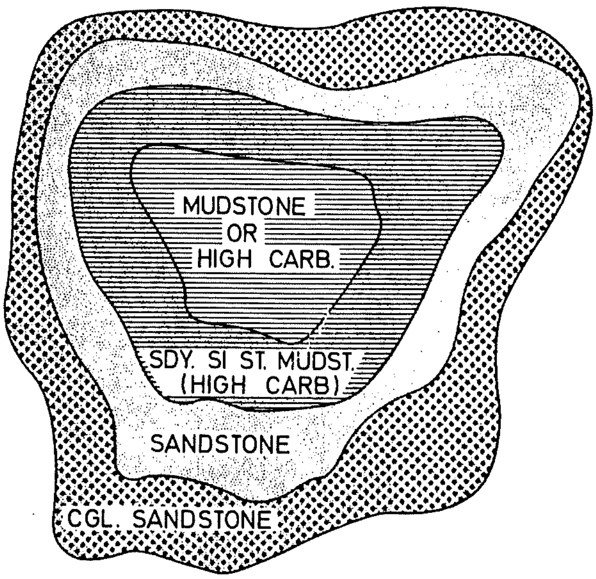
1. Lacustrine Deltas: observed on seismic (Appendix 2B) to prograde into the basin. Frostick et al., (1986) believes there are well developed sands in lacustrine deltas, and facies variations provide sufficient seals to result in excellent hydrocarbon traps. Albian lacustrine deltas prograde into the Penola Trough of Otway Basin generally from the north (Appendix 2B), the location of these deltas can be picked on seismic.

2. Turbidite Sands: are generally associated with and best developed in Unit II. The thickest sand occurs at the base of Unit II, close to the basin edge (Casterton 1 and 2, and Lucindale 1), and has been informally termed the Heathfield Sandstone Member (Williamson et al., 1987). The turbidite sands become coarser to the top of Unit II, and there is the possibility of more reservoir sands in the upper sections of Unit II.

3. Channel Sands: are possibly developed in the fluvially dominated Unit V, and are present at the base of the Eumeralla in Casterton 1 and Banyula 1. Strong gas flows were recorded from this sand in Katnook 1 (Mineral Industry Quarterly (SA), 1989), and the interpretation of meandering stream deposition for this unit (Chapter 4.2) implies that the sands would be difficult to track due to their sinuous distribution. The basal Eumeralla Formation sand is an important economic target, and an attempt should be made to map the channel distribution, or alternatively a revision of this interpretation.

4. Shoreline Sands: develop in response to sediment dispersion by hydraulic energy (Reineck and Singh, 1980), and fringe the edges of lakes (Fig 30). These sands may or may not be developed in the Eumeralla Formation, but their depth of burial would be shallow, making their reservoir potential questionable, due to a lack of seals.

Figure 30



(from Reineck and Singh,1980)

Fig. 350. Schematic distribution of sediments in a lake. (Compare with Fig. 351.) (Modified after Twenhofel 1932)

7.2 Reservoir Seals, Structure and Migration

Generally the reservoirs in the Eumeralla have excellent seal development due to the interbedding of silts and sandstones. However, significant structures have not developed in the Penola Trough apart from roll-over anticlines adjacent to large listric faults (SAGASCO Resources, 1989). Reservoir sands are best developed near the highs, therefore stratigraphic traps (pinchouts and intra-Eumeralla unconformities (Appendix 2A)), near highs represent some of the best potential hydrocarbon traps, especially in Unit II.

Migration of hydrocarbons from source rocks to Eumeralla Formation reservoir sands probably took place along faults penetrating both source rock and reservoirs. It is difficult to envisage hydrocarbon migration to the sands through the thicknesses of silts and shales present between source rock and reservoir without faulting. An exception are the channel sands of Unit V which are adjacent to basal Eumeralla Formation source rocks.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Correlations within the Eumeralla Formation across the Penola Trough have resulted in five sub-divisions representing facies changes within the formation. Correlations were based on wireline log character, palynology, sedimentology and seismic character. However, correlations were made difficult by the presence of potassium-rich lithic fragments resulting in 'hot' Eumeralla Formation sands, severely limiting the effectiveness of the gamma ray tool.

The uppermost unit (Unit I) was deposited in a distal marine-estuarine environment with fluvial/lacustrine influence. The sediments of Unit I onlap (from the west) onto the underlying sediments (Appendix 2A) indicating the opening of a seaway from the west.

The underlying Unit II was deposited in a relatively deep lacustrine environment with water depths 20-40m onshore, with the possible development of a very deep lacustrine environment offshore. The lake is formed by the ponding of water against the footwall of normal faults. The sediments are generally fine grained, apart from interbedded sands deposited as storm generated turbidites, and lacustrine deltas.

A shallow lacustrine environment is the setting for the deposition of Unit III, which overlies the floodplain deposited sediments of Unit IV. Unit IV represents the transition between fluvial (Lower Eumeralla Formation) and lacustrine (Upper Eumeralla Formation) environments.

The basal unit of the Eumeralla Formation (Unit V) is dominantly fluvial, with meandering streams and associated backswamp sub-environments responsible for significant coal accumulations.

Major fault movement during the deposition of the Eumeralla Formation did not commence until the Middle Albian (105 Ma). Post mid-Albian sediments (Unit I and II) were deposited in NW-SE trending troughs (Figs 15 and 16) reflecting activation of the second stage rift faults towards breakup. Palaeo-topography during the deposition of the Lower Eumeralla (Units III, IV and V) is indicated to be relatively flat (Figs 17, 18 and 19). Interpretation of seismic indicated mid-Albian fault activation, and increasing subsidence (D Coelho, pers. comm.)

The Eumeralla Formation can be divided into two groups based on mineralogy. The Lower Eumeralla Formation is quartz rich relative to the Upper Eumeralla Formation which has significantly more amounts of plagioclase and chlorite. The Lower Eumeralla Formation probably had significant amounts of sediments reworked from the underlying quartz rich Crayfish Formation. The lithic nature of the Upper Eumeralla Formation is due to active volcanism during deposition.

The Eumeralla Formation sediments have two cement types; ferroan calcite and kaolinite. The calcite is generally restricted to Unit III (except in shallower wells), and the kaolinite is distributed throughout the formation.

Cementation is the Eumeralla Formation generally occurs in two stages; an isopachous pore lining, followed by a pore filling stage.

The calcite cemented zones have a distinctive log signature, (fast transit times and reduced SP), but the kaolinite cement is generally not distinguishable on wireline logs, although effective porosity is reduced.

Both cement types occlude primary porosity. The only areas where significant porosities develop is where fluids moved by compaction have dissolved the margins of weathered acid igneous fragments to enhance the primary porosity. Cement inhibits compaction, and therefore little or no secondary porosity is developed in cemented sandstones.

Reservoirs are present in the storm generated turbidite sands (Unit II), and the basal Eumeralla Formation channel sands (Unit IV). It is possible that reservoirs are present in lacustrine deltas and shoreline sands, and along intra-Eumeralla unconformities. The best reservoir quality sands develop on structural highs.

Numerous intra-formation seals are well developed, but this implies migration from source rock to reservoir must take place along faults.

Structure is reasonably well developed, but is not sufficiently large enough for major anticlinal development, apart from roll-over anticlines. Stratigraphic traps are an important exploration target in the Eumeralla Formation.

The SP log is the most useful wireline tool for delineating Eumeralla Formation sands. With careful analysis of the caliper log confirming the SP delineated sands, it is recommended that attention be paid to obtaining the best SP log possible by correct hole conditioning. Then the SP combined with the caliper, can overcome the problem of a bland GR log caused by high potassium sands.

REFERENCES

Allen, P.A. and Collinson, J.D. - 1986. Lakes; in Reading H.G., 1986, Sedimentary environments, Springer-Verlag, pp 63-94.

Cohen, A.S., Ferguson, D.S., Gram, P.M., Hubler, S.L. and Sims, K.W. - 1986. The distribution of coarse grained sediments in modern Lake Turkana, Kenya: implications for clastic sedimentation models of rift lakes; from Frostick, L.E. et al (editors), 1986, Sedimentation in the African Rifts. Geological Society Special Publication, No 25, pp 127-139.

Etheridge, M.A., Branson, J.C., Stuart-Smith, P.G. - 1985. Extensional basin forming structures in Bass Strait and their importance for hydrocarbon exploration. APEA Journal, pp 344-361.

Falvey, D.A. and Mutter, J.C. - 1981. Regional plate tectonics and the evolution of Australia's passive continental margin. BMR Journal of Australian Geology and Geophysics, 6, pp 1-29.

Frakes, L.A., Borger, D., Apthorpe, M., Wiseman, J., Dettmann, M., Alley, N., Flint, R., Gravestock, D., Ludbrook, N., Backhouse, J., Skwarko, S., Scheibnerova, V., McMinn, A., Moore, P.S., Bolton, B.R., Douglas, J.G., Christ, R., Wade, M., Molnar, R.E., McCrowran, B., Balme, B.E. and Day, R.A.-

1987. Australian Cretaceous shorelines, stage by stage. Palaeogeography, Palaeoclimatology, Palaeoecology, Vol 59, pp 31-48.

Frakes, L.A. and Francis, J.E. - 1988. A guide to Phanerozoic cold polar climates from high latitude ice rafting in the Cretaceous, Nature, Vol 333 (6173), pp 547-549.

Frostick, L.E. and Reid, I. - 1986. Evolution and sedimentary character of lake deltas fed by ephemeral rivers in the Turkana basin, northern Kenya; from Frostick, L.E. et al (editors), 1986, Sedimentation in the African rifts, Geological Society Special Publication, No 25, pp 113-125.

Gibbs, A. - 1987. Development of extension and mixed-mode sedimentary basins; from Coward, M.P., Dewey, J.F. and Hancock, P.L. (editors), 1987, Continental extensional tectonics. Geological Society Special Publication, No 28, pp 19-33.

Gibling, M.R. - 1988. Cenozoic lacustrine basins of southeast Asia, their tectonic setting, depositional environment and hydrocarbon potential; from Fleet, A.J., Kelts, K. and Talbot, M.R. (editors), 1988, Lacustrine source rocks. Geological Society Special Publication, No 40, pp 341-351.

Gore, P.J.W. - 1987. Lacustrine sequences in an early Mesozoic rift basin - Culpeper Basin Virginia, USA; in Fleet, A.J., Kelts, K. and Talbot, M.R. (editors), 1988. Lacustrine Petroleum Source Rocks, Geological Society Special Publication, No 40, pp 247-278.

Gravestock, D.I., Hill, A.J. and Morton, J.G.G. - 1986. A review of the structure geology and hydrocarbon potential of the Otway Basin in South Australia. Department of Mines and Energy, South Australia, Rept BR No 86/77.

Haines, P.W. - 1988. Storm dominated mixed carbonate/siliciclastic shelf sequence displaying cycles of hummocky cross-stratification, Late Proterozoic Wonoka Formation, South Australia. Sedimentary Geology, Vol 58, pp 237-254.

Haq, B.U. et al - 1987. Mesozoic - Cenozoic cycle chart; in Bally, A.W., Atlas of seismic stratigraphy - volume 1, AAPG Studies in Geology #27.

Heggarty, K.A., Weissel, J.K. and Mutter, J.C. - 1988. Subsidence history of Australia's southern margin: Constraints on Basin Models. AAPG Bulletin, Vol 72(5), pp 615-633.

Helby, R., Morgan, R. and Partridge, A.D. - 1987. A palynological zonation of the Australian Mesozoic; in Jell, P.A. (editors), Studies in Australian Mesozoic Palynology, Publ AAP, pp 1-85.

Katz, B.J. and Rosendahl, B.R. - 1989. Lacustrine basin exploration: Case studies and modern analogues; AAPG Research Conference. AAPG Bulletin, Vol 73 (9), pp 1140-1194.

Kelts, K. and Hsu, K.J - 1978. Freshwater carbonate sedimentation; in Lerman, A. (editor), Lakes: Chemistry, geology, physics, Springer-Verlag, New York, pp 295-323.

Laing, S., Dee, C.N. and Best, P.W. - 1989. The Otway Basin. APEA Journal, 1989, pp 417-429.

Leeder, M.R. and Gawthorpe, R.L. - 1987. Sedimentary models for extensional tilt-block / half graben basins; in Coward, M.P., Dewey, J.F. and Hancock, P.L. (editors), Continental extensional tectonics. Geological Society Special Publication, No 28, pp 139-152.

Megalla, M. - 1986. Tectonic development of Victoria'a Otway Basin - A seismic interpretation; in Glenie R.C. (editor). Second South-eastern Australia Oil Exploration Symposium, pp 210-218.

Mineral Industry Quarterly, South Australia, No 53, March 1989, Katnook gas discovery. Department of Miens and Energy.

Morgan, R. - 1987. Palynology, Appendix 1; in Connard The petroleum geology of the Otway Basin, A non-exclusive study, February, 1987.

O'Brien, G.W. - 1987. Otway Basin stratigraphy - a general review; Otway Basin workshop, extended abstracts. BMR Record 1987/9, pp 31 34.

Reineck, H.E. and Singh, I.B. - 1980. Depositional sedimentary environments with reference to terrigenous clastics, Springer-Verlag, pp 298-299.

Rosendahl, B.R., Reynolds, D.J., Lorben, P.M., Burgess, C.F., McGill, J., Seatt, D., Lambiase, J.J. and Derksen, S.J. 1986 - Structural expressions of rifting: lessons from Lake Tanganyika, Africa; from Frostick, L.E. et al (editors), 1986, Sedimentation in the African rifts. Geological Society Special Publication, No 25, pp 29-43.

SAGASCO Resources Limited - 1989. Preliminary report on the prospectivity of vacant areas H, I and J (Ex PEL 8) Otway Basin, South Australia.

Scott, D.L. and Rosendahl, B.R. - 1989. North Viking Graben an East African perspective. AAPG Bulletin, Vol 73 (2), pp 155-165.

Sprigg, R.C. - 1986. A History of the Search for Commercial Hydrocarbons in the Otway Basin Complex, in; Glenie, R. (editor), Second South-Eastern Australia Oil Exploration Symposium, pp 173-200.

Struckmeyer, H.E. - 1988. Source rock and maturation characteristics of the sedimentary sequence of the Otway Basin, Australia. PhD, University of Wollongong.

Struckmeyer, H.E. and Felton, E.A. - 1988. Organic and sedimentary facies of the Early Cretaceous Otway Group, Otway Basin, southern Australia, 9th Australian Geological Convention, Abstracts, 21, pp 383-384.

Veevers, J.J. - 1988(b). Seafloor magnetic lineation off the Otway/West Tasmanian Basins: ridge jumps and the subsidence history of the southeast Australian margins. Australian Journal of Earth Sciences, Vol 35, pp 451-462.

Veevers, J.J. and Eittreim, S.L. - 1988(a) - Reconstruction of Antarctica and Australia at breakup (95±5 Ma) and before rifting (160 Ma). Australian Journal of Earth Sciences, Vol 35, pp 355-362.

Williamson, P.E., Collins, D.N. and Falvey, D.A. - 1989(b). Crustal structure and formation of a magnetic quiet zone in the Australian southern margin. Marine and Petroleum Geology, Vol 6, pp 221-231.

Williamson, P.E., O'Brien, G.W., Swift, M.G., Felton, E.A., Scherl, A.S., Lock, J., Exon, N.F. and Falvey, D.A. - 1987. Hydrocarbon potential of the offshore Otway Basin. APEA Journal, 1987, pp 173-194.

Williamson, P.E., Swift, M.C., O'Brien, G.W. and Falvey, D.A.- 1989(a). Two-stage Early Cretaceous rifting of the Otway Basin margin of southeastern Australia: Implications for rifting of the Australian southern margin. Australian BMR Publications.

Yu, S.M. - 1988. Structure and development of the Otway Basin. APEA Journal, pp 243-254.

APPENDICES

APPENDIX 1

Thin Section Descriptions

WELL: CRAYFISH 1 **DEPTH:** 2273' **UNIT:** II

Macro-Description

Fine grained, green/grey lithic sandstone. Porosity fair to poor, permeability fair. Sample looks well sorted, quartz granules range from subrounded to sub-angular. Soft and friable.

Micro-Description

Fine grained, well sorted, lithic arenite. Tangential and slightly sutured contacts indicates a fair degree at compaction. The mineralogy is dominated by lithics, quartz and plagioclase with biotite, chlorite and traces of muscovite. The grains are mostly angular, and vary from low to moderate sphericity.

There are only small amounts of primary porosity even though there is no matrix. Primary porosity has been nearly destroyed by compaction. However, significant amounts of secondary porosity have developed from the dissolution of framework grains, particularly orthoclase, with lithics and chlorite also showing signs of dissolution. The porosity is generally ineffective due to the lack of pore interconnection. There are traces of authigenic clay growth coating the framework grains.

Lithics	-	30%	Matrix	-	0%	
Quartz	-	20%	Cement	-	Trace	
Plagioclase	-	19%				
Biotite	-	5%	Porosity	-	Primary	3%
Illite	-	3%		-	Dissolution	5%
Orthoclase	-	2%				
Muscovite	-	1%				
					Total	8%

WELL: CRAYFISH 1 **DEPTH:** 2776' **UNIT:** II

Macro-Description

Fine grained, grey/green lithic sandstone. Well sorted with subrounded quartz granules; porosity and permeability average, the sand is soft and friable.

Micro-Description

Very fine-fine-grained, well sorted litharenite. Tangential and minor suture contacts indicate a fair degree of compaction. The mineralogy is dominated by lithics, and quartz, with illite plagioclase, muscovite, chlorite, biotite, orthoclase and organic matter. Linear fabrics of mud rip up clasts are present. These layers have the poorest porosity due to the presence of a dusty clay matrix which blocks most of the pore spaces.

The cement is probably kaolinite (from XRD) and has an uneven distribution appearing in irregular patches. The porosity is secondary and develops from the dissolution of framework orthoclase, and minor lithics, chlorite and organic matter. However, where the cement is concentrated there is little secondary porosity developed. There are a few rims of authigenic clay present, but no pore filling cement.

Lithics	-	34%	Matrix	-	Traces		
Quartz	-	20%	Cement	-	7%		
Illite	-	12%					
Plagioclase	-	10%	Porosity	-	Primary	1%	
Muscovite	-	3%		-	Dissolution	4%	
Chlorite	-	3%					
Biotite	-	3%					
Orthoclase	-	2%			Total	5%	
Organic matter	-	1%					

WELL: CRAYFISH 1 **DEPTH:** 3300' **UNIT:** II

Macro-Description

Micritic (?) limestone. Grey/green and hard with conchoidal fracture.

XRD:

Calcite, quartz and plagioclase dominant, with chlorite, kaolinite/smectite and muscovite/illite.

WELL: CRAYFISH 1 DEPTH: 3849' UNIT: III

Macro-Description

Very fine grained, hard grey/green, well cemented, calcareous, lithic sandstone. Well sorted, well-subrounded quartz grains. Porosity and permeability poor.

Micro-Description

Fine grained to very fine grained, well sorted, well cemented, quartzose litharenite. Tangential contacts imply early cementation. The mineralogy is dominated by quartz, lithics, and illite, with biotite, chlorite, plagioclase, muscovite and orthoclase. The grains are generally sub-spherical and angular to sub-rounded. No fabric is present.

There is probably no matrix present, but all primary porosity is filled with calcite cement with minor kaolinite and possible anhedral quartz. There is no primary porosity remaining but traces of secondary porosity are present. The calcite cement occurs in two stages: a pore lining - followed by a pore filling stage.

Lithics	33%	Cement	20%
Quartz	20%	CO_3	14%
Orthoclase	4%	Kaolinite	1%
Illite	4%	Possible anhedral quartz	1%
Chlorite	4%	Porosity	1%
Muscovite	4%		
Organic Matter	2%		

WELL: CRAYFISH 1	DEPTH: 3855'	UNIT: III

Macro-Description

Fine grained, grey/green lithic sandstone. Fair sorting, with sub-rounded to sub-angular grains, average porosity and permeability. Matrix appears to be clay rich.

Micro-Description

Fine grained, moderately well sorted, litharenite. Many of the grain contacts are straight line or tangential, but there are also grains floating in a clay cement. The mineralogy is dominated by lithics and quartz, with plagioclase, biotite, chlorite orthoclase, illite, and organic matter. The organic matter shows some minor bedding is present. The grains are generally angular to sub-rounded with low to high sphericity.

The cement is randomly distributed and is indicated by XRD to be kaolinite. Porosity is poorly developed in areas of cement. The porosity is mostly secondary, from the dissolution of orthoclase and some lithic and chlorite framework grains. Grains in areas of secondary porosity are in contact, whereas the areas with grains floating in cement are tight.

Lithics	-	30%	Matrix	-	trace	
Quartz	-	25%	Cement	-	13%	
Plagioclase	-	7%				
Biotite	-	7%	Porosity	-	primary	2%
Chlorite	-	7%		-	dissolution	4%
Orthoclase	-	4%				
Illite	-	3%				
Organic Matter	-	1%			Total	6%

WELL: PENOLA 1 DEPTH: 1' from top #7 UNIT: II

Macro-Description

Fine grained, grey/green lithic (micaceous) sandstone. Sand is poorly consolidated, and therefore soft and friable. Porosity is average, permeability is fairly good. Sand is well sorted with sub-rounded to sub-angular grains.

Micro-Description

Very fine-grained, moderately sorted litharenite. The sands are well compacted where there is no matrix. The mineralogy is dominated by lithics and quartz, with plagioclase, chlorite biotite orthoclase, illite, muscovite and organic matter. Matrix rich, lithic dominated fabrics illustrate bedding in the sand. The lithic beds are poorly sorted with angular to sub-angular low sphericity grains. The clean beds are well sorted with sub-rounded grains of moderate sphericity.

The matrix is almost exclusively found in the lithic layers, and is a clay, probably kaolinite. The porosity is confined to the matrix free layers and is nearly all secondary. Most of the porosity is from the dissolution of orthoclase and lithic framework grains. Minor fracture and shrinkage slightly enhance the porosity. The porosity is slightly reduced by compaction. There is no pore filling cements, although there are very minor authigenic overgrowths.

Lithics	-	35%	Matrix	-	10%	
Quartz	-	22%	Cement	-	trace	
Chlorite	-	8%				
Plagioclase	-	7%	Porosity	-	primary	1%
Biotite	-	5%		-	dissolution	5%
Orthoclase	-	3%		-	fracture	1%
Illite	-	2%		-	shrinkage	trace
Muscovite	-	1%				
Organic Matter	-	trace				
					Total	7%

WELL: PENOLA 1 DEPTH: 10" from bottom #11 UNIT: II

Macro-Description

Fine grained - soft and friable, poorly consolidated grey/green lithic sandstone with coaly fragments. Good to average sorting with sub-rounded to sub-angular grains. Average porosity, with reasonable permeability.

Micro-Description

Fine grained, moderately well sorted litharenite. Tangential contacts and floating framework grains in cement indicate matrix was introduced before significant compaction. The mineralogy is dominated by lithics and quartz with plagioclase, biotite, orthoclase, muscovite, illite and chlorite, with traces of organic matter and heavy minerals. Matrix accounts for 16% of the sample. The grains are angular to sub-rounded with low sphericity.

Most of the primary pore spaces have been filled with a dusty clay cement, indicated by XRD to be kaolinite. Nearly all primary porosity has been occluded by cement. Some small amounts of secondary porosity has developed from the dissolution of orthoclase, chlorite and lithic framework grains.

thin rims of authigenic cement are present on the gains, but the mineralogy cannot be determined in thin sections.

Lithics	-	27%	Matrix	-	2%	
Quartz	-	24%	Cement	-	16%	
Plagioclase	-	8%				
Biotite	-	6%				
Orthoclase	-	5%	Porosity	-	primary	0.5%
Illite	-	2%		-	dissolution	2.5%
Muscovite	-	2%				
Organic Matter	-	1%				
Microcline	-	1%				3%
Heavy Minerals	-	trace				

WELL: PENOLA 1 **DEPTH:** 2' from top #14 **UNIT:** IV

Macro-Description

Hard, dark grey, non calcareous mudstone.

XRD:

Abundant quartz and plagioclase, with kaolinite/smectite and illite/muscovite.

WELL: PENOLA 1 DEPTH: 2' FORM BOTTOM #14 UNIT: IV

Macro-Description

Light grey, very fine grained calcareous lithic sandstone with carbonaceous fragments, and iron staining (?). Average sorting of sub-rounded to sub-angular grains, the sandstone is hard, well cemented with poor porosity and permeability.

Micro-Description

Very fine grained, well sorted, well cemented, litharenite. The framework grains are floating in an iron rich calcite cement, virtually no grain to grain contacts are evident. The mineralogy is dominated by lithics and quartz, with traces of organic matter, biotite, chlorite, orthoclase and muscovite.

All primary porosity is occluded by the iron rich calcite cement. Some minor secondary porosity has developed from the dissolution of framework grains. The ferrous calcite cement has corroded the rims on most of the framework grains.

Lithics	-	35%	Matrix	-	0%		
Quartz	-	25%	Cement	-	25%		
Organic Matter	-	4%					
Biotite	-	3%	Porosity	-	primary		0%
Orthoclase	-	3%		-	dissolution		2%
Chlorite	-	2%					
Muscovite	-	1%					
							2%

WELL: KALANGADOO 1 DEPTH: 3406.5' UNIT: II

Macro-Description

Fine grained grey/green lithic sandstone. Poorly cemented, and soft and friable. Average porosity and fair permeability. Good sorting of rounded to sub-angular grains.

Micro-Description

Fine grained, well sorted, litharenite. Grain contacts are tangential or straight line. The mineralogy is dominated by lithics and quartz, with plagioclase, biotite, chlorite, muscovite and organic matter. The grains are angular to subrounded, and subspherical.

Some minor amounts of clay matrix are concentrated where lithics dominate, traces of authigenic cement are observed on grain edges. The porosity is reduced by both compaction and matrix, compaction being the dominating influence. Most of the porosity is secondary, developed from the dissolution of framework grains.

Lithics	-	36%	Matrix	-	6%	
Quartz	-	24%	Cement	-	1%	
Plagioclase	-	12%				
Biotite	-	4%	Porosity	-	primary	1%
Illite	-	3%		-	dissolution	6%
Chlorite	-	3%				
Muscovite	-	2%				
Organic Matter	-	2%			Total	7%

WELL: KALANGADOO 1 DEPTH: 5289' UNIT: II

Macro-Description

Grey, fine grained, lithic calcareous sandstone, with mud rip up clasts, and cross bedding. Well sorted sub-angular to sub-rounded grains. Sandstone is hard and tight, with poor porosity and permeability.

Micro-Description

Very fine to fine grained, moderately sorted, sublitharenite. Grains are floating in an iron rich carbonate cement, indicating diagenesis took place very early. The mineralogy is dominated by quartz and lithics with plagioclase muscovite, chlorite and biotite. The grains are generally angular and non-spherical. Micaceous minerals show bedding.

All primary, intergranular porosity has been occluded by an iron rich carbonate cement, with only traces of secondary porosity, as a result of grain dissolution.

The pore filling ferrous calcite has corroded the edges of the framework grains.

Lithics	-	33%	Matrix	-	0%		
Quartz	-	25%	Cement	-	21%		
Plagioclase	-	6%					
Orthoclase	-	5%	Porosity	-	primary	0%	
Chlorite	-	3%		-	dissolution	trace	
Biotite	-	2%					
Organic Matter	-	2%					
Muscovite	-	2%					
Illite	-	1%					

WELL: KALANGADOO 1 DEPTH: 5629' UNIT: IV

Macro-Description

Fine grained, light grey quartzose sandstone with minor lithics. Sand has average to poor porosity and permeability and is well sorted with sub-rounded grains. The sand is cross bedded, and hard due to cementation.

Micro-Description

Fine grained, moderately sorted, sublitharenite. Grains are floating in clay cement with some grains in tangential contact. The mineralogy is dominated by quartz, lithics and plagioclase, with orthoclase, chlorite, biotite, organic matter and muscovite. The grains are generally angular and non-spherical.

The cements accounts for 20% of the sample and is widely distributed. XRD indicates the cement is kaolinite. Primary porosity is totally occluded by the cement with some secondary porosity present as a result of framework grain dissolution. Traces of pore filling carbonate cement are present.

Quartz	-	36%	Matrix	-	traces		
Lithics	-	16%	Cement	-	20%		
Plagioclase	-	13%					
Orthoclase	-	7%	Porosity	-	primary	0%	
Chlorite	-	3%		-	secondary	1%	
Biotite	-	2%					
Organic Matter	-	1%					
Muscovite	-	1%					

WELL: KALANGADOO 1 **DEPTH:** 5630' **UNIT:** IV

Macro-Description

Medium grey, fine grained quartzose, calcareous sandstone with minor lithics. Well sorted, sub-rounded grains, the sandstone is hard and tight, with cross bedding and mud rip up clasts.

Micro-Description

Fine grained, well sorted, litharenite. The grains are generally floating in an iron rich calcite cement. The mineralogy is dominated by lithics and quartz with plagioclase, biotite, chlorite and muscovite. The grains are generally angular. Stratification of the sediment is evidenced by planar layers of mud rip up clasts.

The cement occludes all primary porosity and there is no evidence of matrix. Traces of secondary porosity is present due to the dissolution of framework grains, and alteration by the cement. Framework grain boundaries are becoming corroded from the presence of the cement.

Lithics	-	34%	Matrix	-	0%		
Quartz	-	25%	Cement	-	23%		
Plagioclase	-	5%					
Chlorite	-	4%	Porosity	-	primary		0%
Orthoclase	-	3%		-	dissolution		trace
Illite	-	3%					
Biotite	-	2%					
Muscovite	-	1%				Total	< 1%

WELL: KALANGADOO 1 DEPTH: 6132' UNIT: V

Macro-Description

Fine grained, grey calcareous sandstone, approximately 50% quartz and 50% lithics. Sandstone is hard and tight with carbonaceous fragments, and is well sorted with sub-rounded grains.

Micro-Description

Fine grained, well sorted, litharenite. The grains are generally floating in an iron rich calcite cement. The mineralogy is dominated by lithics and quartz, with biotite, plagioclase, orthoclase, illite, and muscovite. The grains are angular to sub-angular and generally non-spherical wisps of organic matter illustrate bedding in the slide.

There is no matrix present, and there is no primary porosity due to the pore filling ferrous carbonate cement. There is possibly a double rim of carbonate cement present; the first is pore lining and the second is pore filling, however corrosion has obscured the grain edges and made identification difficult.

Lithics	-	33%	Matrix	-	0%		
Quartz	-	25%	Cement	-	27%		
Biotite	-	6%					
Plagioclase	-	3%	Porosity	-	primary	0%
Orthoclase	-	3%		-	dissolution	trace
Illite	-	2%					
Muscovite	-	1%					
					Total	< 1%

WELL: GELTWOOD BEACH 1 **DEPTH:** 4411' **UNIT:** I

Macro-Description

Grey/green, fine grained lithic sandstone, well sorted sub-rounded to sub-angular grains. Porosity and permeability are poor, the sandstone is moderately hard and well consolidated.

Micro-Description

Fine grained, moderately sorted, feldspathic litharenite tangential and slightly sutured contacts indicate compaction. The mineralogy is dominated by lithics and quartz, with plagioclase, biotite, chlorite, muscovite and organic matter. The grains are angular to sub-rounded. Bedding can be observed by the orientation of flakey minerals such as biotite and muscovite, and organic matter.

Most of the primary pores have been filled with a clay cement that occludes nearly all the primary porosity. From XRD the clay is probably a kaolinite (see SEM). The primary porosity is reduced by compaction authigenic cements and matrix, however minor secondary porosity is developed from grain dissolution. A thin iopachous rim of authigenic cement coats many grains.

Lithics	-	32%
Quartz	-	20%
Plagioclase	-	12%
Biotite	-	10%
Chlorite	-	4%
Orthoclase	-	3%
Muscovite	-	1%
Organic Matter	-	trace

Matrix	-	16%	
Cement	-	1%	
Porosity	-	primary	trace
	-	dissolution	1%

WELL: GELTWOOD BEACH 1 DEPTH: 1' from top #12 UNIT: II

Macro-Description

Medium grained, grey/green lithic sandstone with carbonaceous material. Porosity is good and permeability is excellent. The sand is moderately consolidated, and consists of sub-angular grains (of variable sphericity) of average sorting.

Micro-Description

Medium grained, moderately sorted, feldspathic litharenite. The grains are moderately well compacted. The mineralogy is dominated by lithics, quartz and plagioclase with illite, orthoclase, biotite, chlorite, muscovite and traces of organic matter. This sample shows trimodality in the lithic component with fresh basic volcanics, altered acid igneous and sedimentary rock fragments. The grains are angular to sub-rounded, and generally non-spherical. Wisps of organic matter and mud rip-up clasts show the bedding.

There is no matrix present in the sample. Porosity has been significantly reduced by compaction. But, the remaining primary porosity has been greatly enhanced by framework grain dissolution. Minor authigenic cement growths coat the framework grains.

Lithics	-	35%	Matrix	-	0%	
Quartz	-	20%	Cement	-	1%	
Plagioclase	-	14%				
Illite	-	6%	Porosity	-	primary	7%
Orthoclase	-	4%		-	dissolution	9%
Biotite	-	2%		-	shrinkage	trace
Chlorite	-	1%				
Muscovite	-	1%				
					Total	16%

WELL: GELTWOOD BEACH 1 **DEPTH:** 7' from top #13 **UNIT:** II

Macro-Description

Fine-medium grained, grey lithic sandstone with mud intraclasts. Sand is fairly soft with average to poor consolidation. The matrix appears to be clay rich. Porosity and permeability are average to good. Sand is well sorted, with sub-angular grains of high sphericity.

Micro-Description

Fine-medium grained, moderate to well sorted, feldspathic litharenite. Grain boundaries are tangential to slightly sutured indicating compaction. The mineralogy is dominated by lithics, quartz and plagioclase, with biotite, illite, chlorite, orthoclase, muscovite and organic matter. The grains are angular to sub-rounded. Large rip-up mud clasts illustrate bedding within the slick.

A clay cement is randomly distributed throughout the sample. XRD indicates it is a kaolinite. Primary porosity has largely been occluded by the cement, and reduced by compaction. However, in the areas without cement primary intergranular porosity has been enhanced by the dissolution of framework grains.

Lithics	-	34%	Matrix	-	0%		
Quartz	-	21%	Cement	-	6%		
Plagioclase	-	12%					
Biotite	-	6%					
Illite	-	6%	Porosity	-	primary		3%
Chlorite	-	5%		-	dissolution		4%
Orthoclase	-	2%					
Muscovite	-	1%					
Organic matter	-	trace				Total	7%

WELL: GELTWOOD BEACH 1 **DEPTH:** 11235' **UNIT:** V

Macro-Description

Very fine grained, grey, non-calcareous lithic sandstone. The sand is well cemented, hard and dense, with poor porosity and permeability. The sand consists of moderately sorted sub-angular grains.

Macro-Description

Very fine grained, moderately sorted, quartzose litharenite. The grains are generally in tangential or straight line contact, but grains floating in clay cement are common. The mineralogy is dominated by lithics and quartz, with plagioclase, biotite illite, chlorite, orthoclase, muscovite, and organic matter. The grains are generally angular to sub-angular with low sphericity. Wisps of organic matter across the slide indicate the presence of bedding.

Cement fills most of the pore spaces across the slide. XRD indicates a kaolinite composition. The matrix has occluded all primary pore spaces, and prevented the development of any secondary porosity. Minor amounts of pore filling calcite cement are present.

Lithics	-	30%	Matrix	-	0%
Quartz	-	28%			
Plagioclase	-	7%	Cement	-	16%
Biotite	-	6%			
Illite	-	5%	Porosity	-	traces
Chlorite	-	4%			
Orthoclase	-	2%			
Muscovite	-	1%			
Organic matter	-	1%			

WELL: BEACHPORT 1 DEPTH: 2099' UNIT: II

Macro-Description

Fine grained, grey/green lithic sandstone with very good permeability and good porosity. The sand is soft and friable, and is poorly cemented. The sorting is good and the grains are sub-rounded.

Micro-Description

Fine grained, moderately well sorted, litharenite. Dominantly tangential grain contacts indicate moderate compaction. The mineralogy is dominated by lithics and quartz, with chlorite, plagioclase, illite, biotite, orthoclase, organic matter and muscovite. The grains are sub-angular to sub-rounded, with average sphericity. Mud clasts and organic matter illustrate bedding trends.

There is no matrix present. Porosity is at 16% with most of it primary intergranular due to low compaction. The primary porosity is enhanced by framework grain dissolution. There is an insufficient amount of cement to determine any cement stratigraphy.

Lithics	-	35%	Matrix	-	0%		
Quartz	-	30%					
Chlorite	-	5%	Cement	-	trace		
Plagioclase	-	4%					
Illite	-	4%	Porosity	-	primary		10%
Biotite	-	3%		-	dissolution		6%
Orthoclase	-	2%					
Organic matter	-	1%					
Muscovite	-	trace				Total	16%

WELL: BEACHPORT 1 **DEPTH:** 2289' **UNIT:** II

Macro-Description

Fine-medium grained, grey/green lithic sandstone with good permeability and porosity. The sand is soft and friable and has grains of variable roundness and sphericity with average sorting.

Micro-Description

Fine to medium grained, moderately sorted, litharenite. The grains are mostly in tangential contact, implying little compaction. The mineralogy is dominated by lithics, quartz, orthoclase, plagioclase, biotite, chlorite, muscovite and illite. The grains are angular and non-spherical. The sand is massive.

There is no matrix present and only some minor authigenic cement growths on the rims of framework grains. Porosity is well developed and is mostly primary with enhancing secondary porosity. The authigenic growths are unable to be identified in thin section.

Lithics	-	30%	Matrix	-	0%	
Quartz	-	21%				
Orthoclase	-	13%	Cement	-	trace	
Plagioclase	-	12%				
Biotite	-	4%	Porosity	-	primary	11%
Chlorite	-	3%		-	dissolution	4%
Muscovite	-	1%				
Illite	-	1%				
					Total	15%

WELL: BEACHPORT 1 DEPTH: 2292' UNIT: II

Macro-Description

Fine-medium grained, grey/green lithic sandstone with excellent permeability and good porosity. The sand is extremely soft and friable, with average sorting of grains and variable sphericity and roundness.

Micro-Description

Fine-medium grained, well sorted litharenite. Tangential contacts are most common, with some contacts sutured, indicating slight compaction. The mineralogy consists of volcanic lithic fragments and quartz with minor plagioclase, weathered orthoclase (illite), biotite, chlorite, muscovite and traces of carbonaceous material. The sample has a trimodal lithic composition, with an altered acidic igneous component, a fresh basic volcanic component and a siltstone component. The grains are sub-angular to sub-rounded and generally non-spherical. The sand is massive.

There is no matrix present in the sample. Porosity is excellent. Most of the porosity is primary intergranular and it has been enhanced by the dissolution of framework grains, mainly the orthoclase and acid igneous fragments. Traces of authigenic cement coats some of the framework grains.

Lithics	-	40%	Matrix	-	0%		
Quartz	-	16%					
Plagioclase	-	7%	Cement	-	trace		
Illite	-	6%					
Biotite	-	3%	Porosity	-	primary	15%	
Chlorite	-	3%		-	dissolution	8%	
Muscovite	-	2%					
Organic matter	-	trace					
					Total	23%	

WELL: BEACHPORT 1 **DEPTH:** 2296′ **UNIT:** II

Macro-Description

Green mudstone, with soapy texture when wet.

XRD

Rich in chlorite (clinochlore IIB), which is responsible for colour. Also quartz and plagioclase rich.

