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THE HYDROCARBON POTENTIAL OF THE JURASSIC AND LOWER CRETACEOUS SEDIMENTS FROM FIVE WELLS IN THE EROMANGA BASIN, SOUTH AUSTRALIA

BY

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ABSTRACT

Organic matter in the Jurassic and Lower Cretaceous sediments from five wells in the central Eromanga Basin was studied microscopically. The Lower Jurassic Birkhead Formation, Late Jurassic to Lower Cretaceous Murta Member and Lower Cretaceous Transition Beds were sampled over their entire sections.

The dispersed organic matter (d.o.m.) of the Birkhead Formation is dominated by vitrinite, with exinite prominent and inertinite less important. The Murta Member and Transition Beds are dominated by exinite and inertinite with vitrinite a significant but minor component. The exinite content is proportional to total d.o.m. content in all three units indicating that variation in the total d.o.m. content is in response to varying rates of sedimentation. Examination of coals show that vitrinite is the dominant maceral with inertinite and exinite as variable minor components.

On the basis of the coal and d.o.m. data gathered some comment is made on the depositional environment of the three units. The Birkhead Formation was deposited in a lacustrine environment with associated forest swamps, open marsh swamps and exposed swamps. The Murta Member was laid down in a barrier coastline environment. The Transition Beds are marine in origin.

Vitrinite reflectance studies indicate that rank and geothermal gradients vary in a complex fashion along the line of section. This is the result of varying depth of burial, variable thermal input from different parts of the basement and thickness of the Pre-Jurassic sedimentary sequence. The Murteree Nappacoongee anticlinal trend was a source of high heat flow in Jurassic-Cretaceous time.

A large proportion of the shales comprising the Murta Member are high quality petroleum source rocks containing Type-I and Type-II kerogen. Unfortunately, the material studied is probably immature. Future work should concentrate on delineating areas where the Murta Member is characterized by higher levels of maturity. The source rocks of the Birkhead Formation and Transition Beds occur over smaller intervals than in the Murta Member and contain Type-III kerogen. Therefore, their petroleum potential is relatively low.

INTRODUCTION

Until recently the Eromanga Basin (Figure 1) was thought to have limited hydrocarbon potential. Exploration was concentrated on the underlying Cooper Basin which contains major gas reserves and some liquid hydrocarbons. Samples from the Post-Triassic were either not collected or not examined. Some work was done on the stratigraphy of the Eromanga Basin including papers by Nugent (1969) and Vine (1966).

The Eromanga Basin is now regarded as a major target for hydrocarbon exploration. A.J. Kantsler, M. Smyth and B. Stevenson have all been involved in studies of source rocks. Such studies are still in their early stages.

The major aim of this project was to determine the source rock potential of the Jurassic and Lower Cretaceous sediments from five wells in the vicinity of the Murteree-Nappacoongee anticlinal trend (Figure 2). The quality of source rocks depends on the amount and type of dispersed organic matter (d.o.m.) present and the maturity of the rocks. Polished sections of particular shale and coal from the Birkhead Formation, Murta Member and Transition Beds were examined microscopically to determine this. Samples were generously supplied by the Interest Holders*.

Using the data gathered in this study the lateral and vertical variations in coal, d.o.m. type and content were noted. Comments on the environment of deposition were made. Lateral and vertical rank variations across the line of section were noted and used to provide information on temperature gradients.

TABLE 1

Well	Longitude	Latitude	Sponsor
Dullingari North-1	140° 51'55.5"E	28° 04'36"S	Santos, Delhi, Vamgas, SAOGC.
Nappacoongee-2	140° 46'50"E	28° 01'44"S	Santos, Delhi, Vamgas, SAOGC, Pursuit.
Wilpinnie-1	140° 44'10"E	28° 03'38"S	Santos, Delhi, Vamgas, SAOGC, Pursuit.
Della-8	140° 39'51"E	28° 05'46.7"S	Santos
Della-7	140° 36'18.83"E	28° 06'28.81"S	Santos, Delhi, Vamgas, SAOGC, Pursuit.

* Santos Ltd., Delhi International Oil Corporation (Operator), Vamgas Ltd., S.A. Oil and Gas Corporation Pty. Ltd., and Pursuit Oil N.L.

1 GEOLOGY

1.1 Regional Setting

The Eromanga Basin is a part of the Great Artesian Basin. It is the central one of three main Jurassic-Cretaceous downwarps. To the north it merges with the Carpentaria Basin and to the south east merges with the Surat Basin. It unconformably overlies the Permo-Triassic Cooper Basin.

The geology of the area has been described by Nugent (1969), Vine (1966) and Kantsler, et al. (in press). The following discussion draws on these works and personal experience gathered while working on the Eromanga Basin for the South Australian Department of Mines and Energy.

1.2 Structure

Sedimentation in the Eromanga Basin was initiated during Early Jurassic time by major epeirogenic downwarping of most of eastern Australia (Kantsler, et al., in press). The deepest part of the basin lies above the Cooper Basin. According to Vine (1966) the structure comprises a belt of domes, periclines and anticlines many of which are the subdued expression of tighter folds in the underlying basin. These, in turn, are growth structures resulting from sedimentation over periodically uplifted basement blocks. Earlier periods of basin formation have resulted in elongate faults and fault induced monoclines. Low angle dips dominate due to the relatively undisturbed nature of the basin.

The wells studied are all located in the vicinity of a sinuous, narrow, north-easterly trending anticlinal zone; the Murteree - Nappacoongee (MN) anticlinal trend. This trend is bound to the north by the Nappamerri Trough and to the south by the Tenappera Trough (Figure 1).

1.3 Stratigraphy

A generalized stratigraphic column is presented in Figure 3.

The Jurassic sequence is composed of thick sandstone units alternating with shale-siltstone interbeds and minor coal seams. The sandstones are quartzose, angular to subrounded and porous. Pores are filled to varying degrees with clay minerals such as kaolinite and by siliceous and locally calcareous cements. Grainsize varies from very fine to very very coarse.

Sorting ranges from good to very poor. The shale-siltstone interbeds are grey in colour, carbonaceous, micaceous and occasionally pyritic.

The source of sediment for the Eromanga Basin throughout the Jurassic was probably the land surface along the western margins of the Great Artesian Basin (Nugent, 1969). He claims that high energy fluviatile sedimentation dominated in the western part of the basin while further to the east, in the area under study, this was interrupted by deposition in lower energy environments.

The Jurassic was generally deposited under conditions of continental sedimentation although several marine incursions have been suggested (Vine, 1966; Delhi, pers. comm., 1980). The Jurassic sequence begins with the basal Hutton Sandstone of braided fluvial origin which unconformably overlies the Triassic Nappamerri Formation.

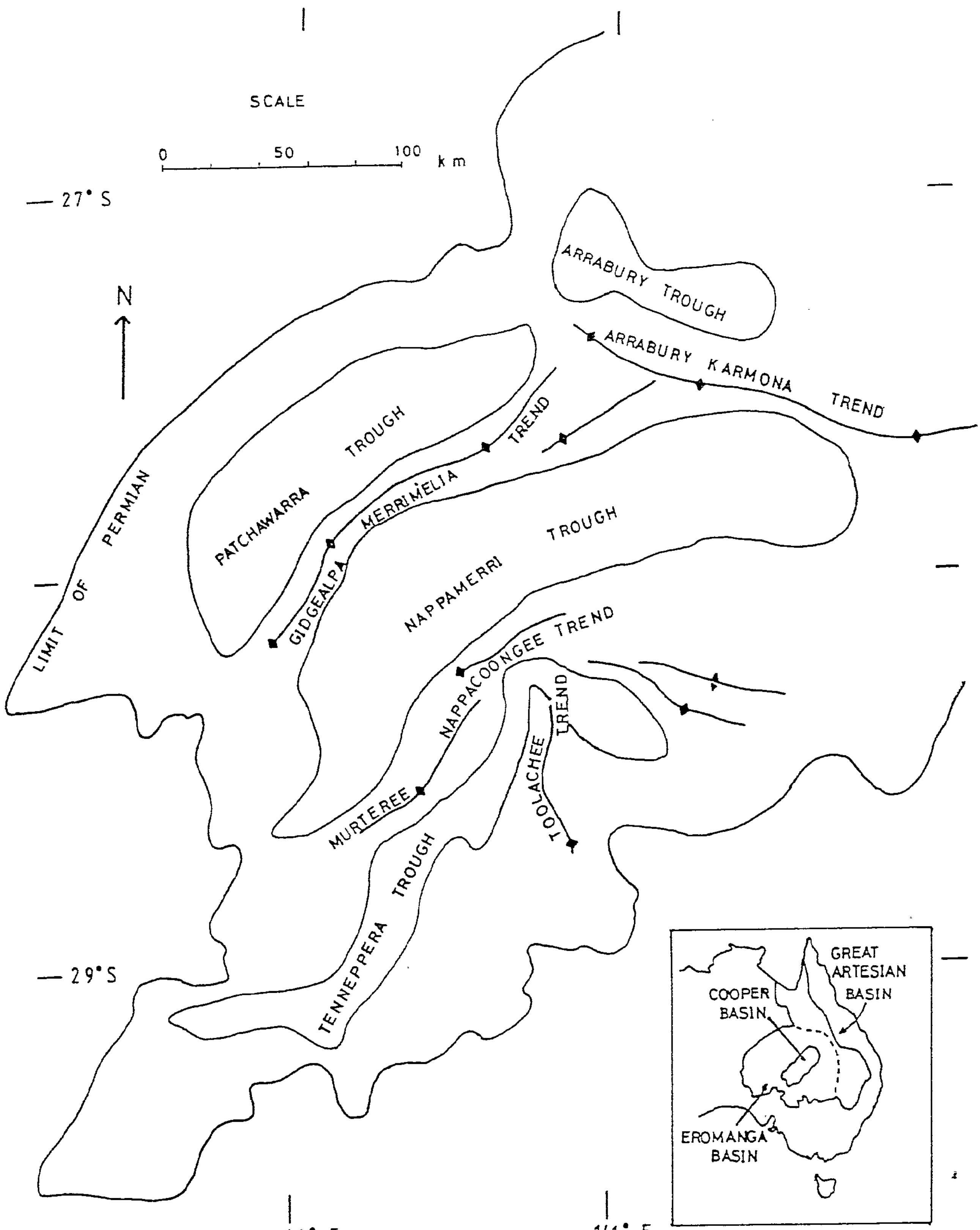
According to Nugent (1969) irregular shale and coal beds near the base of the Hutton Sandstone were probably deposited in locally restricted lake, swamp or marsh environments. The unit displays abrupt thickness variations. Nugent (op. cit.) claims this indicates that large parts of the basin remained topographically positive at this time with rivers and streams cutting through the area, leaving isolated areas of sediment to be preserved. Low energy depositional conditions followed deposition of the Hutton Sandstone. The shales and silts of the Birkhead Formation were laid down in a predominantly lacustrine environment with some contribution from forest swamp facies.

This was followed by deposition of the Mooga Formation which may have been laid down in a barrier coastline environment. Such a complex consists of four laterally related environments. These are, from west to east, fluviatile coastal plain, lagoonal and tidal flat complex, shoreface sand (T. Mount, pers. comm., 1980) and shallow water environment. The fluviatile coastal plain facies is represented by the Namur Member which passes vertically and laterally into the Murta Member of Late Jurassic-Early Cretaceous age. The lower part of this upper member represents the lagoonal tidal flat complex. This passes into thin sands thought to represent a shoreface bar. The shallow water facies which succeeds the shoreface sands is represented by shales. The Mooga Formation was built up as the complex transgressed westward across the flood plain surface.

The Lower Cretaceous Transition Beds are composed of grey, carbonaceous, micaceous, glauconitic shale and siltstones. The presence of glauconite and marine fossils would indicate the Transition Beds are marine (T. Mount, pers. comm., 1980).

FIGURE 1

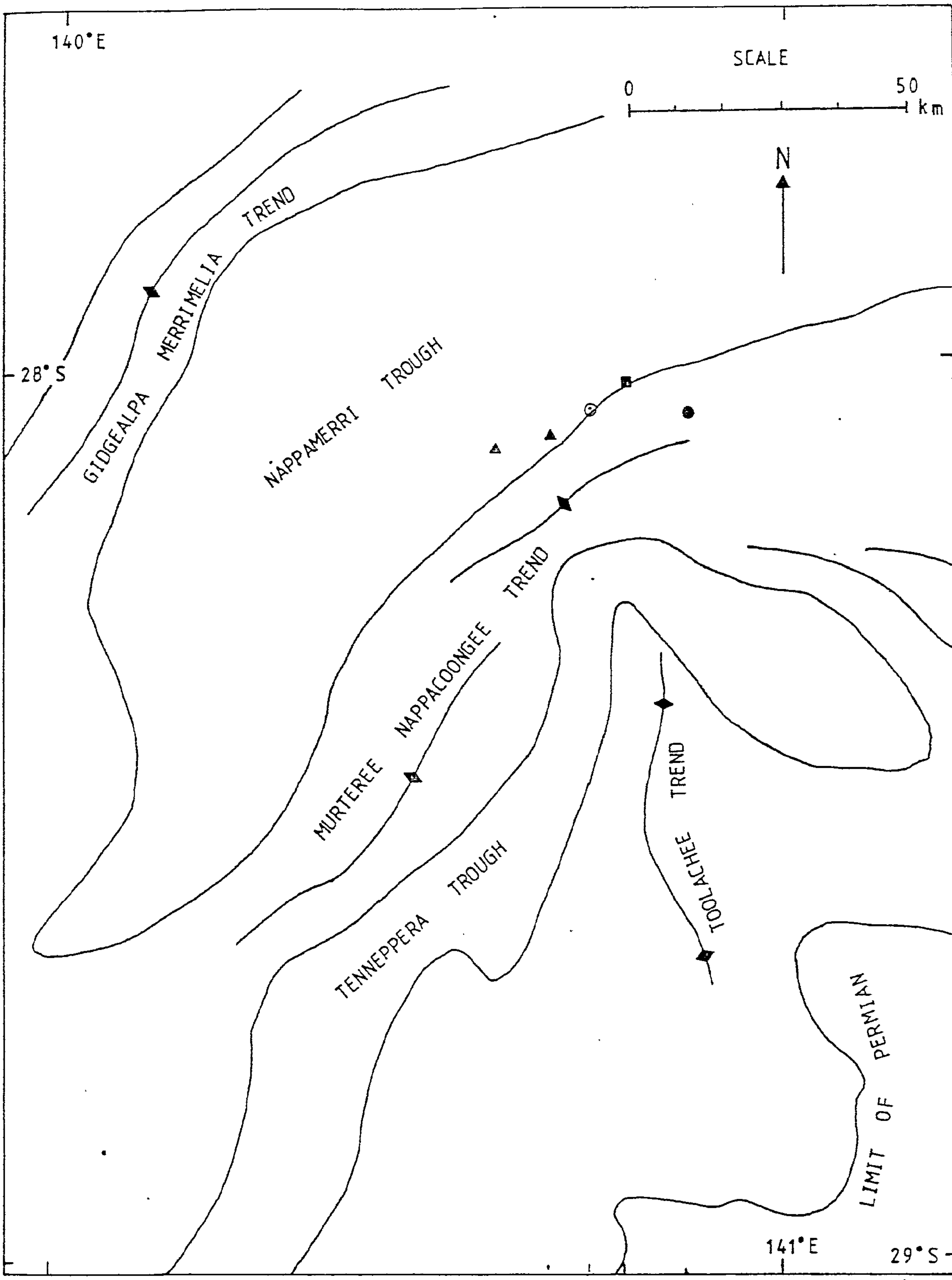
SOUTH COOPER BASIN



After Lonergan (1979)

FIGURE 2

WELL LOCATION MAP



● DULLINGARI NORTH - 1

■ NAPPACOONGEE - 2

○ WILPINNIE - 1

▲ DEILA - 8

△ DELLA - 7

S.M.M. '80

COOPER BASIN

GENERALIZED STRATIGRAPHY

PERIOD	EPOCH	STAGE	GROUP	FORMATION (MAX THICKNESS IN m)	HYDRO-CARBONS	ENVIRONMENTS
QUATERNARY & TERTIARY				UNNAMED		
CRETACEOUS	UPPER	CENOMANIAN		WINTON FM		FLUVIAL – LACUSTRINE
CRETACEOUS	LOWER	ALBIAN		TAMBO FM		SHALLOW MARINE
CRETACEOUS	LOWER	APTIAN		ROMA FM		SHALLOW MARINE
CRETACEOUS	LOWER	NEOCOMIAN		TRANSITION BEDS		SHALLOW MARINE
JURASSIC	UPPER			MOOGA FM		BARRIER COASTLINE
JURASSIC	MIDDLE			BIRKHEAD FM	☼ ◒	LACUSTRINE
JURASSIC	LOWER			HUTTON SS	● ☼	FLUVIAL
TRIASSIC	MIDDLE TO LOWER			NAPPAMERRI FM 494	☼	LACUSTRINE – FLUVIAL
PERMIAN	UPPER	TARTARIAN / KAZANIAN	GIDGEALPA GROUP	TOOLACHEE FM 158	☼	FLUVIAL
PERMIAN	LOWER	ARTINSKIAN	GIDGEALPA GROUP	DARALINGIE BEDS 95		DELTAIC
PERMIAN	LOWER	ARTINSKIAN	GIDGEALPA GROUP	ROSENEATH SH 81		LACUSTRINE
PERMIAN	LOWER	ARTINSKIAN	GIDGEALPA GROUP	EPSILON FM 88	☼	DELTAIC
PERMIAN	LOWER	ARTINSKIAN	GIDGEALPA GROUP	MURTEREE SH 79	☼	LACUSTRINE
PERMIAN	LOWER	ARTINSKIAN	GIDGEALPA GROUP	PATCHAWARRA FM 681	☼	UPPER-DELTAIC
PERMIAN	LOWER	ARTINSKIAN TO SAKMARIAN	GIDGEALPA GROUP	MOORARI BEDS	☼	FLOOD PLAIN
PERMIAN	LOWER	ARTINSKIAN TO SAKMARIAN	GIDGEALPA GROUP	TIRRAWARRA SS 122	●	FLUVIAL
PERMIAN	LOWER	SAKMARIAN		MERRIMELIA FM 396		PERIGLACIAL
CARBONIFEROUS				? ? ? GRANITE INTRUSION		
DEVONIAN				INNAMINCKA RED BEDS		
PRE-DEVONIAN				UNNAMED		

BEDOES (1973)

2 COAL

2.1 Coal maceral content

Caving represents a significant problem in the study of coals in samples taken from rock cuttings. Some doubt must, therefore, exist as to the reliability of data gathered from samples with low coal contents. In such cases the coal may be totally derived from caving from overlying strata. Consequently, such data must be viewed with some suspicion.

In this study coal is defined as organic matter with a concentration of greater than 60% of total matter (M. Smyth, pers. comm., 1980). If the concentration is less than 60% the organic matter is classified as dispersed organic matter.

The coals of the Eromanga Basin are rich in vitrinite with exinite and inertinite as variable, minor components. The coal maceral data for the five wells is displayed on histograms showing vitrinite, inertinite and exinite contents as percentages of total coal (Figures 4-8). The data for each of the three sampled units is also displayed on triangular plots of the three maceral groups (Appendix II).

2.1.1 Vitrinite

Vitrinite forms from the mouldering and peatification of the lignin and cellulose of plant-cell walls. Tellocollinite and desmocollinite are the dominant vitrinite macerals. Tellocollinite is the structureless vitrinite which occurs in thick layers (Plate 1, a). Desmocollinite forms the matrix for clarite and clarodurite (Plate 2). Tellinite and collinite also occur but are less important. Tellinite is the more common of the two and forms the cell walls where vitrinite displays cellular structure. These cells are filled with clay, collinite and resinite. Collinite forms by the infilling of cells with colloidal humic gel precipitated from humic solutions (Stach, 1975).

The classification of suberinite poses a problem. It is cell wall material of woody tissues which qualifies it as vitrinite, but in brown coals it fluoresces indicating it is an exinite (Smyth, pers. comm., 1980). As it has the same environmental significance as vitrinite, coming from woody tissue which has not suffered oxidation before burial, it is classified here as a vitrinite maceral. It is abundant in the Birkhead Formation.

No trends are observed within or between wells, either in vitrinite content or type.

2.1.2 Inertinite

Inertinite is thought to be derived from the same material as vitrinite but to have undergone a greater degree of oxidation. The cellulose and lignin from the cell walls of plants undergo charring, oxidation, mouldering and fungal attack before deposition or on the peat surface.

Inertodetrinite is the dominant inertinite maceral with semifusinite and fusinite less common and rare sclerotinite. Fusinite is typified by well preserved cellular structure and white to yellow colour. The cell lumens are empty or rarely filled with clay (Plate 3, c). The semifusinite is white to light grey in colour and has a less well preserved cellular structure. The inertodetrinite consists of fine particles less than 30 microns in size (Stach, 1975). The particles are fragments of fusinite and semifusinite and occur within intermediates (Plate 3, a). Sclerotinite is extremely rare. It is found in the Birkhead Formation and Murta Member only. Sclerotinite is derived from fungal remains (Plate 4, c).

Sample D7-38, taken from the Birkhead Formation in Della-7, has a 60% fusinite content. This is the only sample studied where vitrinite is not the dominant maceral. It indicates that localized oxidizing conditions existed during deposition of the Birkhead Formation.

No trends are observed within or between wells either in inertinite content or type.

2.1.3 Exinite

Exinite is formed from the relatively hydrogen rich parts of plants. Exinite macerals present are sporinite, resinite, cutinite and alginite which are derived from spores and pollen, leaf cuticle, plant resin and algae respectively.

Sporinite is the dominant exinite maceral in all three units studied (Plate 2, a). Resinite is a dominant maceral in the Birkhead Formation also. In the Murta Member resinite is also important being the dominant exinite maceral in some samples (Plate 2, a). It is an important component in the Transition Beds comprising up to 30% of the total exinite content in individual samples but usually minor. Cutinite is important in the Birkhead Formation becoming locally dominant at its base (Plate 2, b,c). It is only a minor component in the two upper units. Rare alginite is only found at the base of the Murta Member and Birkhead Formation in Dullingari North-1 (Plate 2, b,c).

There are no recognizable trends in the total exinite content of coals either within wells or between them. The resinite and cutinite content decreases as one passes up the section.

2.2 Coal microlithotypes

The way in which the various macerals are combined is important. Bands in coal greater than 50 microns across and known as microlithotypes are defined to facilitate such studies (Stach, 1975). A table defining the various microlithotypes is listed in Appendix II.

Determinations were only made where the coal content of a sample was greater than 10% in order that the data be statistically reliable. The wells studied contain little coal and therefore microlithotypes could only be studied from a limited number of samples. These are listed in Table 2.

TABLE 2

Sample	Vitrite	Clarite	Duroclarite	Inertite	Vitrinertite	Durite
DN-16 M	40	20	32	4	4	-
DN-17 M	42	27	23	8	-	-
DN-18 M	58	19	14	8	-	-
DN-19 M	58	22	8	6	3	3
DN-20 M	60	28	10	2	-	-
D8-50 B	50	39	8	-	-	3
W-45 B	53	38	-	-	9	-
D7-42 B	74	9	-	13	4	-

M = Murta Member

B = Birkhead Formation

The Birkhead Formation is characterized by discontinuous coal seams. Della-7, Della-8 and Wilpinnie-1 each contain one sample with a significant coal content. They have a high combined vitrite and clarite content. Samples D8-50 and W-45 have high contents of both while D7-42 is dominated by vitrite. Sample D8-50 is the only one of the three to contain duroclarite and durite. Samples W-45, D7-42 contain minor vitrinertite. Sample D7-42 alone contains minor inertite.

The coals found at the base of the Murta Member in Dullingari North-1 are the only significant coals found in the member. Microlithotypes were determined for samples DN-16, 17, 18, 19, 20, the five consecutive 3.05 metre intervals located at the base of the member. These coals display an obvious trend passing up the well. At the base the coals are rich in vitrite and clarite and poor in duroclarite. Passing upwards the coals become richer in duroclarite at the expense of vitrite and clarite. The data is displayed on a triangular plot divided into areas characteristic of different sedimentary environments (Smyth, 1979), (Figure 9). This figure indicates that the trend is due to a change in environment of deposition; from fluvial to brackish water.

No determinations could be made in the Transition Beds due to the paucity of coal.

3 DISPERSED ORGANIC MATTER

The main purpose of this thesis is the study of the dispersed organic matter (d.o.m.) in each of the three sampled units. Dispersed organic matter, unresolvable at a magnification of 480X under white or UV reflected light could not be considered in the ensuing discussion.

Data is presented in three different ways. Histograms displaying the maceral contents as percentages of total d.o.m. and total rock were prepared for each of the five wells (Figures 4-8). Triangular plots of the three maceral groups were also prepared for each of the three sampled units (Appendix II).

3.1 Birkhead Formation

The total d.o.m. content decreases from west to east across the section. That is the total d.o.m. content decreases as the thickness of the Birkhead Formation decreases.

A characteristic of the formation is the cyclic nature of the total d.o.m. content. The base of the formation has a relatively low total d.o.m. content; less than 2% in all wells. Passing upwards this increases to in excess of 3% before again decreasing to less than 2%. The cycle is then repeated.

The cyclic nature can be seen best in Della-7 and Della-8. These cycles may be present in the other three wells but are difficult to resolve. In Wilpinnie-1 and Nappacoongee-2 unsampled intervals pose a problem. Also the size of intervals sampled has a significant effect on resolution and thus on recognition of trends. In the case of Dullingari North-1, this together with the fact that the formation is very thin at this location probably hinders recognition of the cycles. Sampling over smaller intervals may allow the cycles to be recognized in these wells.

The cycles may be in response to variations in the rate of supply of organic matter relative to rate of sedimentation. Either an increase in rate of organic matter supply or decrease in rate of sedimentation will result in an increase in the total d.o.m. content of the rocks (Tissot and Welte, 1978). Variation in total d.o.m. content may also be due to variation in grain size of the sediments allowing varying degrees of oxidation (Tissot and Welte, op. cit.). The coarser the sediments the greater the rate of oxidation and so the less organic matter preserved.

A study of the rock cuttings indicates that there is no obvious relationship between the total d.o.m. content and grain size in the Birkhead Formation. Thus the cycles may be the result of variations in the rate of organic matter supply relative to rate of deposition of sediments. The exinite content is proportional to the total d.o.m. content. This indicates that the rate of supply of organic matter was relatively constant with variations in total d.o.m. content the result of variations in rate of sedimentation.

Vitrinite is the dominant maceral in the d.o.m. of the Birkhead Formation. The classification of d.o.m. into maceral types is difficult because it is usually not possible to compare one type with another. Therefore, no attempt was made to subdivide vitrinite into its various maceral types. It tends to be elongate and coarse (Plate 5, c) compared with the associated inertinite which is relatively equidimensional and fine. Thus the inertinite has been transported further than the vitrinite and in the process has undergone the oxidation necessary for its formation. The dominant inertinite maceral is inertodetrinite (Plate 4, c) with minor semifusinite and fusinite.

Exinite is a prominent maceral although rarely dominant. The dominant exinite maceral is sporinite. Resinite is present in significant amounts in the four western wells but is rare in Dullingari North-1. Cutinite and alginite are minor components in all wells with the former being most predominant at the base of the formation.

3.2 Murta Member

The total d.o.m. content of the Murta Member is generally higher than in the other two units. This may indicate a higher rate of supply of organic matter relative to rate of deposition of sediments. The total d.o.m. content displays a complex series of peaks and lows. The lows correspond to coarser sediments which allow a greater degree of oxidation and so a lower rate of preservation for organic matter. Also the coarser sediments would have been associated with a greater rate of sedimentation resulting in dilution of organic matter. This is supported by the fact that the exinite content is proportional to the total d.o.m. content.