WELL: BEACHPORT 1 DEPTH: 3408' UNIT: II

Macro-Description

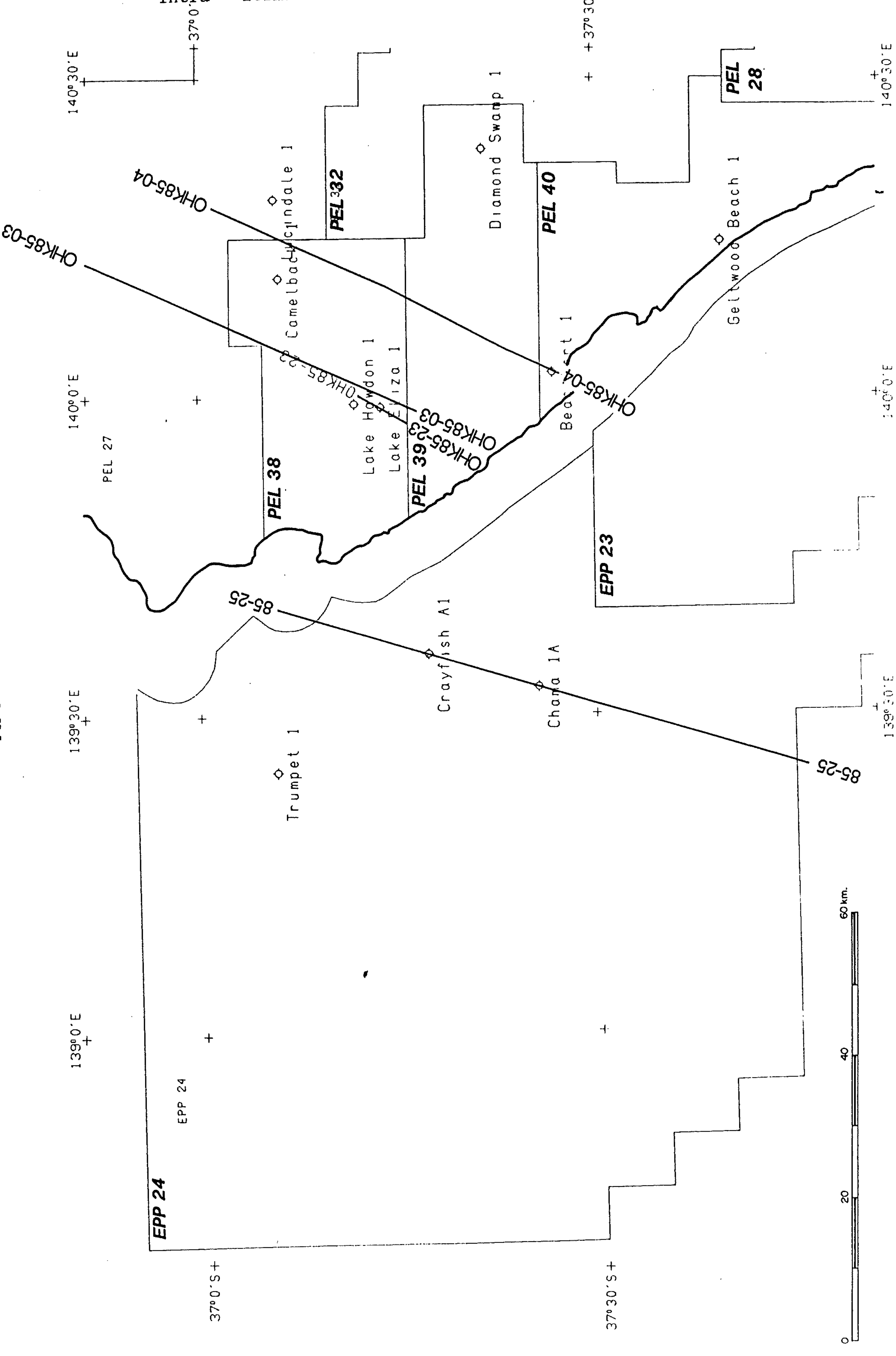
Micrite intraclasts in a very sparry calcite matrix.

XRD

Abundant calcite, quartz and plagioclase.

* Formation boundaries interpreted by D.Coelho (SAGASCO Resources Ltd)
* Intra - formational boundaries interpreted by author.

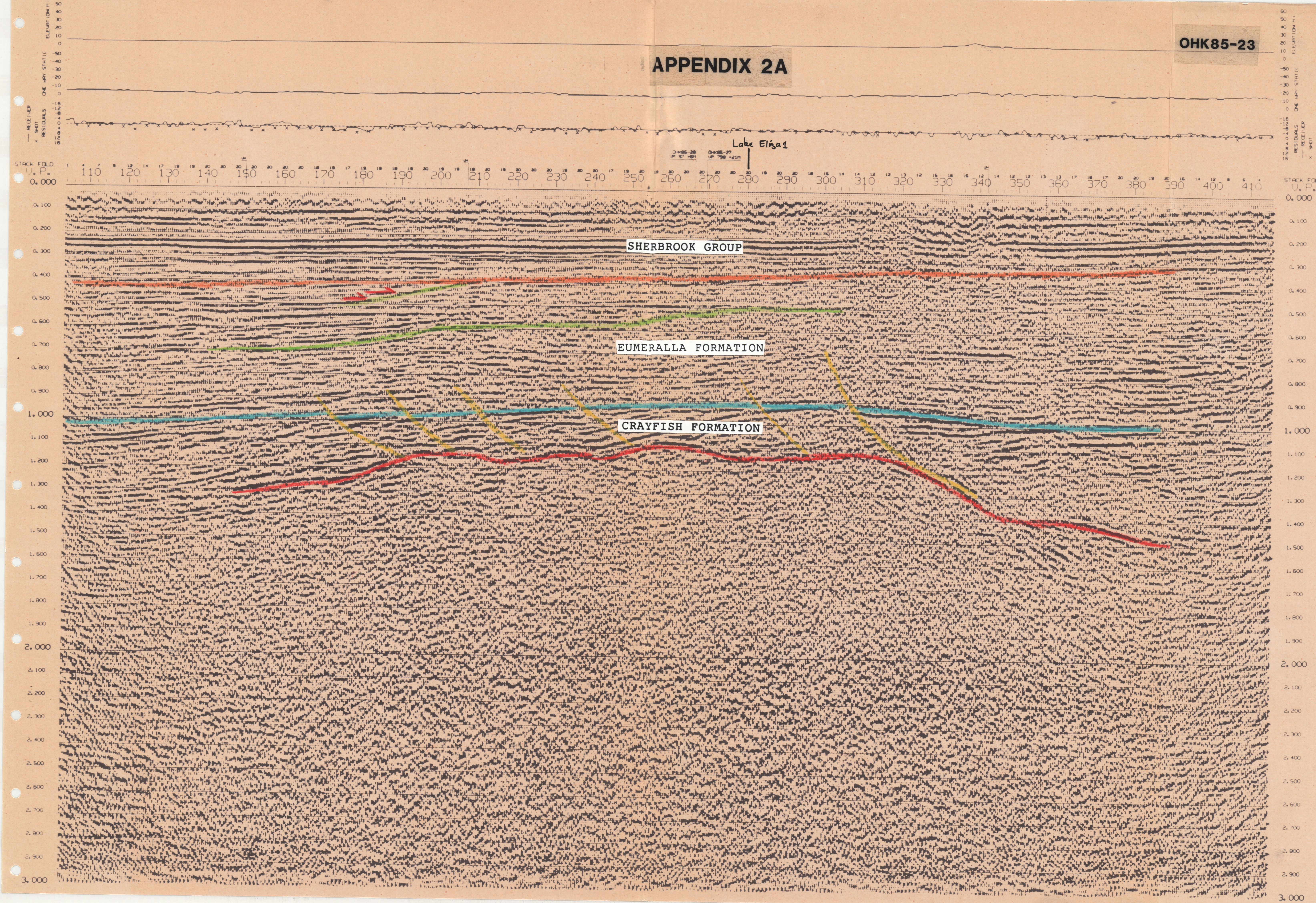
APPENDIX 2



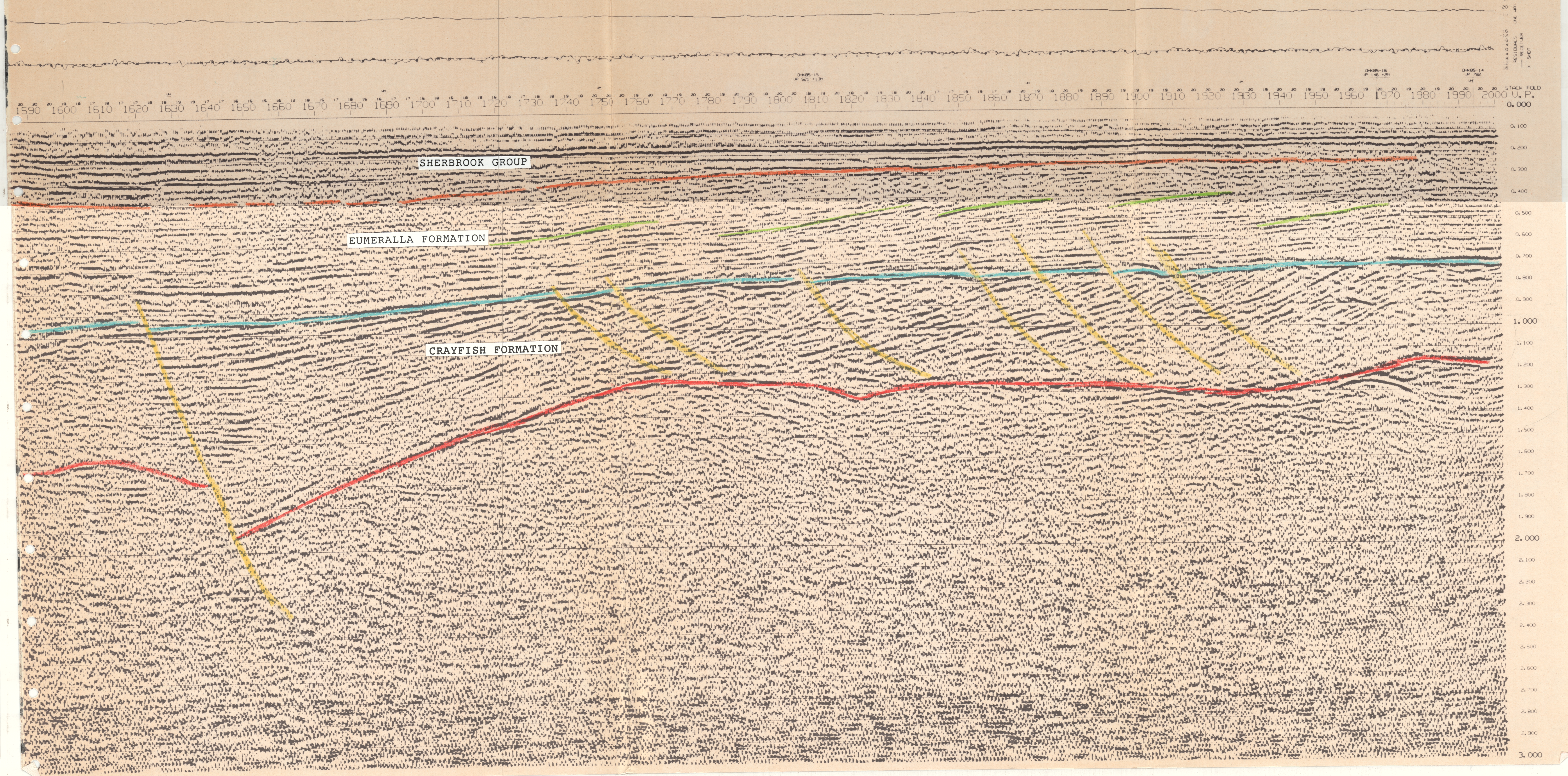
Seismic line locations

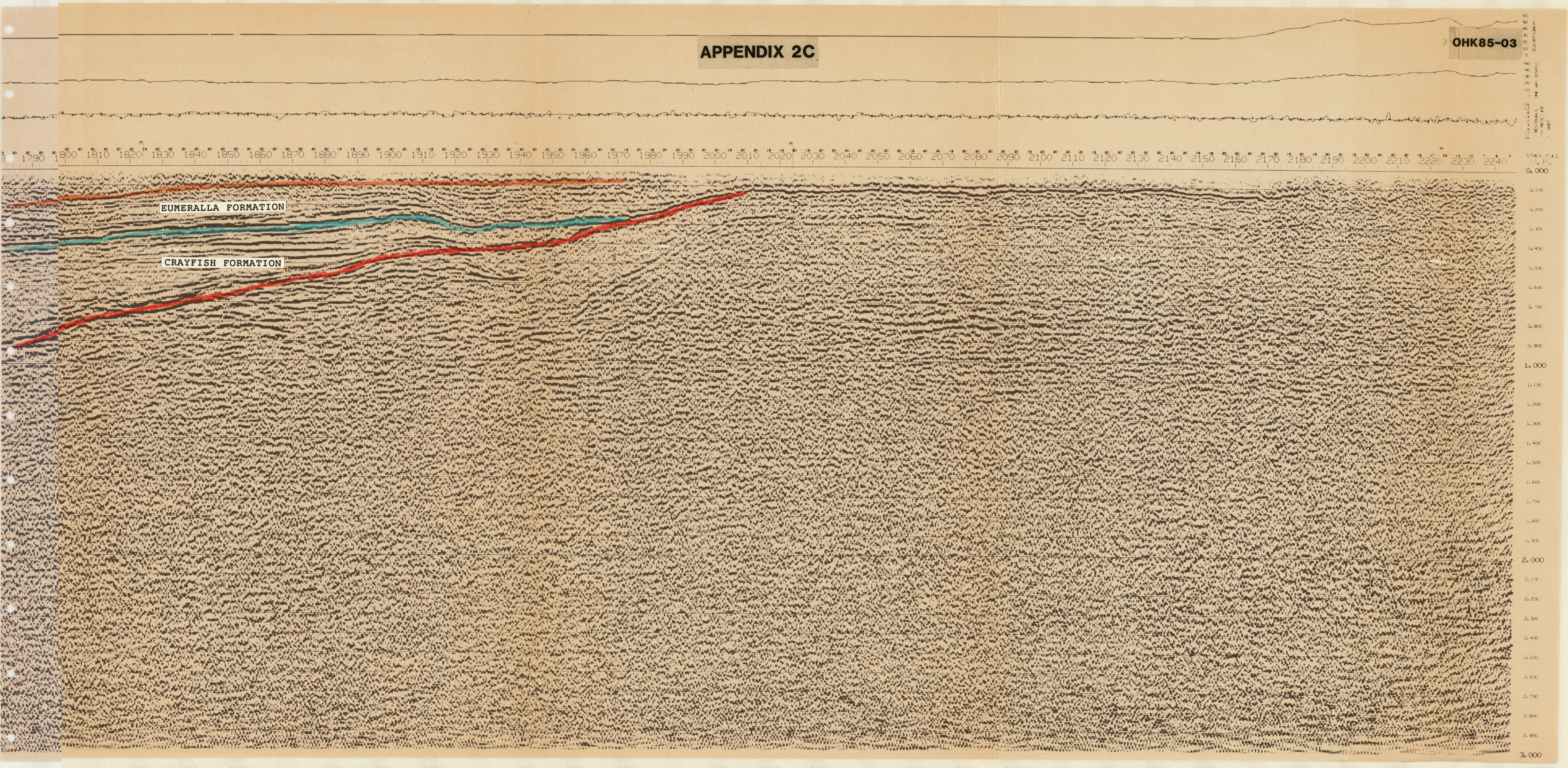
APPENDIX 2A

OHK85-23



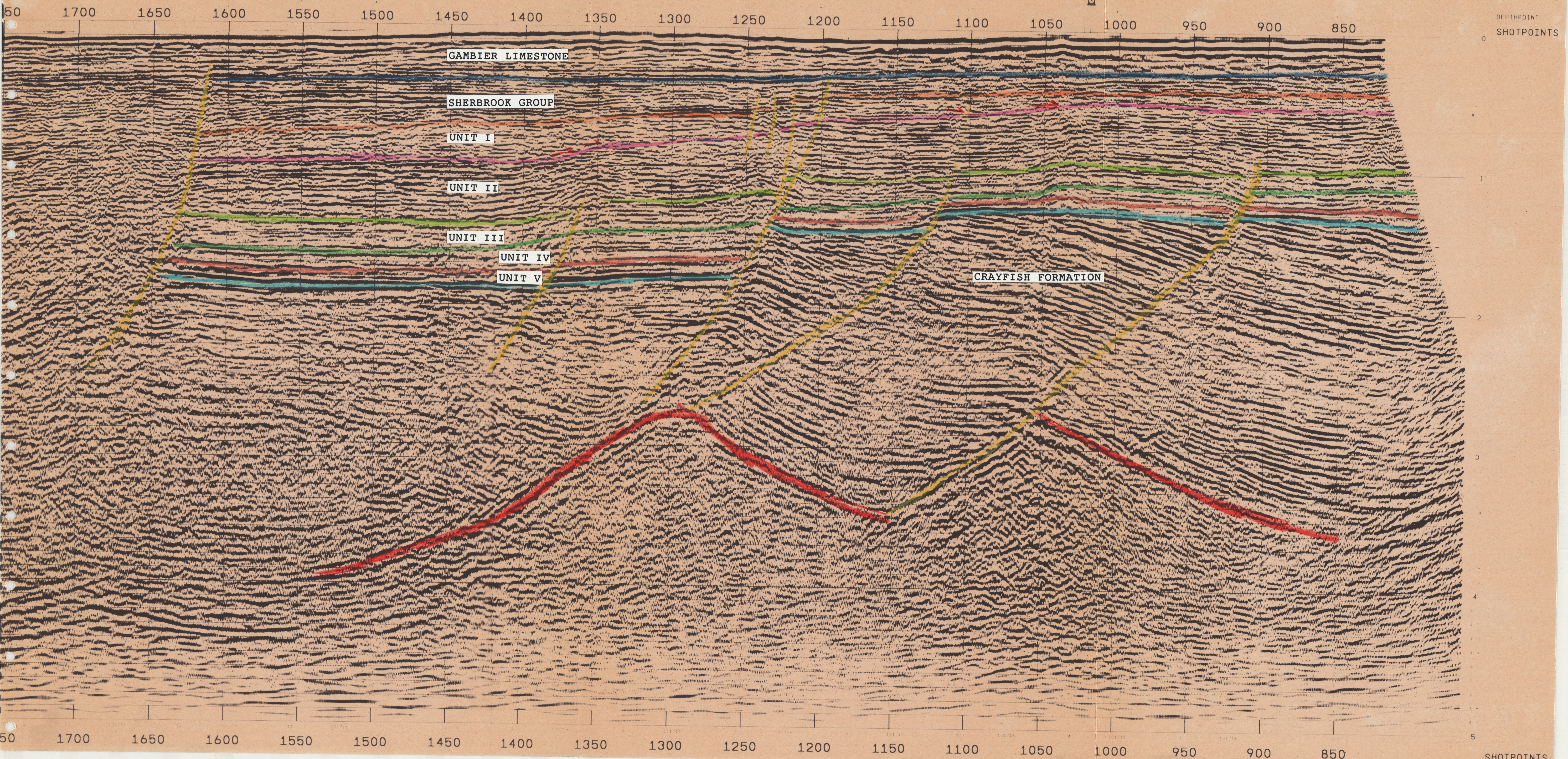
APPENDIX 2B


OHK85-04
SHERBROOK GROUP
EUMERALLA FORMATION
CRAYFISH FORMATION
S.P.
0.000
1.000
2.000
3.000


APPENDIX 2C
OHK85-03
EUMERALLA FORMATION
CRAYFISH FORMATION
0.000
1.000
2.000
3.000

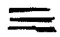
APPENDIX 2D

85-25

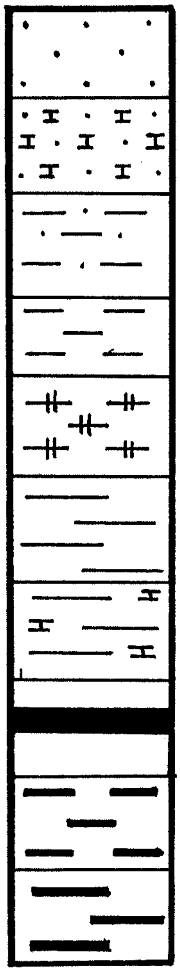


APPENDIX 3

Symbol information

Scour surface	
Micro faulting	
Slumps	
Ripples	
Iron staining	■
Flame structures	
Linsen bedding	
Granules	
Ripple cross laminations	
Climbing ripples	
Coaly detritus	
Mud rip–up clasts	
Trough cross bedding	
Hummocky cross stratification	
Planar bedding	
Planar cross bedding	
Bioturbation	

LITHOLOGY KEY



Sandstone

Calcareous sandstone

Sandy siltstone

Siltstone

Calcareous siltstone

Mudstone

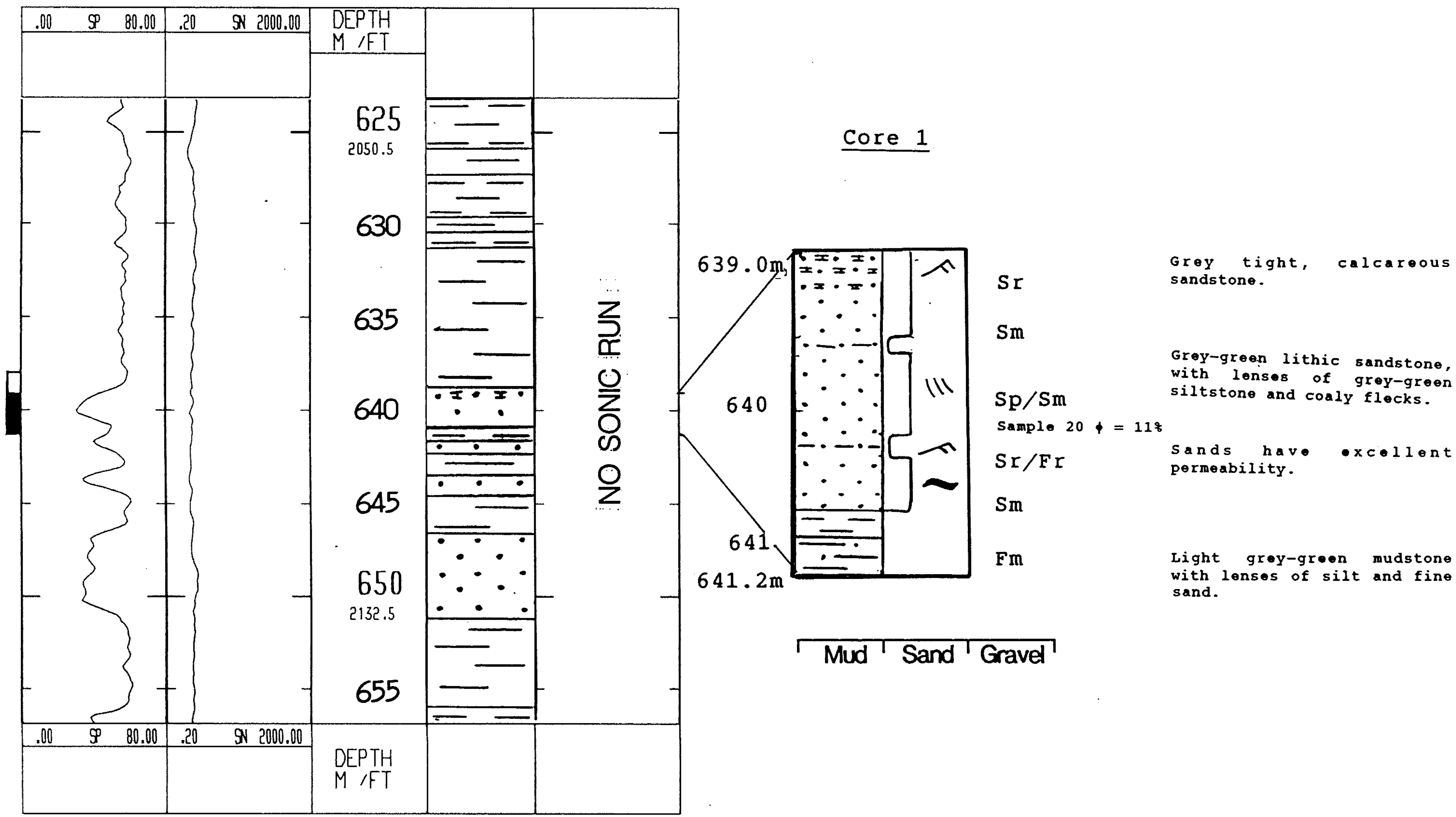
Calcareous mudstone

Coal

Organic rich siltstone

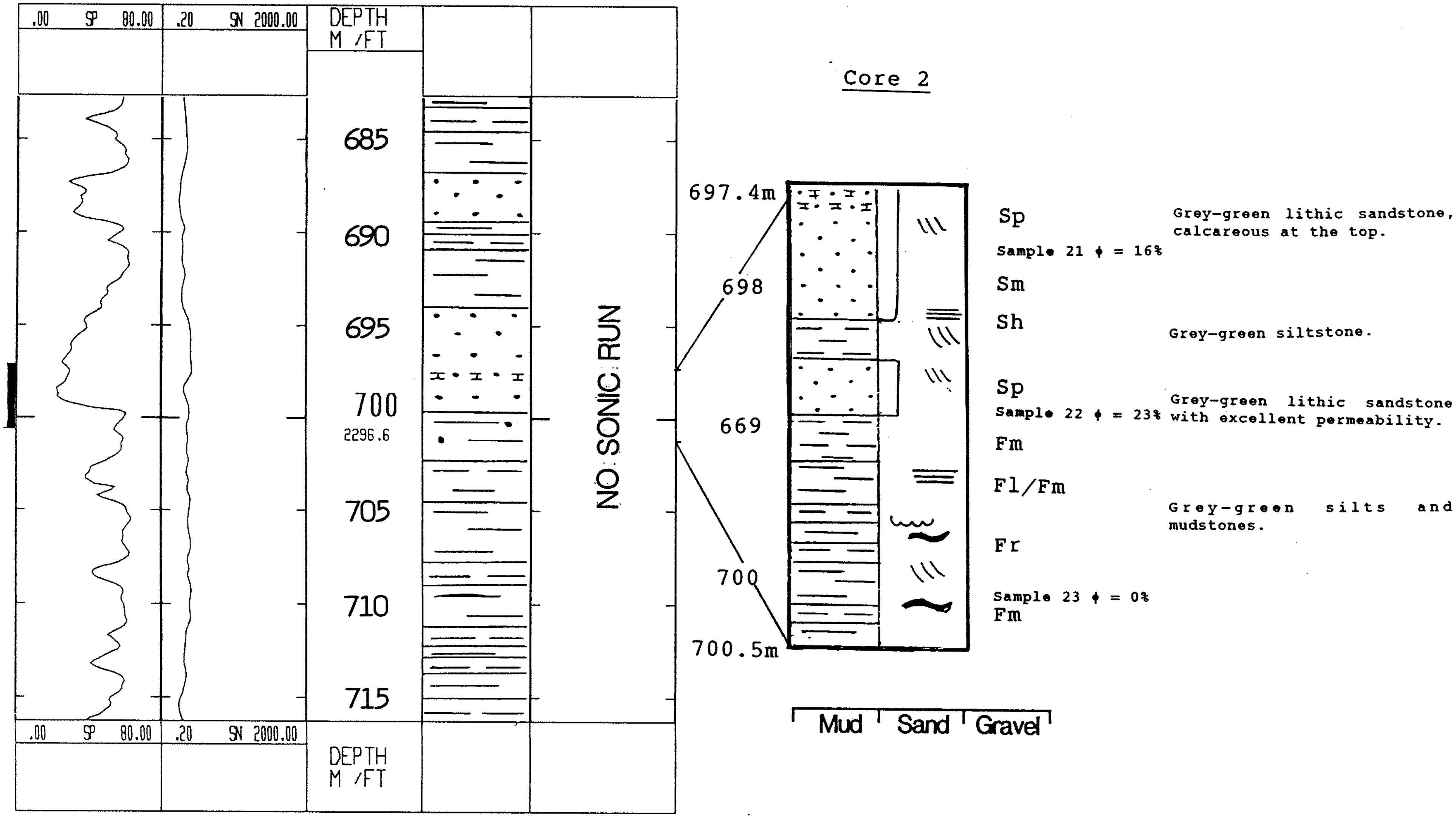
Organic rich mudstone

BEACHPORT 1

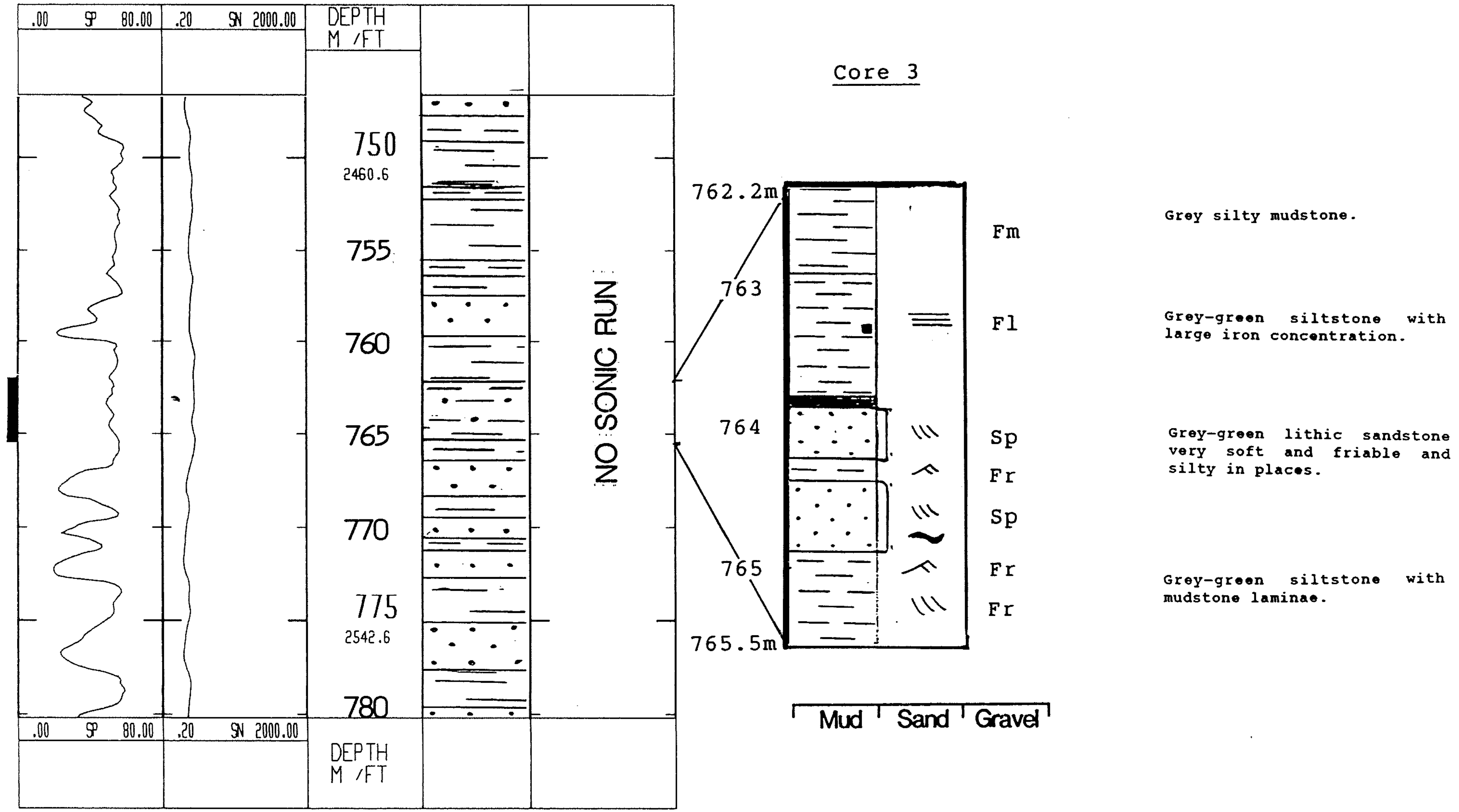


.00 SP 80.00
.20 SN 2000.00
DEPTH M /FT
625
2050.5
630
635
640
645
650
2132.5
655
NO SONIC RUN
Core 1
639.0m
640
641
641.2m
Sr
Sm
Sp/Sm
Sample 20 ϕ = 11%
Sr/Fr
Sm
Fm
Grey tight, calcareous sandstone.
Grey-green lithic sandstone, with lenses of grey-green siltstone and coaly flecks.
Sands have excellent permeability.
Light grey-green mudstone with lenses of silt and fine sand.
Mud
Sand
Gravel

BEACHPORT 1

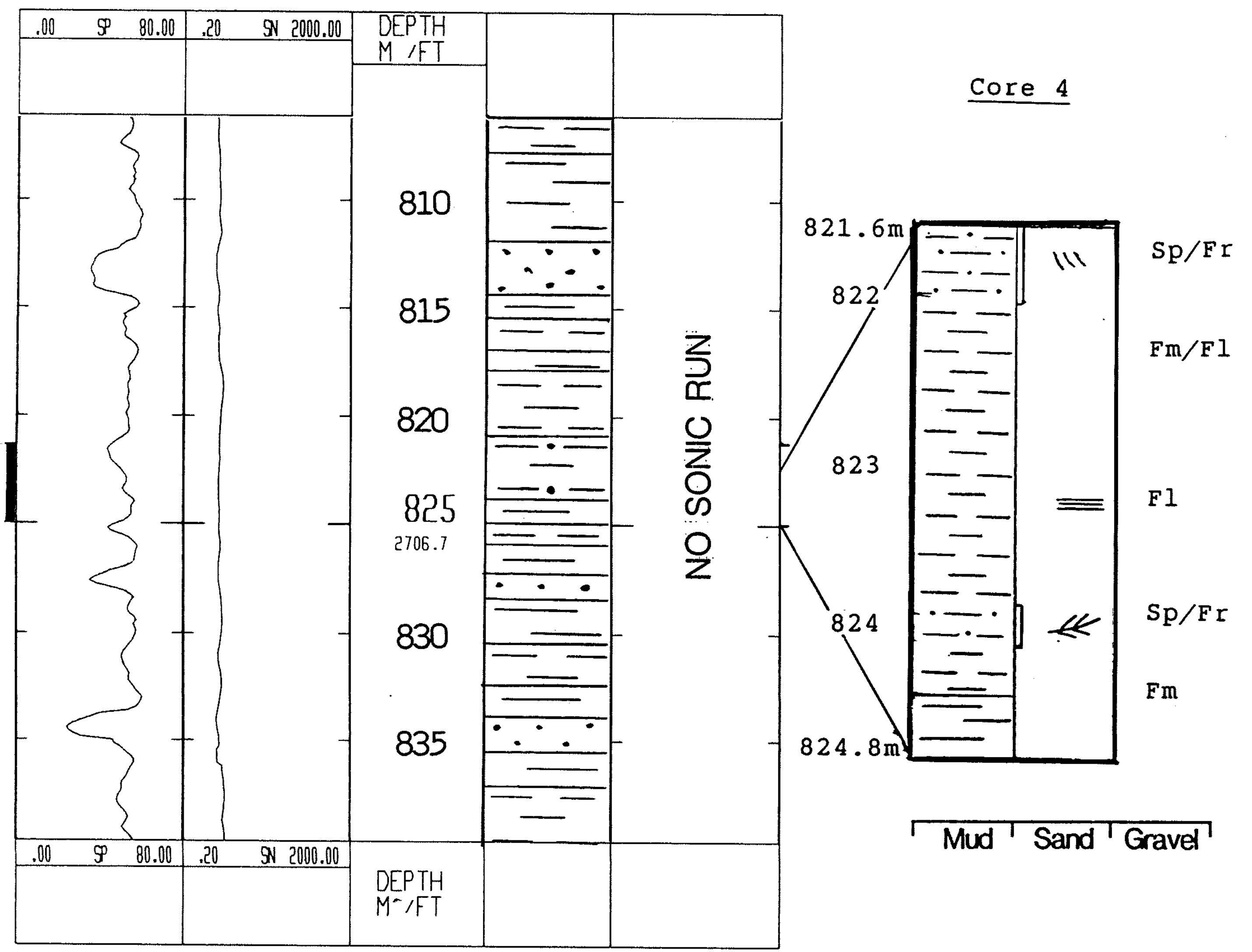

.00 SP 80.00
.20 SN 2000.00
DEPTH M /FT
685
690
695
700
2296.6
705
710
715
NO SONIC RUN
Core 2
697.4m
698
669
700
700.5m
Sp
Sample 21 ϕ = 16%
Sm
Sh
Sp
Sample 22 ϕ = 23%
Fm
Fl/Fm
Fr
Sample 23 ϕ = 0%
Fm
Grey-green lithic sandstone, calcareous at the top.
Grey-green siltstone.
Grey-green lithic sandstone with excellent permeability.
Grey-green silts and mudstones.
Mud
Sand
Gravel

BEACHPORT 1



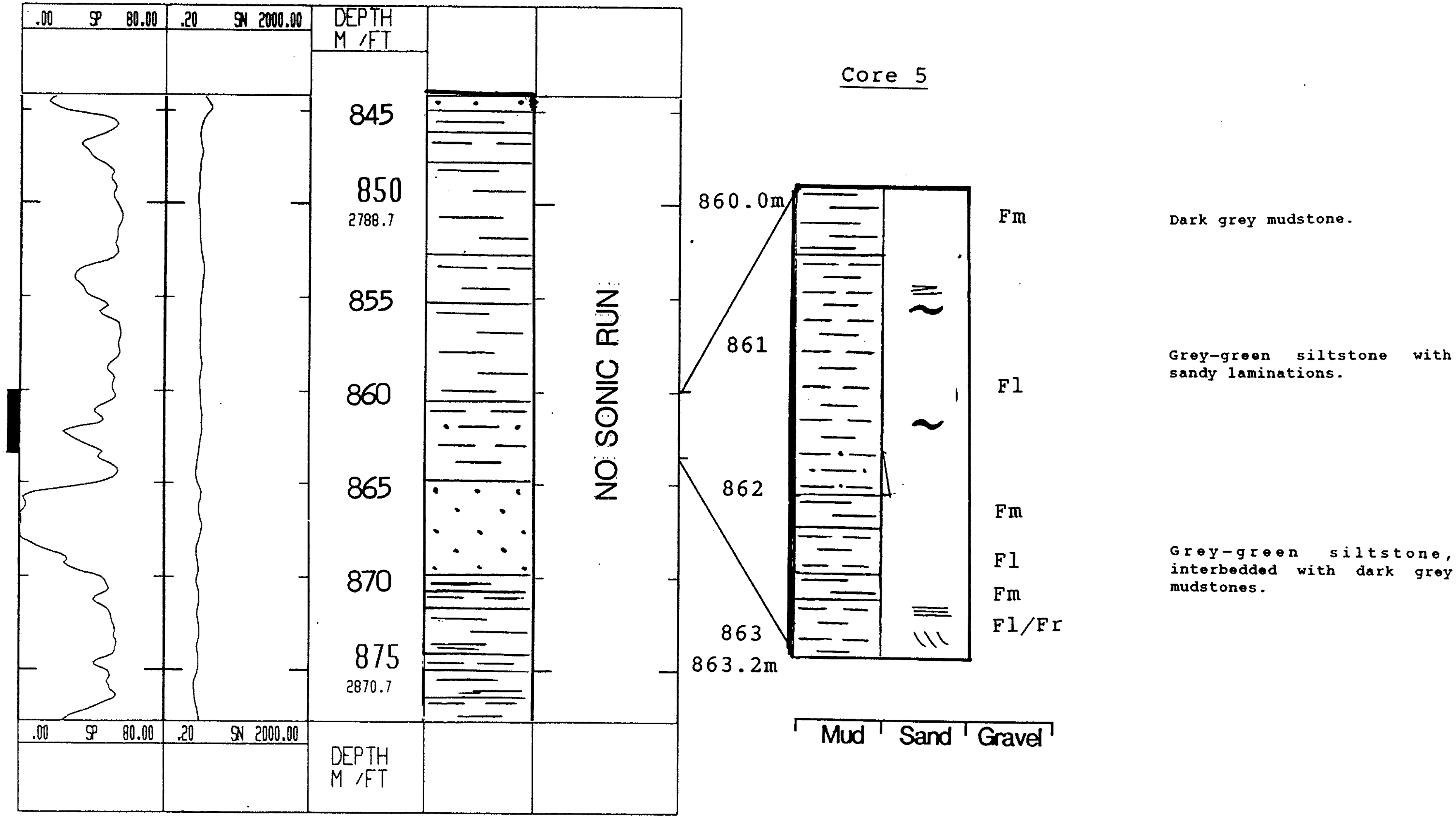
.00 SP 80.00
.20 SN 2000.00
DEPTH M /FT
750
2460.6
755
760
765
770
775
2542.6
780
NO SONIC RUN
Core 3
762.2m
763
764
765
765.5m
Fm
Fl
Sp
Fr
Sp
Fr
Fr
Mud
Sand
Gravel
Grey silty mudstone.
Grey-green siltstone with large iron concentration.
Grey-green lithic sandstone very soft and friable and silty in places.
Grey-green siltstone with mudstone laminae.