The general trend in the total d.o.m. content of the Murta Member can best be seen in Dullingari North-1. Passing up the member the total d.o.m. content at first increases gradually. This trend can also be seen in Della-7 and Nappacoongee-2. Della-8 and Wilpinnie-1 display decreasing total d.o.m. contents passing upward from the base of the member. Sampling to lower intervals may reveal increasing trends in these two wells. Alternatively the period of deposition responsible for the increase in total d.o.m. content may not have taken place in these wells.

After peaking the total d.o.m. content decreases. This corresponds with a lower thin sand which is continuous across the section. Passing out of this sand the total d.o.m. content again peaks in all wells except Wilpinnie-1 and Nappacoongee-2. Logs indicate that unlike the other wells Wilpinnie-1 contains a continuous series of sands resulting in anomalously low total d.o.m. contents. Sampling on a more regular basis may reveal alternating low and high total d.o.m. contents. In the case of Nappacoongee-2 rock cuttings are not available for the interval above the lower sand unit and therefore it is not known how the total d.o.m. content behaves.

The total d.o.m. content then decreases due to the presence of an upper thin sand which is continuous across the section. Following this the total d.o.m. content returns to a base level in all wells.

Exinite and inertinite are the dominant macerals in the Murta Member. The predominant exinite macerals are sporinite and alginite. Sporinite is common throughout the member (Plate 5, b). Passing up from the base of the member the alginite content increases as does the total d.o.m. content (Plate 1, b,c). The alginite content reaches a peak of 25% of the total d.o.m. content before passing into the lower sand and a consequent decrease in alginite content. Between the lower and upper sands alginite is present in minor but significant amounts. Above the upper sand alginite is extremely rare and poorly preserved. The member also contains minor resinite (Plate 5, b) and rare cutinite.

Inertinite is generally less important than exinite. Inertodetrinite is the dominant inertinite maceral. Vitrinite is a variable, relatively minor component of the d.o.m. The proportion of intertinite to vitrinite varies indicating variation in oxidizing conditions with time and location. Della-7 contains higher levels of vitrinite than the other wells at the expense of exinite.

The d.o.m. in the Murta Member is generally finer grained than that in the Birkhead Formation. The vitrinite is not elongate and therefore has been transported just as the inertinite has.

3.3 Transition Beds

The Transition Beds have a relatively lower total d.o.m. content than the Murta Member. The total d.o.m. content varies in a cyclic nature. Passing up through a cycle the total d.o.m. content decreases at a steady rate and then increases sharply. The cycle is then repeated. Minimum values are less than 1.5% in all wells while maximum values are usually greater than 2% and frequently as high as 4%. Unlike the variation found in the other units, that in the Transition Beds is very regular. Within individual wells the maxima and minima are remarkably repetitive. Dullingari North-1, on the eastern end of the section, is the only well which does not exhibit well defined and regular cycles.

It is possible that the cycles within the different wells are related and indicate events which affected sedimentation across the entire section. The variation in total d.o.m. content would appear to be in response to variations in rate of supply of organic matter relative to rate of deposition of sediments. As in the other two units, the exinite content would appear to be proportional to the total d.o.m. content and therefore variation in the latter is due to varying rates of sedimentation.

Exinite and inertinite are the dominant macerals in the Transition Beds with vitrinite a significant, but variable, minor component. Sporinite (Plate 4, a,b) is the dominant exinite maceral with resinite and cutinite as minor and alginite an extremely rare component. Inertodetrinite is the dominant inertinite maceral. The proportion of inertinite to vitrinite varies indicating that oxidizing conditions were variable with time and space as in the Murta Member. The d.o.m. is fine grained and equidimensional again indicating it to be allochthonous.

3.4 Relationship of d.o.m. to coal microlithotypes

Smyth (1979) claims an apparent correlation between the type of d.o.m. and the petrography of the associated coals in the Permian sediments of the Cooper Basin. She claims that exinitic d.o.m. is associated with coals that have high vitrite plus clarite contents, whereas vitrinitic d.o.m. is associated with coals with high intermediate contents.

As previously mentioned, the base of the Murta Member contains signficiant levels of coal. Passing upward the vitrite plus clarite content of these coals decreases while the intermediate content increases.

The d.o.m. at the base is poor in exinite and rich in vitrinite relative to the rest of the member. Passing upward the proportion of exinite increases at the expense of the vitrinite. Therefore, it would appear that exinitic d.o.m. is associated with coals that have high intermediate contents whereas vitrinitic d.o.m. is associated with coals that have high vitrite plus clarite contents.

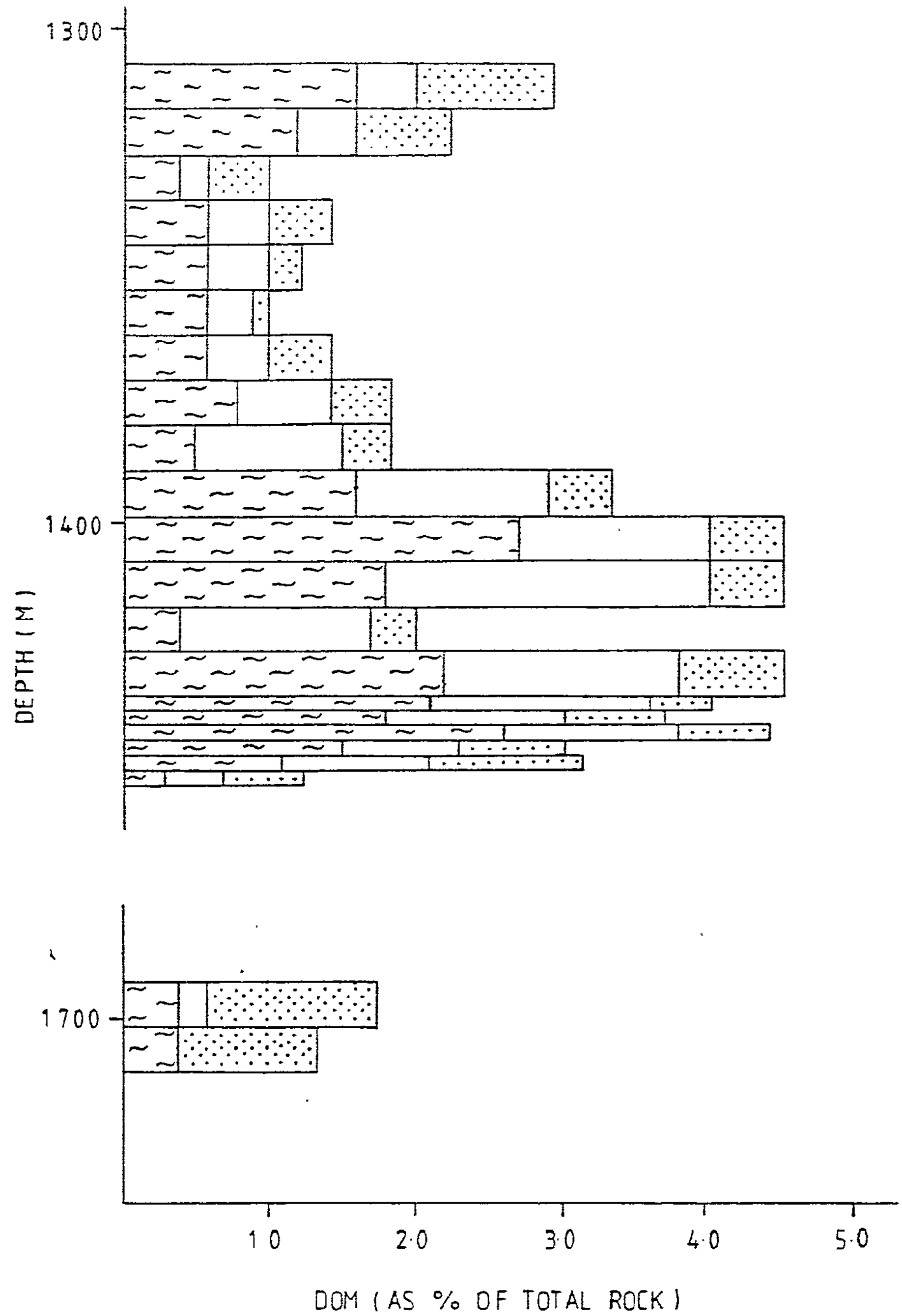
Thus in the Murta Member of the Mooga Formation, the relationship between the type of d.o.m. in the sediments and the petrography of the associated coals would appear to be the opposite of that proposed for Permian sediments by Smyth (1979). This difference is probably a result of deposition in different environments. The Permian sediments had a much stronger terrestrial influence than did the Murta Member. Therefore, it seems doubtful that a unique correlation between d.o.m. type and the petrography of the associated coals exists. Rather separate correlations for deposition in varying environments may be possible.

FIGURE 4-8 LEGEND

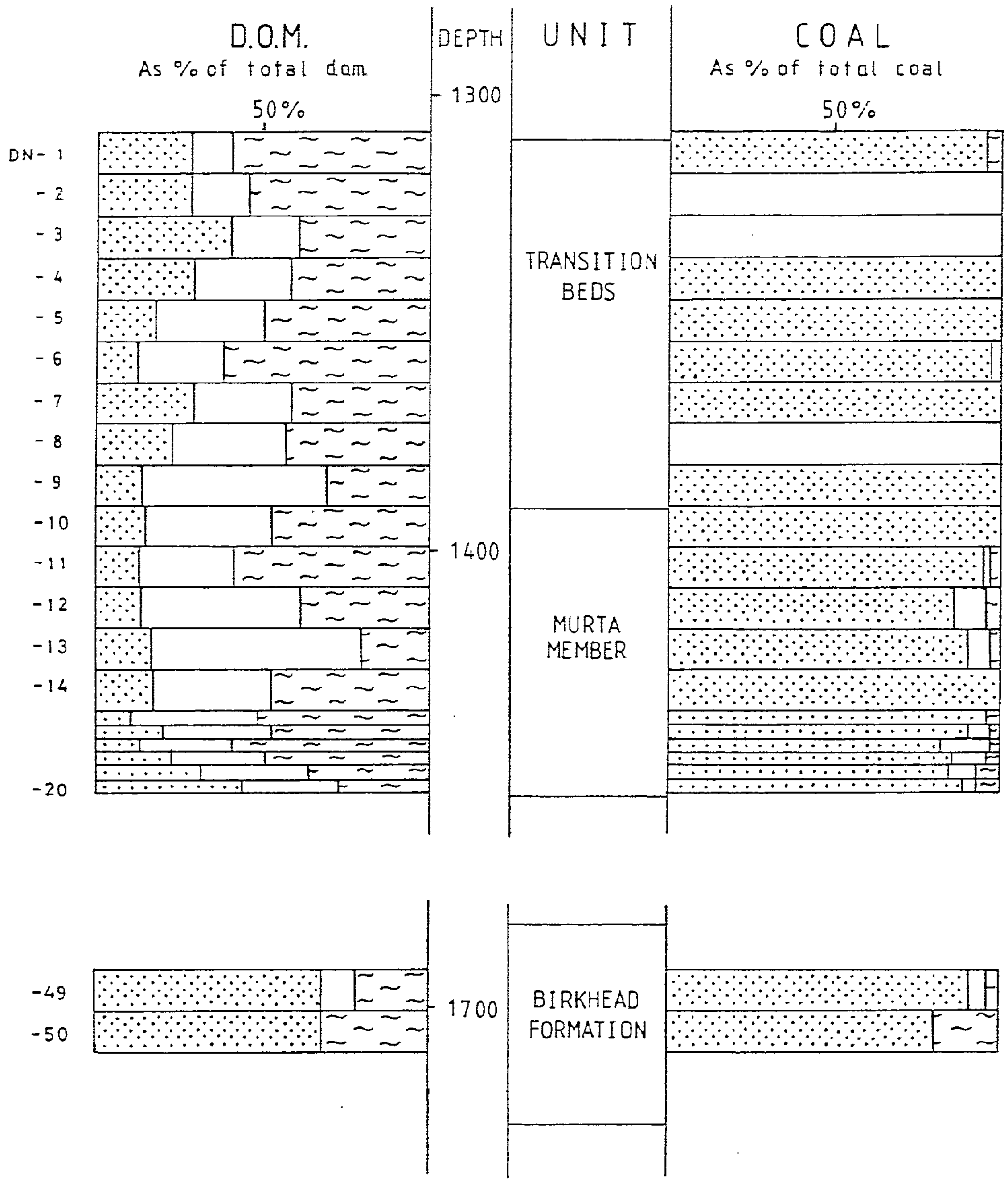
VITRINITE

INERTINITE

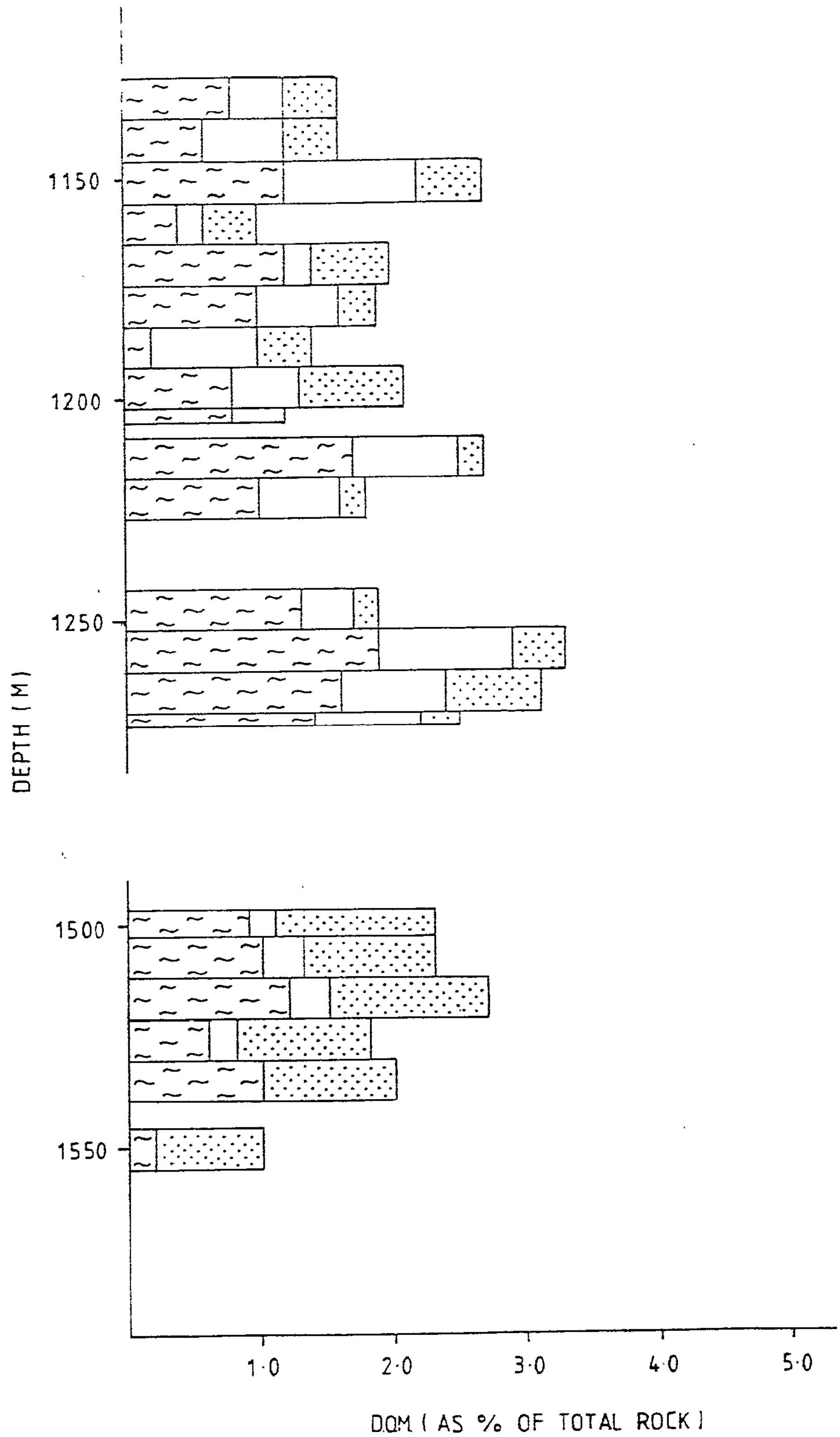
EXINITE


1300
1400
1700
DEPTH (M)
1·0
2·0
3·0
4·0
5·0
DOM (AS % OF TOTAL ROCK)

DULLINGARI NORTH 1 FIGURE 4

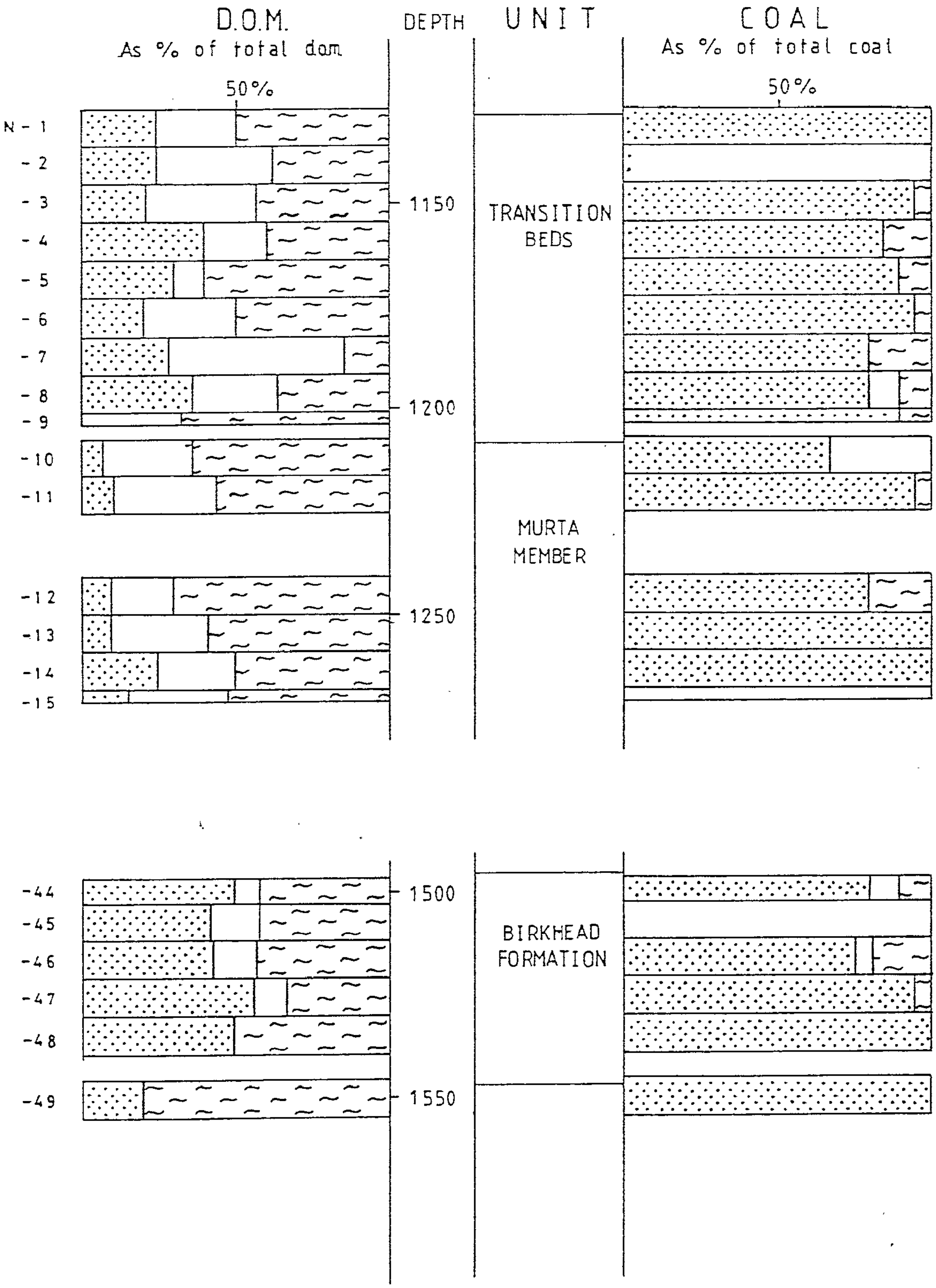


S.M.M. 80

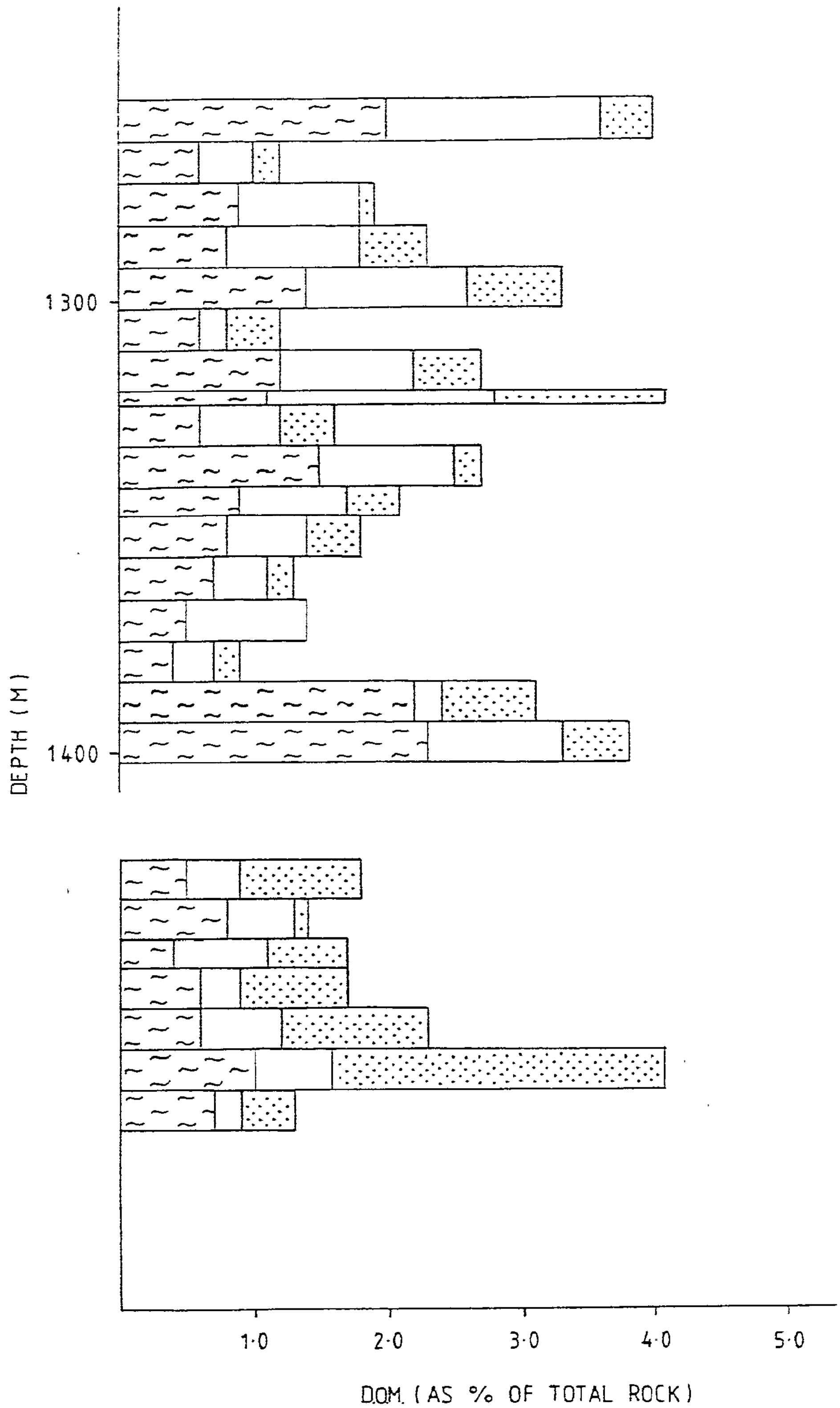

1150
1200
1250
DEPTH (M)
1500
1550
1·0
2·0
3·0
4·0
5·0
DOM (AS % OF TOTAL ROCK)