BEACHPORT 1



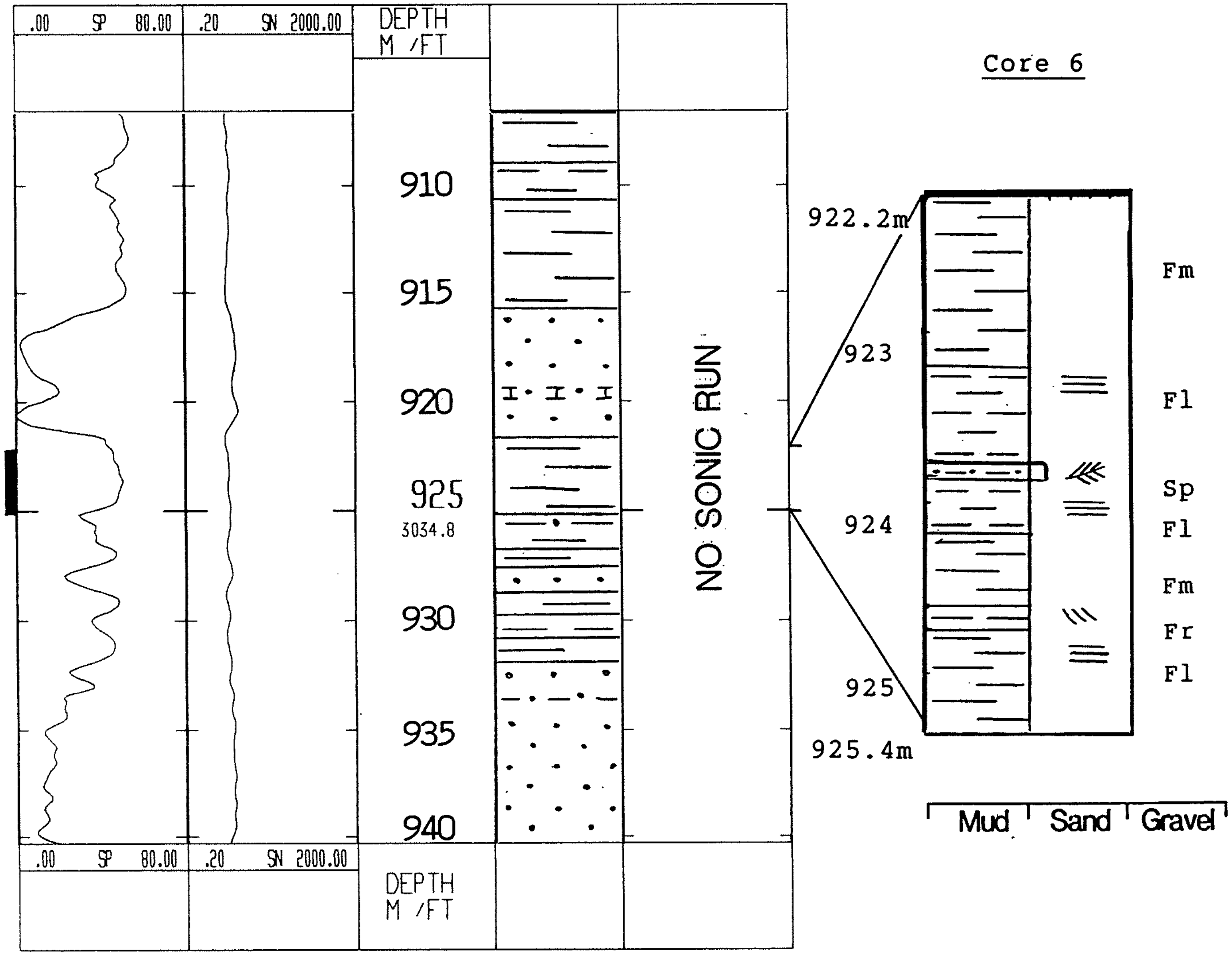
Grey-green siltstone with minor mudstone and fine sand interbeds.

BEACHPORT 1



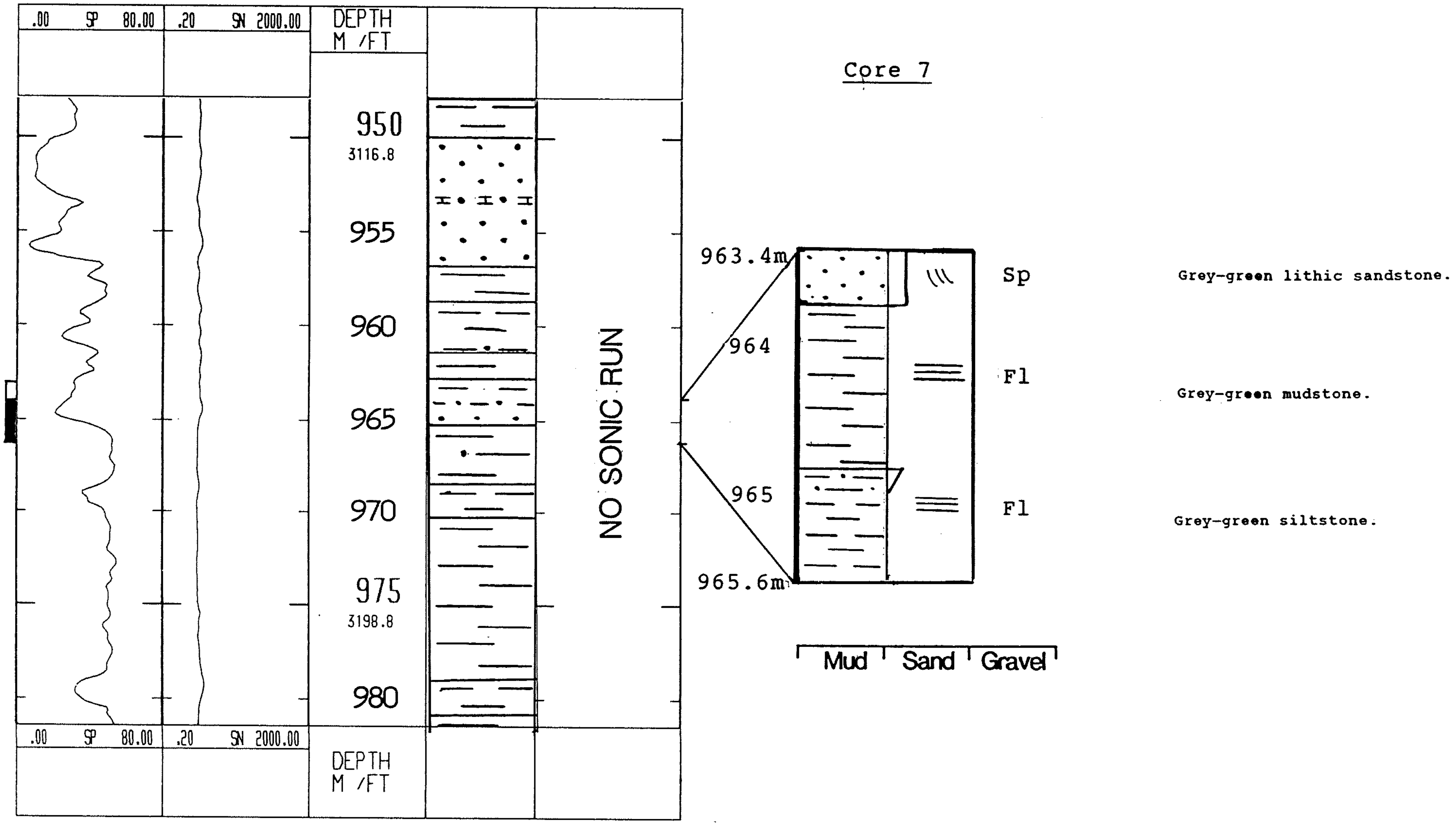
.00 SP 80.00
.20 SN 2000.00
DEPTH M /FT
845
850
2788.7
855
860
865
870
875
2870.7
NO SONIC RUN
Core 5
860.0m
861
862
863
863.2m
Fm
Fl
Fm
Fl
Fm
Fl/Fr
Mud
Sand
Gravel
Dark grey mudstone.
Grey-green siltstone with sandy laminations.
Grey-green siltstone, interbedded with dark grey mudstones.

BEACHPORT 1



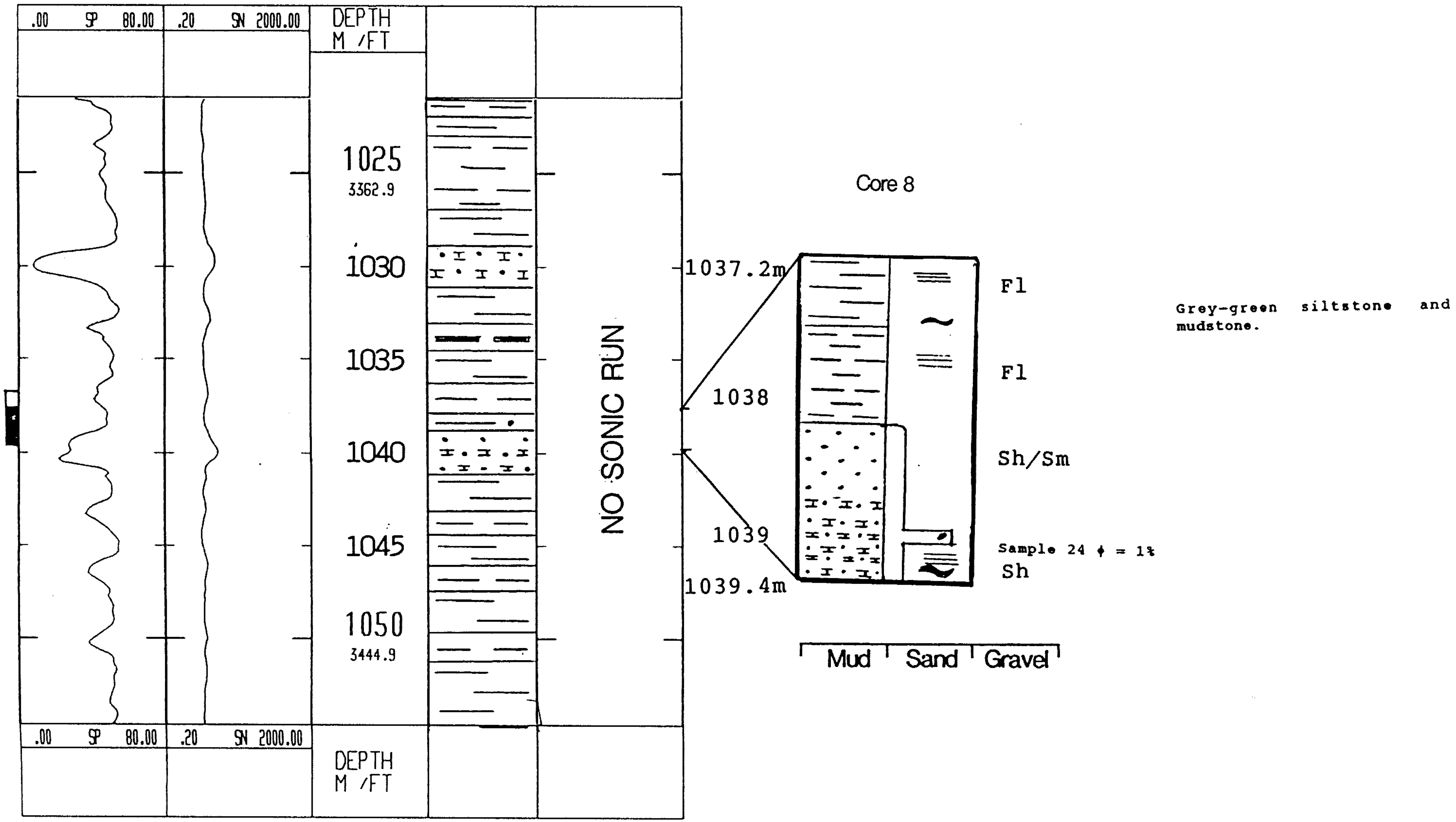
Grey-green siltstones and mudstones.

BEACHPORT 1



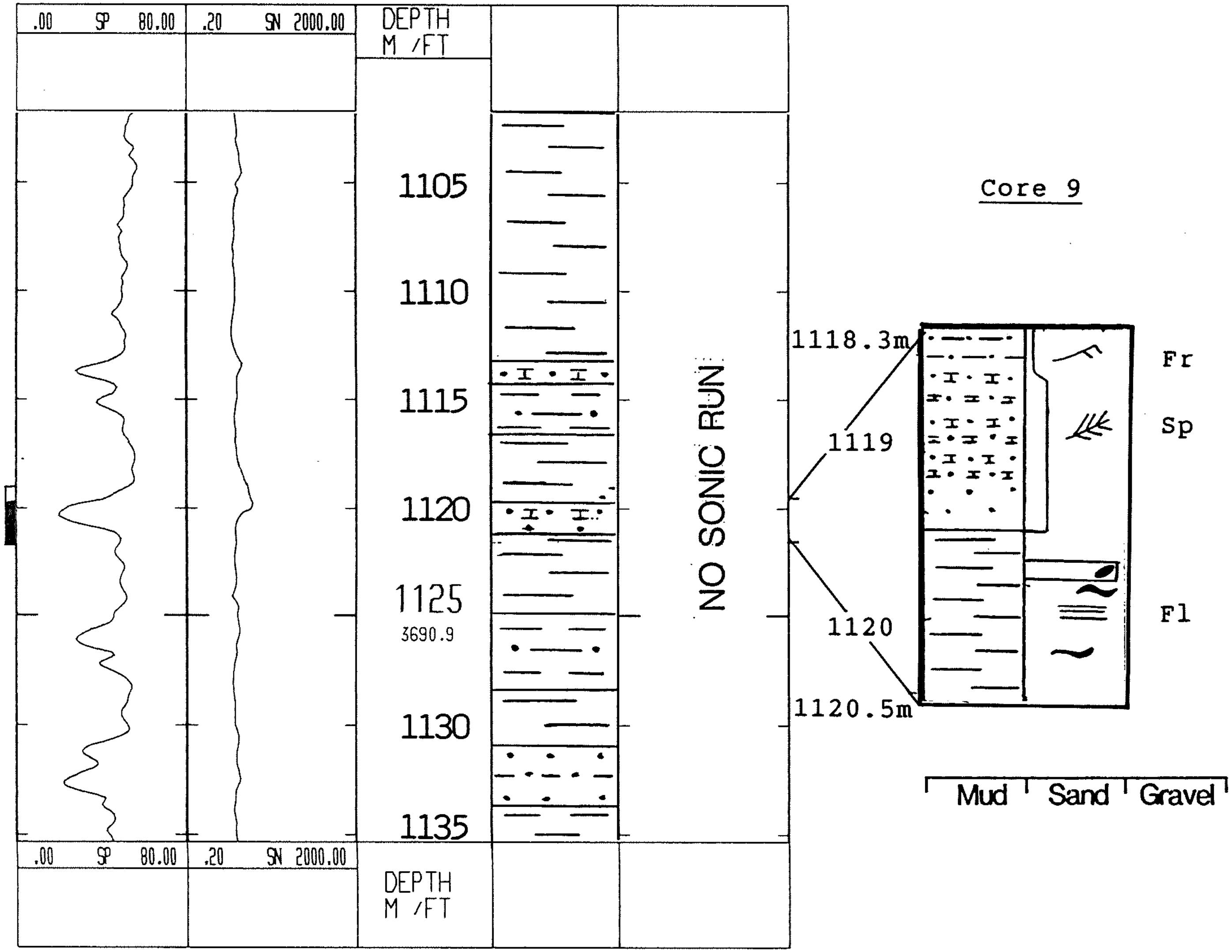
.00 SP 80.00
.20 SN 2000.00
DEPTH M /FT
950
3116.8
955
960
965
970
975
3198.8
980
NO SONIC RUN
Core 7
963.4m
964
965
965.6m
Sp
Fl
Fl
Mud
Sand
Gravel
Grey-green lithic sandstone.
Grey-green mudstone.
Grey-green siltstone.

BEACHPORT 1



.00 SP 80.00
.20 SN 2000.00
DEPTH M /FT
1025
3362.9
1030
1035
1040
1045
1050
3444.9
NO SONIC RUN
1037.2m
1038
1039
1039.4m
Core 8
Fl
Fl
Sh/Sm
Sample 24 ϕ = 1%
Sh
Mud
Sand
Gravel
Grey-green siltstone and mudstone.

BEACHPORT 1

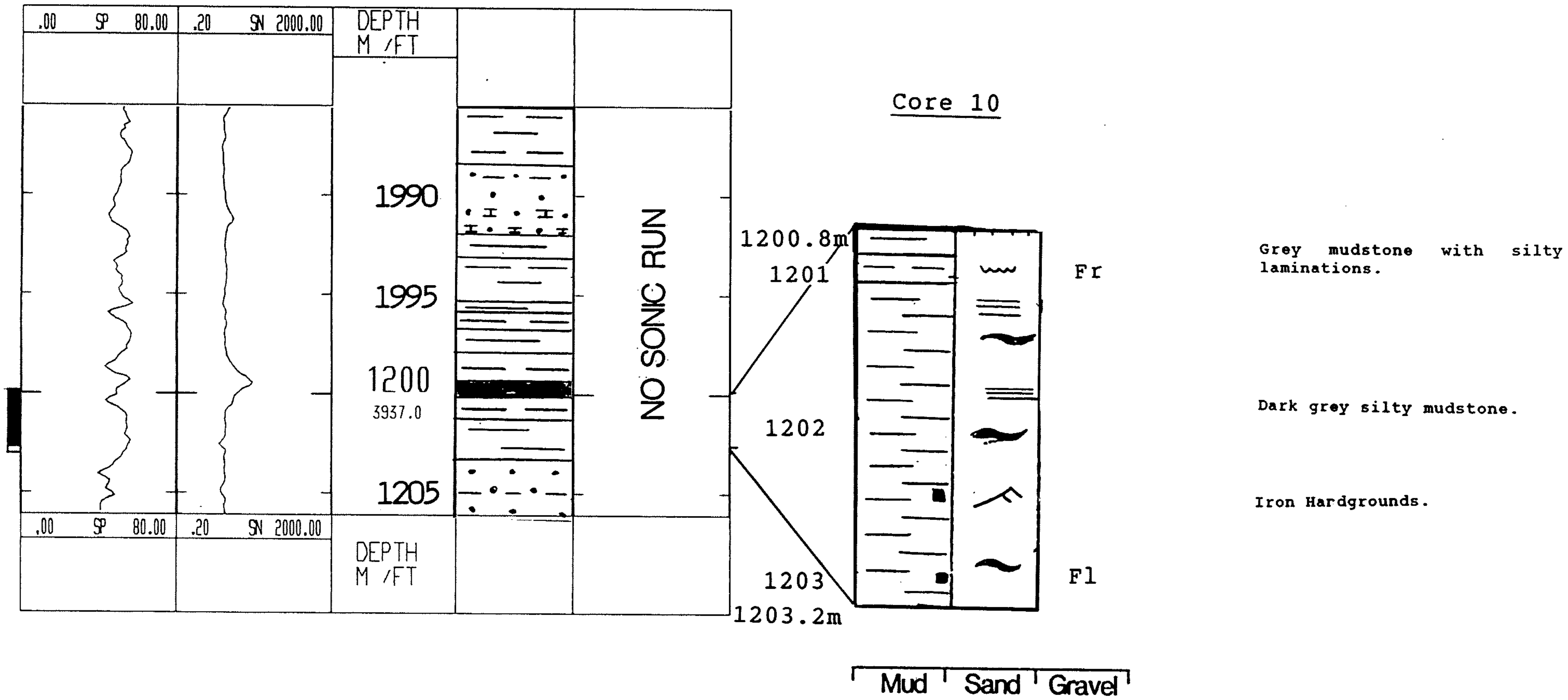


Grey siltstone.

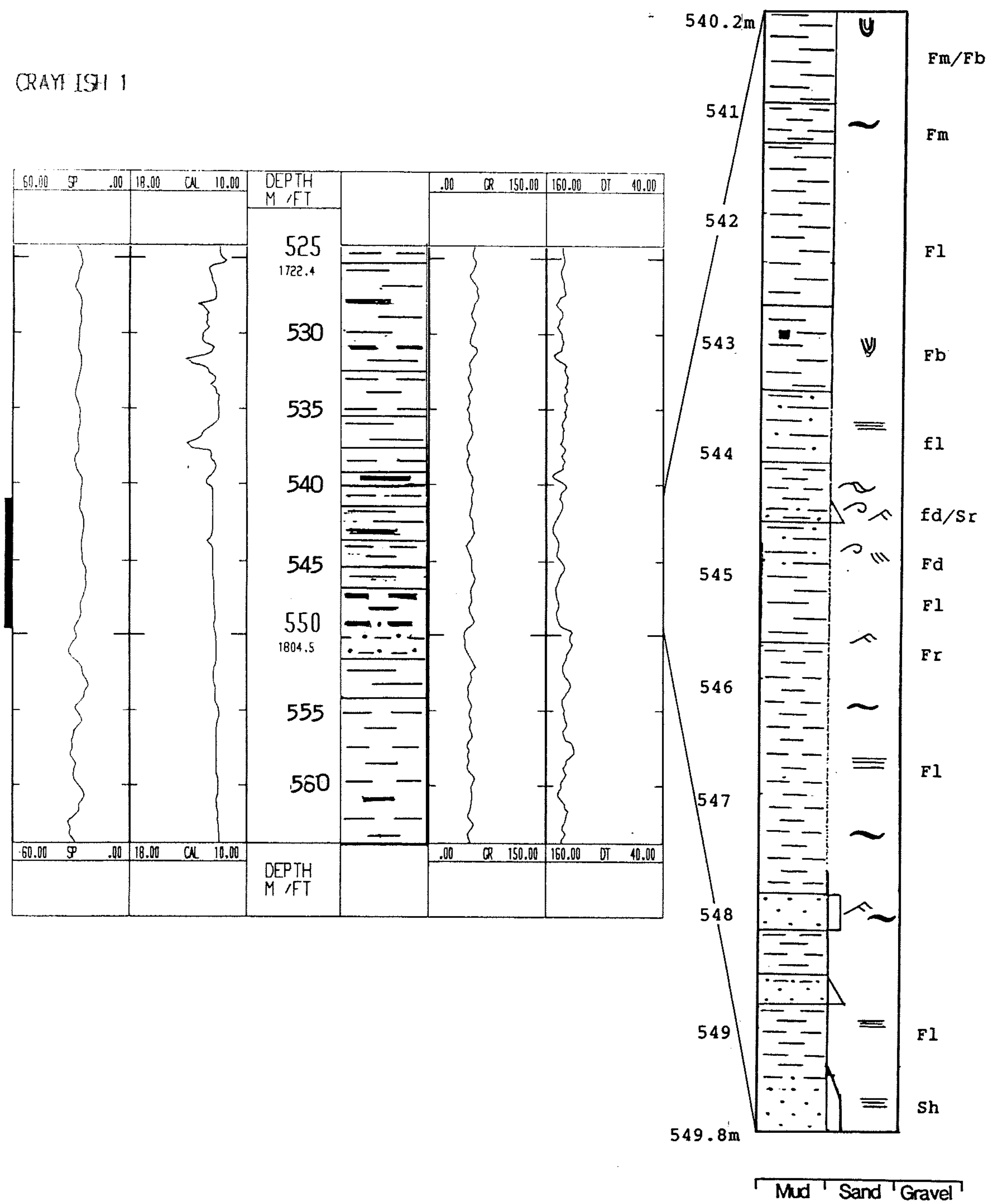
Light grey sandstone, dominantly calcareous.

Grey mudstone, with abundant carbonaceous material.

BEACHPORT 1


.00 SP 80.00
.20 SN 2000.00
DEPTH M /FT
1990
1995
1200
3937.0
1205
NO SONIC RUN
Core 10
1200.8m
1201
1202
1203
1203.2m
Fr
Fl
Mud
Sand
Gravel
Grey mudstone with silty laminations.
Dark grey silty mudstone.
Iron Hardgrounds.

Core 3

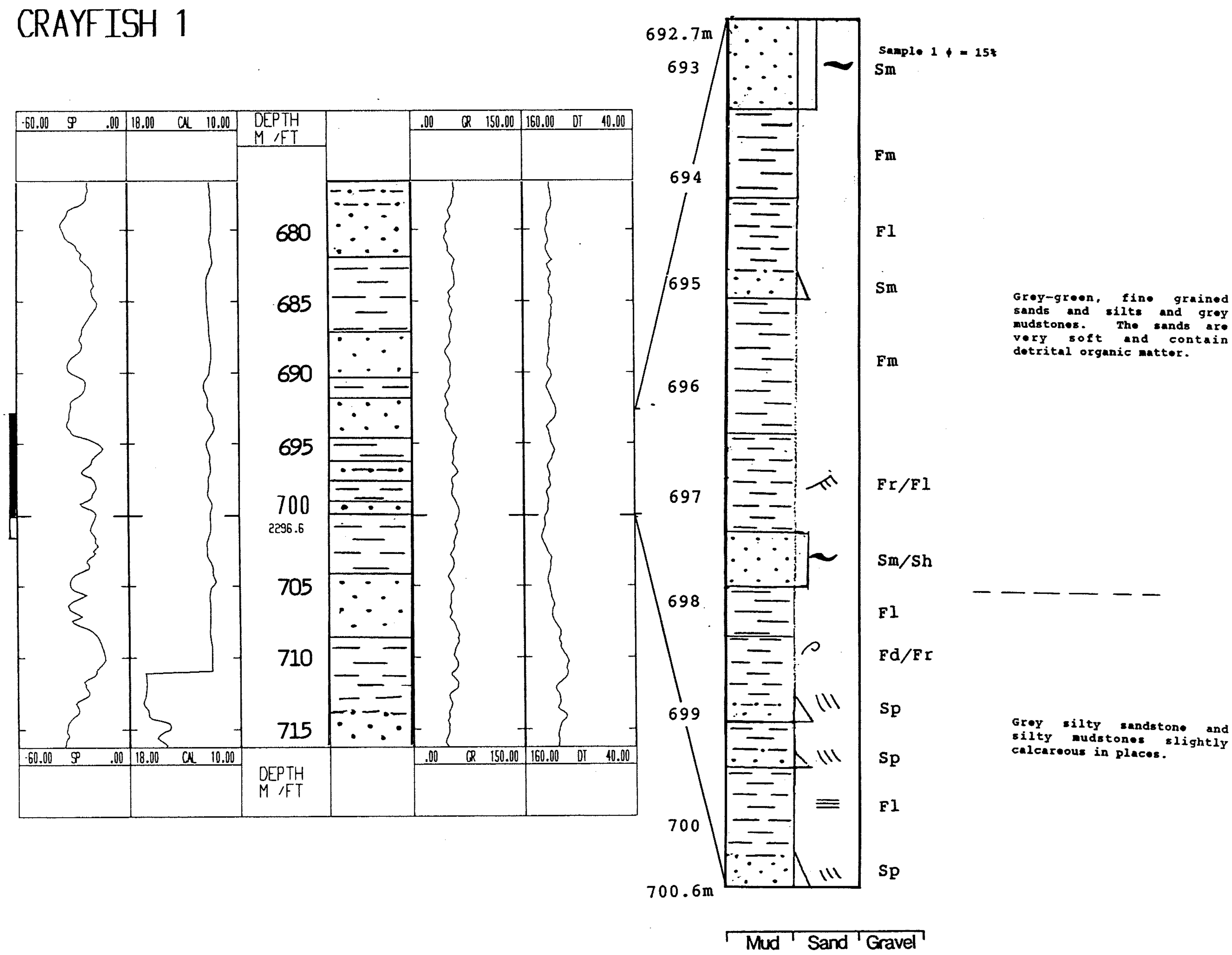


Grey silty mudstone with some bioturbation and iron staining.

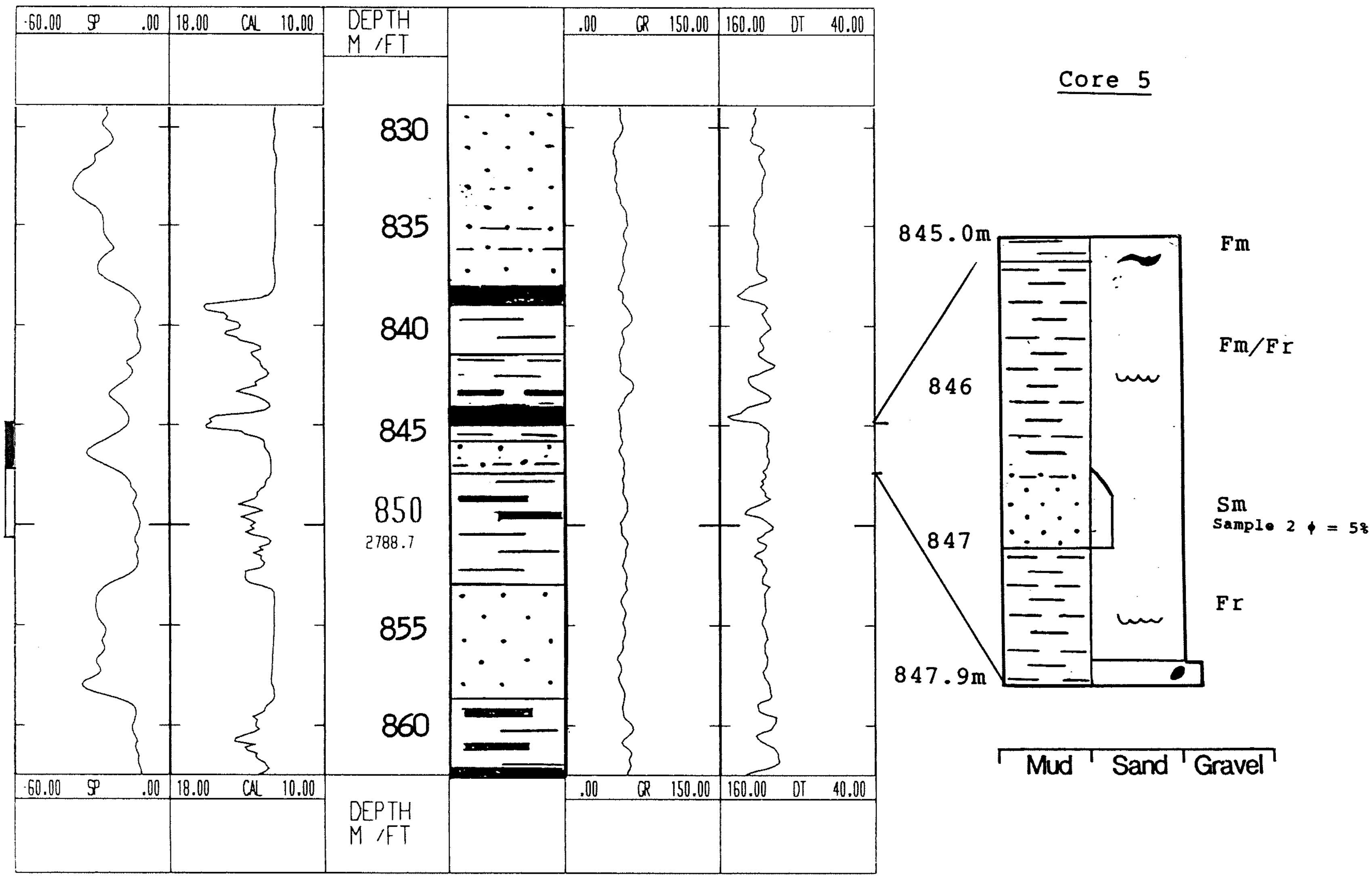
Hummocky cross-stratification

Grey-green silts and fine grained sandstone with abundant carbonaceous detritus.

Core 4

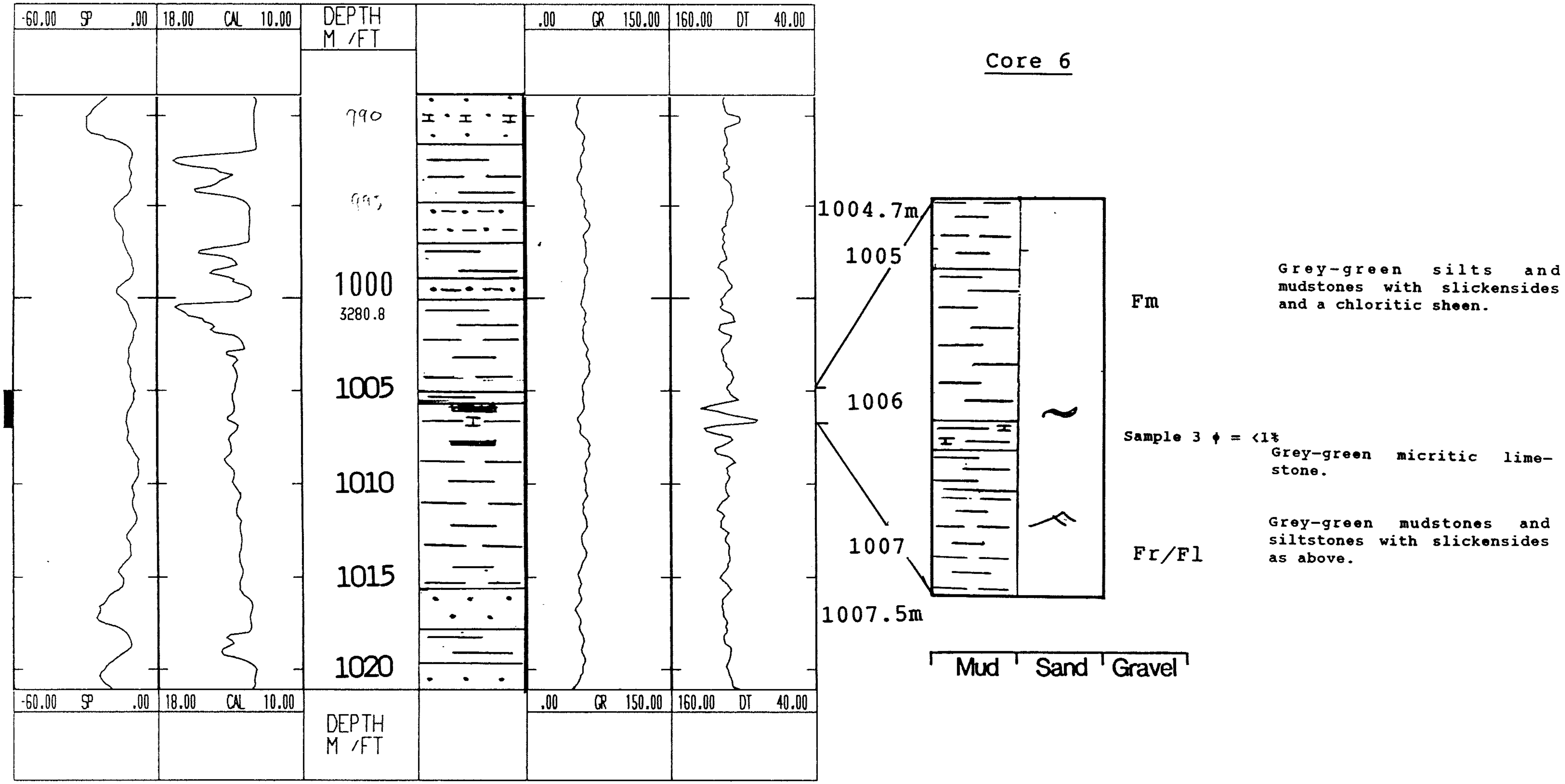

CRAYFISH 1
-60.00 SP .00
18.00 CAL 10.00
DEPTH M /FT
680
685
690
695
700
2296.6
705
710
715
.00 GR 150.00
160.00 DT 40.00
692.7m
693
694
695
696
697
698
699
700
700.6m
Sample 1 ϕ = 15%
Sm
Fm
Fl
Sm
Fm
Fr/Fl
Sm/Sh
Fl
Fd/Fr
Sp
Sp
Fl
Sp
Mud
Sand
Gravel
Grey-green, fine grained sands and silts and grey mudstones. The sands are very soft and contain detrital organic matter.
Grey silty sandstone and silty mudstones slightly calcareous in places.

CRAYFISH 1



Green-grey sandstone with grey mudstones and silts. The sampled sand has good permeability.