NAPPACOONGEE-2

FIGURE 5



S.M.M. 80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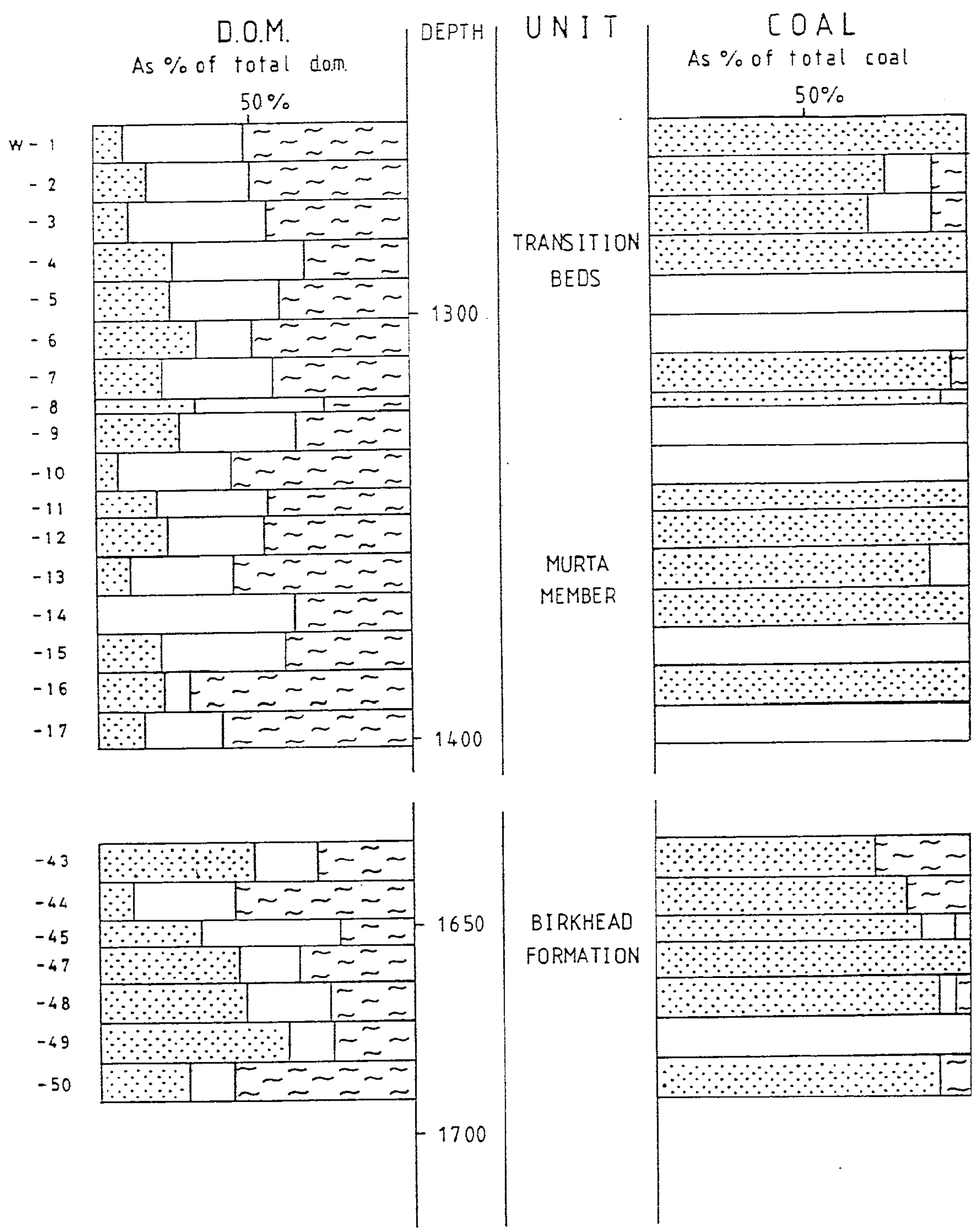
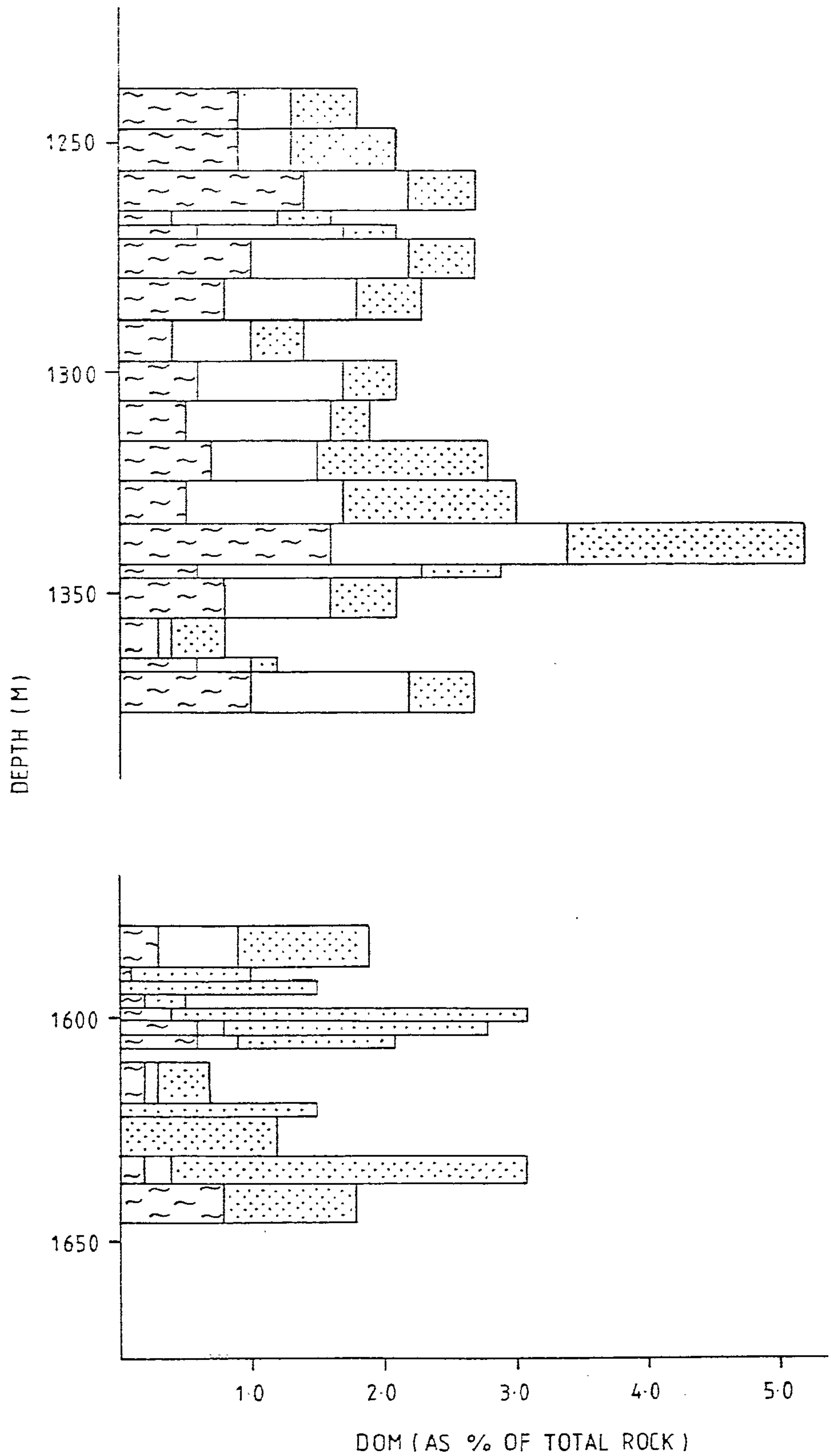
2·0
3·0
4·0
5·0
D.O.M. (AS % OF TOTAL ROCK)

WILPINNIE-1

FIGURE 6

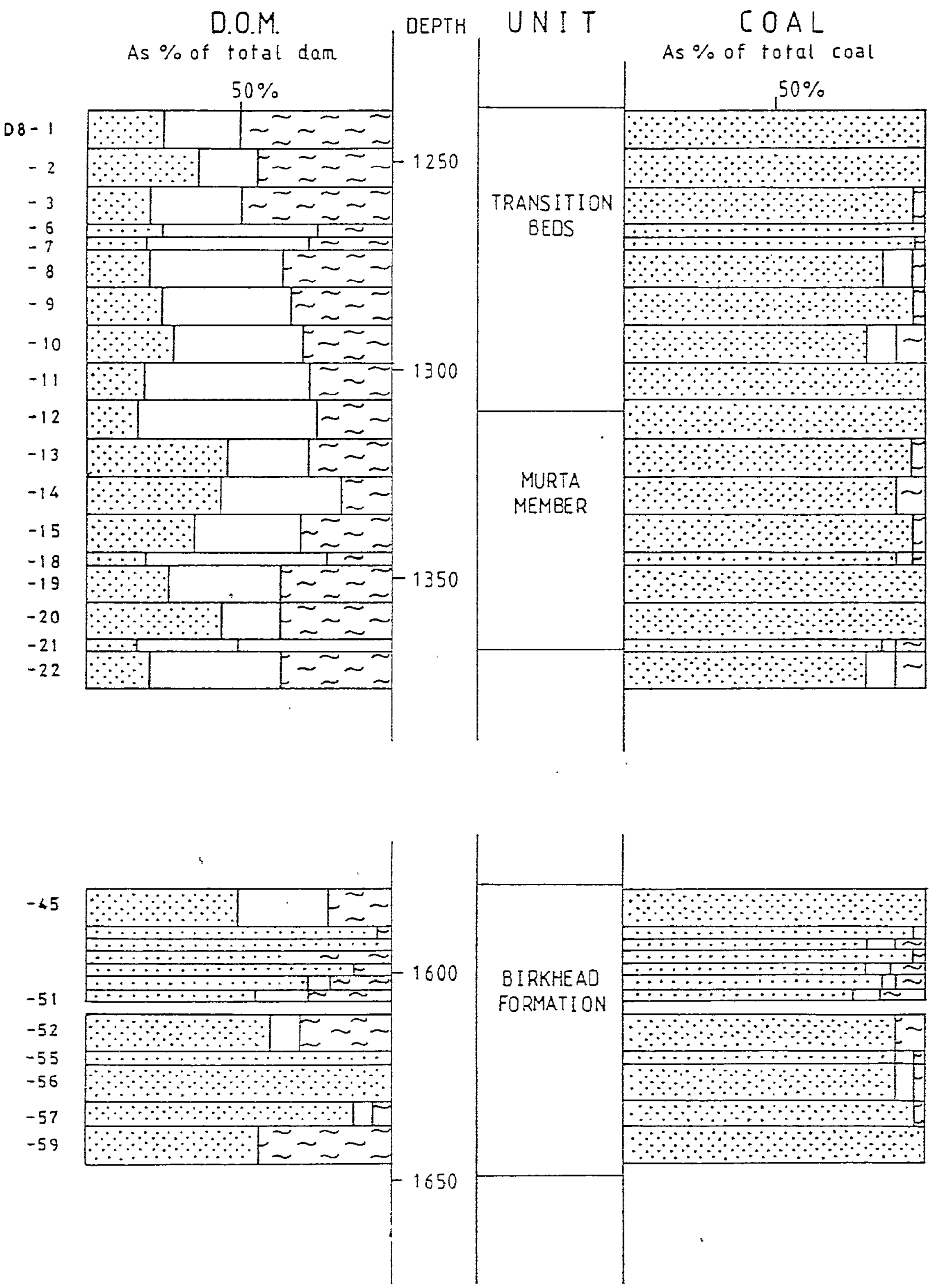


S.M.M. 80

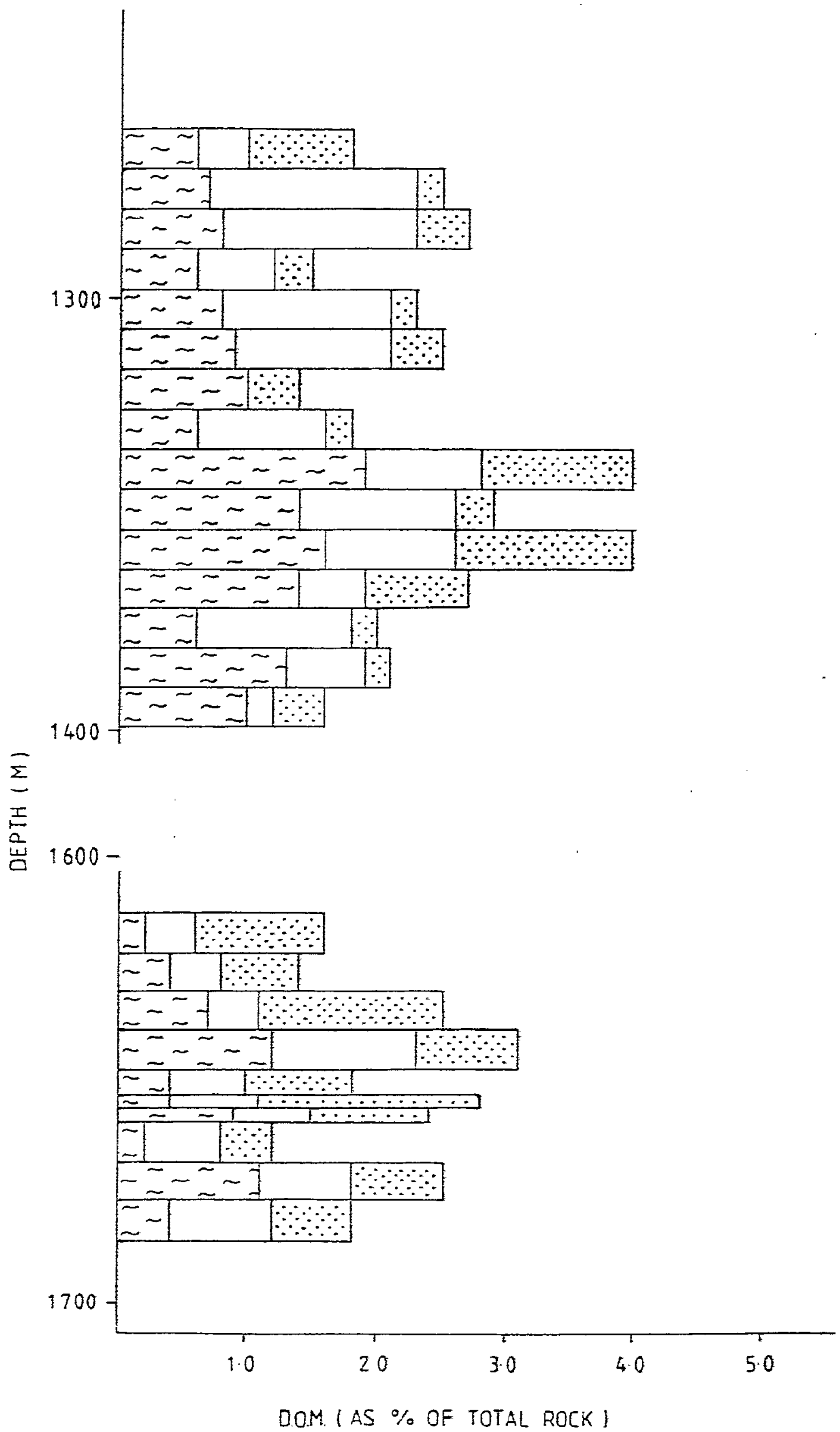

1250
1300
1350
DEPTH (M)
1600
1650
1·0
2·0
3·0
4·0
5·0
DOM (AS % OF TOTAL ROCK)