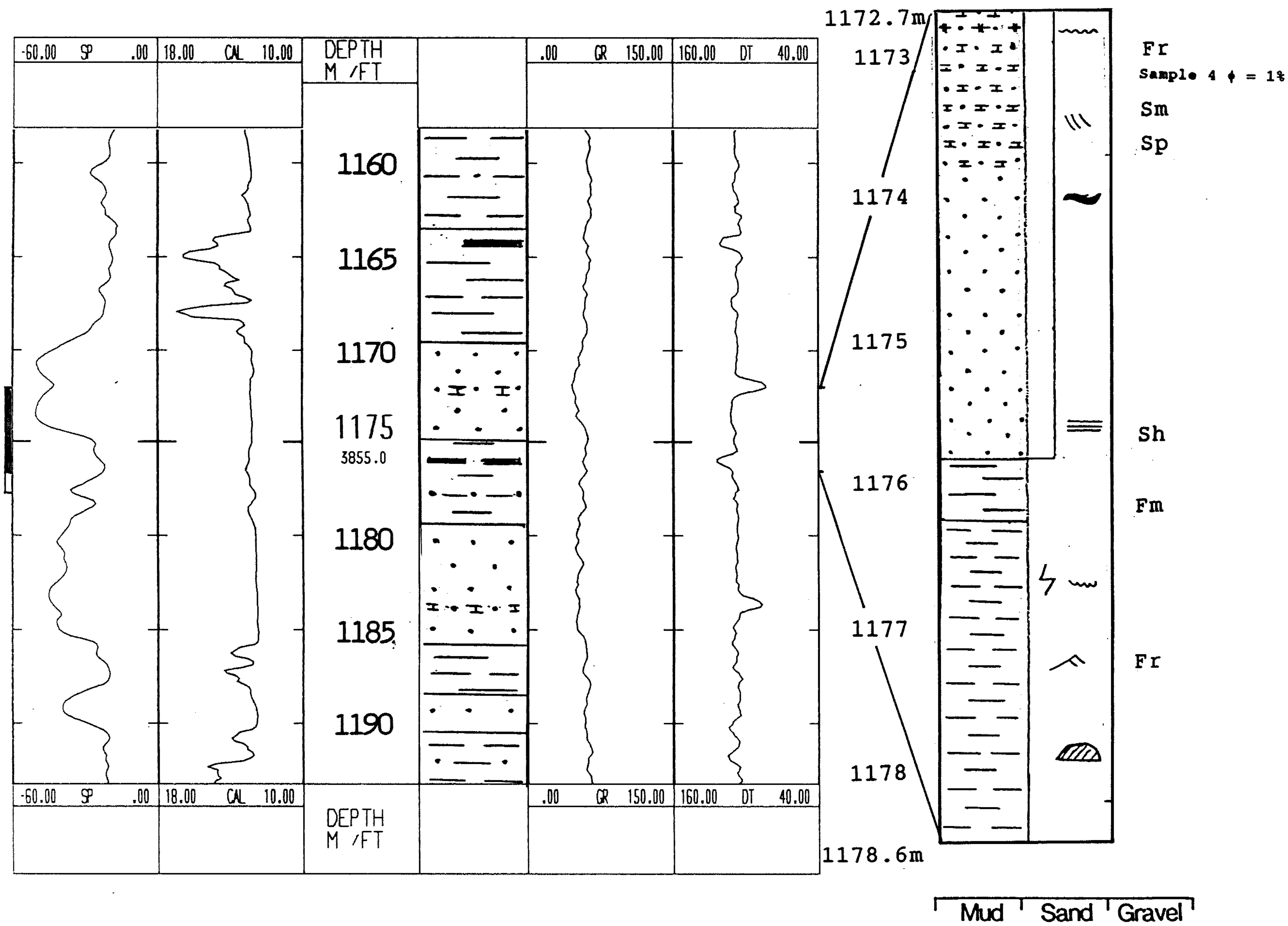
CRAYFISH 1



-60.00 SP .00
18.00 CAL 10.00
DEPTH M /FT
.00 GR 150.00
160.00 DT 40.00
990
995
1000
3280.8
1005
1010
1015
1020
Core 6
1004.7m
1005
1006
1007
1007.5m
Mud
Sand
Gravel
Fm
Grey-green silts and mudstones with slickensides and a chloritic sheen.
Sample 3 ϕ = <1%
Grey-green micritic limestone.
Fr/Fl
Grey-green mudstones and siltstones with slickensides as above.

CRAYFISH 1

Core 8

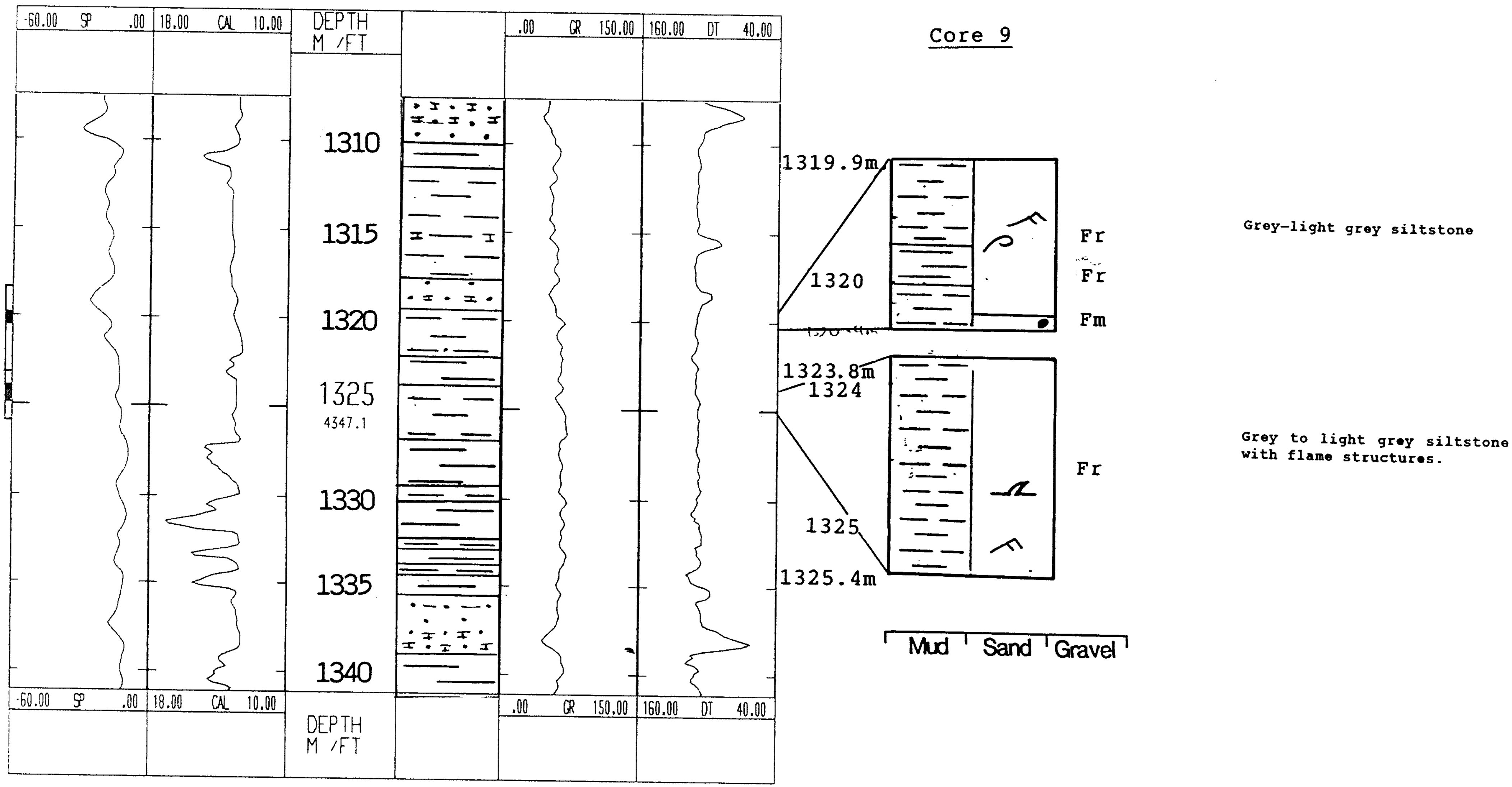


Light grey sandstone calcareous at the top. The permeability is poor in the cemented sands.

Dark grey massive mudstone.

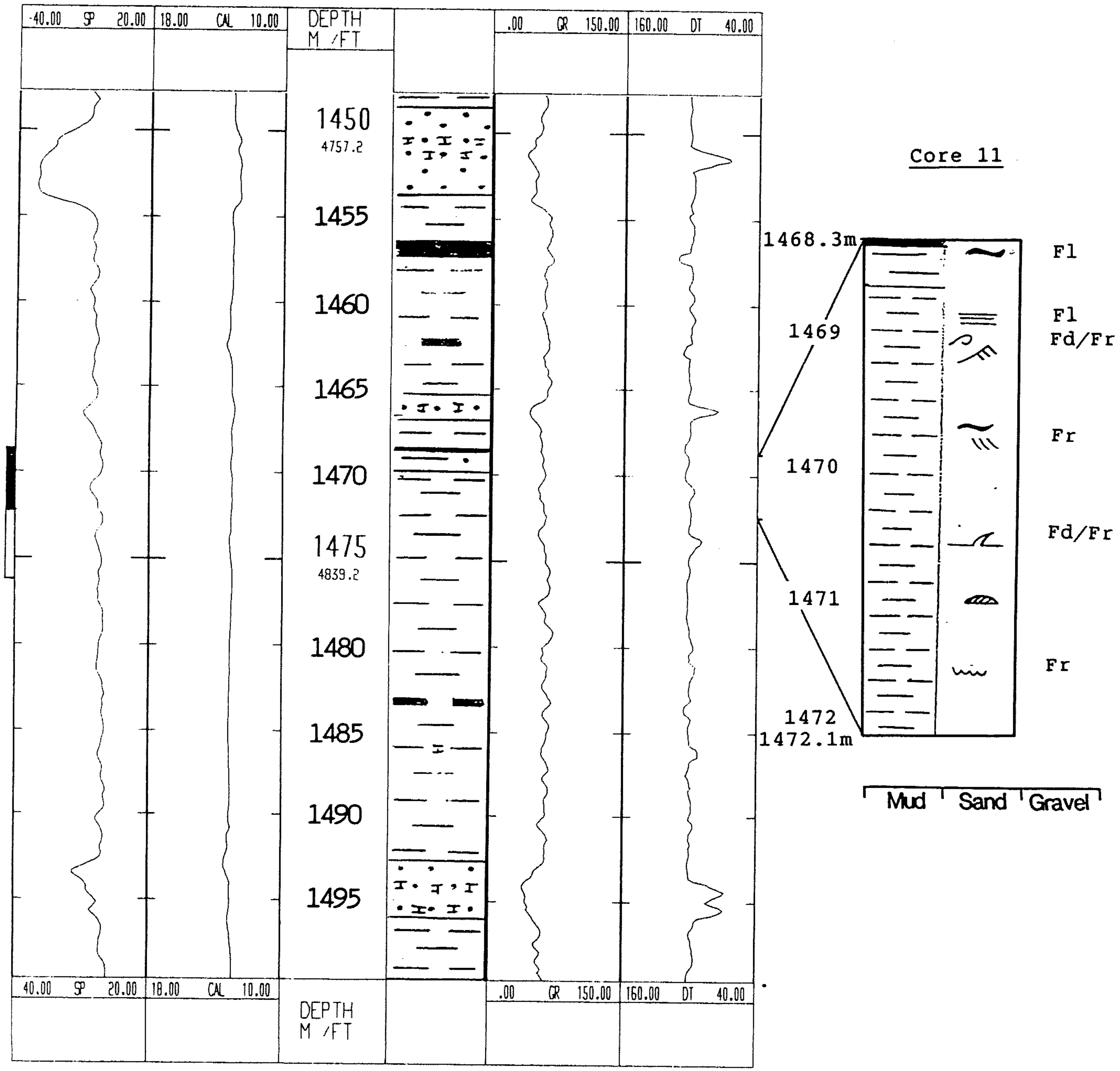
Grey siltstone with many fine sand interbeds and abundant sedimentary structures.

CRAYFISH 1



-60.00 SP .00
18.00 CAL 10.00
DEPTH M /FT
1310
1315
1320
1325
4347.1
1330
1335
1340
.00 GR 150.00
160.00 DT 40.00
Core 9
1319.9m
1320
1323.8m
1324
1325
1325.4m
Fr
Fr
Fm
Fr
Mud
Sand
Gravel
Grey-light grey siltstone
Grey to light grey siltstone with flame structures.

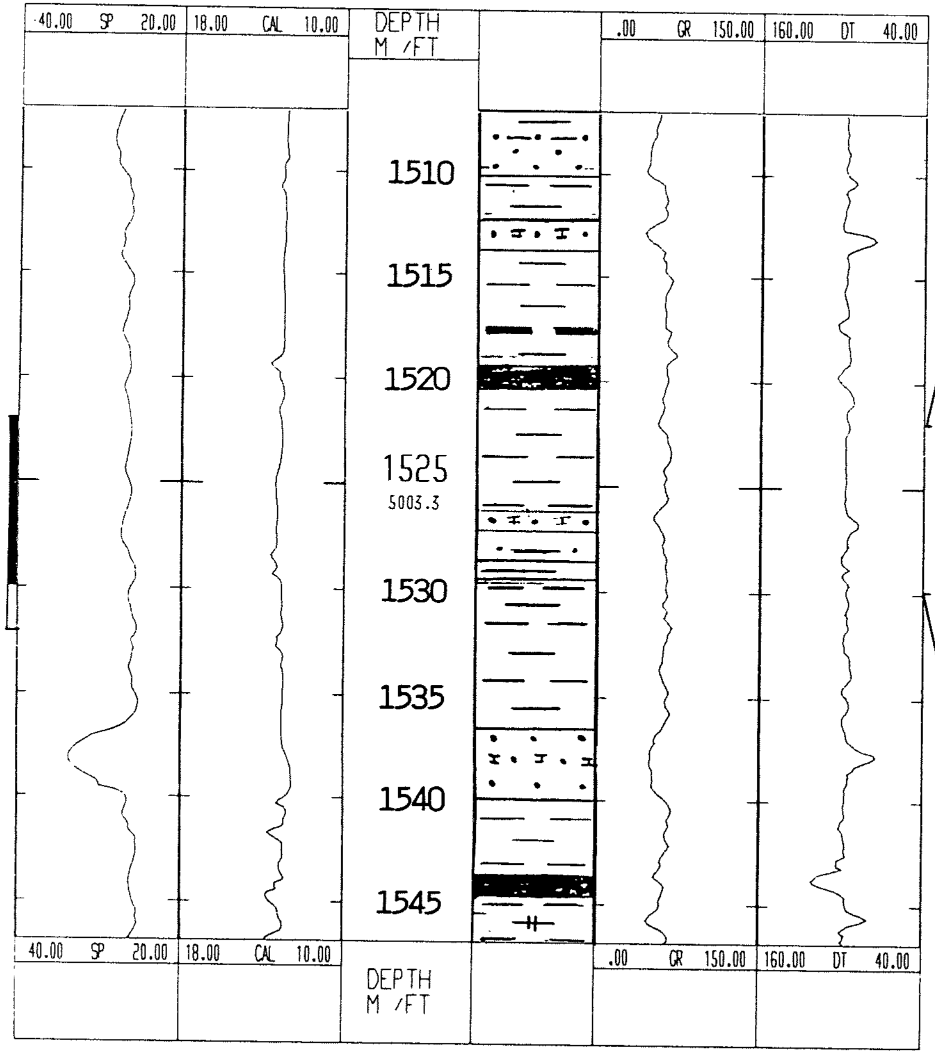
CRAYFISH 1

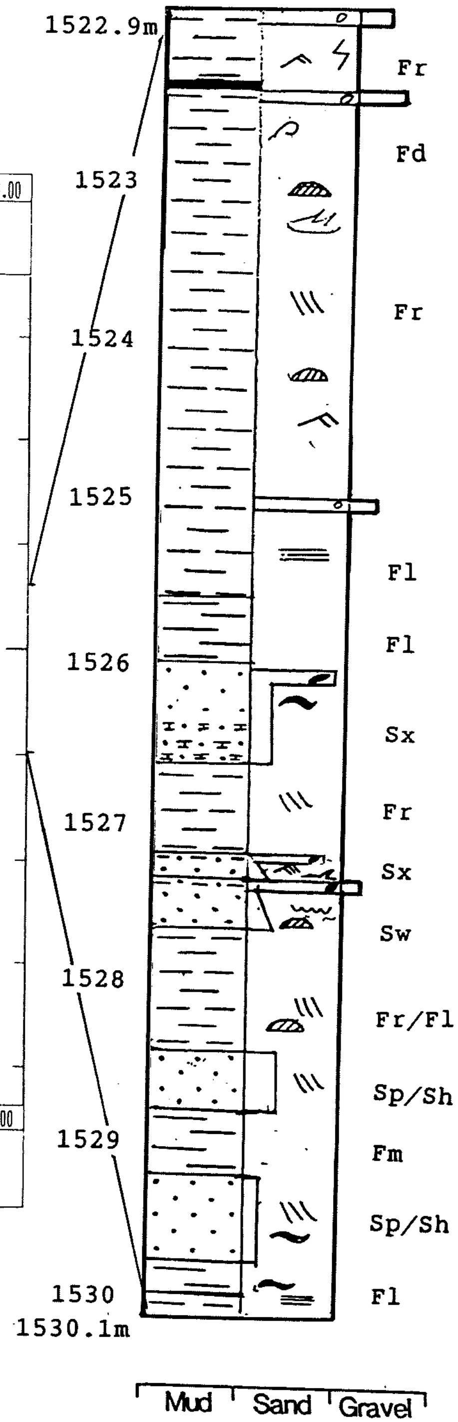


Dark brown coal and dark grey mudstones.

Grey silts interbedded with darker mudstones. Silts show evidence of a turbid environment.

CRAYFISH 1





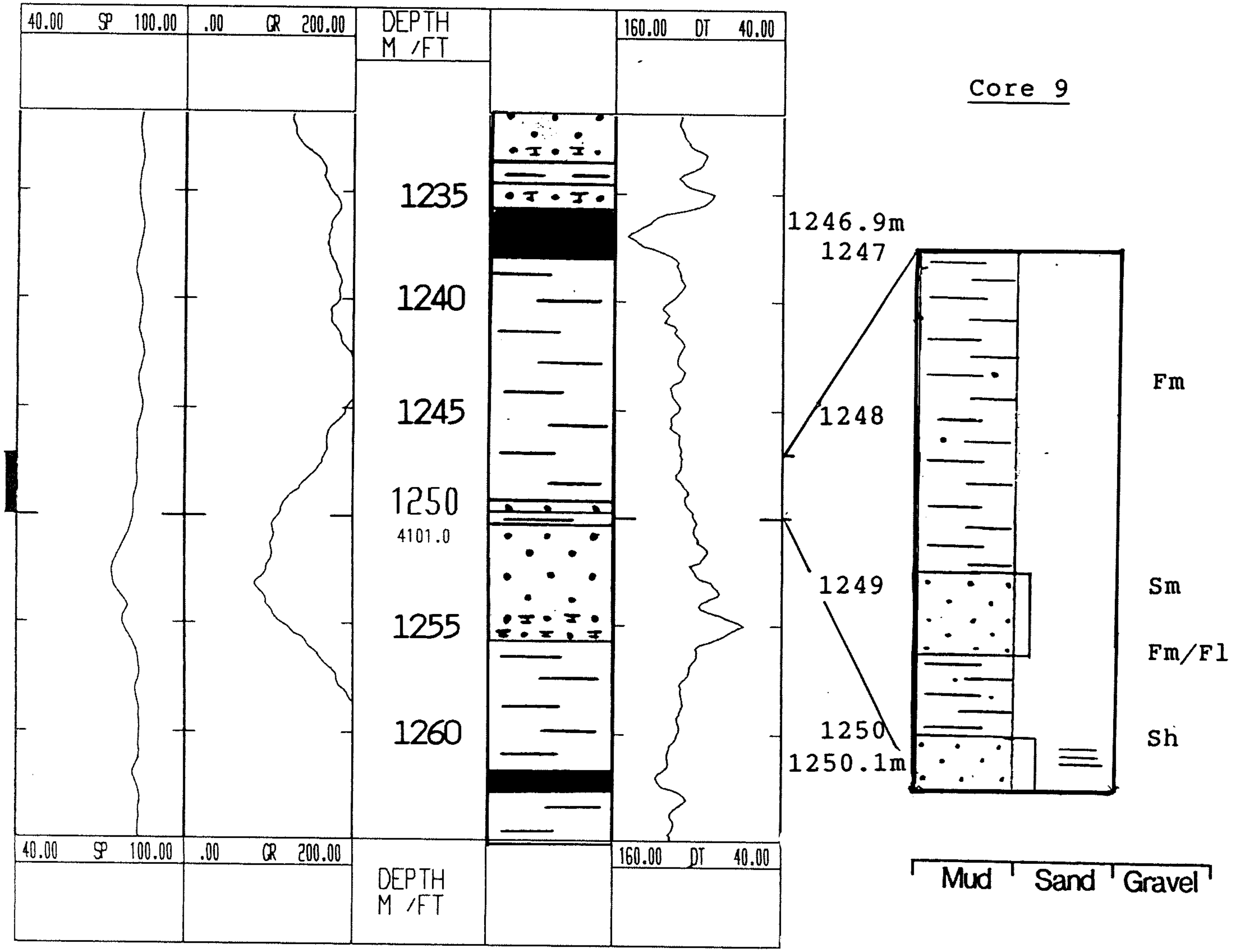
Coarse grained quartz granules within grey siltstone. Coal seam is black and hard with conchoidal fracture.

Light grey sandstone, becoming calcareous towards the bottom, and associated with loss of permeability.

Light grey carbonaceous sandstones and siltstones, sandstones have average to poor permeability.

Dark grey mudstone with conchoidal fracture.

GELTWOOD BEACH 1

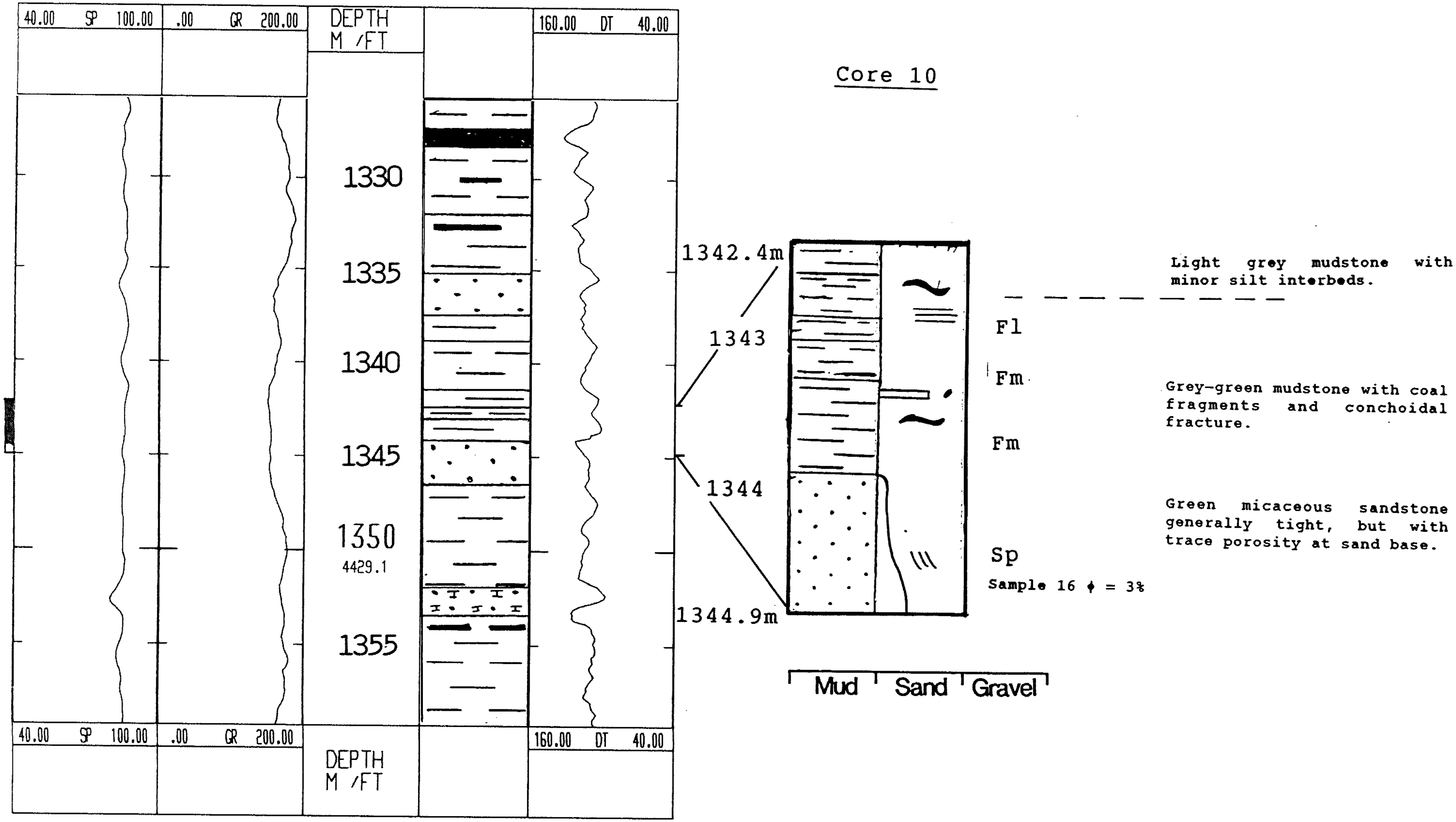


Grey-green mudstone, (bright green when wet) with minor silty interbeds.

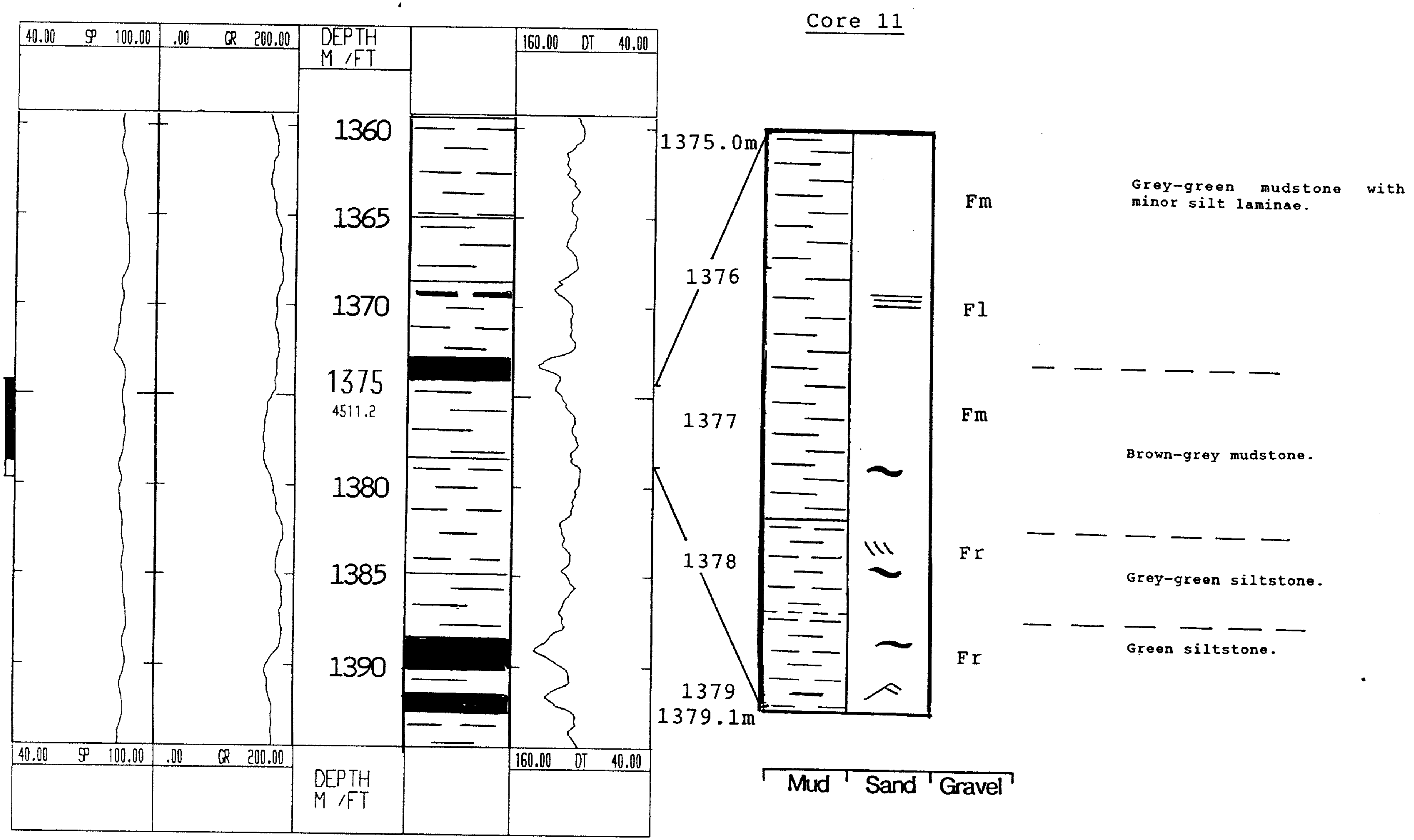
Green lithic sandstone with reasonable sorting and traces of porosity.

Grey-grey sandstone, very soft and friable.