DELLA-8

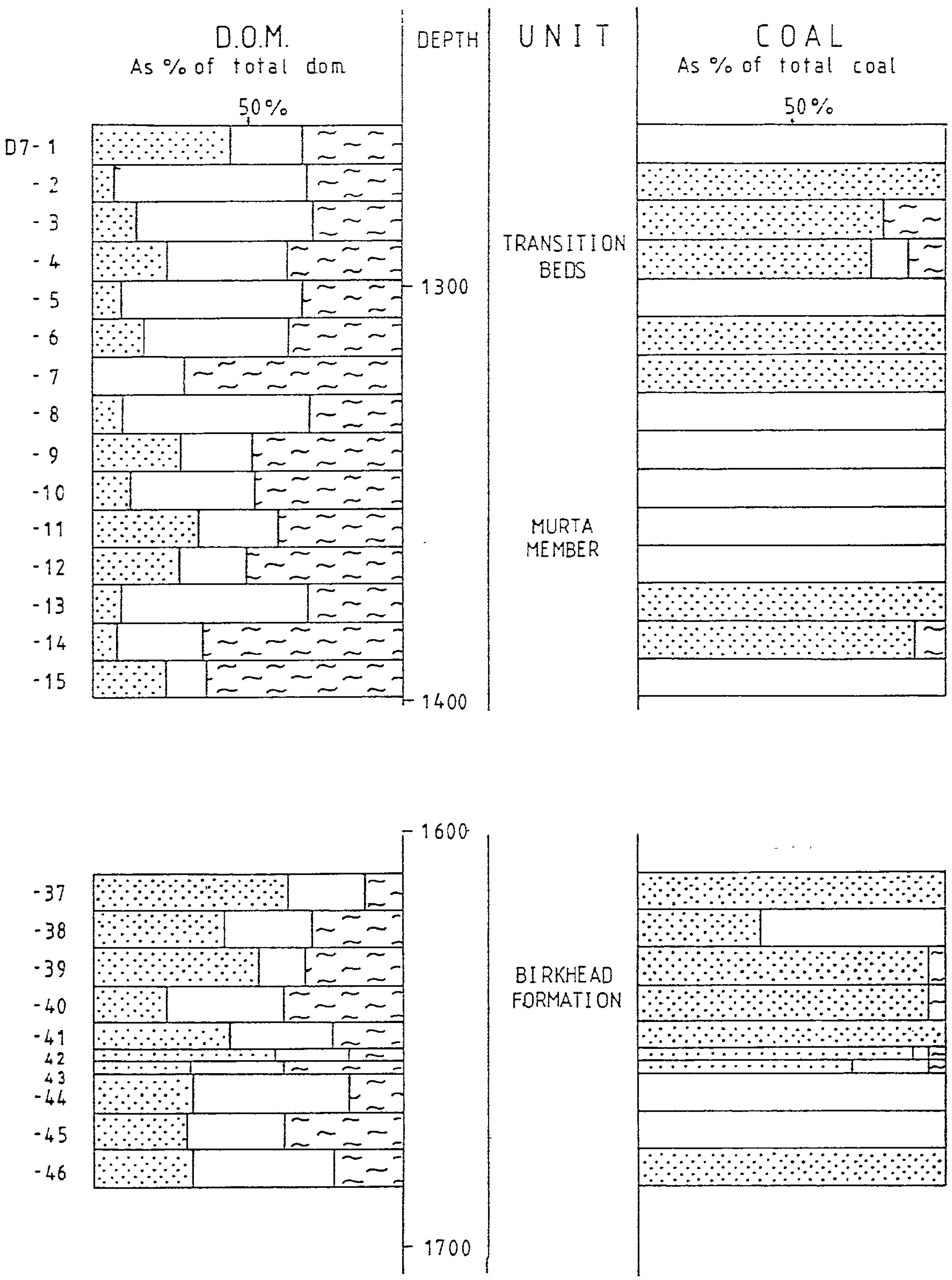
FIGURE 7



S.M.M. 80

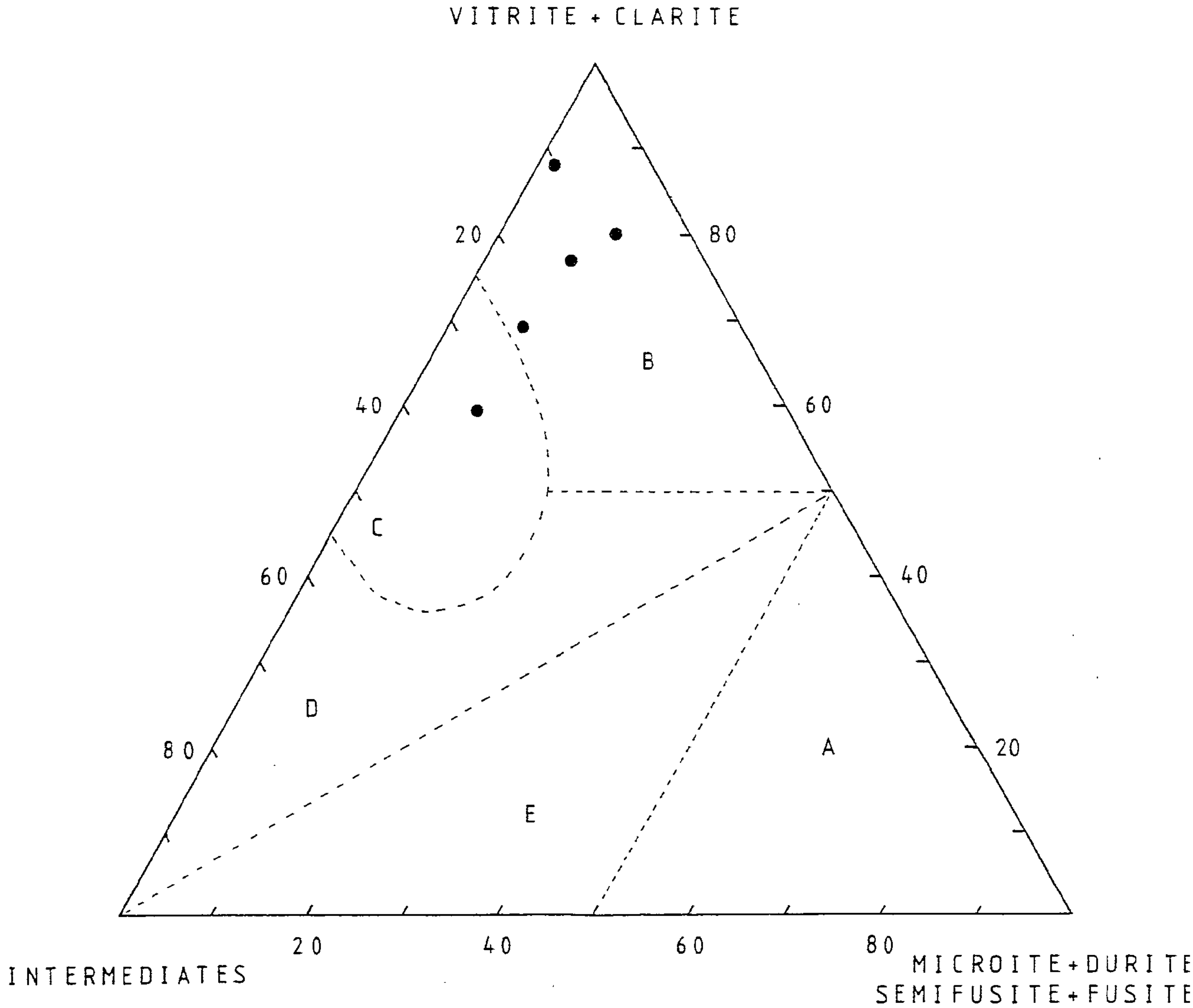

1300
1400
1600
1700
DEPTH (M)
1·0
2·0
3·0
4·0
5·0
D.O.M. (AS % OF TOTAL ROCK)

DELLA-7 FIGURE 8



S.M.M. 80

FIGURE 9



A LACUSTRINE

B FLUVIAL

C BRACKISH WATER

D UPPER DELTAIC

E LOWER DELTAIC

Mod. from Smyth (1979)

4 VITRINITE REFLECTANCE

4.1 Techniques

Vitrinite reflectance measurements were made on three or four samples from each of the wells studied. Further samples were not studied because they contained very low contents of measureable vitrinite. The section studied is only of the order of 400 metres thick. Nevertheless the data collected is adequate for a discussion of its implications to be made.

Reflectance measurements were made using a Leitz Ortholux II Pol BK microscope with a standard deviation of 0.01%. Measurements were made immediately following immersion of samples in oil using a 32X magnification objective. The reflectivity of each polished section measured was calculated from 30-50 measurements on vitrinite and then averaged to give the mean reflectance, $\overline{R}_o$.

Reflectance variations were found to be less than ±0.08% $\overline{R}_o$ in all cases except one. Sample D8-51 was the only exception having a variation of ±0.12% $\overline{R}_o$.

Variation in reflectance values are probably the result of six factors (see Appendix III):

(1) Contamination of underlying strata due to caving.

(2) Reworking of older coals (Stach, 1975).

(3) Hot connate waters moving through lower Jurassic aquifers (Lonergan, 1979).

(4) Variation in the reflectance of the various vitrinite macerals.

(5) Statistical errors due to insufficient measurements for a true Gaussian distribution.

(6) Technical errors due to incorrect identification of macerals.

4.2 Depth Reflectance Curves

Vitrinite reflectance values at the top of the Transition Beds range from 0.30% $\overline{R}_o$ at Dullingari North-1 to 0.41% $\overline{R}_o$ at Della-7 and Nappacoongee-2. The base of the Jurassic has reflectances ranging from 0.56% $\overline{Ro}$ at Della-8 to 0.71% $\overline{R}_o$ at Wilpinnie-1.

The reflectance curves for Della-8, Wilpinnie-1 and Nappacoongee-2 are linear with gradients ranging from 0.38% $\bar{R}_o$/km in Della-8 to 0.56% $\bar{R}_o$/km in Wilpinnie-1. In the case of Dullingari North-1 and Della-7 the reflectance curves are not so obviously linear. They both appear to display a curved profile. The upper portion of the curves are linear in both cases with gradients compatible with those found in the other three wells. For Dullingari North-1 the gradient of the linear upper part of the curve is 0.4% $\bar{R}_o$/km while for Della-7 it is 0.24% $\bar{R}_o$/km. The apparent curved nature of the depth-reflectance curves may be due to separate linear curves in each of the shale intervals sampled. This situation may be the result of suppression of vitrinite reflectance increases due to the retention of CO_2 by the shales.

A line of best fit calculated by linear regression techniques was found to fit all measured data points on the plot. The curved nature of the depth-reflectance curves may therefore simply be a product of natural variation over the very short section involved. The two alternative interpretations are plotted on the depth reflectance curves (Figures 10-14).

TABLE 3 - SUMMARY OF VITRINITE REFLECTANCE DATA

Well	% $\bar{R}_o$ Top Transition Beds	% $\bar{R}_o$ Bottom Jurassic	% $\bar{R}_o$/km Rank Gradient
Della-7	0.41	0.84	0.24 *
Della-8	0.37	0.56	0.38
Wilpinnie-1	0.39	0.71	0.56
Nappacoongee-2	0.41	0.64	0.44
Dullingari North-1	0.30	0.69	0.40 *

* gradient of the linear upper part of the reflectance curve.

4.3 Lateral Rank Trends

Figure 15 displays the lateral and vertical variations in vitrinite reflectance and therefore rank. The stratigraphic horizons were constructed using depths of formation tops supplied by S.A.O.G.C. fitted to the C-horizon profile for the section as determined from the isopach map of that surface supplied by Delhi. The isoreflectance surfaces were constructed by calculating the depth corresponding to the required reflectance value in each well. The equation of the line of best fit for all data points, as calculated by linear regression techniques, was used in this calculation.

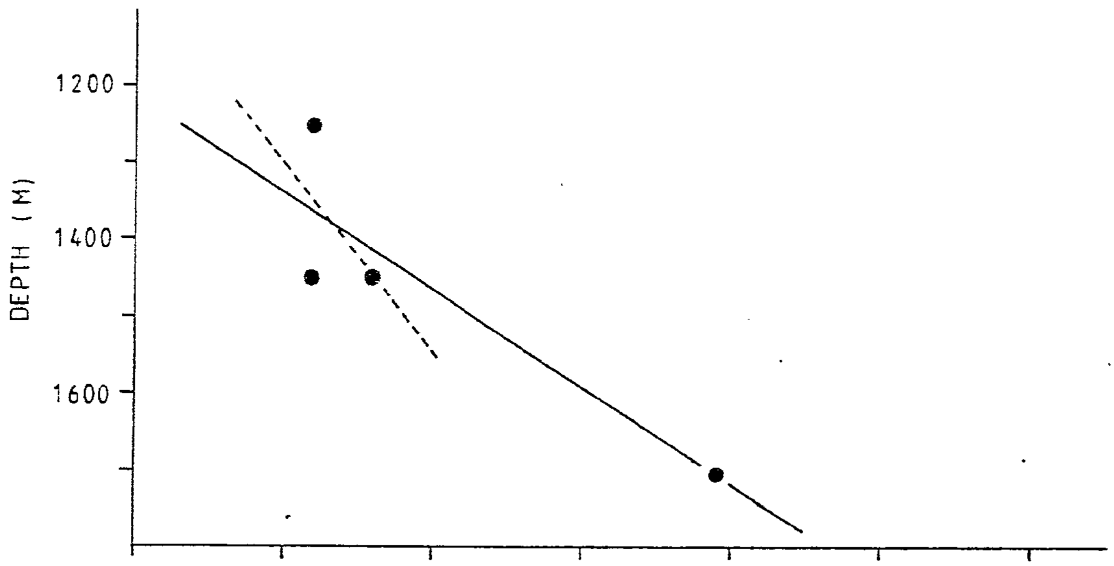
The depth reflectance gradients are steepest over the Nappacoongee Murteree anticlinal trend. This can be seen in Table 3 where Wilpinnie-1 and Nappacoongee-2, the wells overlying the anticlinal high, are listed with their depth reflectance gradients. Passing westward off the anticlinal high the gradient decreases as in Della-8 before again increasing in the case of Della-7. To the east Dullingari North-1 displays what would appear to be an anomalously high gradient. This apparently erroneous result could be the product of unreliable data resulting from the limited number of samples studied and the short interval over which samples were taken.

As Lonergan (1979) found, the isoreflectance surfaces (Figure 15) are generally concordant with stratigraphic horizons as is normally expected. There are departures however. Over the Nappacoongee Murteree anticlinal trend both 0.4% $\bar{R}_o$ and 0.6% $\bar{R}_o$ surfaces are convex upward. At Dullingari North-1 and Della-8 the 0.4% $\bar{R}_o$ and 0.6% $\bar{R}_o$ surfaces are concave upwards occurring at a considerably deeper level than over the anticlinal high. At Della-7 the isoreflectance surfaces again pass up to considerably shallower depths. This well overlies what may be a minor basement high.