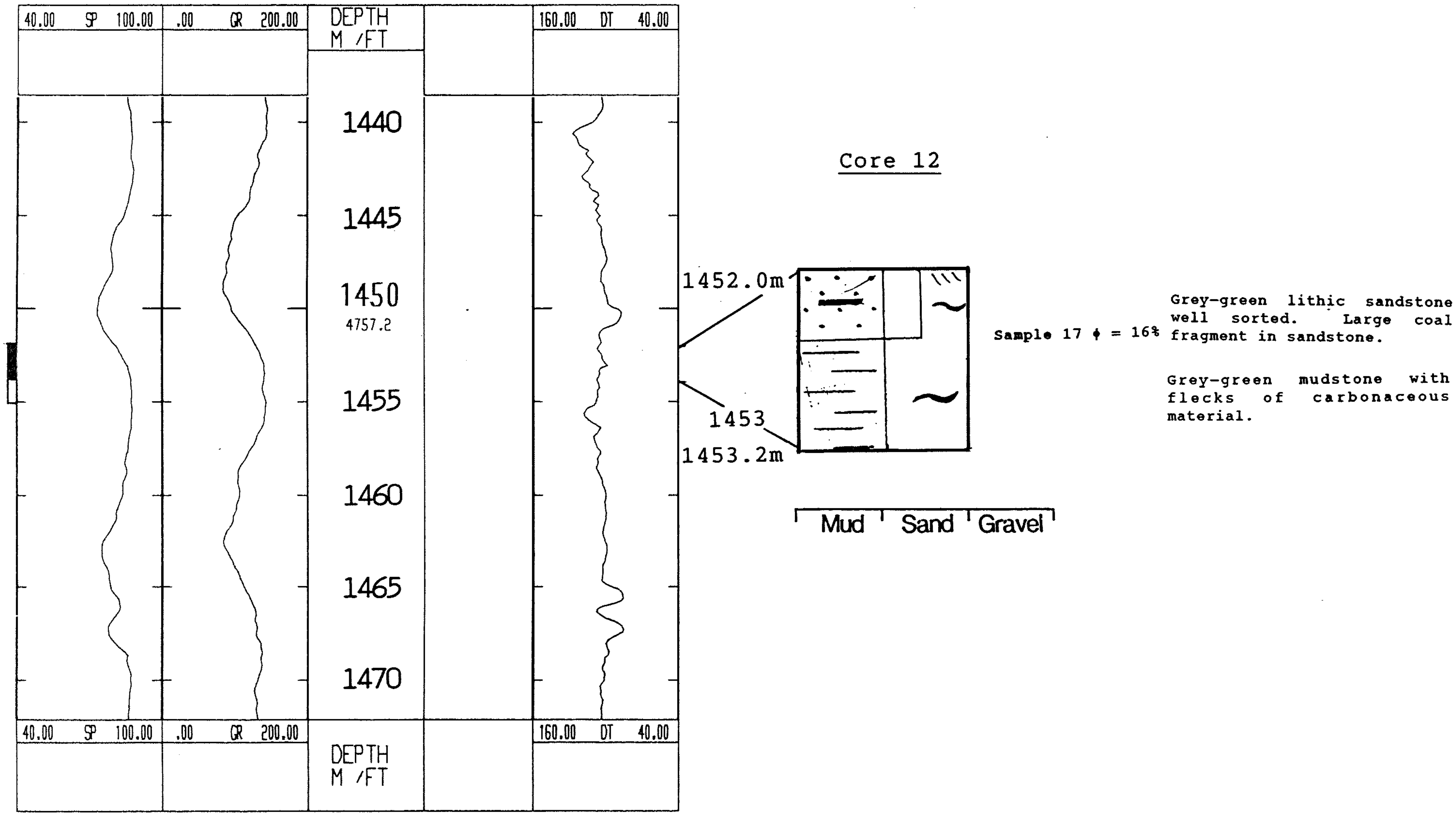
GELTWOOD BEACH 1



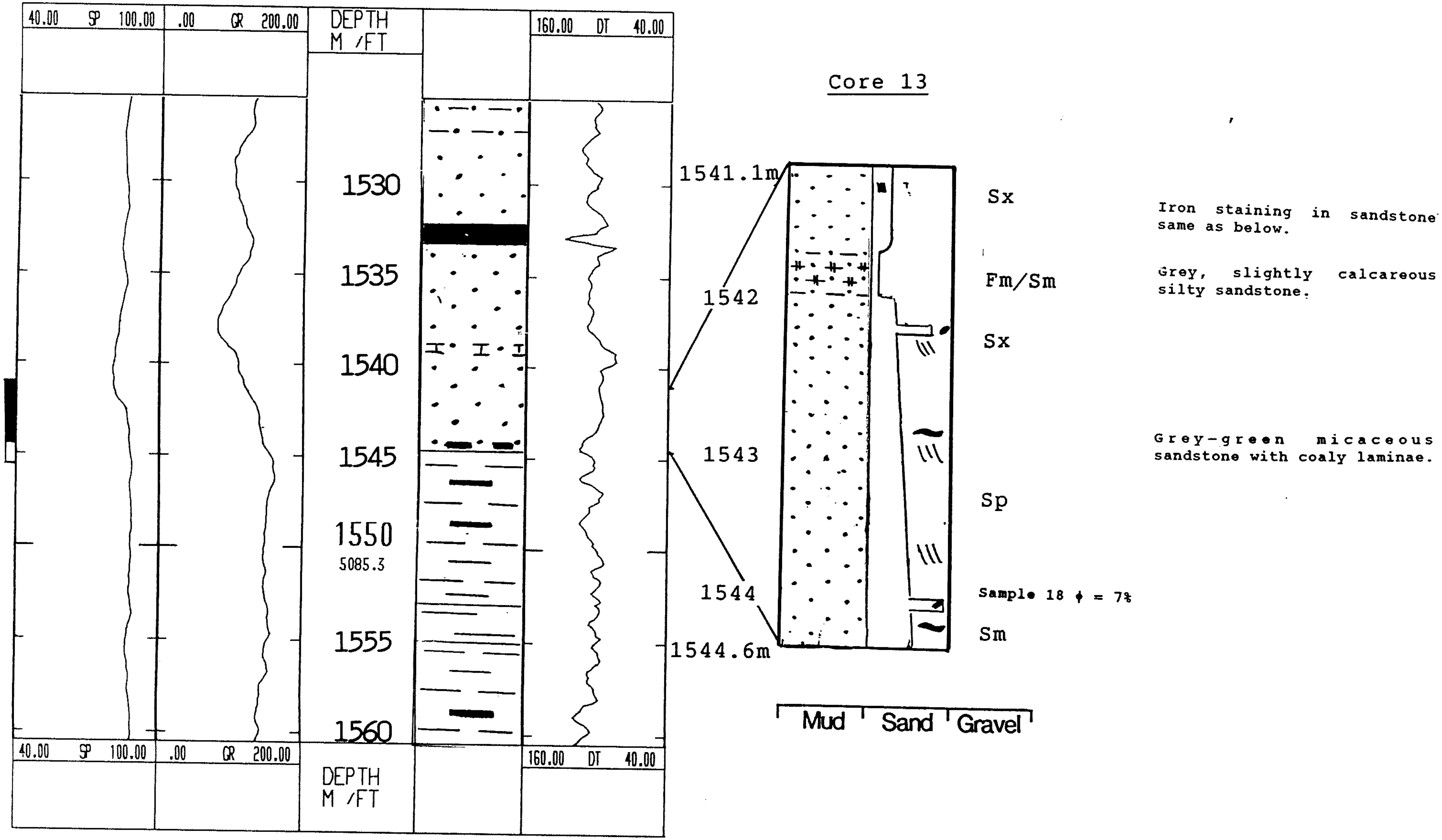
GELTWOOD BEACH 1



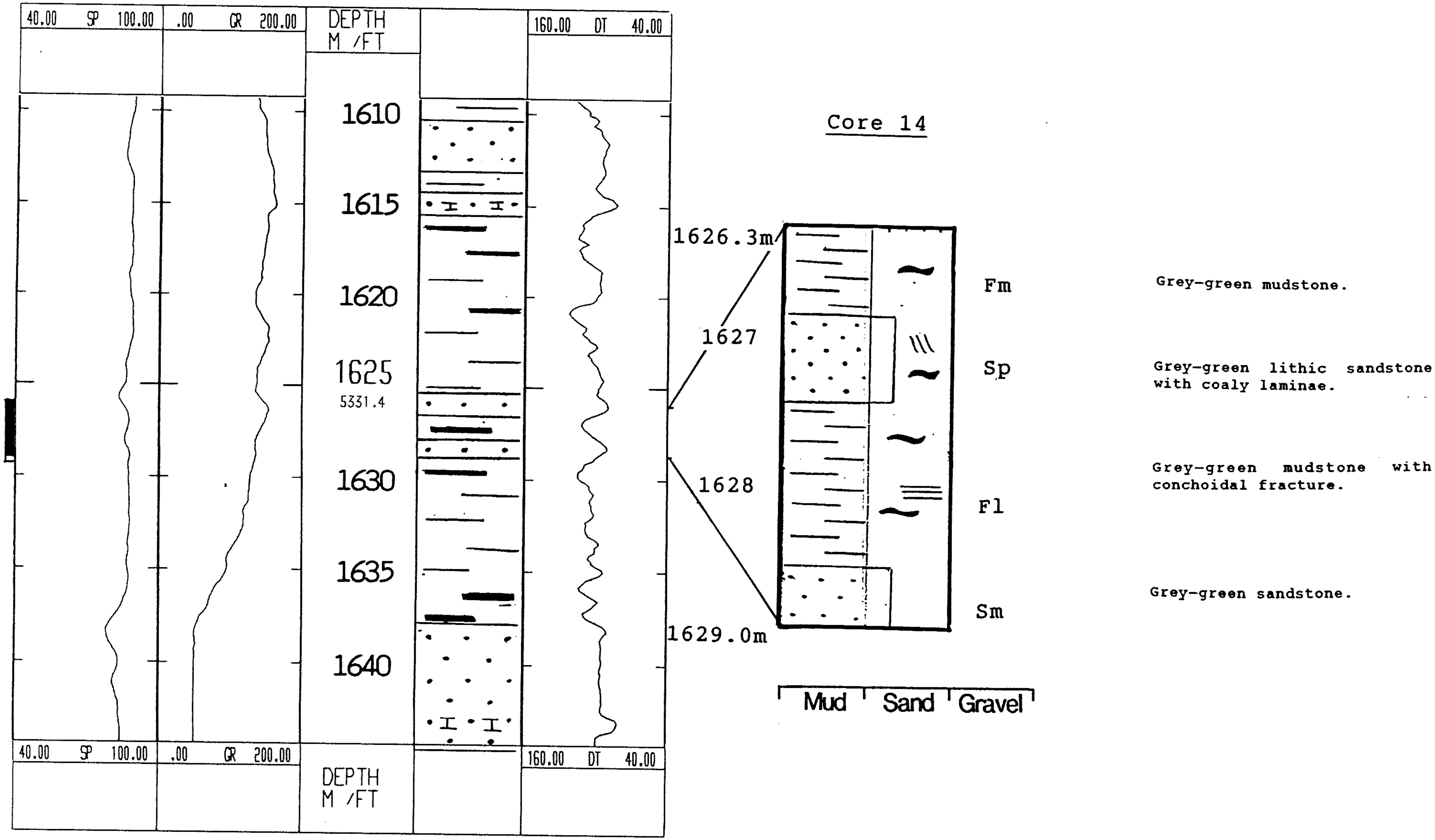
GELTWOOD BEACH 1



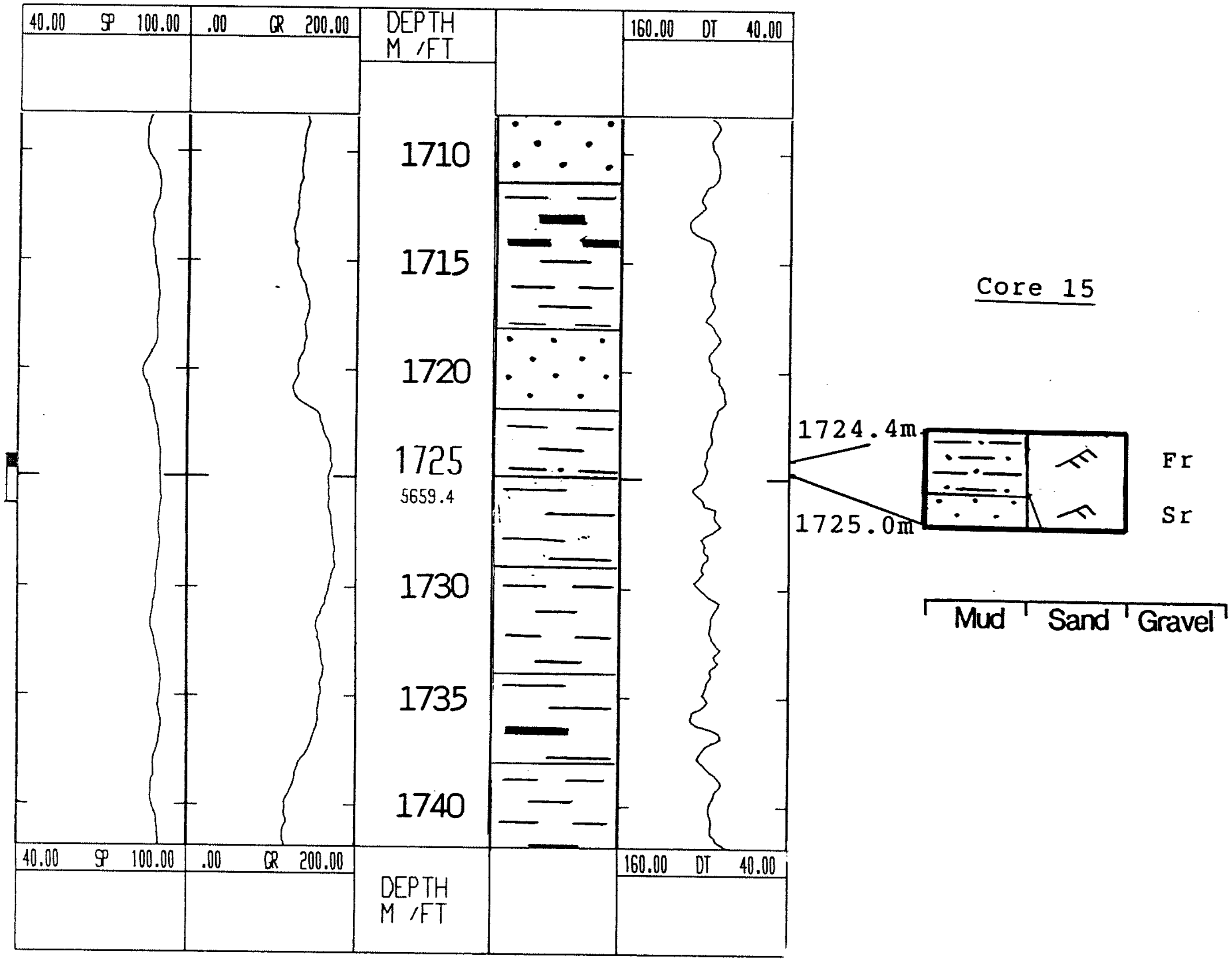
GELTWOOD BEACH 1



GELTWOOD BEACH 1

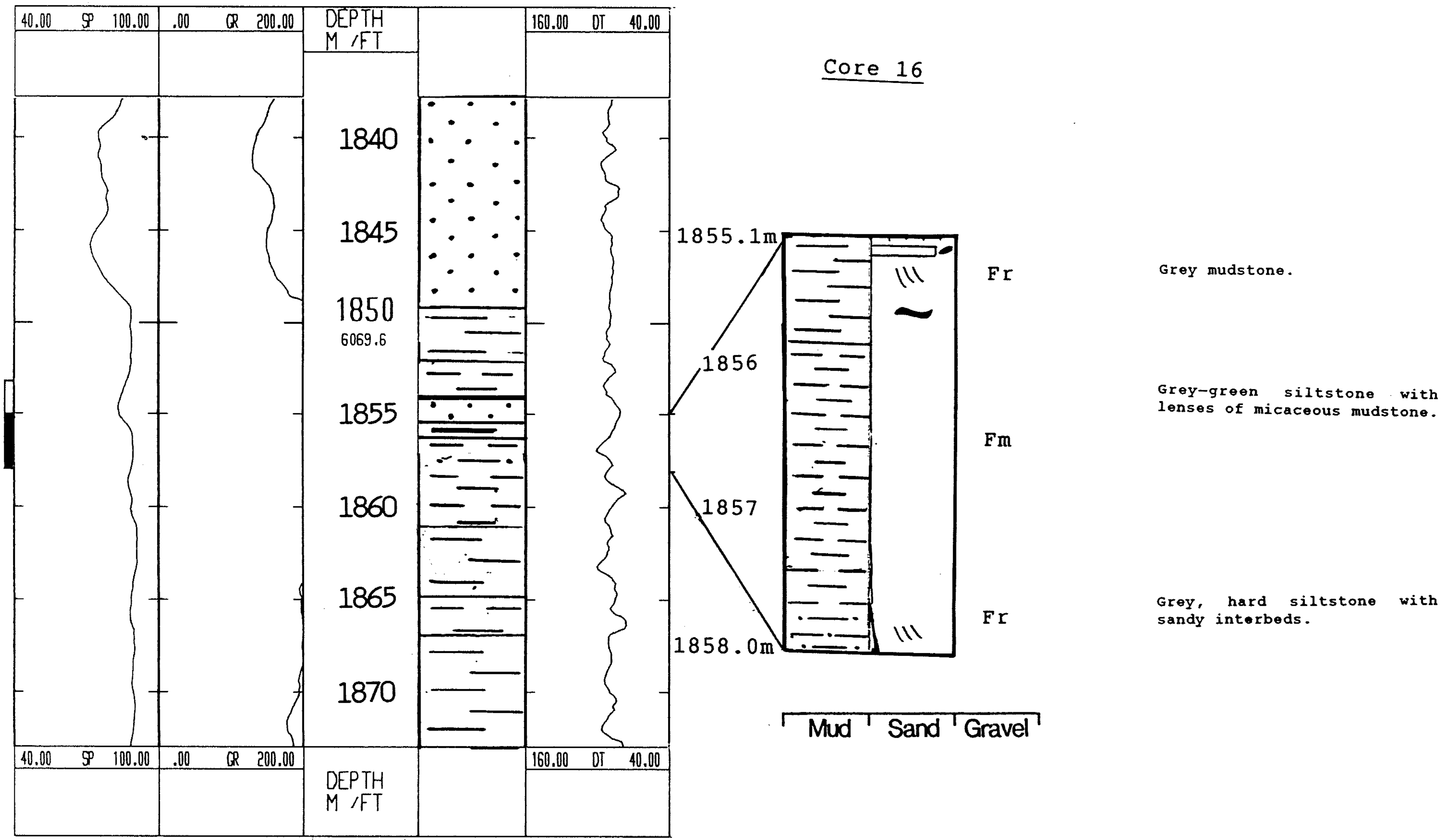


GELTWOOD BEACH 1

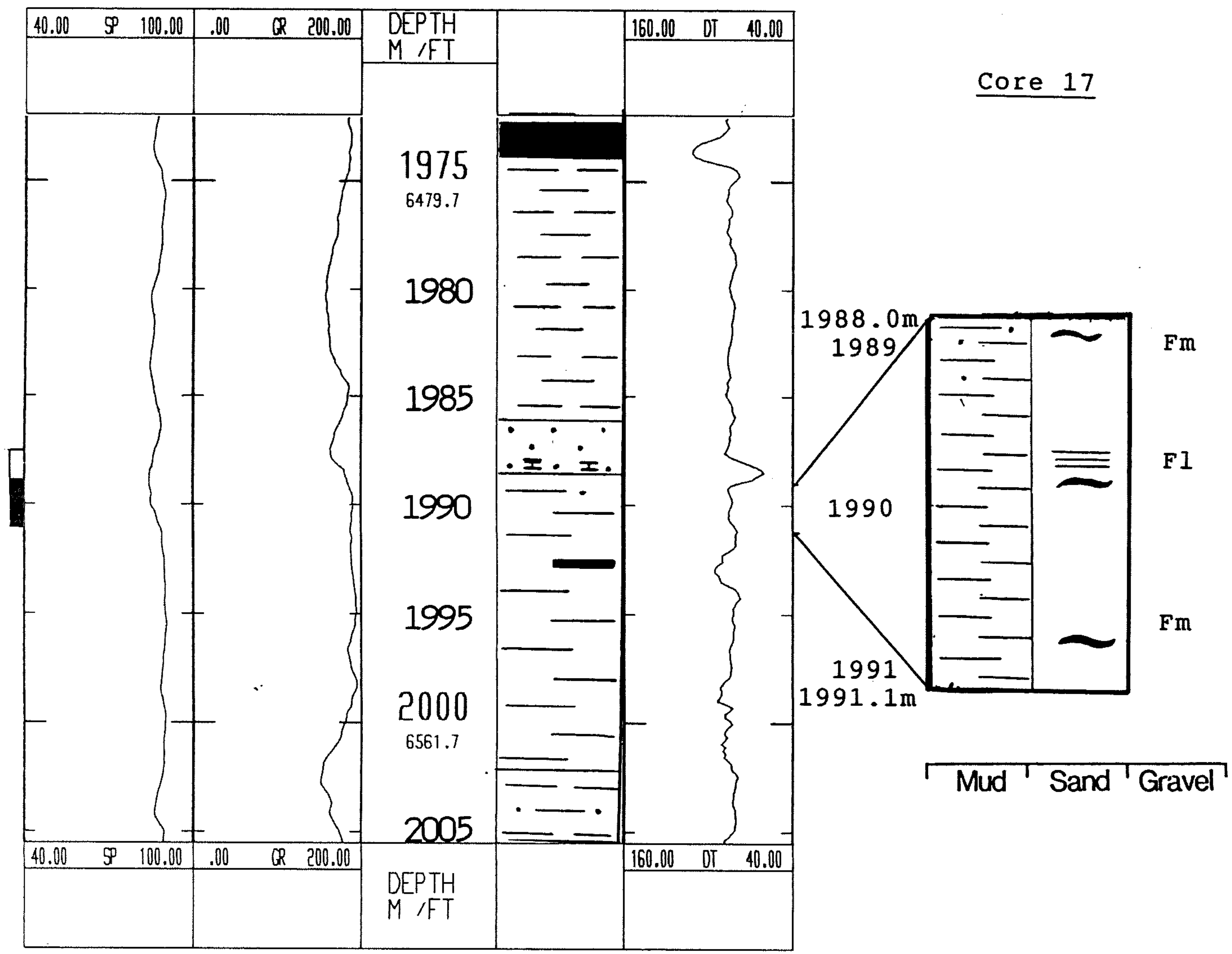


Light grey, slightly green silty sandstone with abundant sedimentary structures.

GELTWOOD BEACH 1

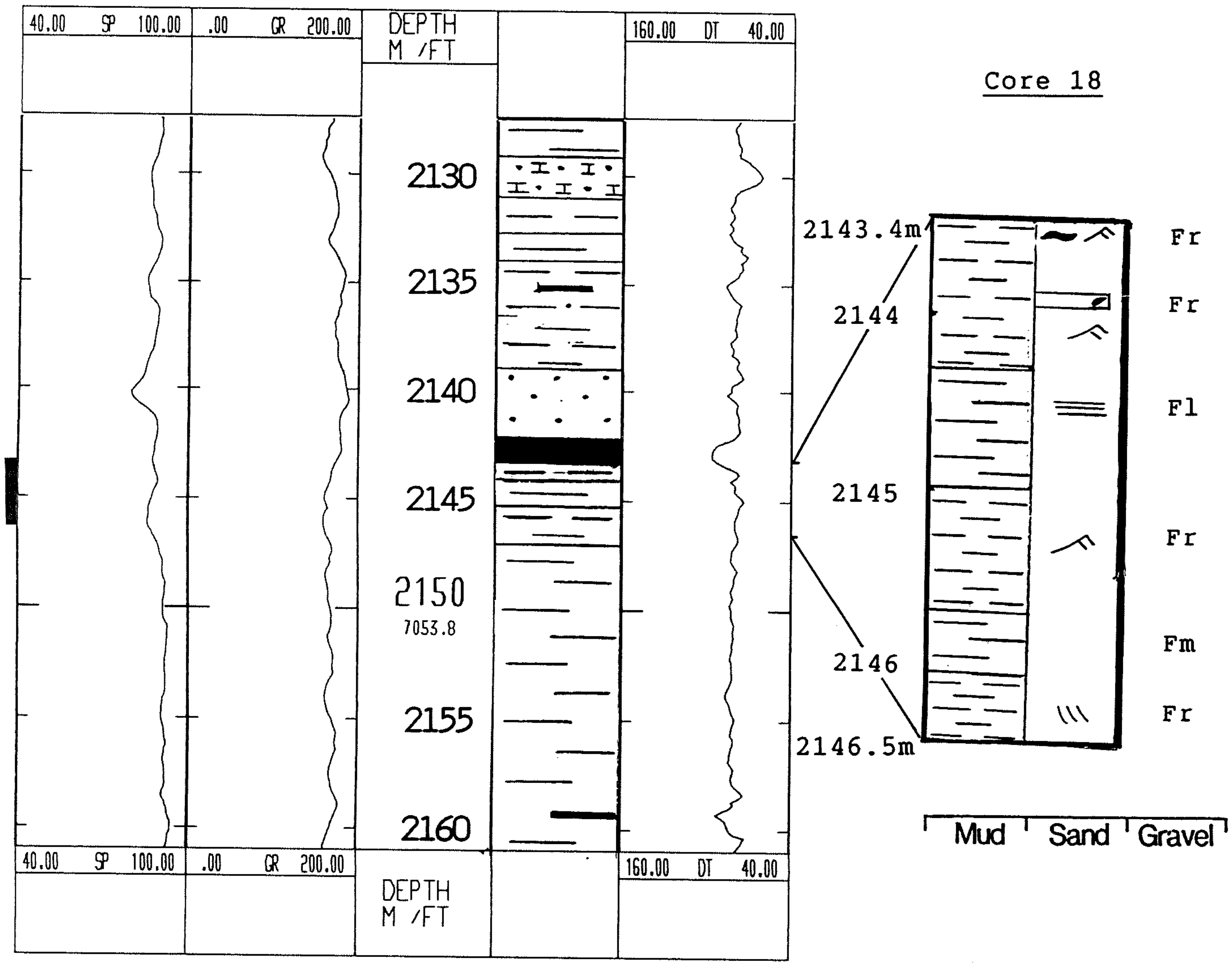


GELTWOOD BEACH 1



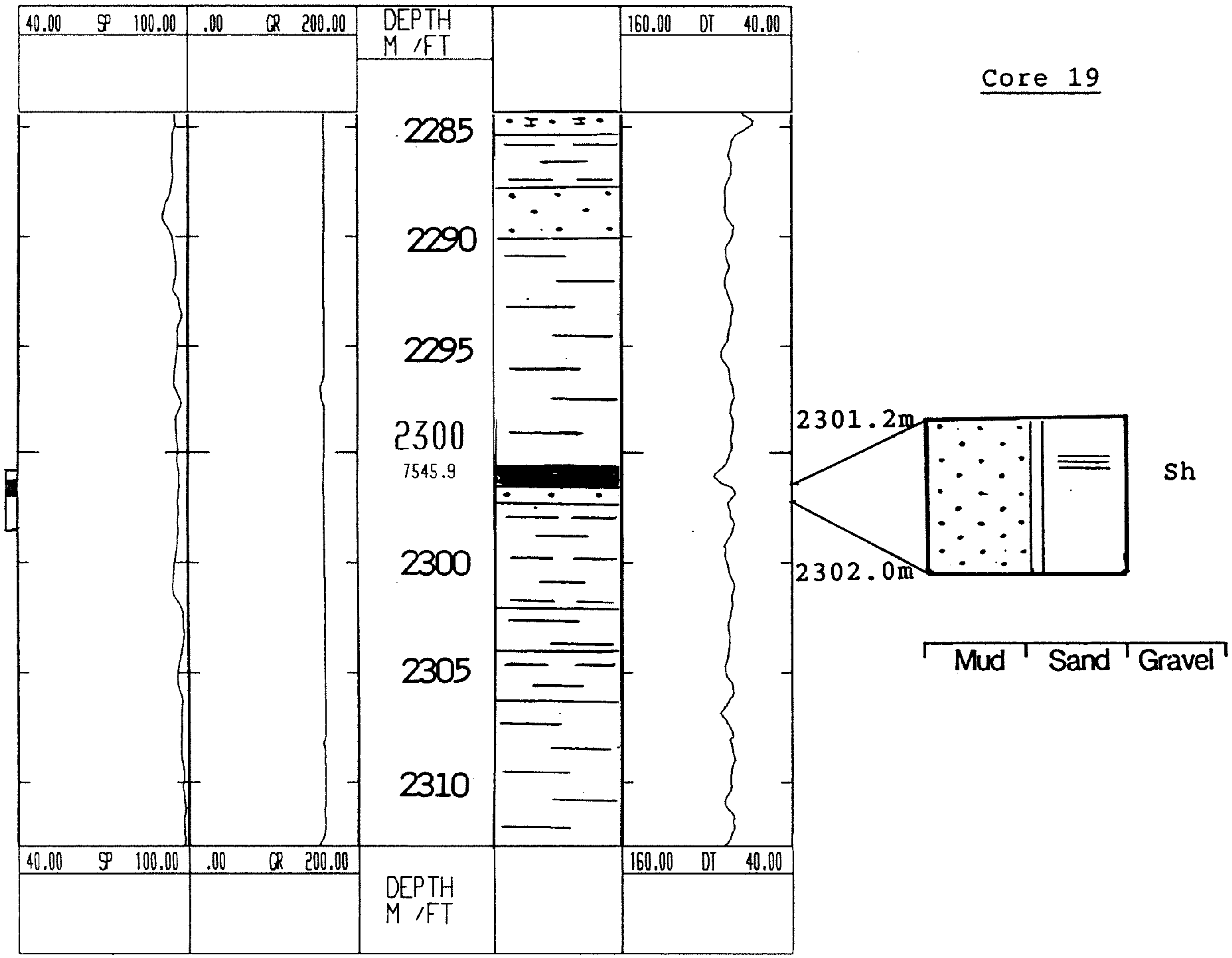
Grey-green mudstone, becoming silty towards the top.

GELTWOOD BEACH 1



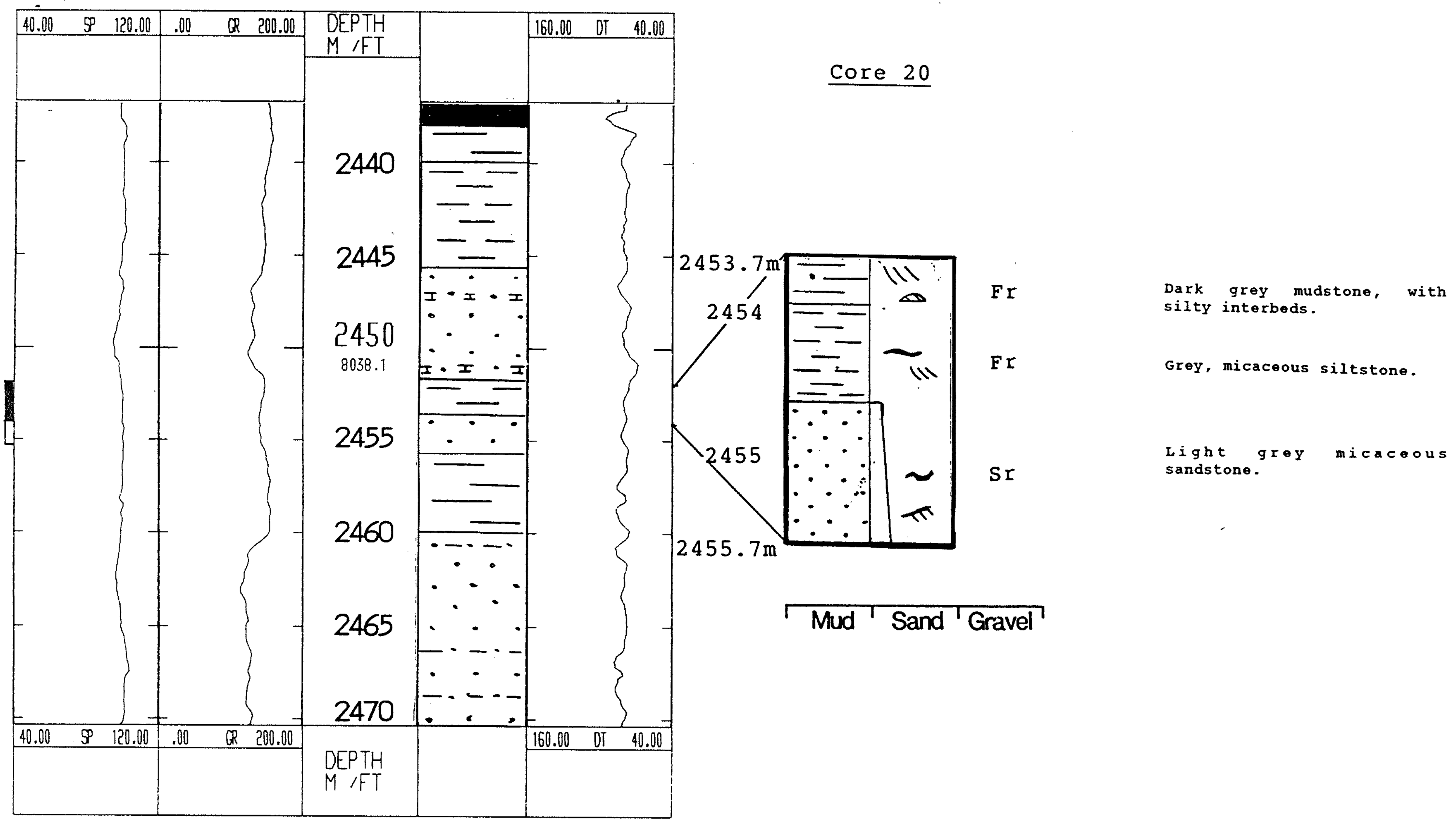
Grey-green siltstone, with laminations of dark grey mudstone and carbonaceous material.

GELTWOOD BEACH 1

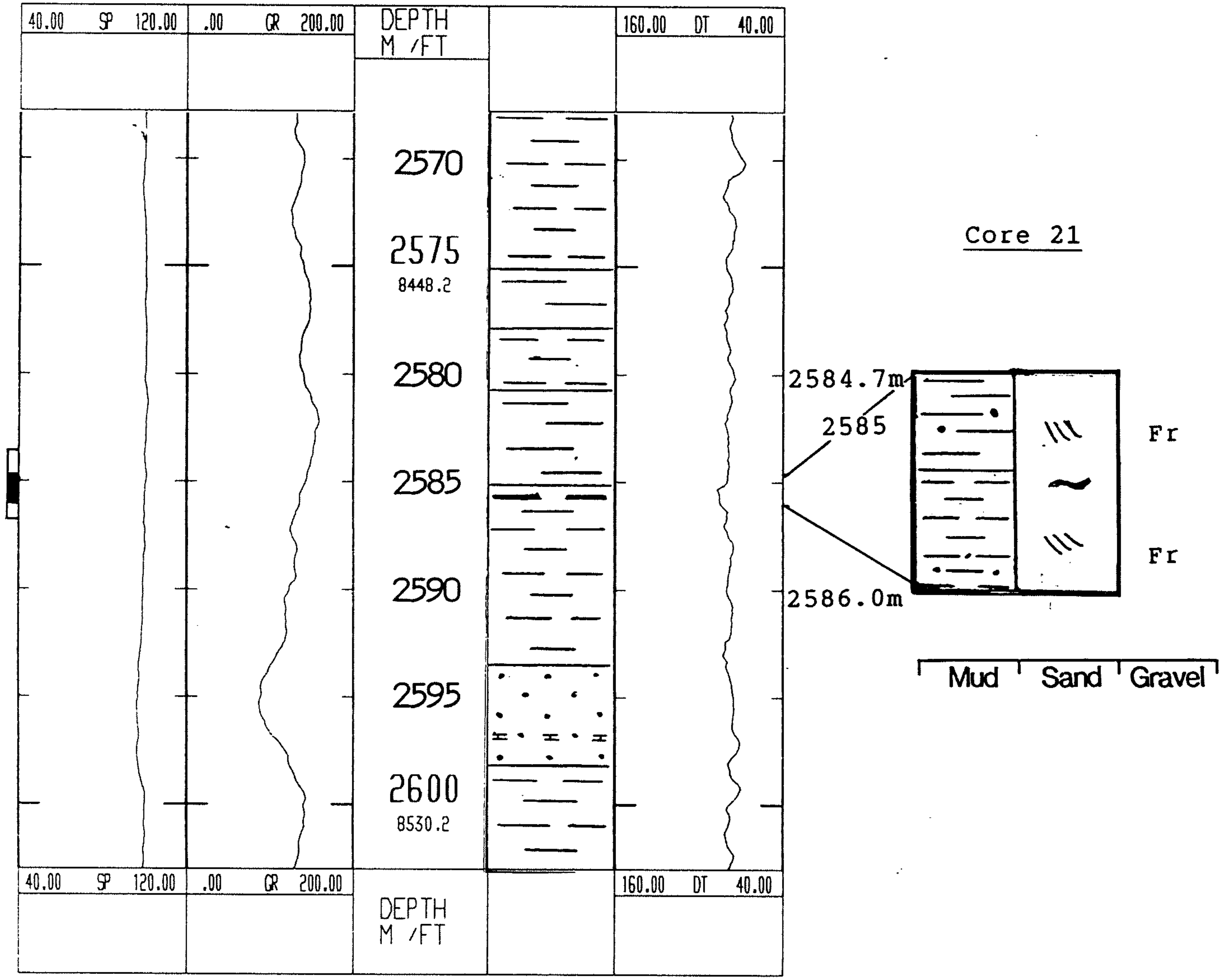


Grey micaceous sandstone.
Slightly green in places.

GELTWOOD BEACH 1



GELTWOOD BEACH 1

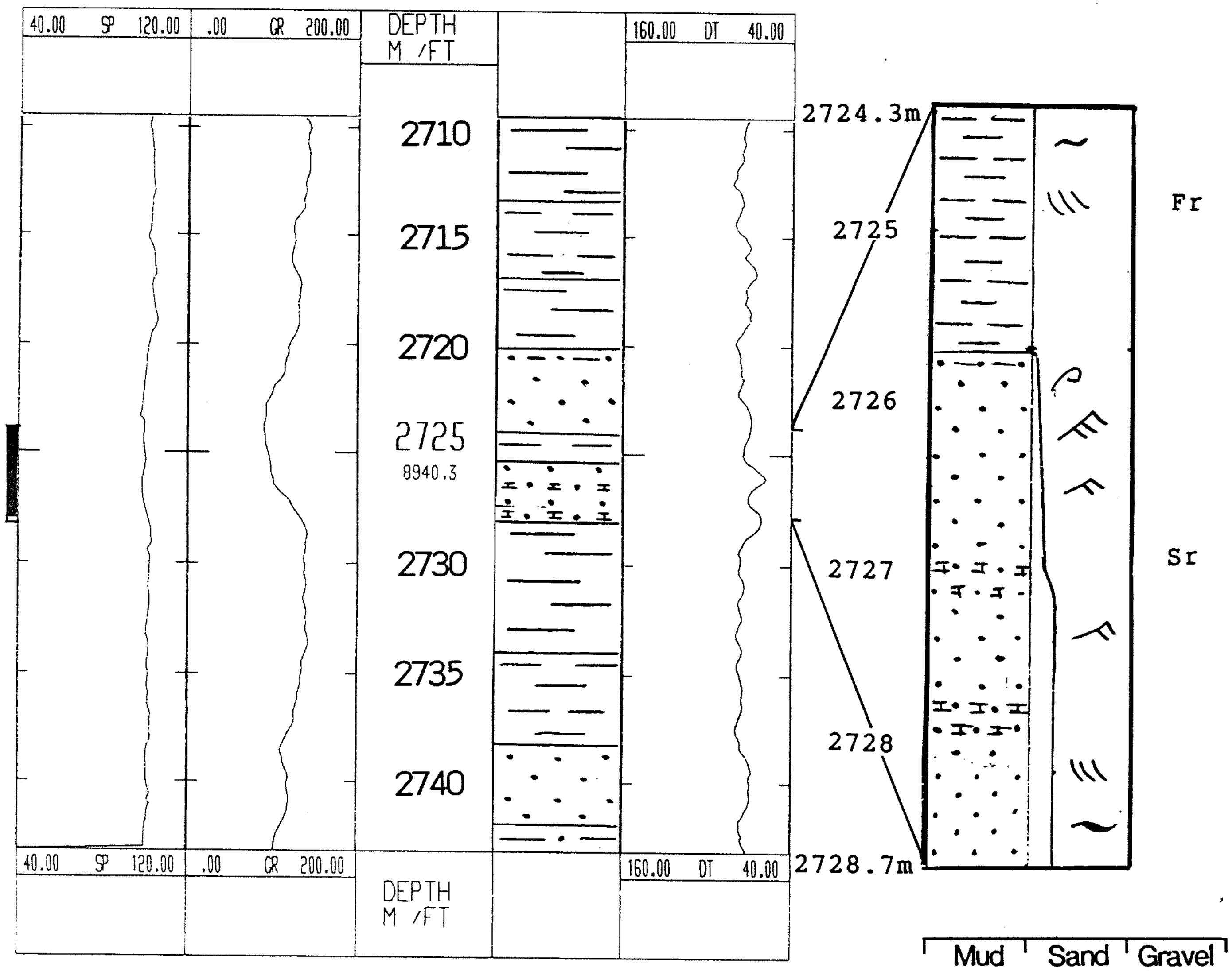


Dark grey mudstone with silty laminae.

Dark grey siltstone with minor sandy interbeds.

GELTWOOD BEACH 1

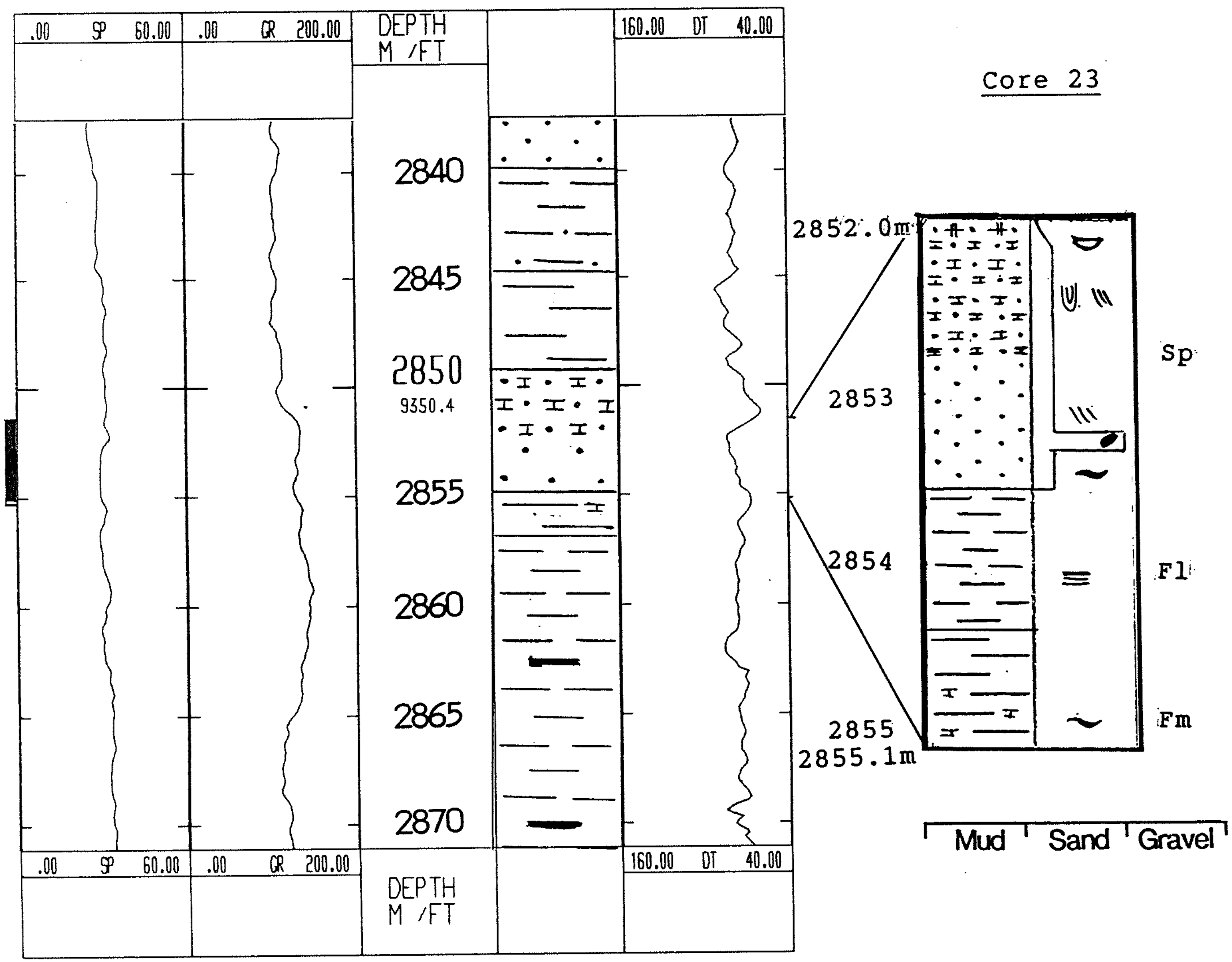
Core 22



Dark grey siltstone with minor sand laminations.

Light grey sandstone, calcareous in places and has coaly laminations at bottom of core.

GELTWOOD BEACH 1

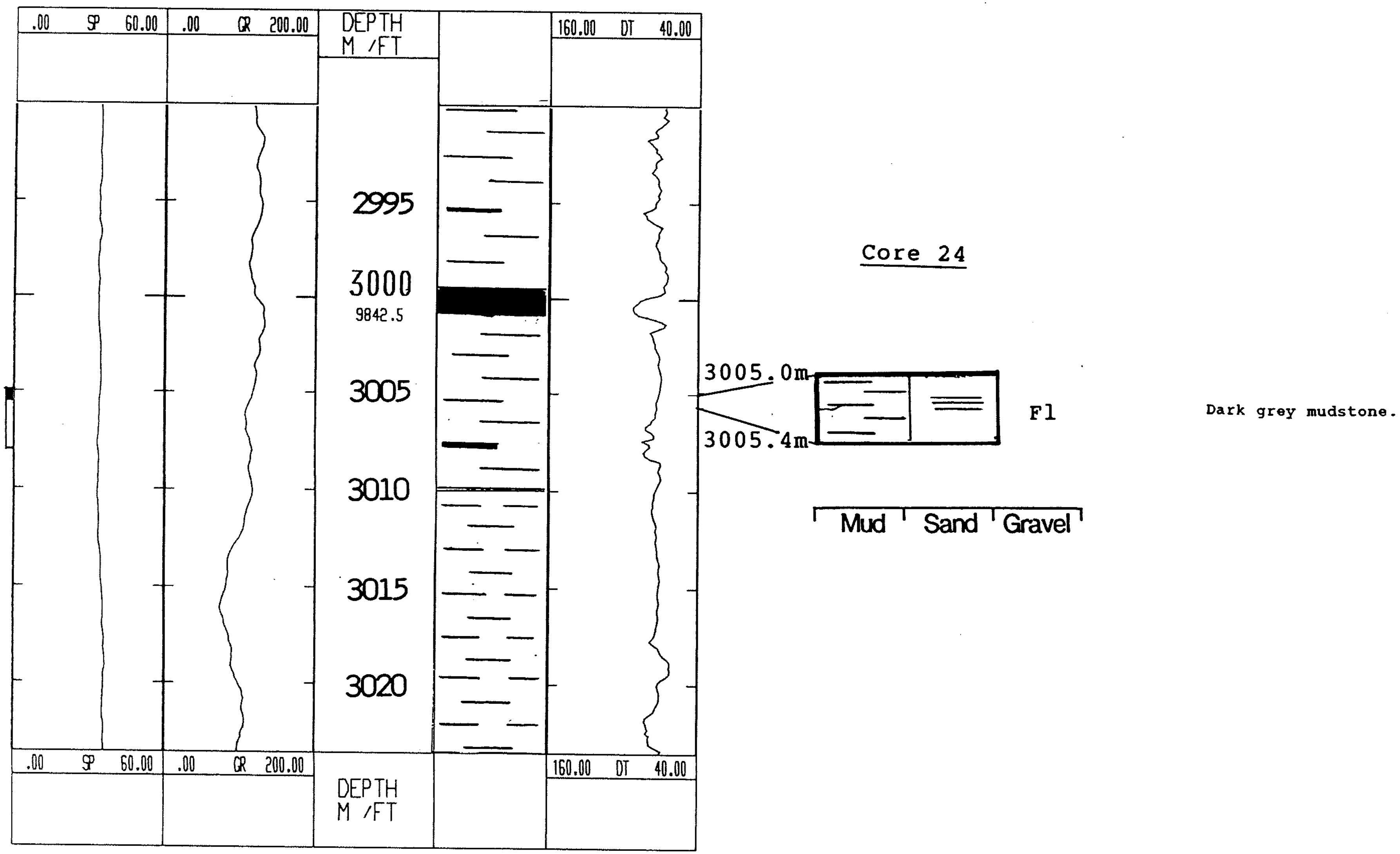


Grey-green sandstone with silt and coaly laminae. hard and tight where calcareous. Burrow is sand filled.

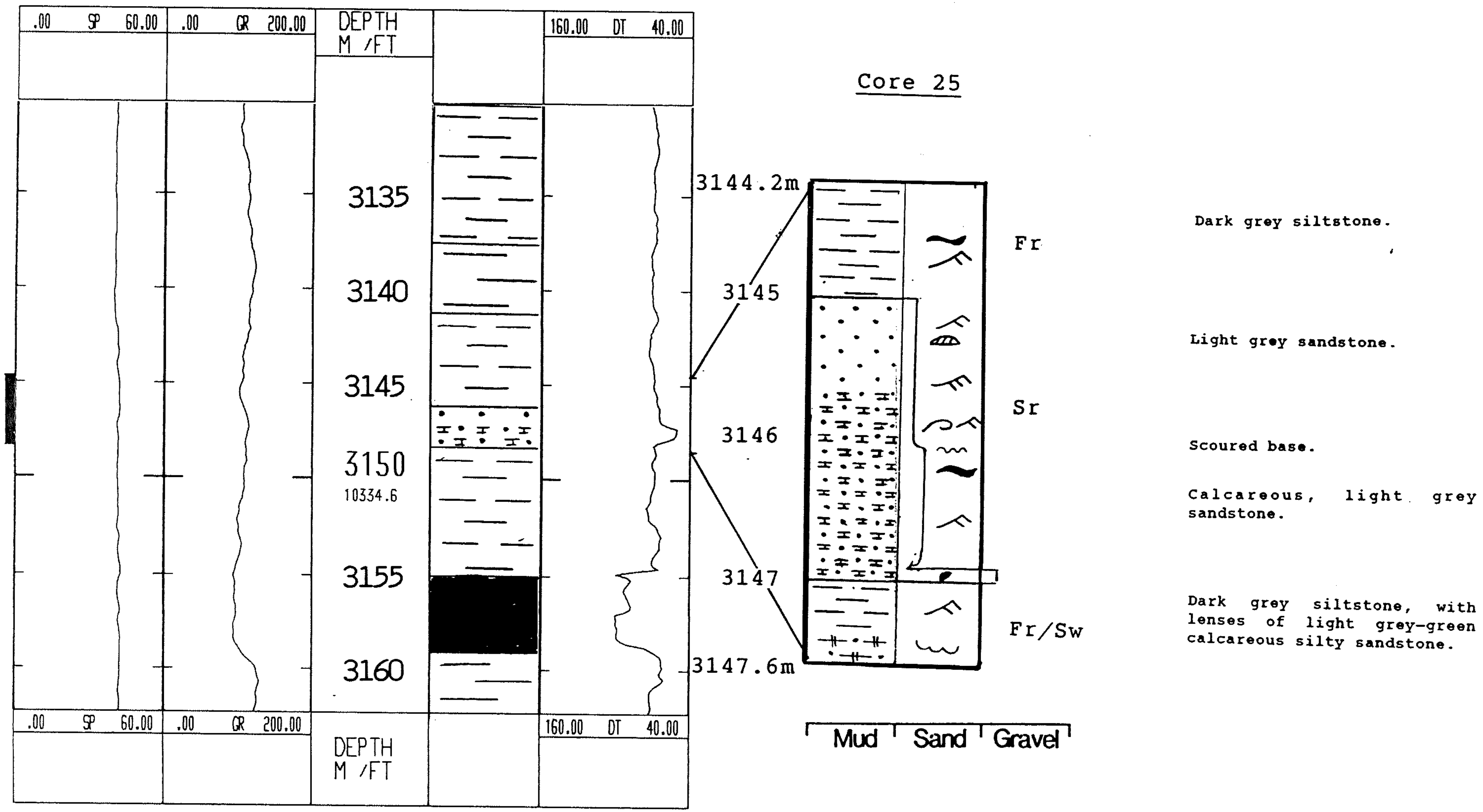
Grey-green siltstone.

Dark grey mudstone with conchoidal fracture.

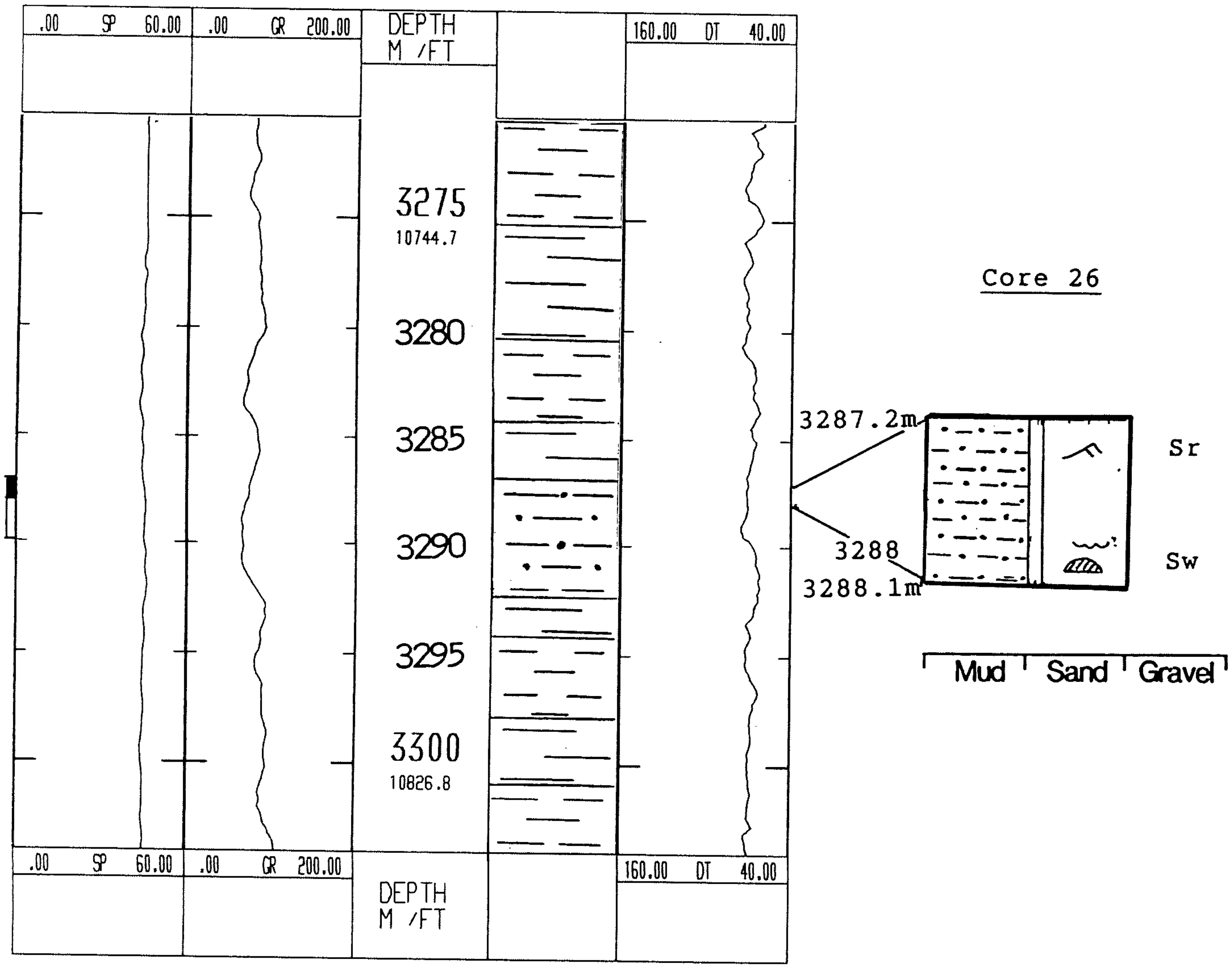
GELTWOOD BEACH 1



GELTWOOD BEACH 1

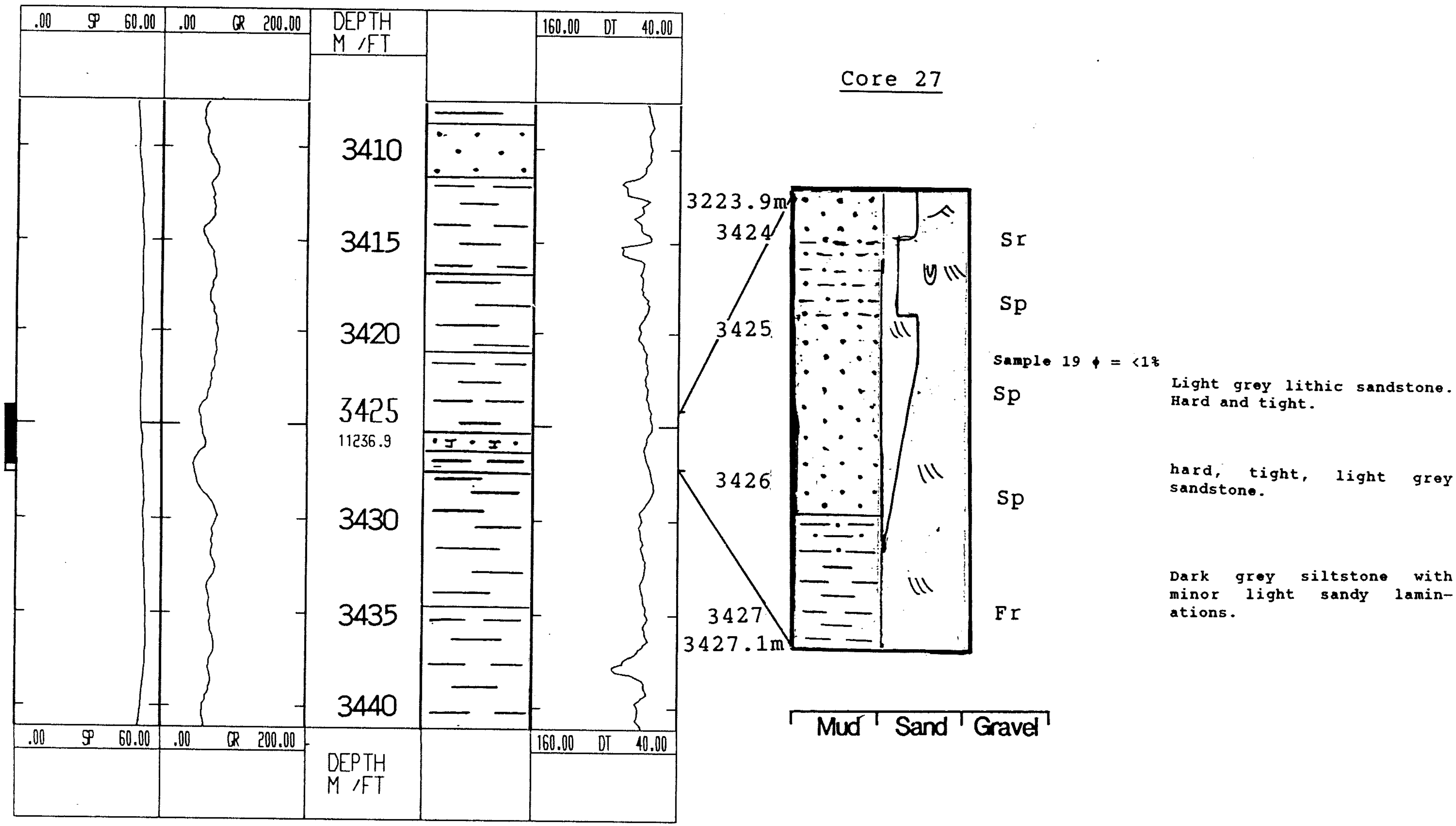


GELTWOOD BEACH 1

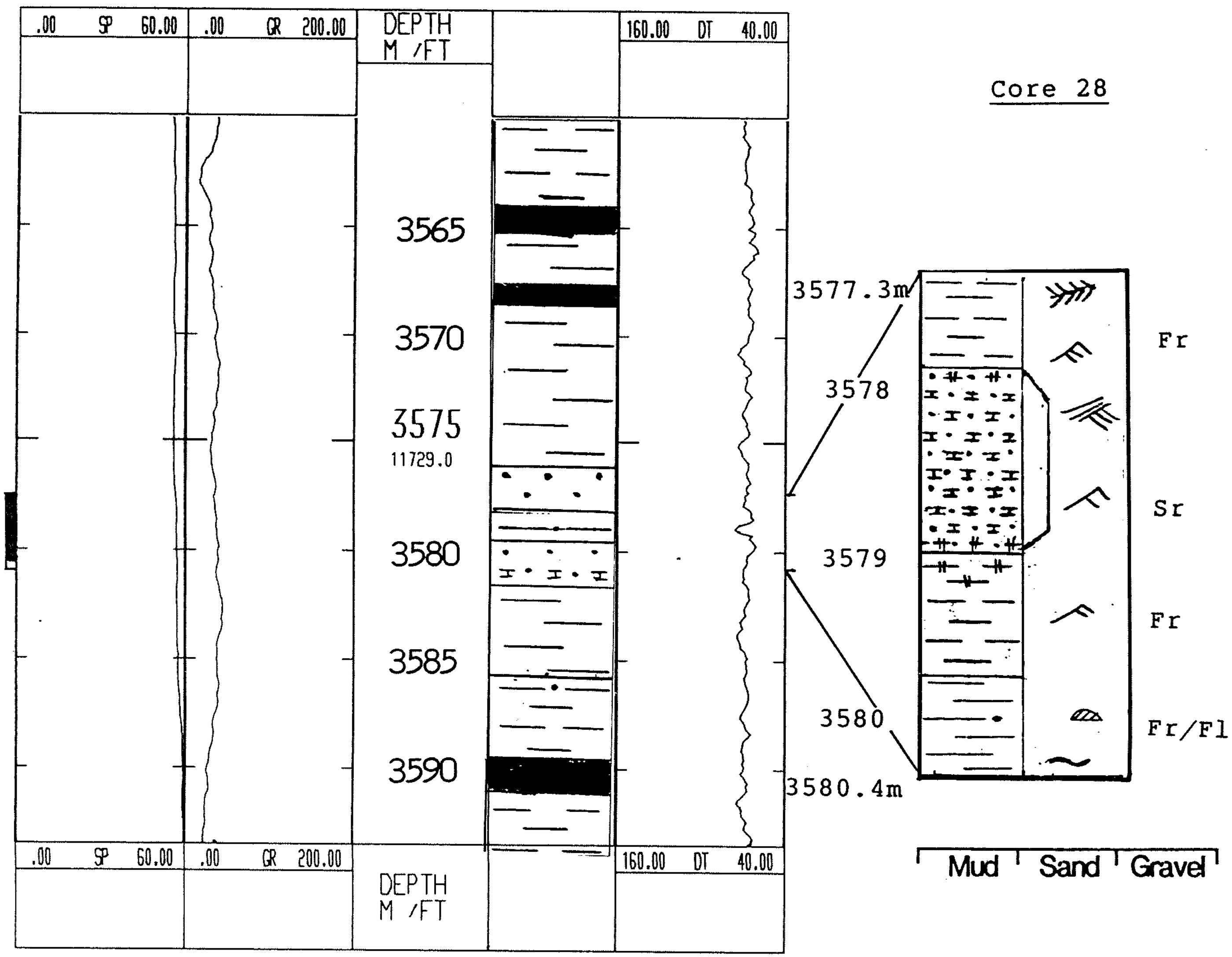


Light grey-green sandstone with common silty interbeds.

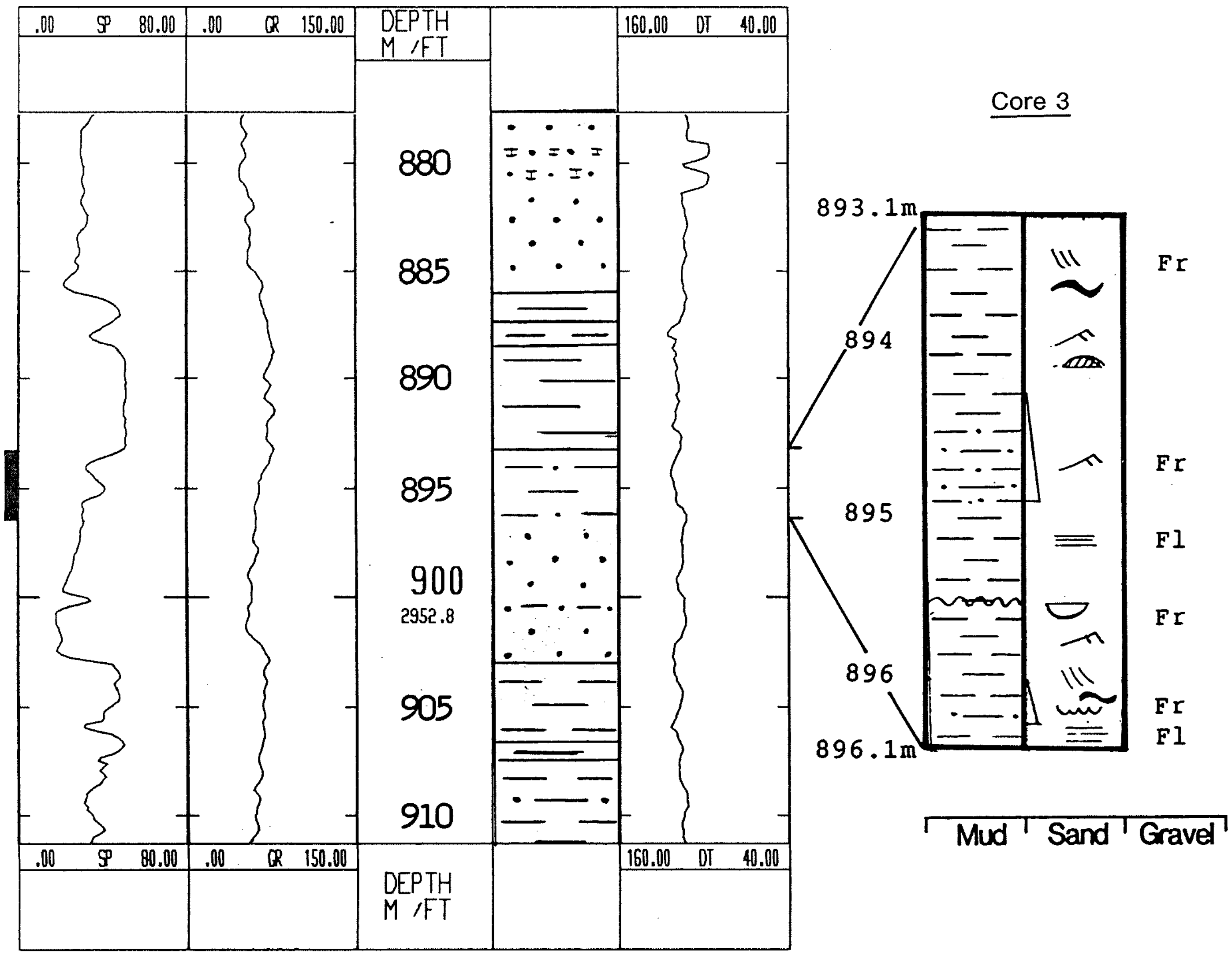
GELTWOOD BEACH 1



GELTWOOD BEACH 1



KALANGADOO 1



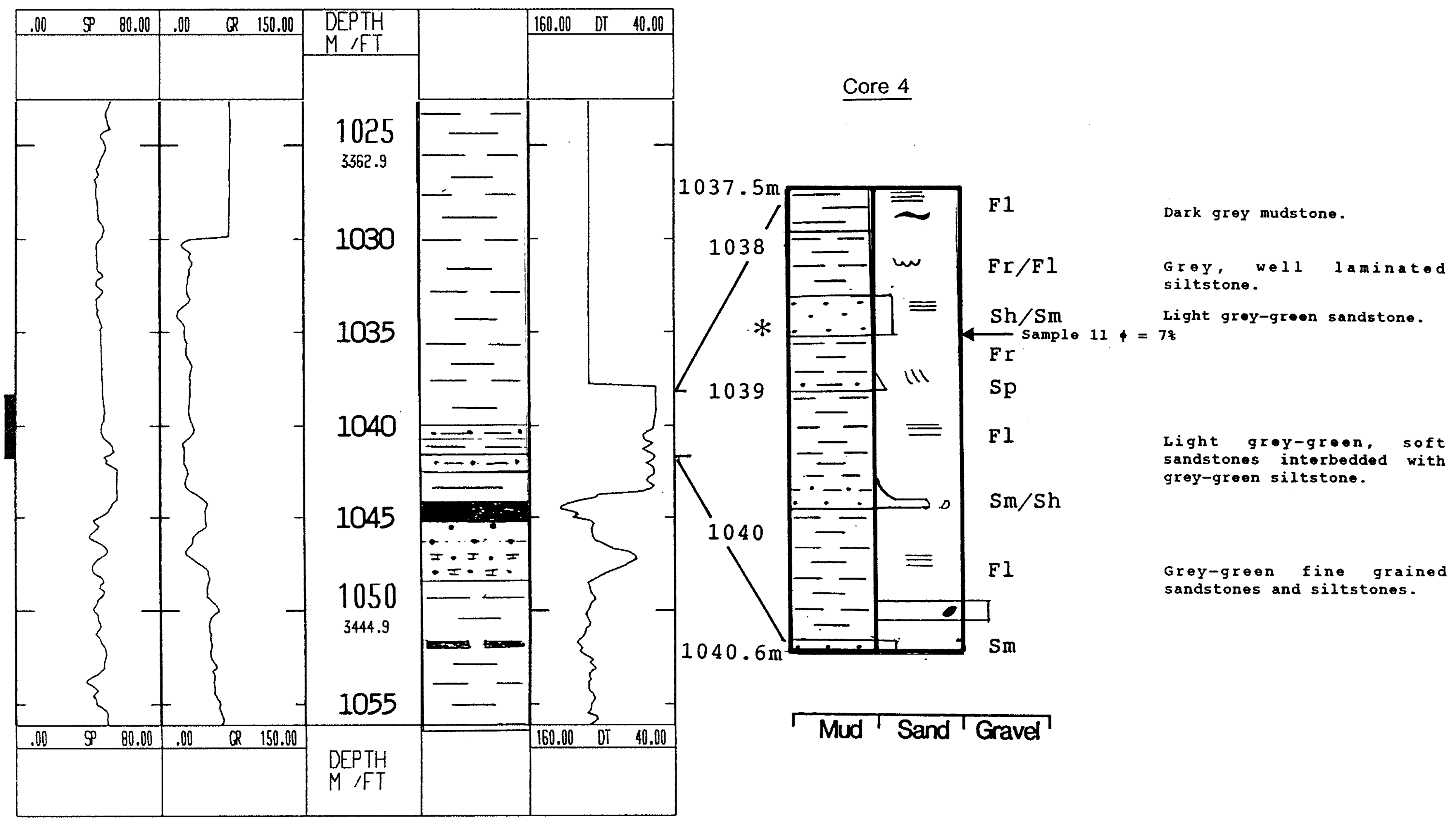
Dark grey, moderately hard siltstone.

Light grey, soft sandy siltstone.

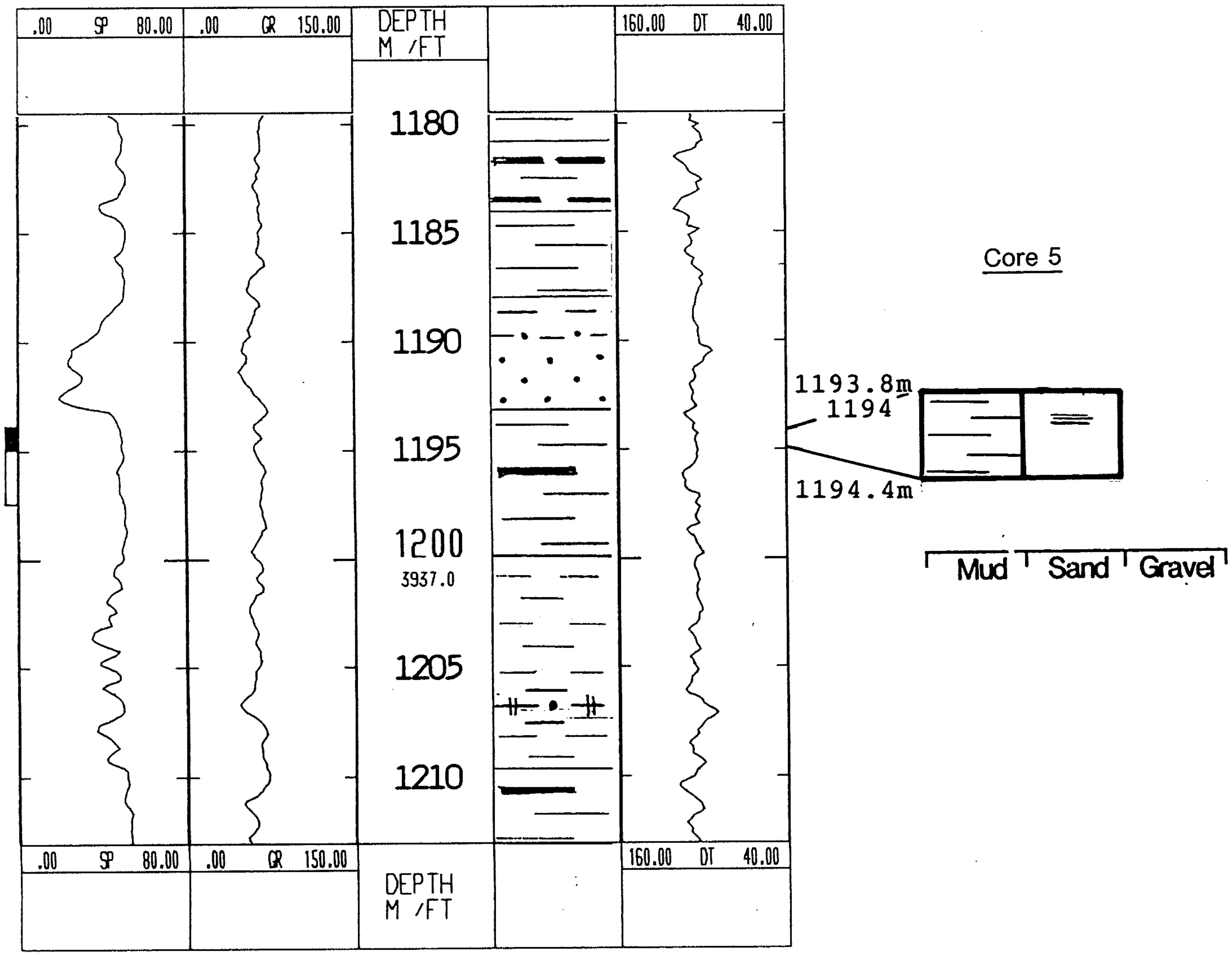
Dark grey, hard siltstone overlying scour surface.

Soft light grey sandy siltstone becoming darker and more carbonaceous at the base.

KALANGADOO 1

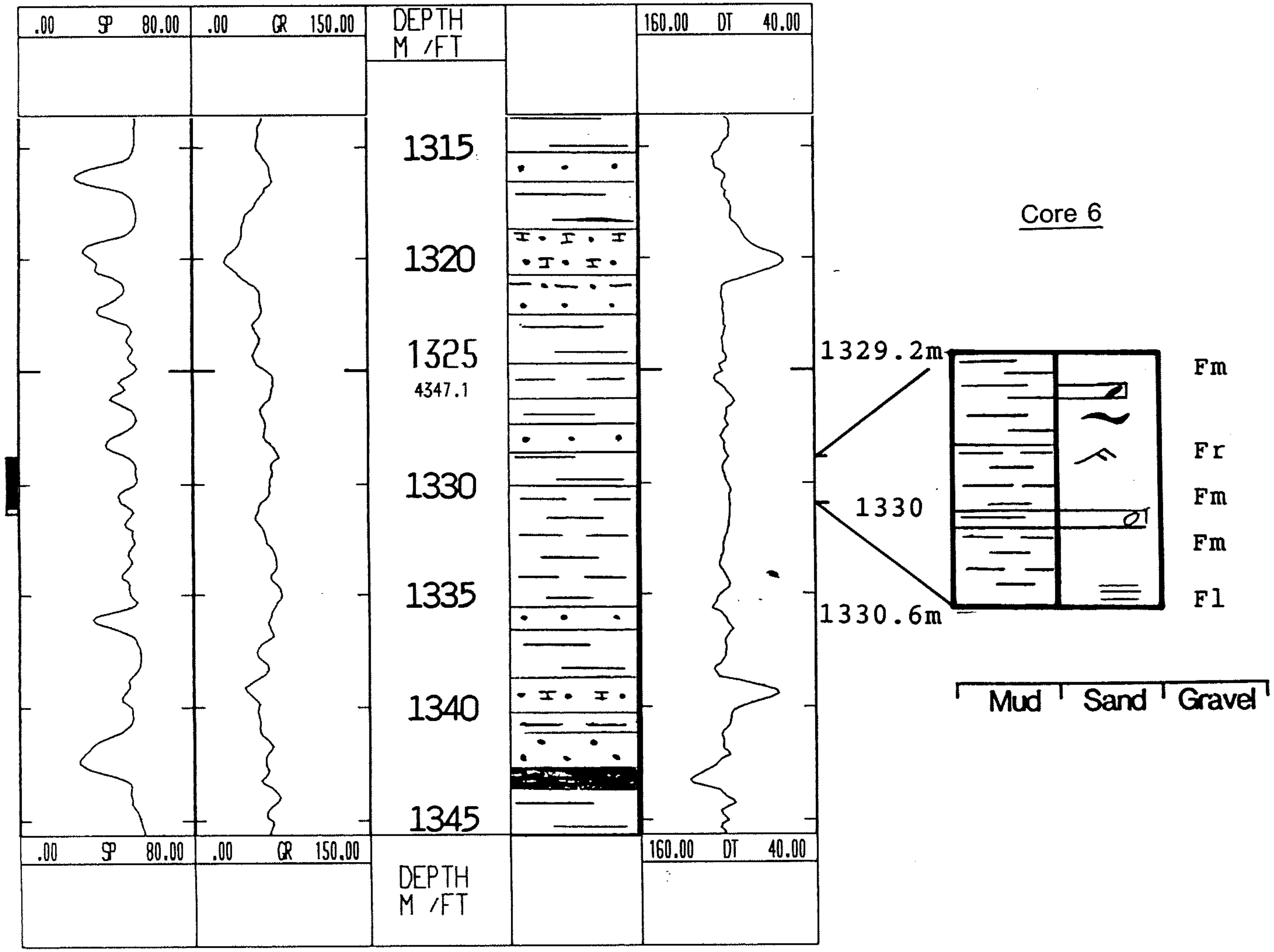


KALANGADOO 1



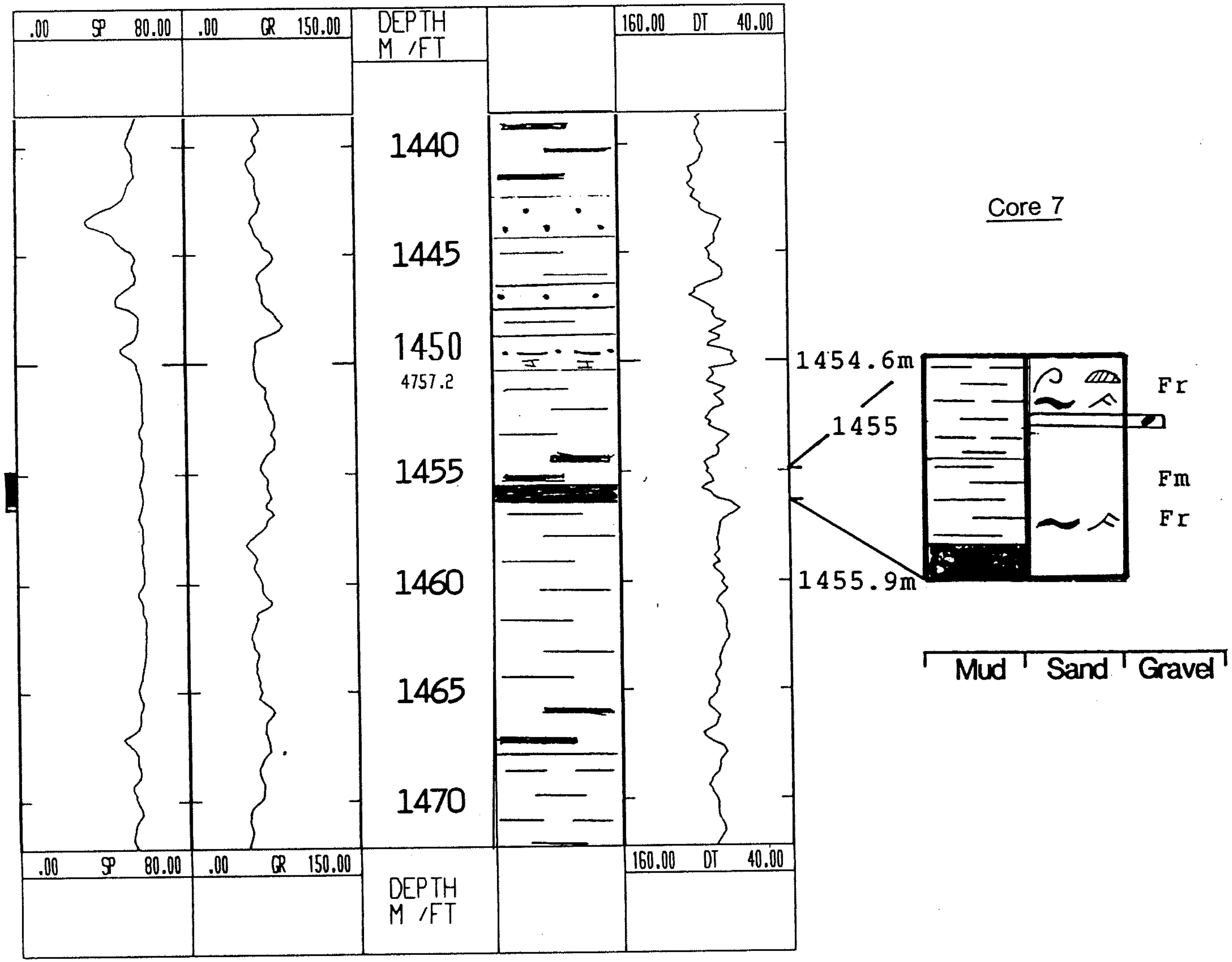
Dark grey mudstone with minor siltstone interbeds.

KALANGADOO 1



Light grey-green siltstone with quartz granules. Grading upwards into a light grey-green mudstone.

KALANGADOO 1

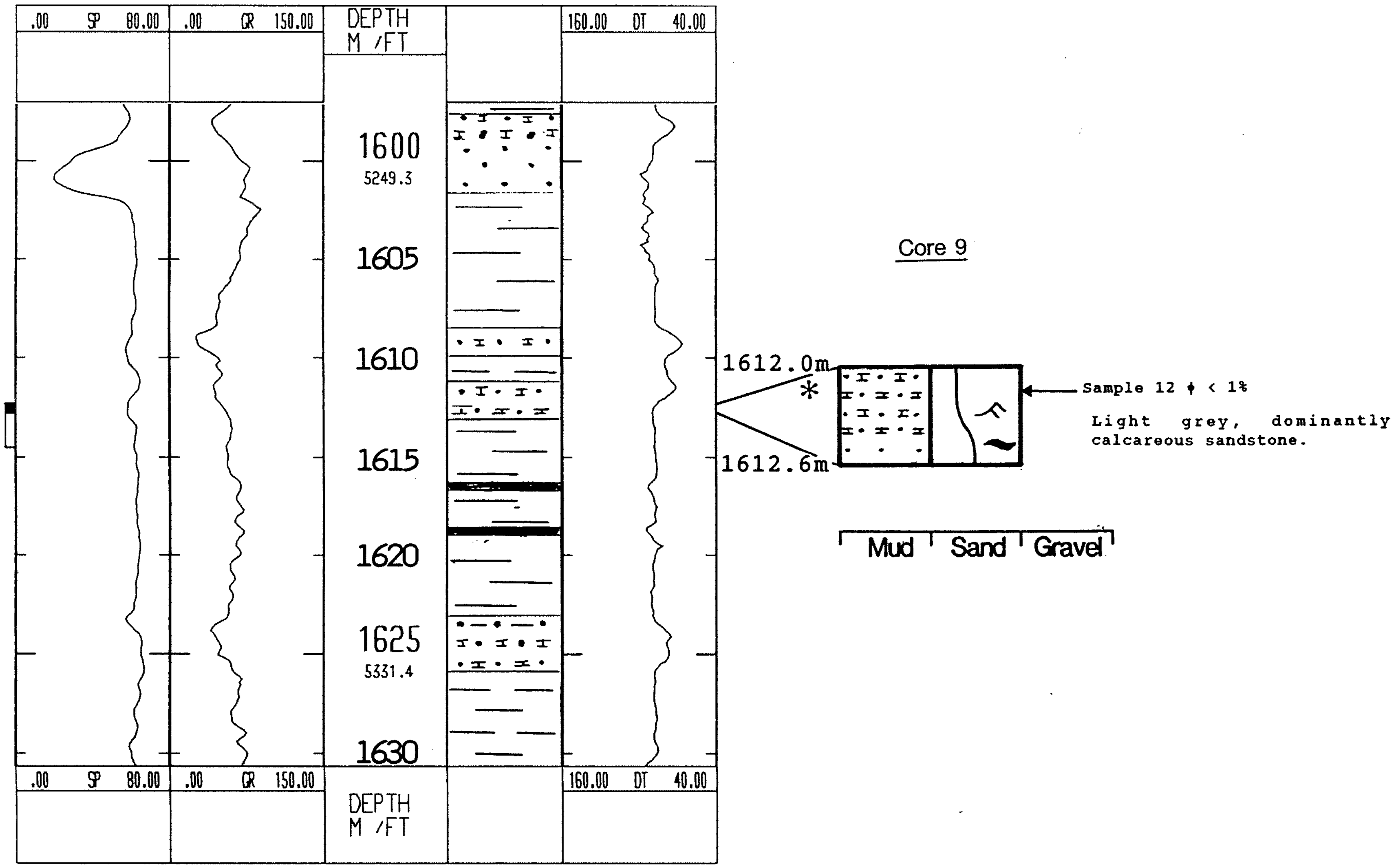


Light grey-green carbonaceous siltstone.

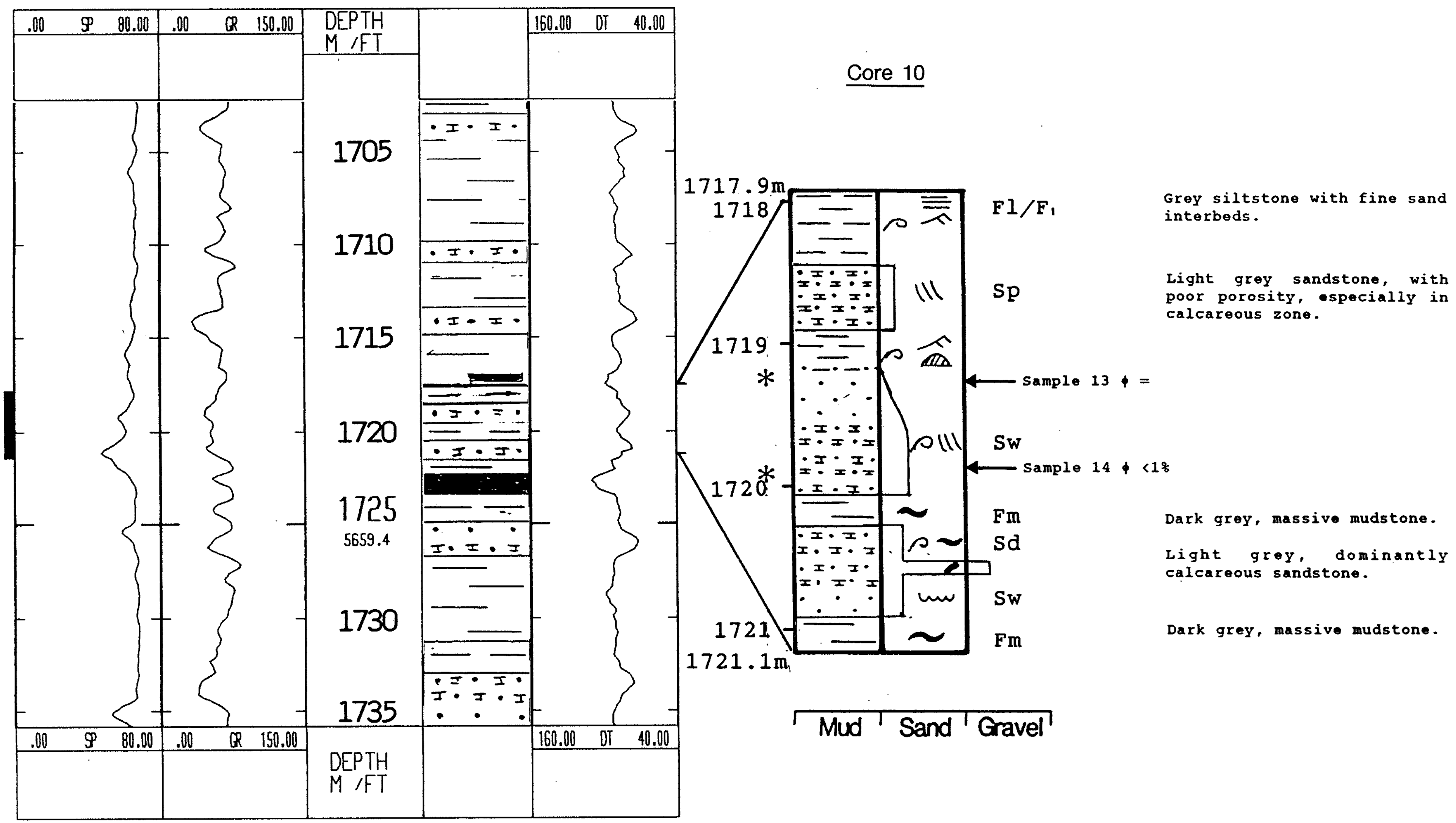
Light grey-green carbonaceous mudstone.