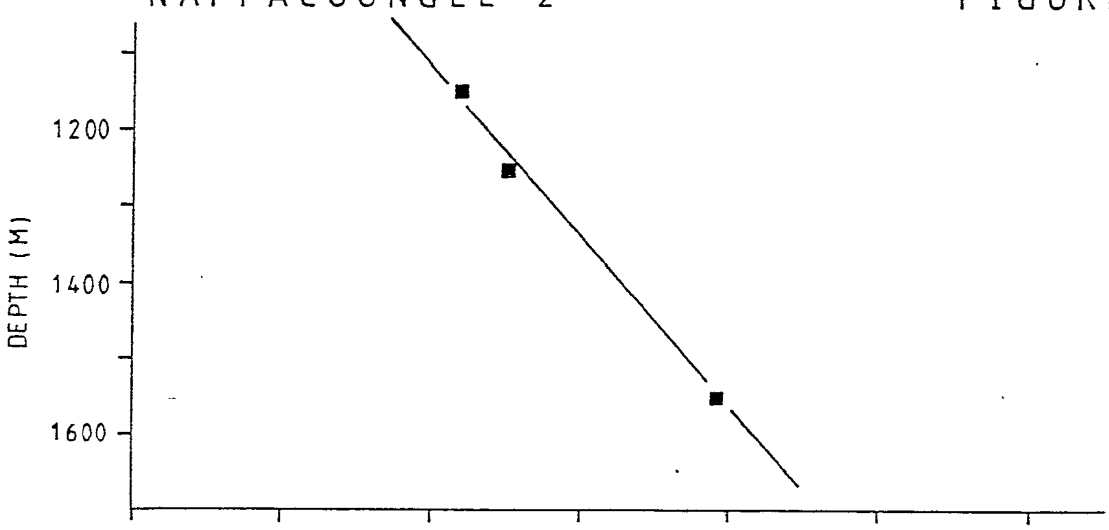
DEPTH REFLECTANCE PROFILES

00411

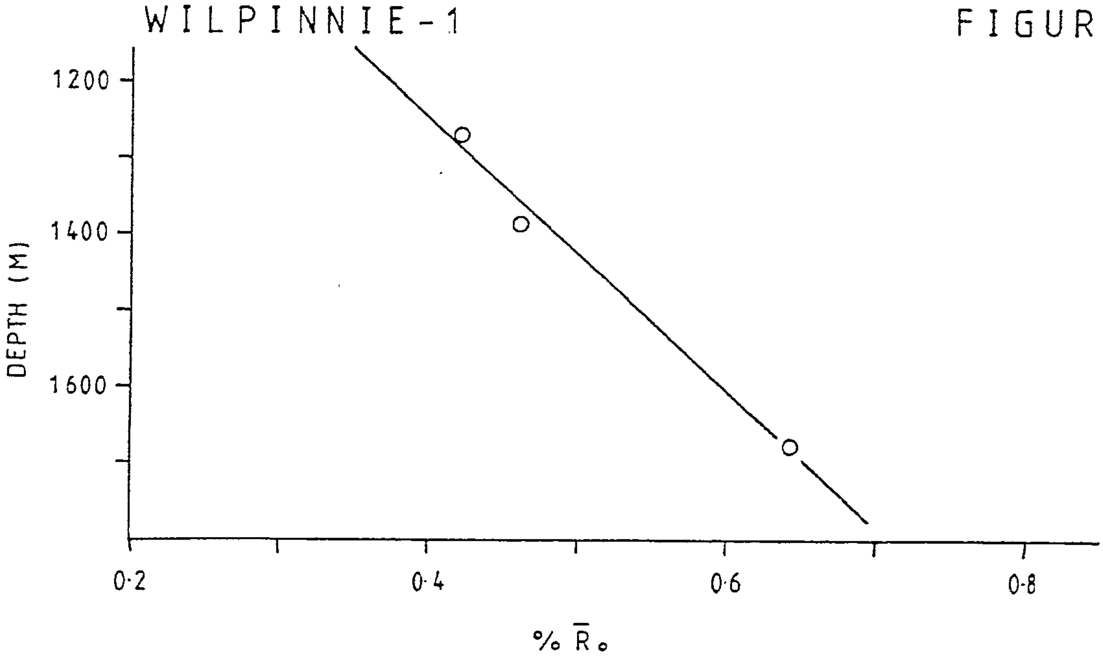
DULLINGARI NORTH-1 FIGURE 10



NAPPACOONGEE-2 FIGURE 11



WILPINNIE-1 FIGURE 12



S.M.M. 80

FIGURE 13

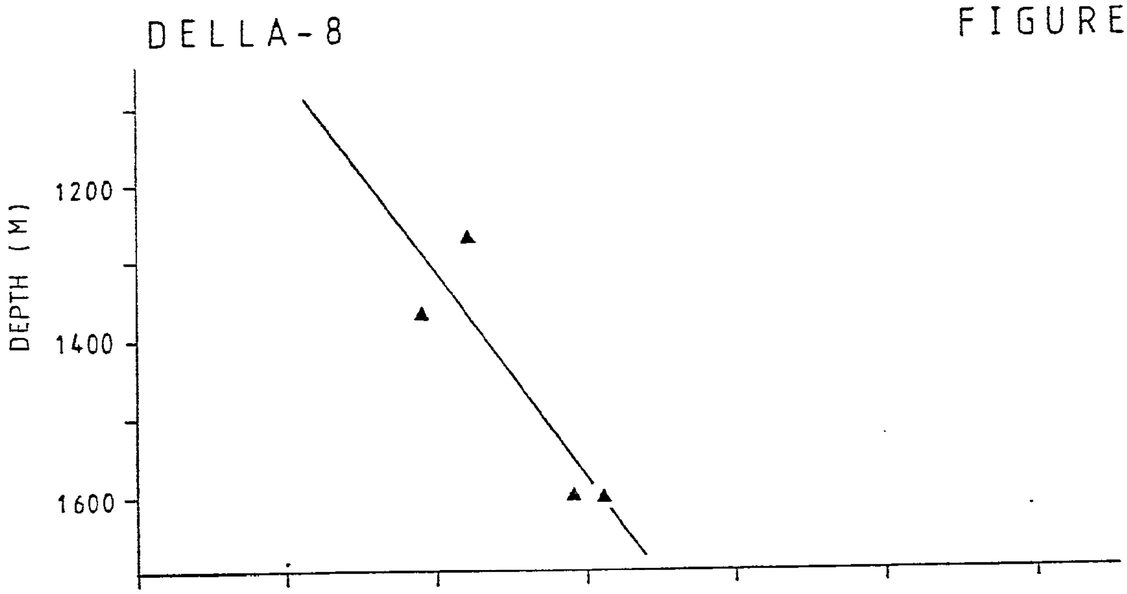
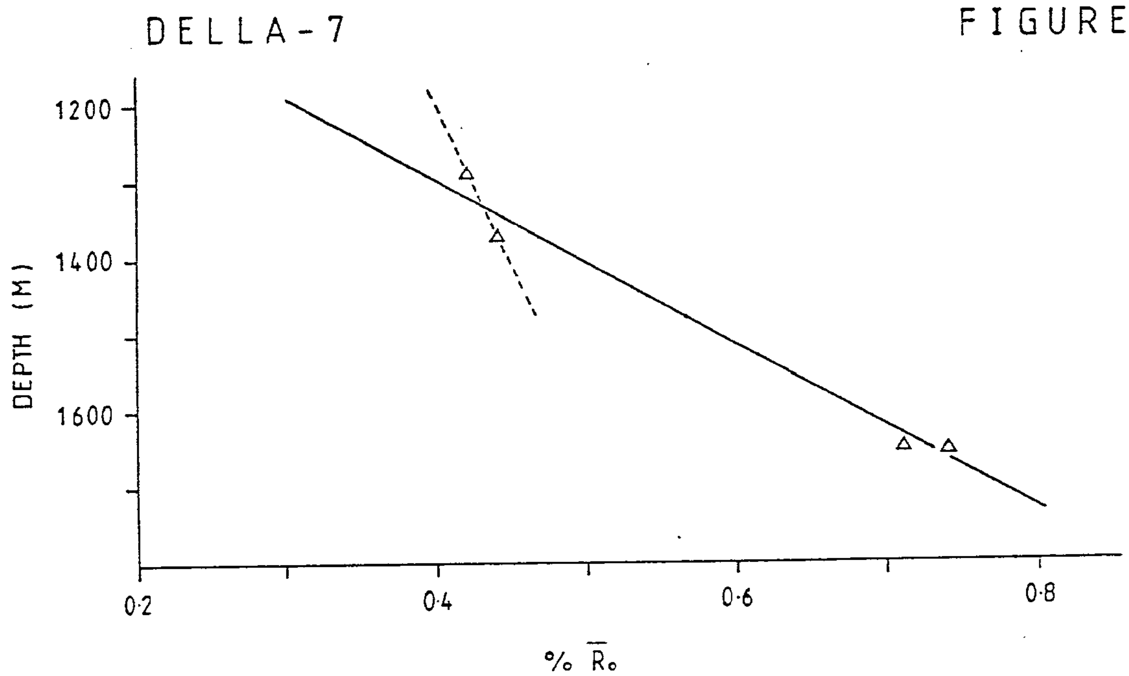
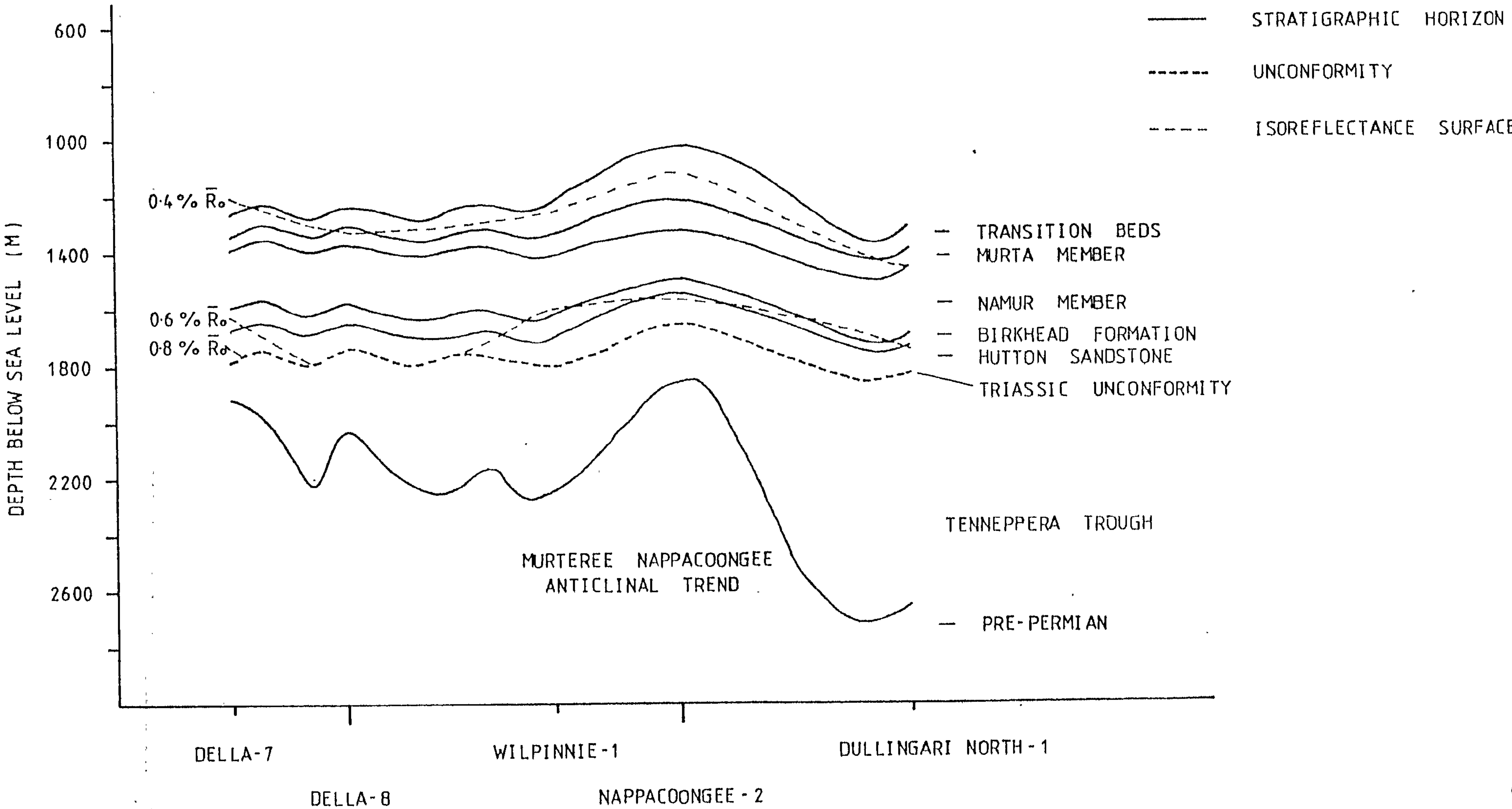


FIGURE 14



S.M.M. 80

FIGURE 15



S.M.M. 80

00413

5 INTERPRETATION

5.1 Environmental Interpretation

The d.o.m. and coal studies undertaken enable some comment to be made on the environments of deposition of the three sampled units. It must be emphasised that the application of d.o.m. and coal studies in interpreting past environments is a useful tool but can not be expected to stand alone. Past and present studies on this subject by other workers are examined to see whether they are supported by data gathered during this work.

5.1.1 Birkhead Formation

All samples studied have high vitrite plus clarite contents. The clarites are usually exinite poor but minor amounts of exinite-rich clarites are present. The dominant exinite maceral in the clarites is sporinite. Towards the base of the formation alginite and cutinite rich clarites are found (Plate 2, b,c). Minor amounts of duroclarite, inertite, vitrinertite and durite are also present. The duroclarite and vitrinertite are vitrinite rich.

The following environmental interpretation of the various coal microlithotypes is taken from Stach (1975).

The vitrinite rich microlithotypes form in forest swamp facies. The vitrite forms from stems, branches and lignified tree roots. For these to be preserved as vitrite a high ground water level is needed to prevent oxidation by the atmosphere. The exinite-poor clarites are formed from forest litter. The exinite-rich clarites dominated by sporinite are derived from open marshes while those with high alginite and cutinite contents probably represent sub-aquatic deposits. The presence of inertite indicates that temporarily dry peat surfaces were exposed to the atmosphere and so underwent oxidation.

It has been accepted in the past that the Birkhead Formation was deposited in a predominantly lacustrine environment with minor swamps and marshes (Nugent, 1969). Logging of rock cuttings from the five wells studied indicate that the sediments of the Birkhead Formation consist of shales, silts and very fine sands as would be expected.