Black bituminous coal with a slickensided surface.

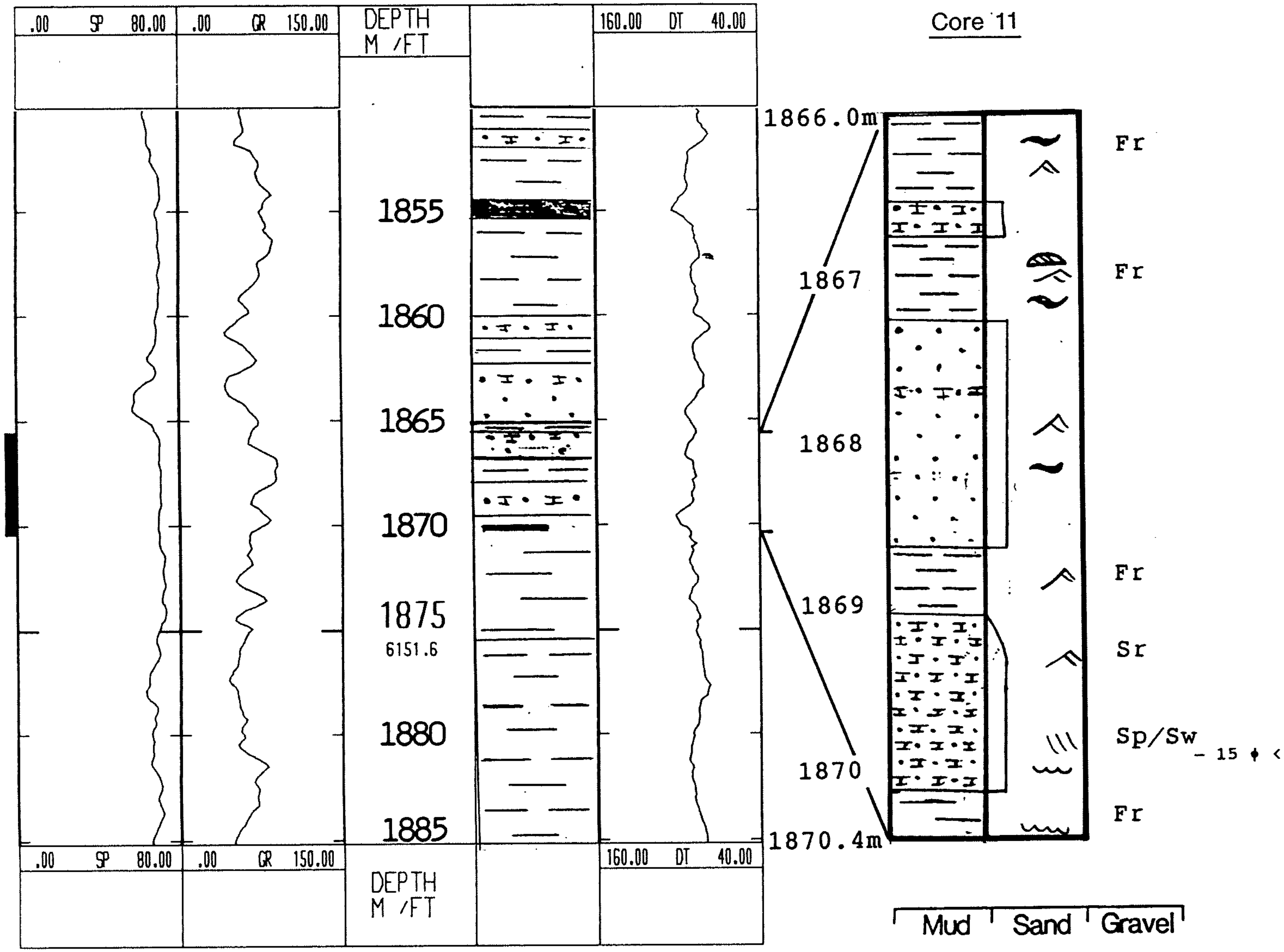
KALANGADOO 1



KALANGADOO 1



KALANGADOO 1



Grey siltstone.

Light grey, tight, sandstone.

Grey siltstone.

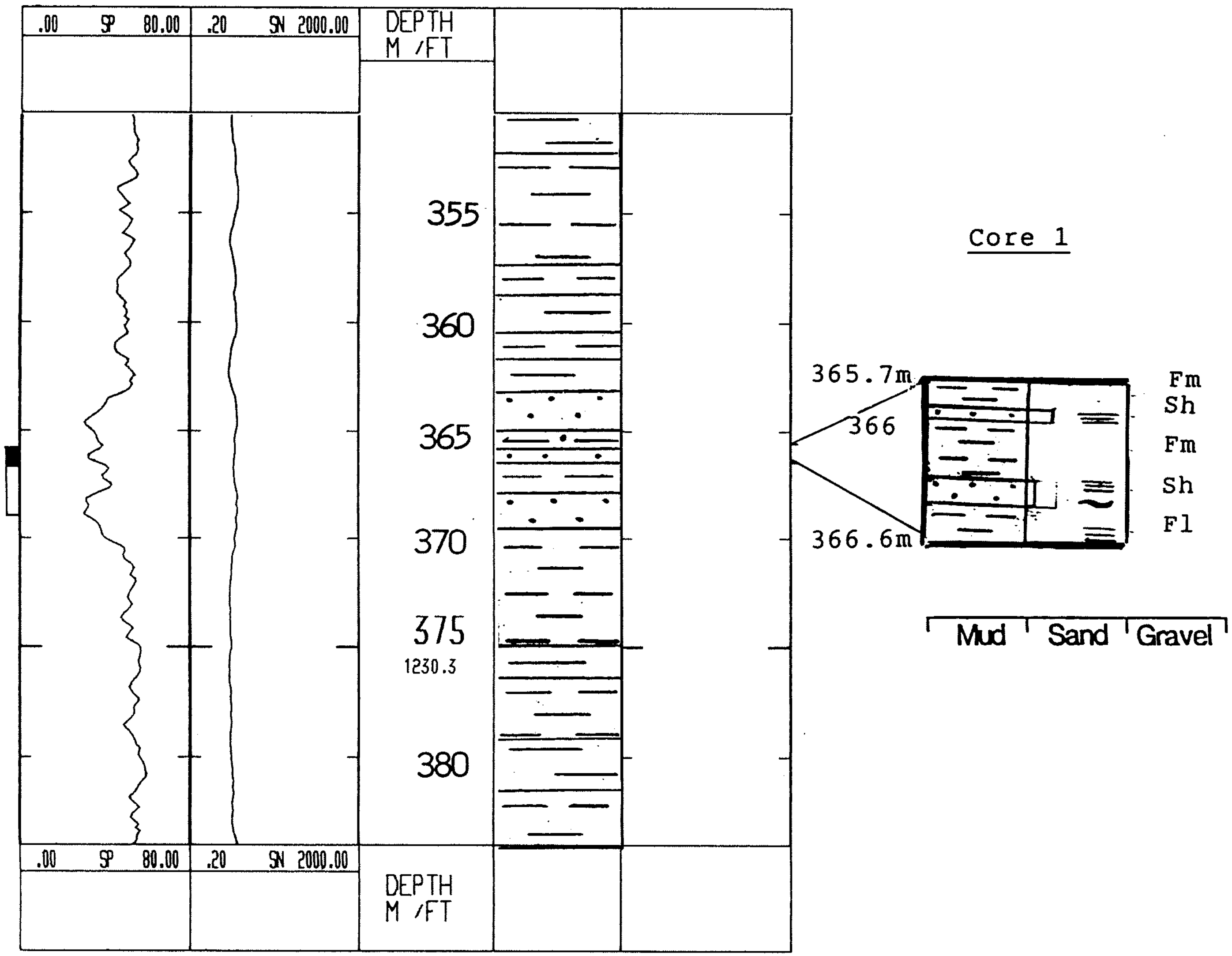
Light grey sandstone, slightly calcareous in places.

Grey siltstone.

Light grey sandstone with silty laminae

Dark grey mudstone with silty laminae.

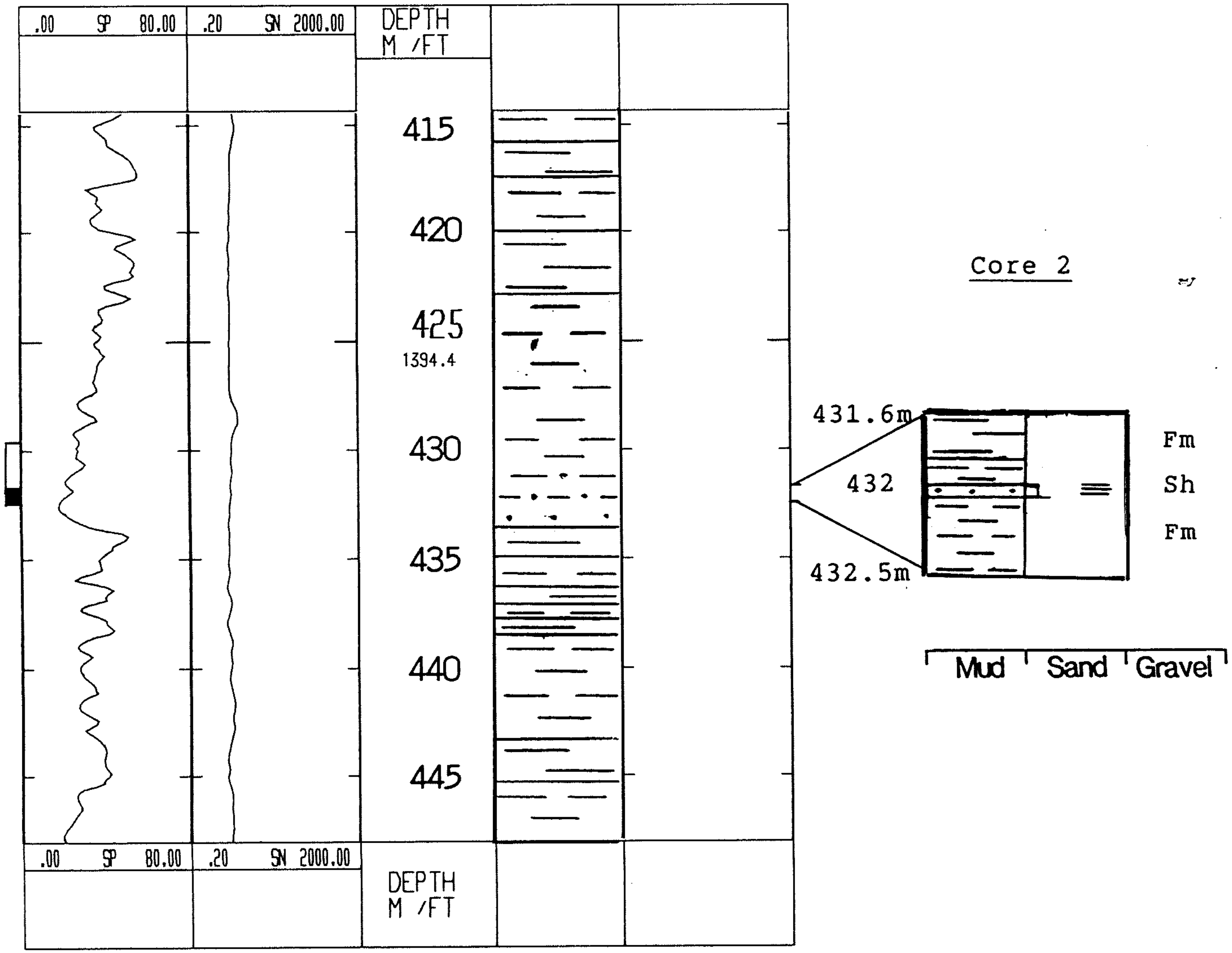
PENOLA 1



Light grey-green lithic sandstone with average porosity and permeability.
Grey-green mudstones and siltstones.

Light grey-green silty sandstone soft and friable with poor porosity.

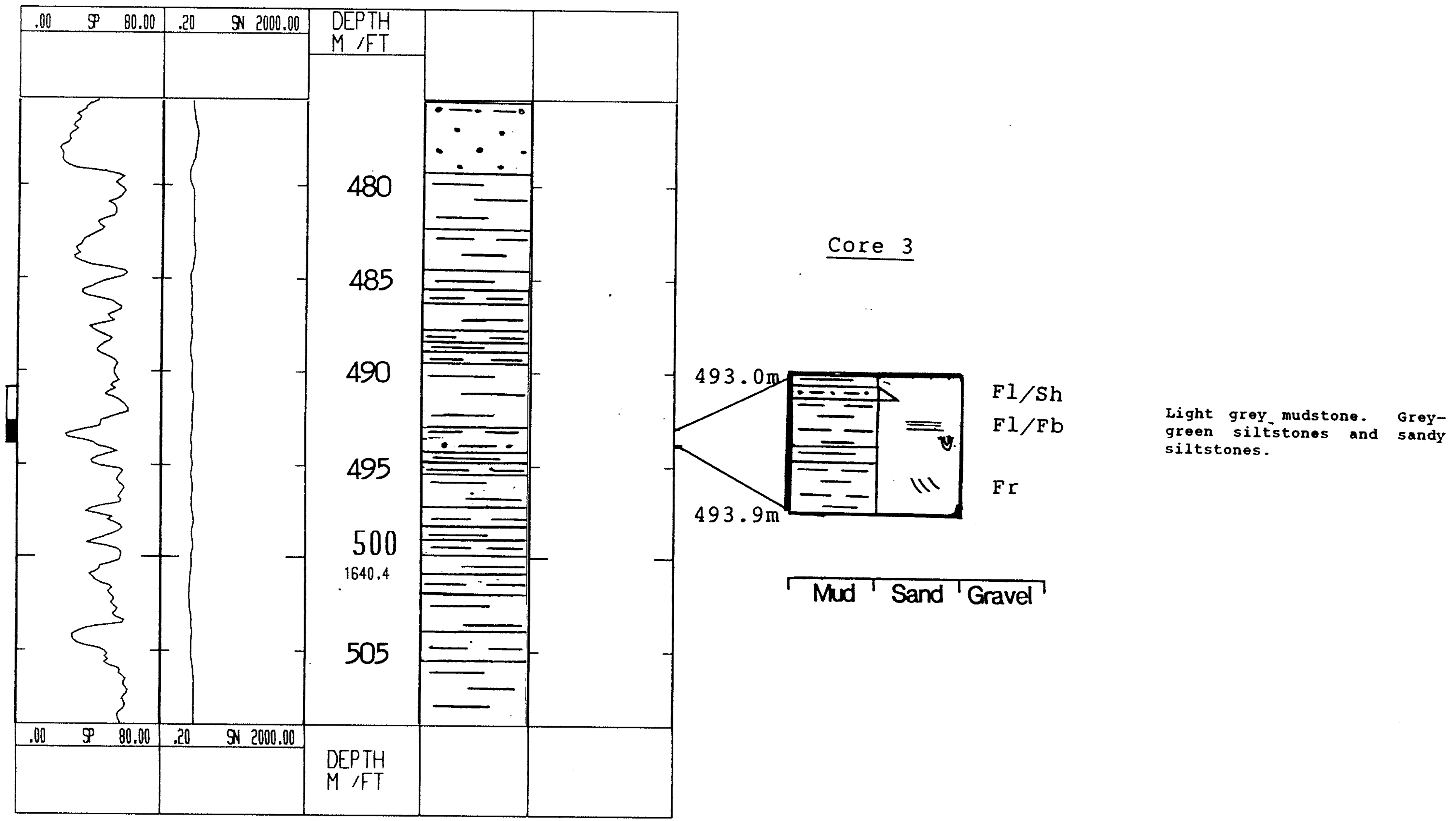
PENOLA 1



Grey siltstones and mudstones.

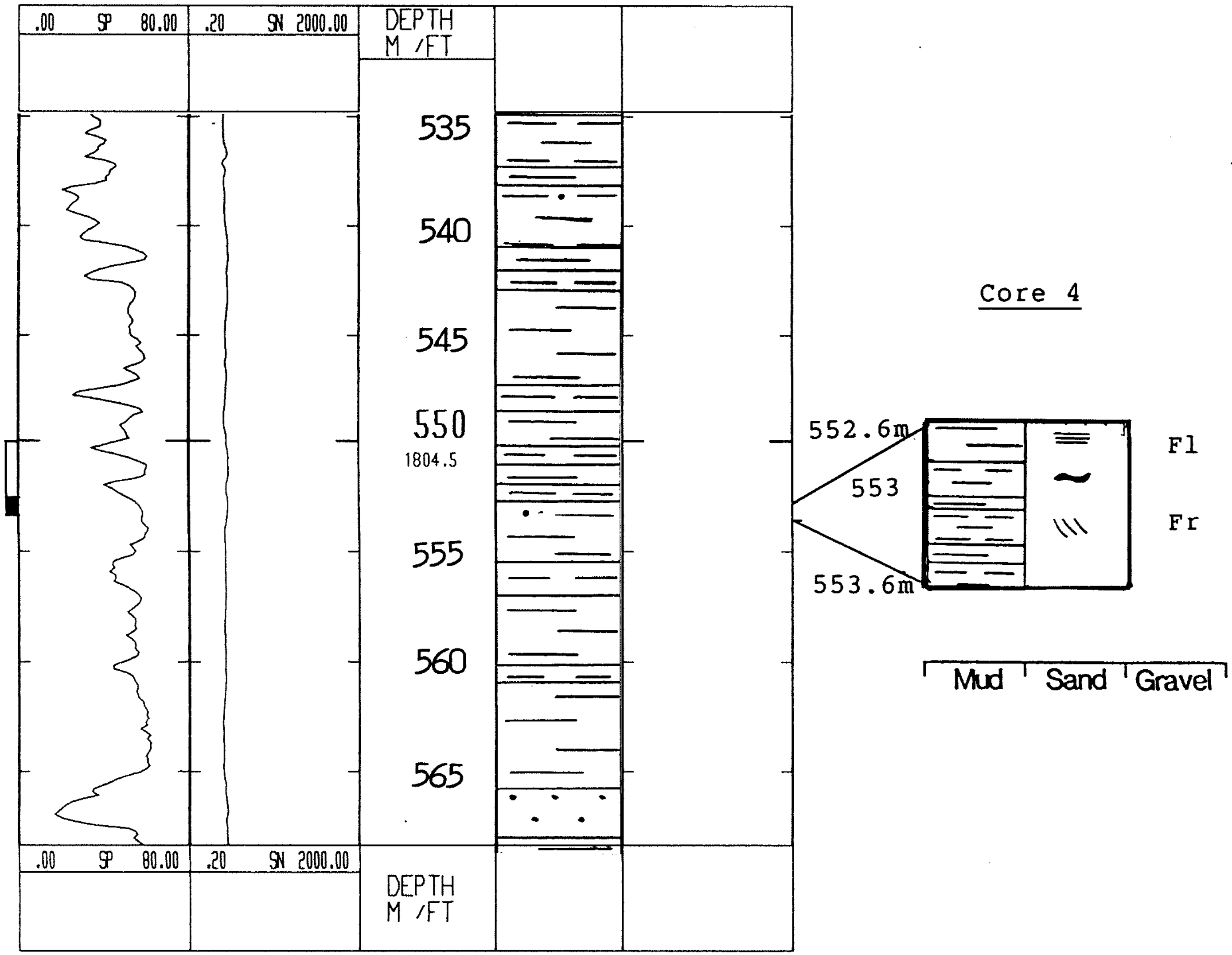
Grey-green, tight, silty sandstone.

PENOLA 1



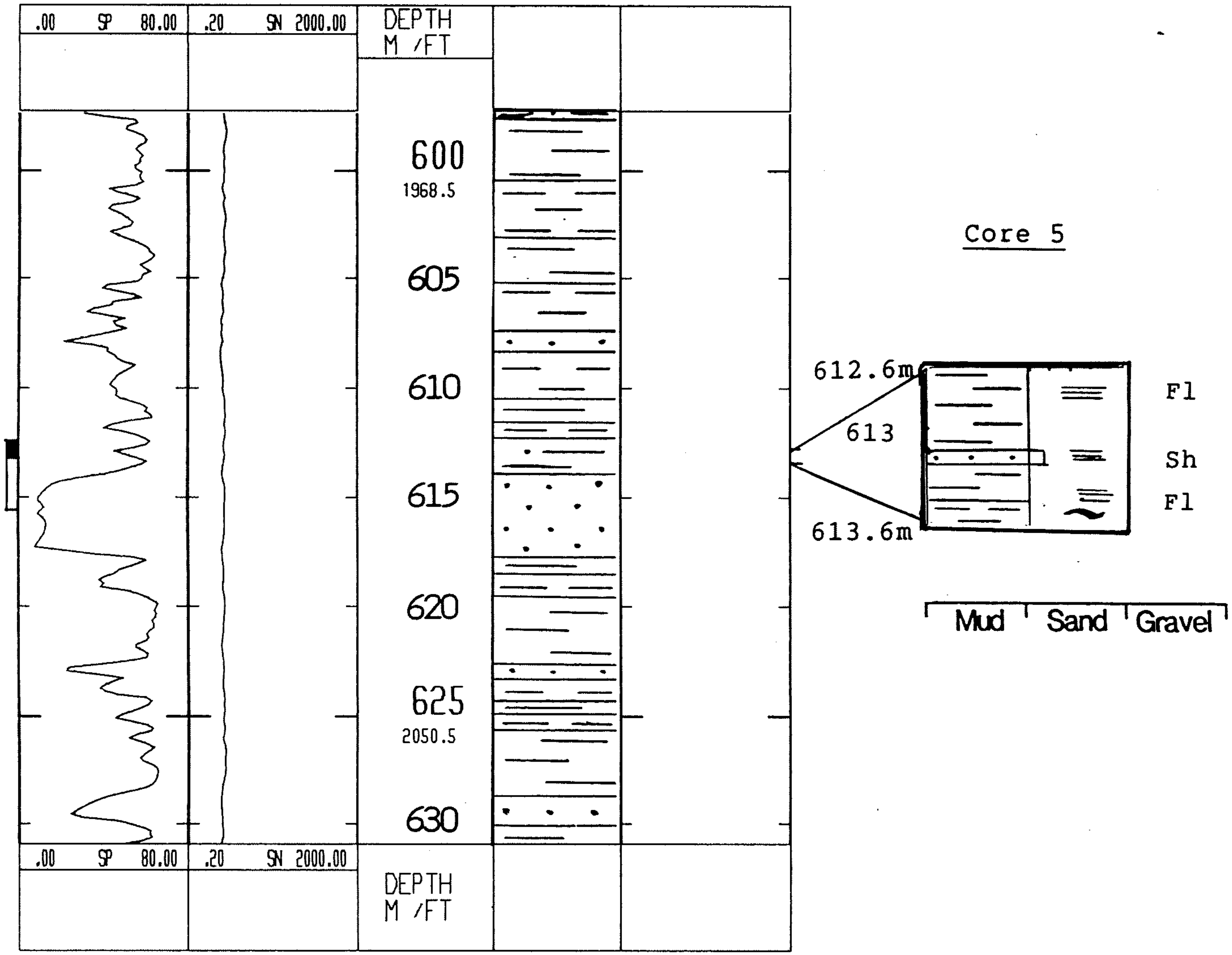
.00 SP 80.00
.20 SN 2000.00
DEPTH M /FT
480
485
490
495
500
1640.4
505
Core 3
493.0m
493.9m
Fl/Sh
Fl/Fb
Fr
Mud
Sand
Gravel
Light grey mudstone. Grey-green siltstones and sandy siltstones.

PENOLA 1



Green-grey mudstones and siltstones, with some large carbonaceous fragments.

PENOLA 1

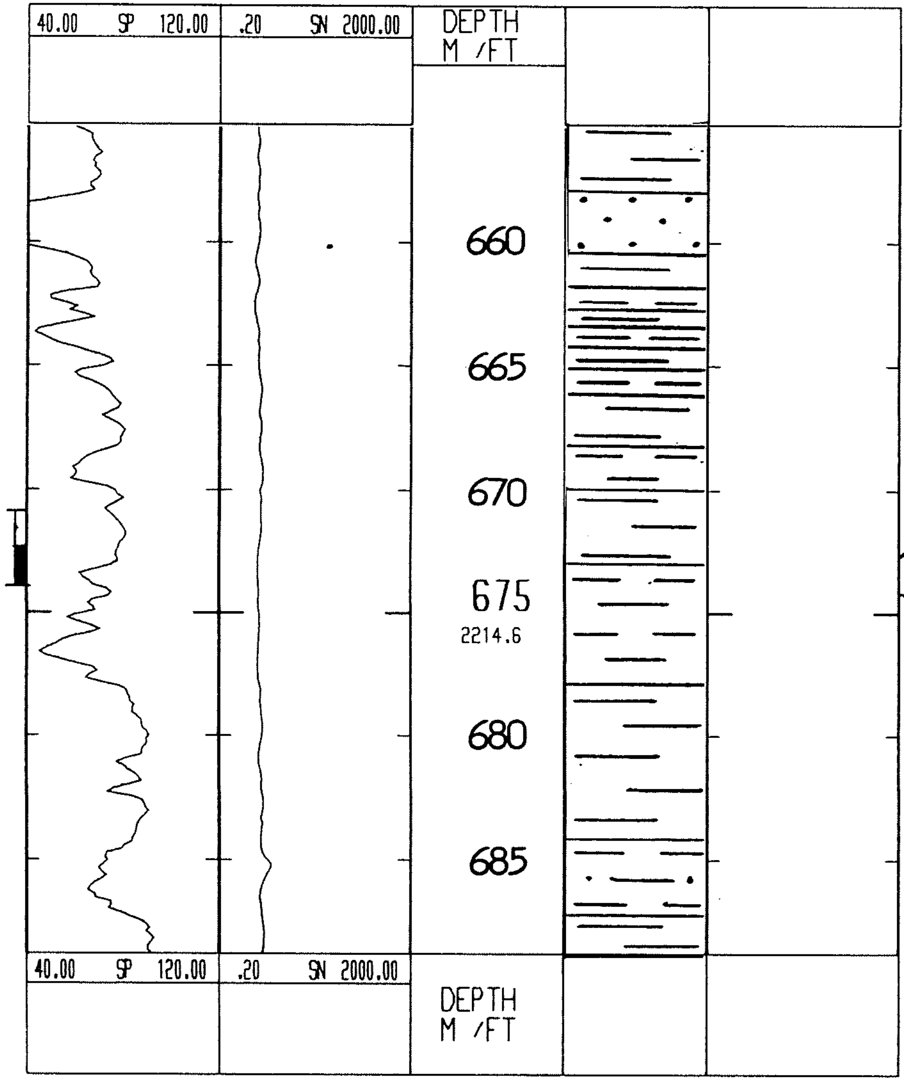


Light grey well laminated mudstone.

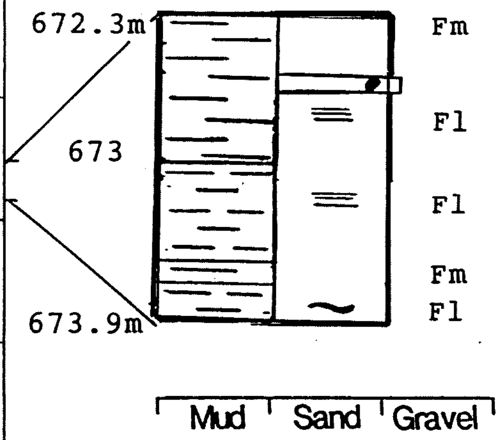
Light grey, soft, micaceous sandstone.

Light grey siltstone.

PENOLA 1



Core 6

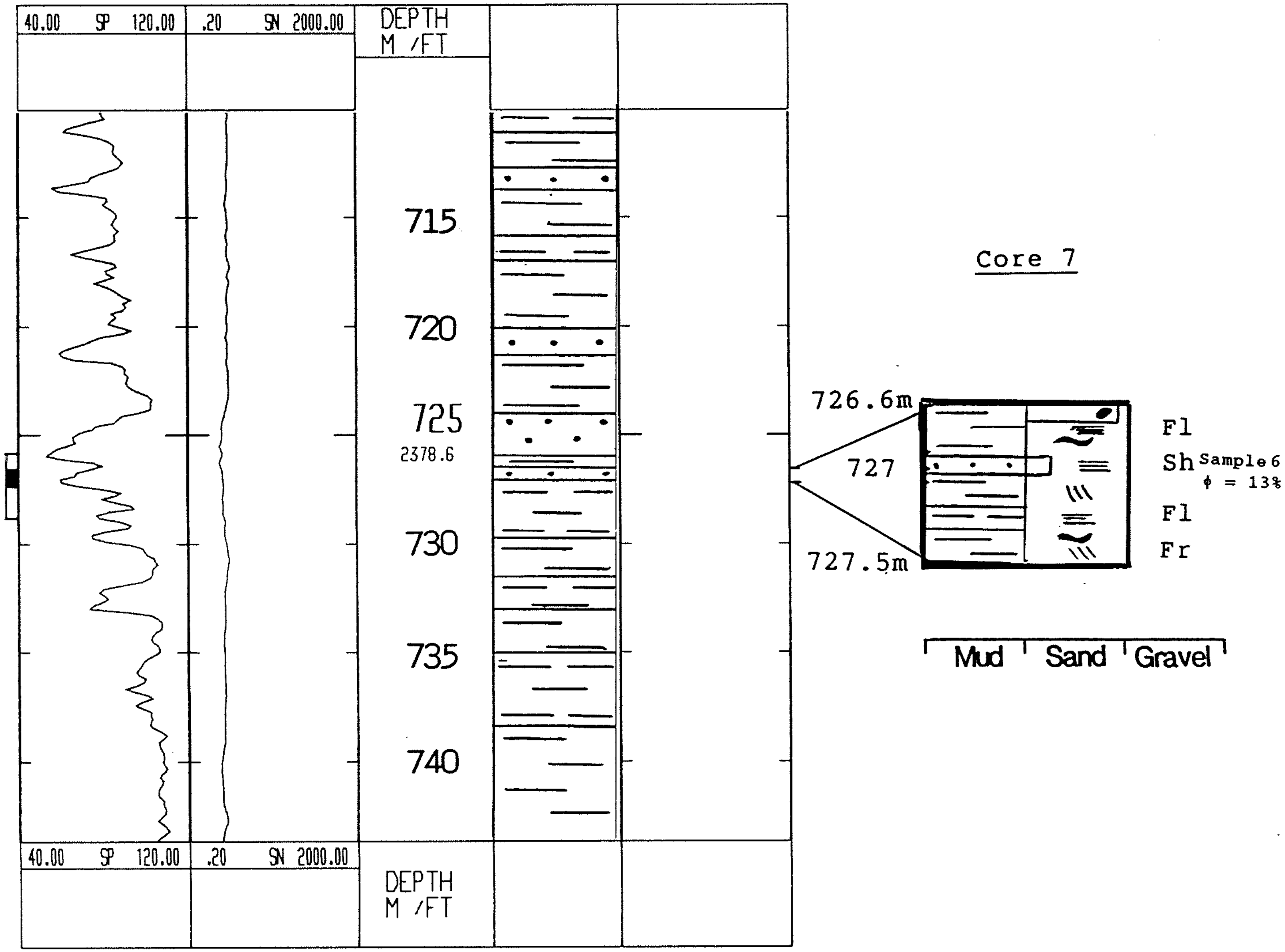


Massive dark grey mudstone with conchoidal fracture.

Grey laminated mudstone.

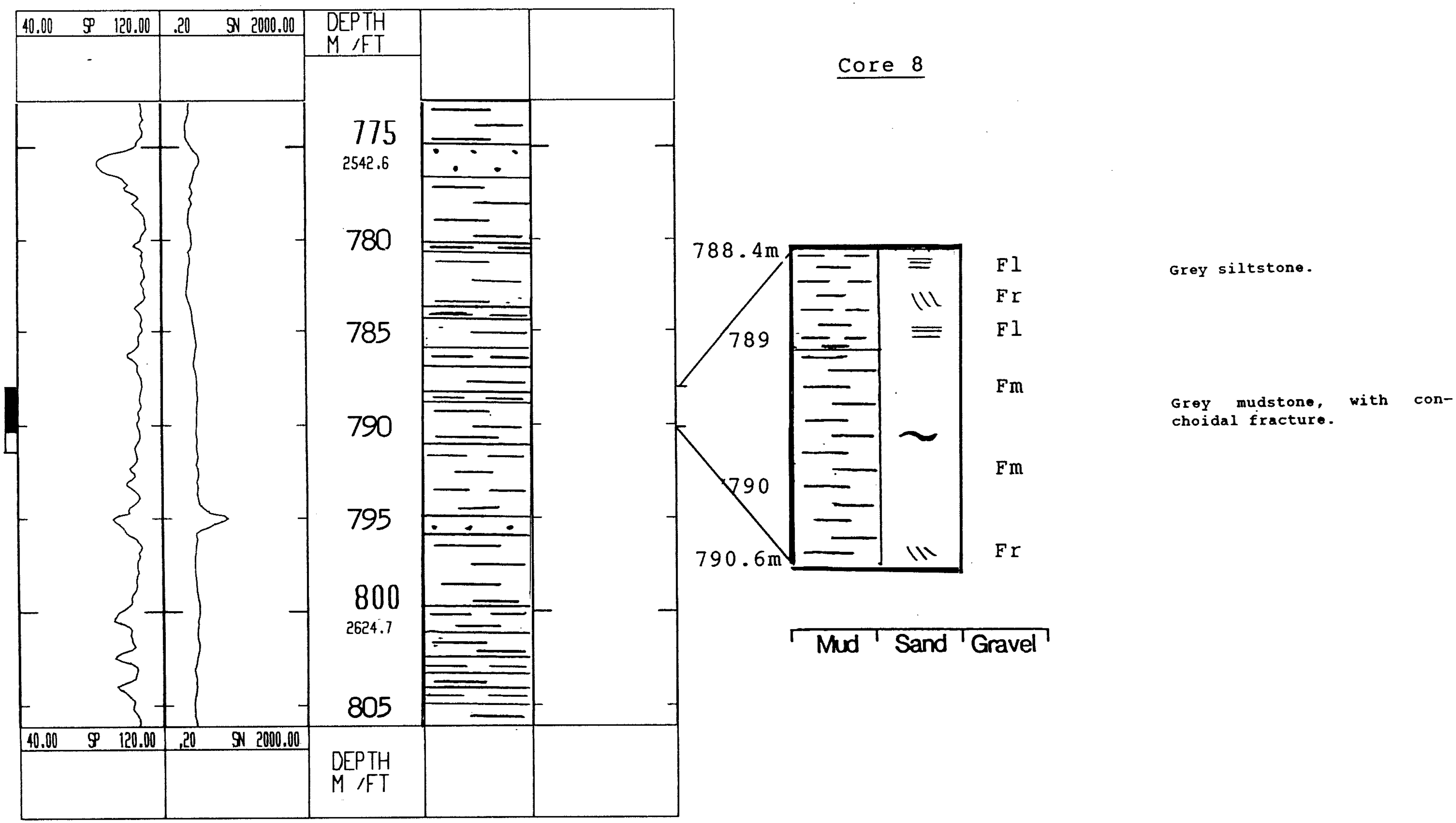
Light grey-green siltstone.

PENOLA 1

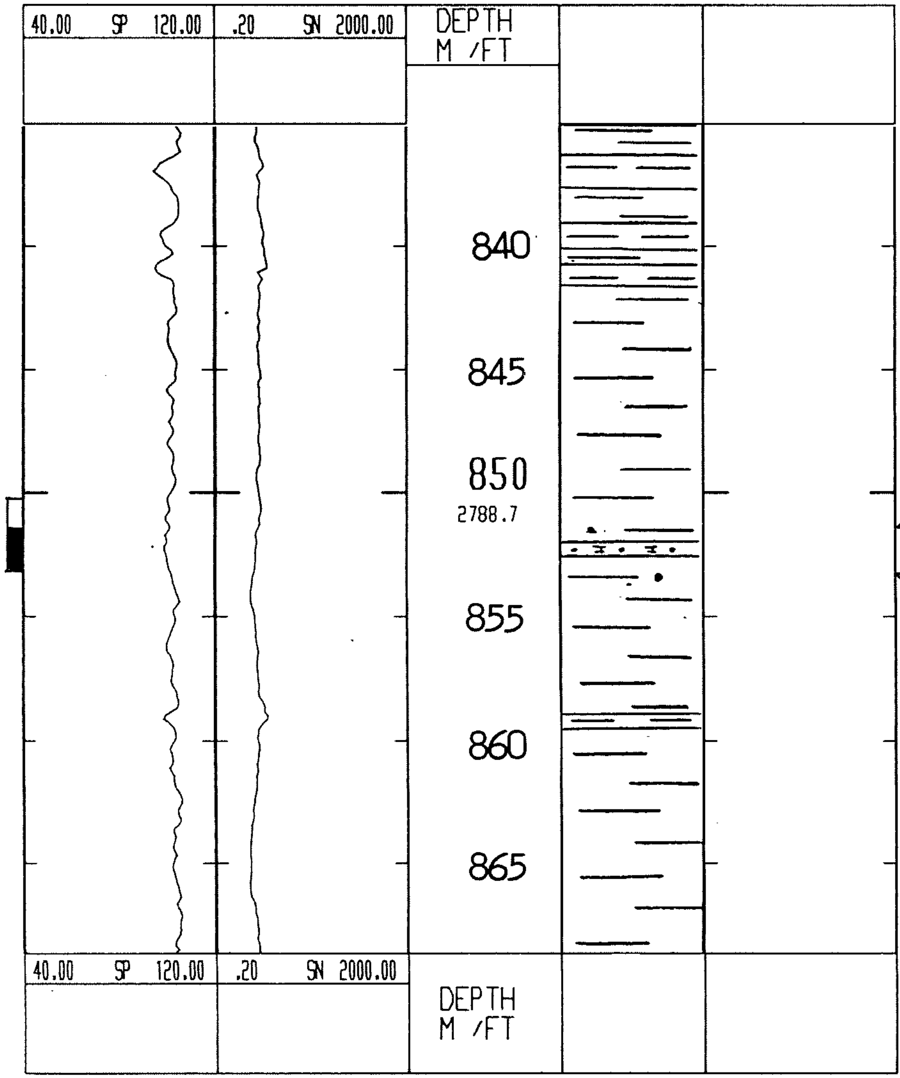


Grey-green micaceous sandstone with very good permeability.
Light grey mudstone.
Light grey-green siltstone.

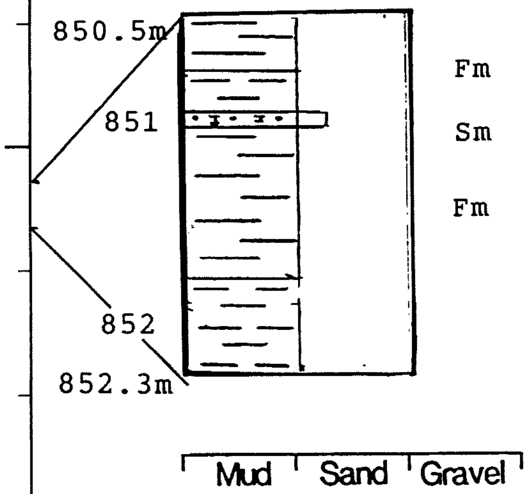
PENOLA 1


40.00 SP 120.00
.20 SN 2000.00
DEPTH M /FT
775
2542.6
780
785
790
795
800
2624.7
805
Core 8
788.4m
789
790
790.6m
Fl
Fr
Fl
Fm
Fm
Fr
Mud
Sand
Gravel
Grey siltstone.
Grey mudstone, with con-
choidal fracture.

PENOLA 1



Core 9



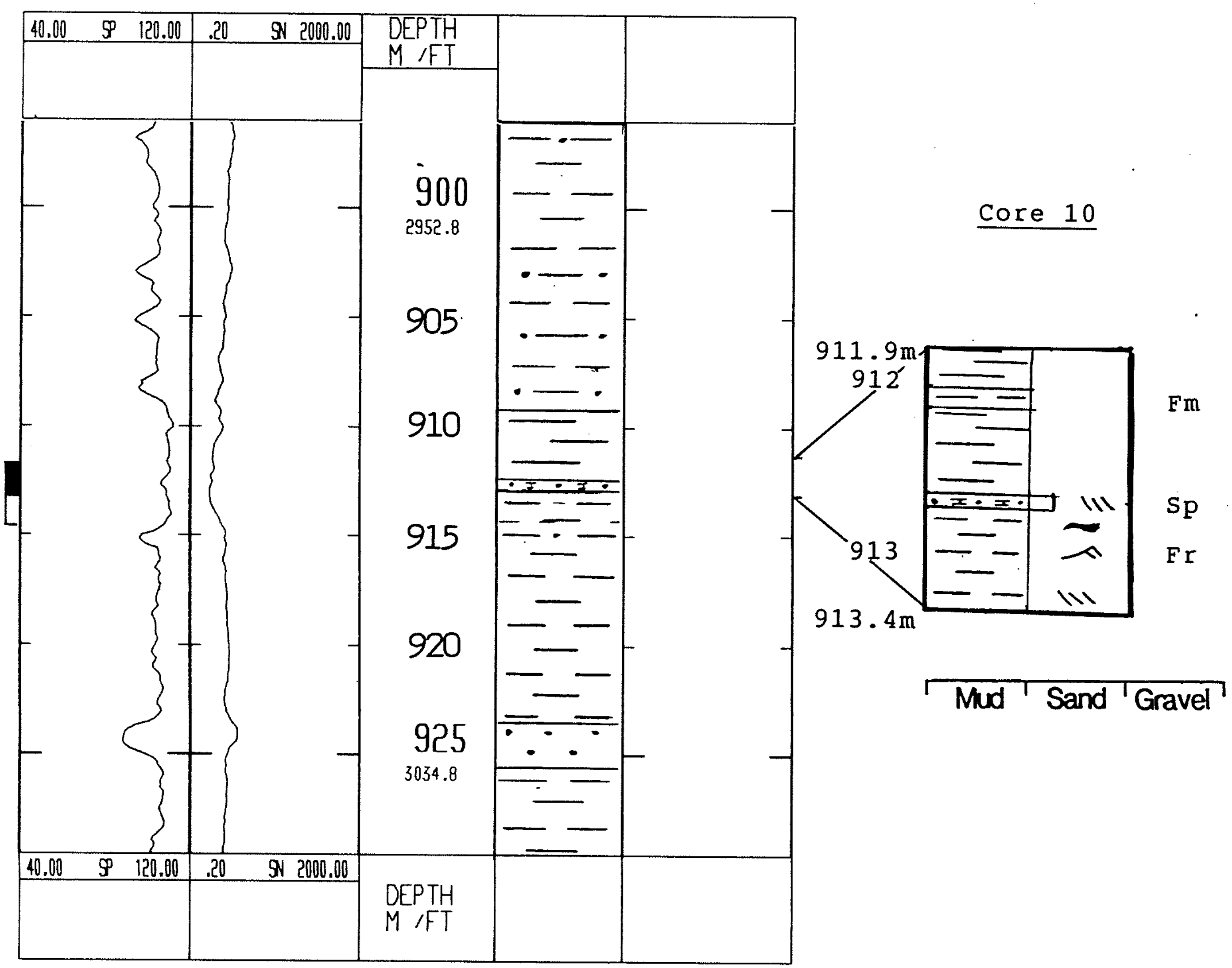
Light grey-green mudstone.

Grey-green calcareous sandstone.

Grey-green mudstone.

Grey-green siltstone.

PENOLA 1

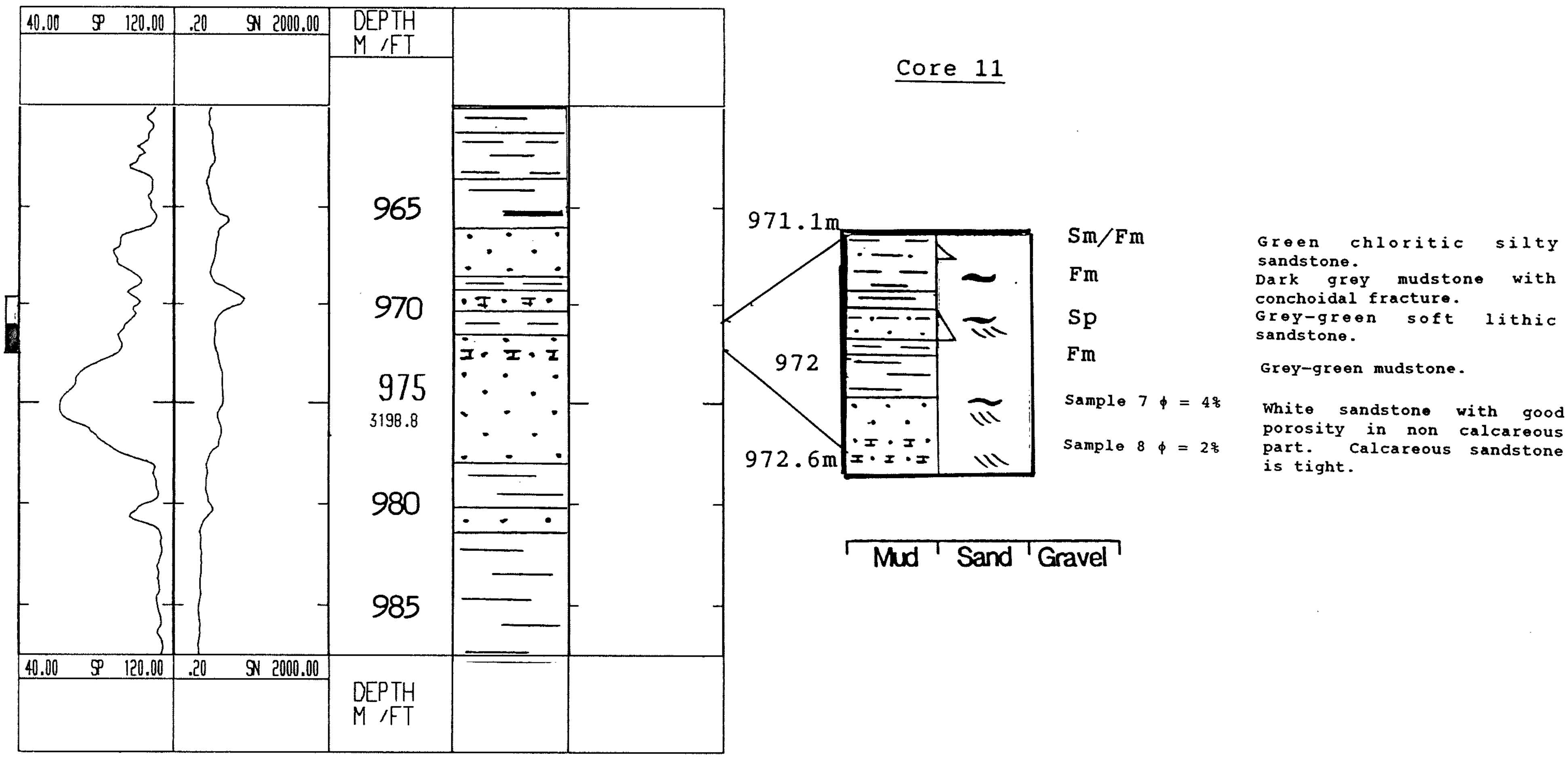


Grey-green mudstone and siltstone.

Grey calcareous sandstone.

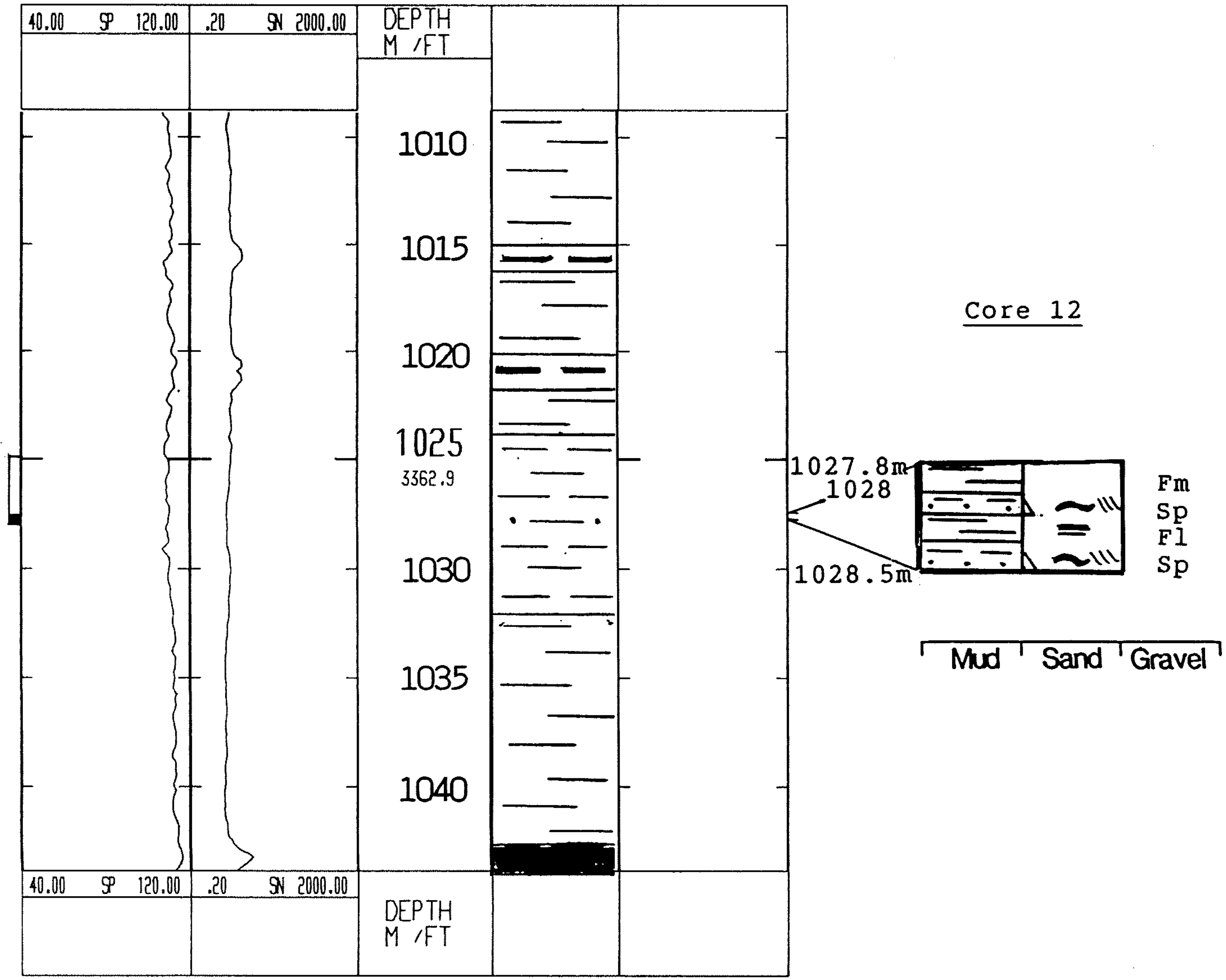
Light grey siltstone, with the bedding outlined by carbonaceous material.

PENOLA 1



40.00 SP 120.00
.20 SN 2000.00
DEPTH M /FT
965
970
975
3198.8
980
985
40.00 SP 120.00
.20 SN 2000.00
DEPTH M /FT
Core 11
971.1m
972
972.6m
Mud
Sand
Gravel
Sm/Fm
Fm
Sp
Fm
Sample 7 ϕ = 4%
Sample 8 ϕ = 2%
Green chloritic silty sandstone.
Dark grey mudstone with conchoidal fracture.
Grey-green soft lithic sandstone.
Grey-green mudstone.
White sandstone with good porosity in non calcareous part. Calcareous sandstone is tight.

PENOLA 1

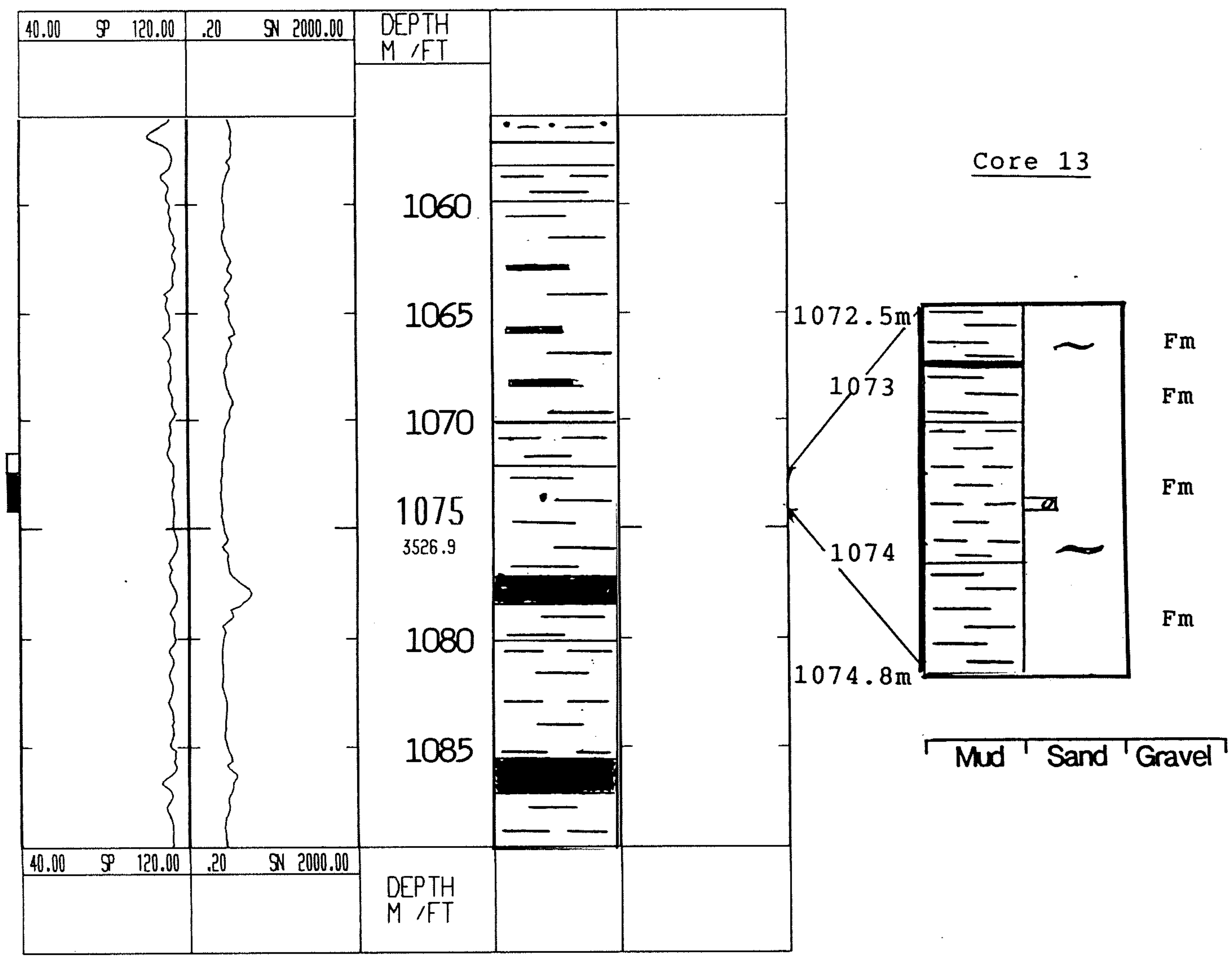


Dark grey mudstone.

Grey tight silty sandstone.

Dark grey tight silty sandstone.

PENOLA 1

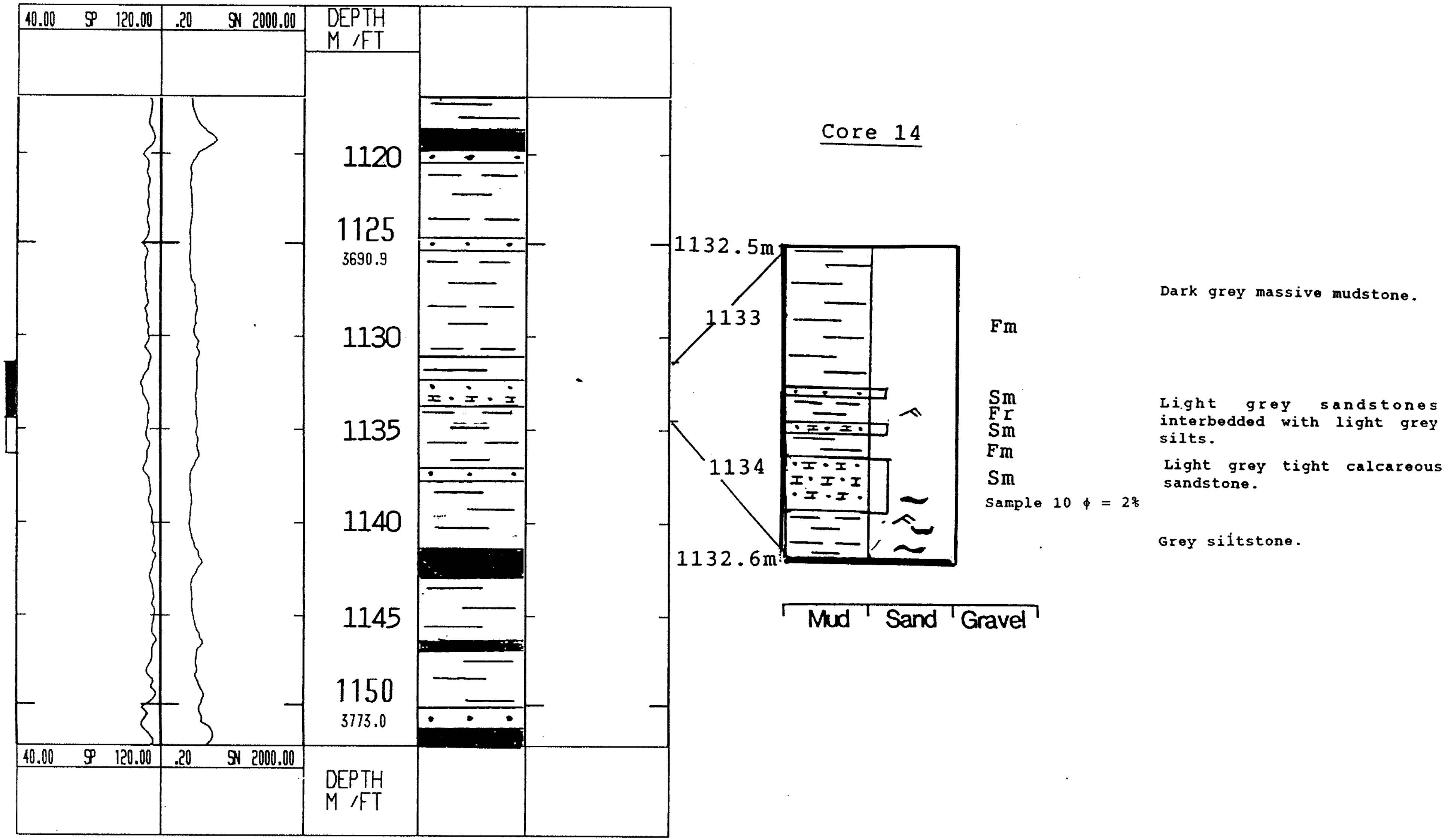


Thin layers of black coal.

Dark grey muddy siltstone, with sand sized granules of quartz.

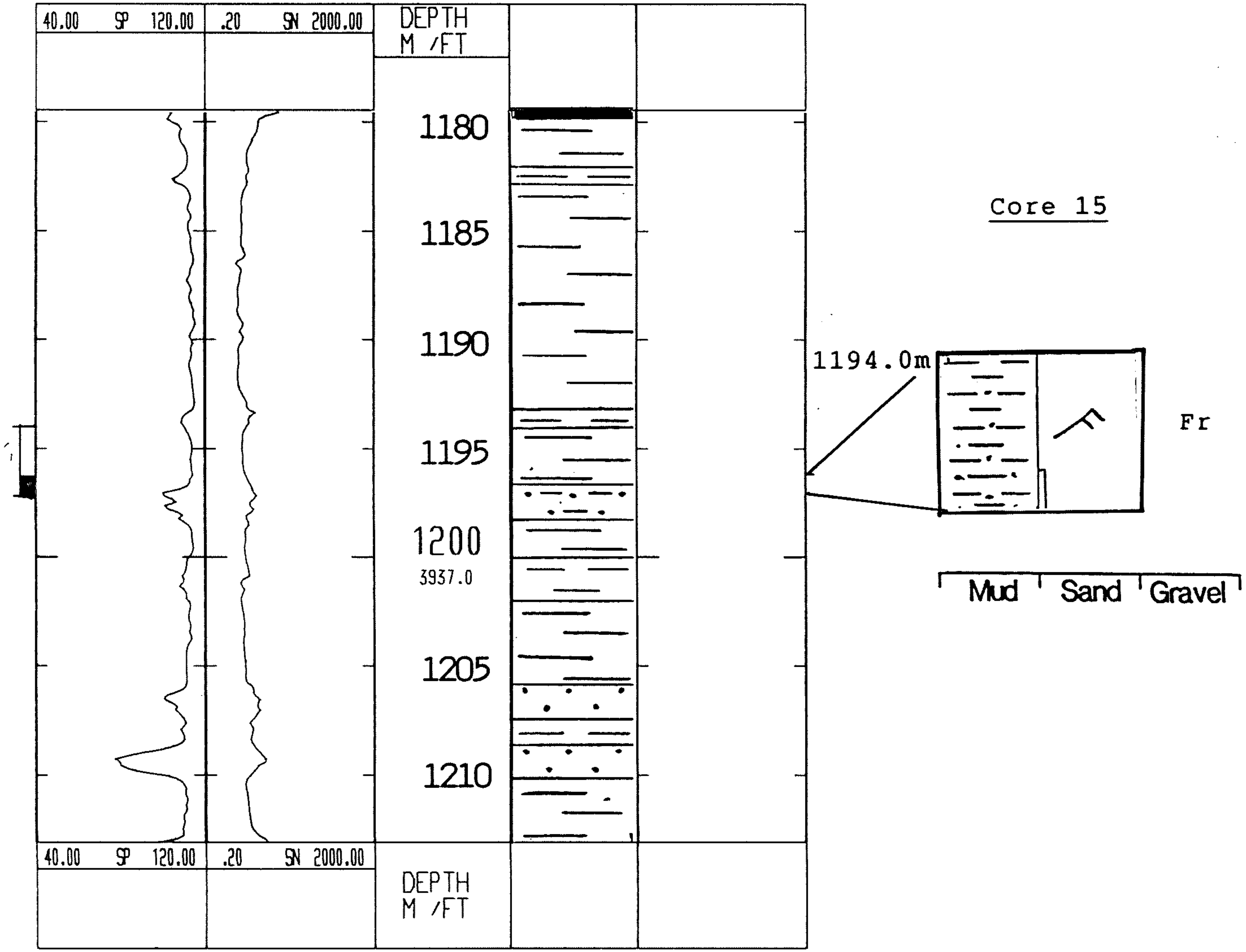
Dark grey massive mudstone with conchoidal fracture.

PENOLA 1



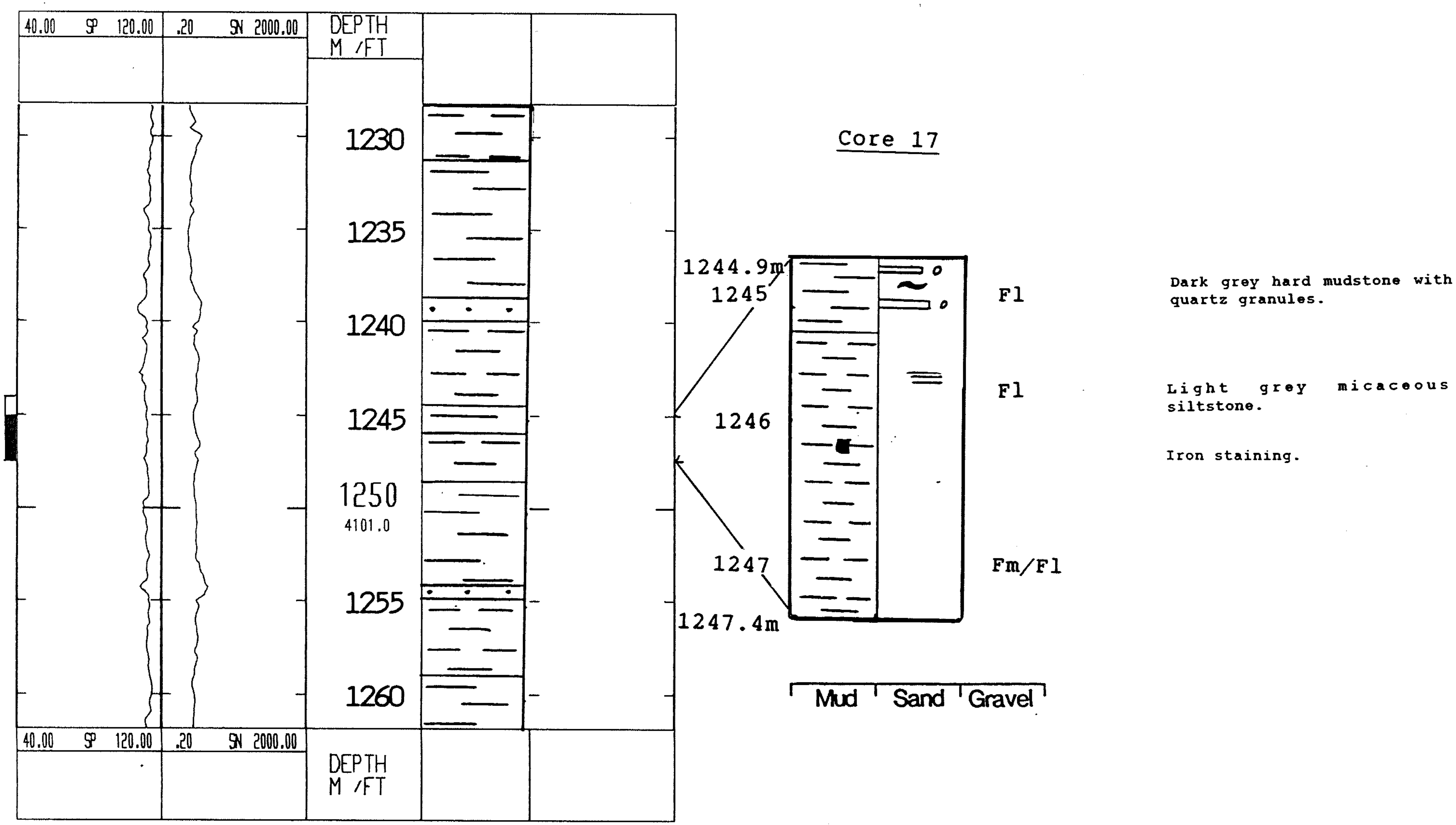
40.00 SP 120.00
.20 SN 2000.00
DEPTH M /FT
1120
1125
3690.9
1130
1135
1140
1145
1150
3773.0
Core 14
1132.5m
1133
1134
1132.6m
Mud
Sand
Gravel
Fm
Sm
Fr
Sm
Fm
Sm
Sample 10 ϕ = 2%
Dark grey massive mudstone.
Light grey sandstones interbedded with light grey silts.
Light grey tight calcareous sandstone.
Grey siltstone.

PENOLA 1



Grey siltstones and very fine grained sandstones.

PENOLA 1



40.00 SP 120.00
.20 SN 2000.00
DEPTH M /FT
1230
1235
1240
1245
1250
4101.0
1255
1260
Core 17
1244.9m
1245
1246
1247
1247.4m
Mud
Sand
Gravel
Fl
Fl
Fm/Fl
Dark grey hard mudstone with quartz granules.
Light grey micaceous siltstone.
Iron staining.

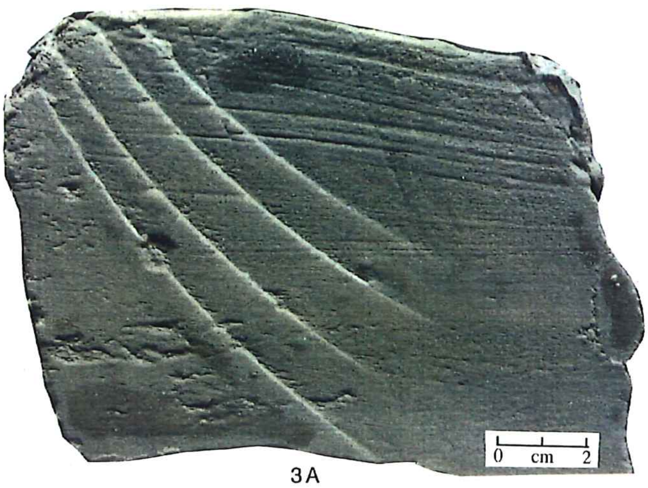
APPENDIX 4

Core Photos

PLATE 3

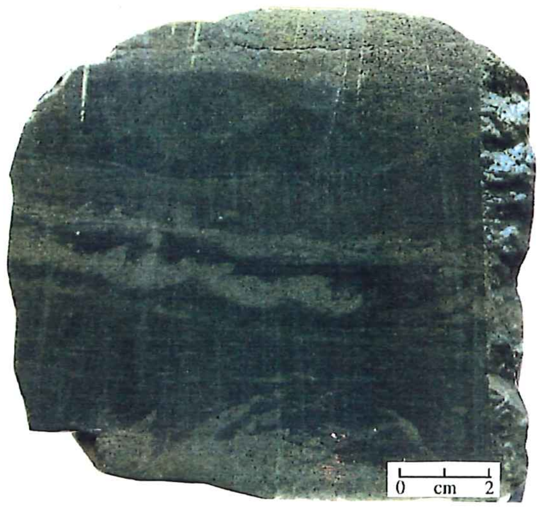
Core photograph descriptions

	Well / depth	Unit	Scale	Description
Plate 3A	Crayfish 1 - 1885'	I	1cm=0.85cm	Hummocky cross sratification
Plate 3B	Crayfish 1 - 1873'	I	1cm=1.15cm	Orgamism burrowings
Plate 3C	Crayfish 1 - 4341'	III	1cm=0.85cm	Flame structures
Plate 3D	Crayfish 1 - 4995'	IV	1cm=0.85cm	Quartz granules, linsen bedding, ripples
Plate 3E	Kalangadoo 1 - 2937'	II	1cm=0.85cm	Scour surface



3A

3B



3C

3D

3E

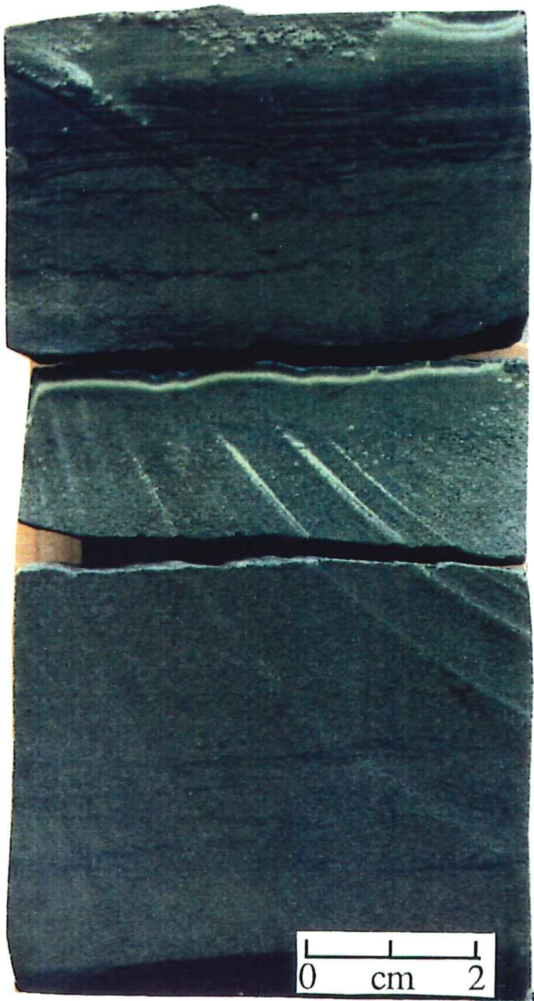
Plate 3

PLATE 4

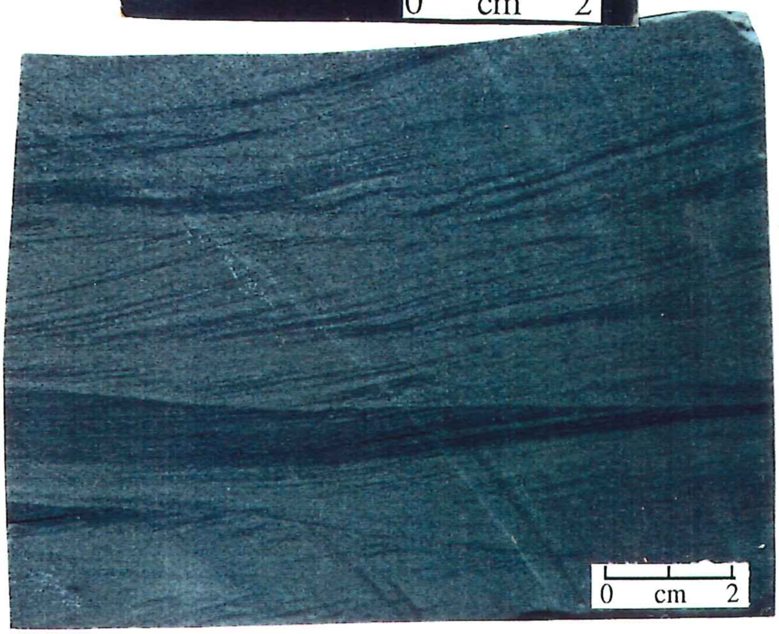
Core photograph descriptions

	Well / depth	Unit	Scale	Description
Plate 4A	Kalangadoo 1 - 3411'	II	1cm=1.15cm	Fining upwards sequence
Plate 4B	Geltwood Beach 1 - core #15	II	1cm=0.85cm	Climbing ripples
Plate 4C	Geltwood Beach 1 - 10321'	IV	1cm=0.85cm	Scour surface
Plate 4D	Beachport 1 - 3940 '	III	1cm=0.85cm	Iron hardgrounds

4A



4B



4C

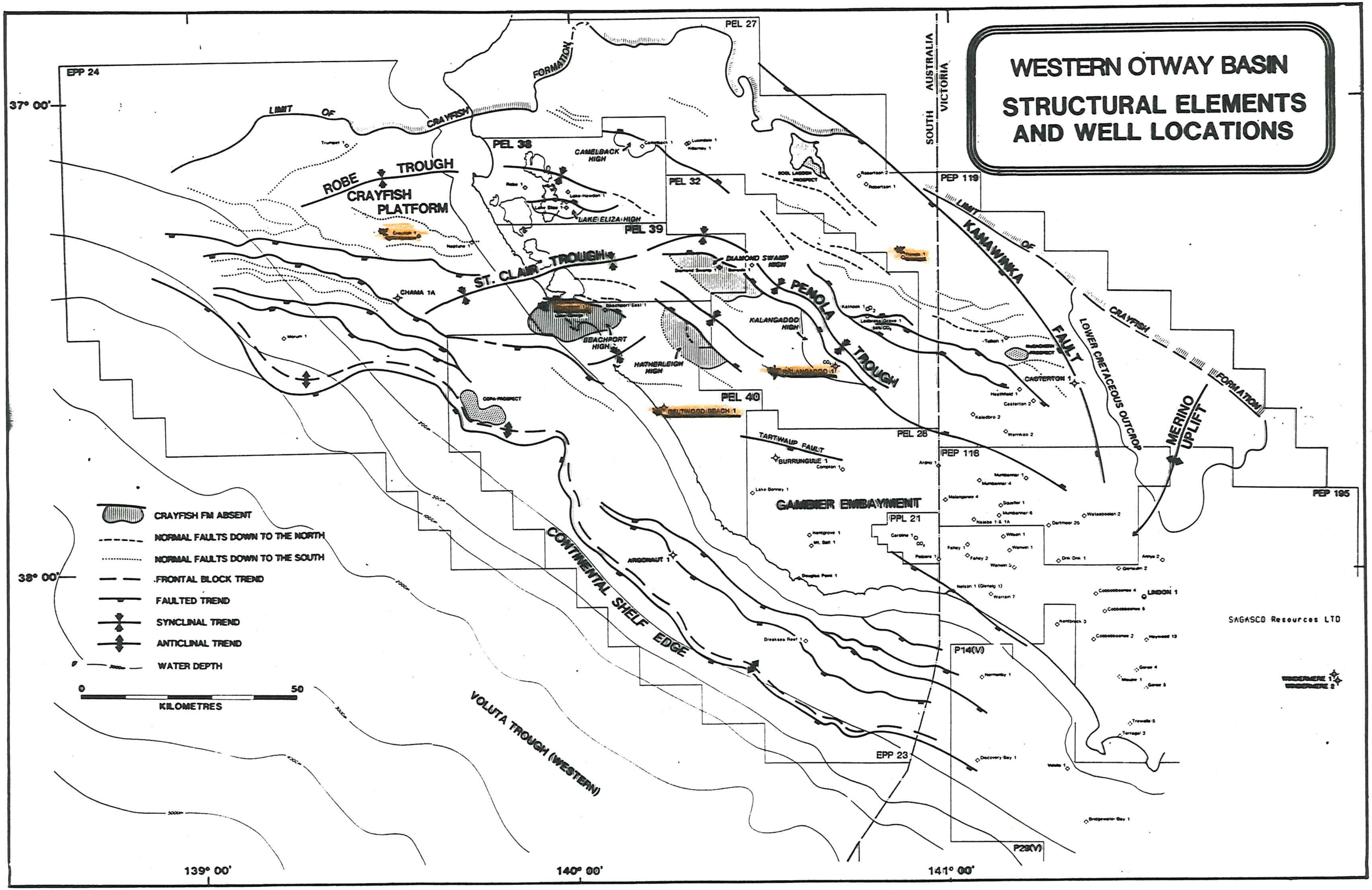
4D

Plate 4

APPENDIX 5

Well Summaries

WESTERN OTWAY BASIN STRUCTURAL ELEMENTS AND WELL LOCATIONS



BEACHPORT 1

Operator : South East Oil
Spud : 01/09/61
TD : 1207.94m
Latitude : 37° 26′ 55" S
Longitude : 140° 02′ 15" E

CRAYFISH 1

Operator : Esso
Spud : 24/09/67
TD : 3199.52m
Latitude : 37° 17′ 22" S
Longitude : 139° 35′ 50" E

GELTWOOD BEACH 1

Operator : Beach Petroleum
Spud : 22/08/63
TD : 3749.09m
Latitude : 37° 39′ 44" S
Longitude : 140° 14′ 35" E

KALANGADOO 1

Operator : Alliance
Spud : 13/05/65
TD : 2755.43m
Latitude : 37° 34′ 28" S
Longitude : 140° 41′ 25" E

PENOLA 1

Operator : Oil Development
Spud : 07/02/61
TD : 1519.45m
Latitude : 37° 20′ 38" S
Longitude : 140° 52′ 35" E