The d.o.m. is dominated by vitrinite. The vitrinite is generally elongate and coarse compared to the associated inertinite indicating that the former has been transported relatively shorter distances. The vitrinite was probably derived from the forest swamps and was deposited close to this environment. The high proportion of vitrinite relative to inertinite indicates rapid deposition and a high groundwater level preventing oxidation by the atmosphere. The existence of these anoxic conditions is supported by the common occurrence of disseminated sulphides.

In summary it is suggested that the Birkhead Formation was deposited in a lacustrine environment with associated forest swamps, open marshes and exposed swamps. Vitrinitic d.o.m. was derived from the forest swamps being deposited close to this environment. Inertinite represents the organic matter which was not deposited close to its source. On the basis of the present study all that can be said with any degree of certainty is that forest swamps and to a lesser extent open marsh swamps, exposed swamps and lakes existed during deposition of the Birkhead Formation and were sites of peat formation.

5.1.2 Mooga Formation

Deposition of the Birkhead Formation was followed by a return to fluviatile conditions giving rise to the Namur Member of the Mooga Formation. This in turn passes into the Murta Member. Passing up from the base of the Murta Member, in all five wells studied, the sequence of facies observed is as follows: shale, thin bottom sand, shale, thin top sand; shale. The facies transitions observed vertically were deposited in laterally related environments.

A barrier coastline complex transgressing to the west may be invoked to explain this situation (Figure 16). Such a complex comprises four laterally related environments (Selley, 1976a). From west to east these are fluviatile coastal plain, lagoonal and tidal flat complex, shoreface bar and offshore shallow water environment. The fact that all four environments are represented in the relatively thick transgressive sequence indicates that the rate of deposition was high.

In this model the Namur Member corresponds to the fluviatile coastal plain. It is generally accepted that this member is composed of alluvium of braided river type (T. Mount, pers. comm., 1980). This is indicated by the shape of the gamma ray logs in all five wells studied. Sediments range in size from shale to very coarse sand.

This passes transitionally eastwards into swamps, tidal flats and lagoons. The swamps would have been sites of peat formation. Thus the presence of coal seams at the base of the Murta Member, above and so adjacent to the fluviatile environment, supports the model. Passing up through the coals and therefore laterally away from the fluvial environment the coals become enriched in duroclarite at the expense of vitrite and clarite (Figure 9). This indicates a transition from peat formation in a fluvial environment to that in a brackish water environment.

The lagoonal and tidal flat complex corresponds to that part of the Murta Member below the top sand. This complex was the site of deposition of interlaminated muds, silts and very fine sands as seen in core from Nappacoongee-2. The high proportion of inertinite to vitrinite supports a tidal flat environment of deposition with organic matter being exposed to the oxidizing effects of the atmosphere. The bottom sand found within the lagoonal and tidal flat complex may be a delta lobe sand (T. Mount, pers. comm., 1980). It is a coarsening upward sand, less well sorted and dirtier than the upper sand.

The lagoonal facies is characterized by the algae *Botryococcus braunii* and d.o.m. derived from terrestrial sources. Algae occurs as concetrations in layers separated by shales dominated by terrestrial d.o.m. This indicates that the lagoonal environment was subject to periodic changes from oxic to anoxic conditions. Anoxic conditions allowed algae to be preserved while oxic conditions prevented this.

The algae is known to thrive in brackish lagoonal environments (Hutton, et al., 1980). It must be emphasised, however, that the algae has a wide salinity tolerance and therefore its presence is in no way diagnostic of any single environment. The algae and the coals that formed in a brackish water environment suggest that the lagoon may have contained brackish water. This would have arisen as a result of restricted communication with a larger body of water lying to the east due to the presence of the shoreface bar.

The shoreface bar corresponds to the upper sand. It is a thin, coarsening upward sequence which has been reworked and so is better sorted and cleaner than the bottom sand. It is not as well sorted as would be expected in the case of a barrier island (T. Mount, pers. comm., 1980).

To the east of the shoreface bar was a large body of shallow water in which the shales above the top sand were deposited. It is not known whether this body of water was marine or lacustrine.

If marine, the lagoonal facies might be expected to contain marine faunas (Selley, 1976b). In fact only one dinoflagellate has been observed (T. Mount, pers. comm., 1980). This absence can be explained, however, if there was a marked salinity difference between the lagoon and the sea (Elliott, 1979). A lagoon with abnormal salinity values results in a small number of species but a large number of individuals. The high algae content supports the concept of a marked salinity difference between the lagoon and the large body of shallow water.

The upper sand is relatively poorly sorted and dirty compared to what might be expected of a barrier sand. This could be explained in terms of a barrier coastline in a lake. The waves acting on the bar would be of lower energy than in a marine environment.

On the basis of the data gathered during this study it can not be said whether the large body of water to the east was freshwater or marine. The lack of algae in the shales above the upper sand indicates that the waters were oxygenated preventing their preservation.

The barrier coastline model presented here is supported by data gathered during this study and by the observations of other workers. More work is required before the model can be substantiated.

5.1.3 Transition Beds

The presence of glauconite and marine fossils would indicate the Transition Beds are marine. The total d.o.m. content varies in a very regular, cyclic manner. It is possible that the cycles within the different wells are related and indicate events which affected sedimentation across the entire section.

These events may have been transgressions and regressions. The gradual decrease in total d.o.m. content would result from the progressive increase in the distance of the site of deposition from the terrestrial source in response to transgression. The relatively rapid increase in total d.o.m. content corresponds to the decrease in distance from the terrestrial source in response to regression. Three of these cycles are indicated during deposition of the Transition Beds. The d.o.m. is derived from terrestrial sources.

5.2 Rank variation and geothermal gradients

Over the Nappacoongee Murteree anticlinal trend the 0.4% $\bar{R}_o$ and 0.6% $\bar{R}_o$ isoreflectance surfaces are convex upwards. According to Kantsler et al. (in press) this upward flexure over the structural high can not be attributed to post-coalification folding since their appears to be no similar effect on isoreflectance surfaces of higher rank.

The structural high must therefore have had a high geothermal gradient in Jurassic-Cretaceous time. Reflectance studies on the Permian-Triassic sediments of the Cooper Basin indicate that the structural high was not associated with a high geothermal gradient at that time (Lonergan, 1979). Kantsler, et al. (in press) propose a post Triassic inversion of the geothermal gradient regime for structurally high areas. This situation may have been the result of migration of hot waters along the faults associated with the growth of structural highs. Lonergan (op. cit.) suggested that lateral movement of hot connate waters out of the troughs due to compaction of sediments contributed to this situation. This argument would appear doubtful for surely if the connate waters were able to raise the rank of the sediments over the structural highs, they should also have raised the rank of the sediments in the troughs. This mechanism of connate water migration probably operated but had no significant effect on the rank of the sediments.

At Dullingari North-1 and Della-8 the 0.4% $\bar{R}_o$ and 0.6% $\bar{R}_o$ isoreflectance surfaces are concave upwards occurring at a considerably deeper level than over the structural high. In the case of Dullingari North-1 this is the result of the great thickness of Pre-Jurassic sediments. As a result heat flow was inhibited and thermal input was consequently transferred to the nearby structural high.

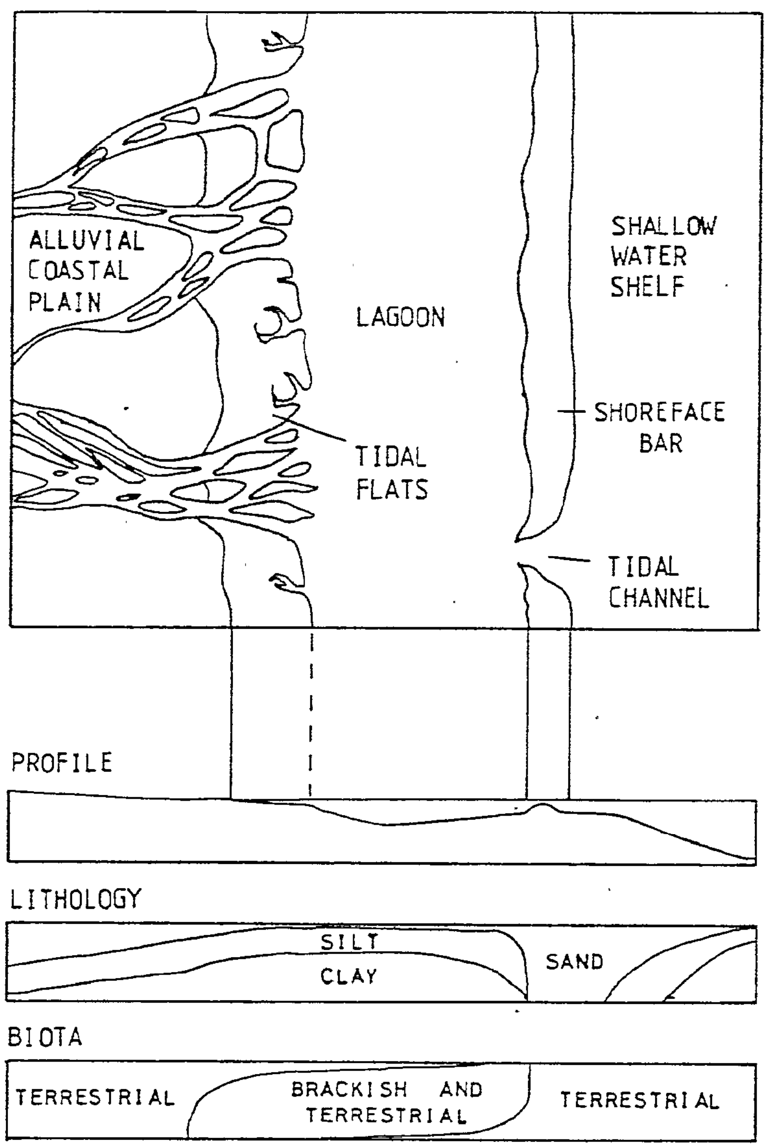
Della-8 does not overly a structural high and therefore the shape of the isoreflectance surfaces is the result of a relatively low geothermal gradient.

Della-7 appears to overly a structural high and thus the convex upward nature of the isoreflectance curves can be explained in the same manner as those associated with the Nappacoongee Murteree anticlinal trend.

According to Kantsler, et al. (in press) the geothermal gradients during Jurassic-Cretaceous time were lower than those operating now. The present geothermal gradients are thought to have arisen only recently possibly dating from the Pliocene.

In conclusion, the rank and geothermal gradients vary in a complex fashion along the line of section. This is in response to varying depth of burial, variable thermal input from different parts of the basement and thickness of the Pre Jurassic sedimentary sequence.

FIGURE 16



SCHEMATIC MODEL OF DEPOSITIONAL ENVIRONMENT OF THE MURTA MEMBER

Mod. from
Selley (1976b)

6 HYDROCARBON POTENTIAL

In determining the hydrocarbon potential of the Eromanga Basin five factors must be considered (Appendix IV).

(1) The organic matter content of the source rocks.

(2) The type of organic matter contained in the source rocks.

(3) The maturity of the source rocks.

(4) Migration.

(5) Reservoirs.

6.1 Birkhead Formation

The total d.o.m. content is generally lower than in the Murta Member. Only Della-7 and Della-8 contain shales with total d.o.m. content greater than 2.8% and so show promise as source rocks. Wilpinnie-1 and Nappacoongee-2 contain shales with greater than 2% total d.o.m. and so may be significant. The intervals over which these percentages occur are relatively short.

Vitrinite is the dominant maceral with exinite prominent and inertinite less common (Plate 5, c). The d.o.m. is terrestrial in nature. According to Tissot and Welte (1978) this corresponds to Type-III kerogen and therefore has a low oil potential. Kantsler, et al. (in press) are more optimistic about the oil potential of rocks dominated by terrestrial d.o.m. quoting the Gippsland Basin as an example.

The mean vitrinite reflectances, $\bar{R}_o$, at the base of the Murta Member range from 0.51 in Della-8 to 0.74 in Della-7. Thus the source rocks of the Birkhead Formation fall within the main maturity zone of oil generation.

The Birkhead Formation would appear to lack suitable reservoir rocks although minor stratigraphic traps may occur.

In summary the petroleum potential of the Birkhead Formation is less than the Murta Member.

The coal seams within the Birkhead Formation have reflectances ranging from 0.49% to 0.74% $\bar{R}_o$. Therefore, it is unlikely that they could be the source of commercial gas deposits.

6.2 Murta Member

The total d.o.m. content is generally higher than in the other two sampled units. Below the lower sand the total d.o.m. content is greater than 2.8% in Dullingari North-1, Wilpinnie-1 and Nappacoongee-2. Therefore these rocks contain sufficient d.o.m. to be source rocks. In Della-7 and Della-8 the total d.o.m. content is less than 2.8% but greater than 2% and so may still be significant. Between the lower and upper sands the total d.o.m. content is greater than 2.8% in Dullingari North-1, Della-7 and Della-8. In Wilpinnie-1 the total d.o.m. content is low over this interval while in Nappacoongee-2 it could not be sampled. Above the upper sand the total d.o.m. content is in the vicinity of 2.8% or greater in Dullingari North-1, Nappacoongee-2, Della-7 and Della-8. The intervals over which these percentages occur are much greater than in the Birkhead Formation.

Exinite is the dominant maceral in the d.o.m. of the Murta Member. The predominant exinite macerals are sporinite (Plate 5, a) and alginite (Plate 1, b,c). The alginite content increases passing up from the base of the unit reaching a maximum of 25% of the total d.o.m. content and then continuing in significant quantities as high as the base of the upper sand. Sporinite is common throughout. Resinite (Plate 5, a) and cutinite are minor components. Where algae occurs as concentrations the d.o.m. corresponds to Type-I kerogen. Where algae does not occur as concentrations the d.o.m. corresponds to Type-II kerogen. These kerogen types have good potential for petroleum and gas.

Reflectivity studies would appear to indicate that the main stage of oil generation has not commenced. Mean vitrinite reflectances, $\overline{R}_o$, at the base of the Murta Member range from 0.36% in Dullingari North-1 to 0.46% in Wilpinnie-1. This indicates that the source rocks of the Murta Member are immature. It must be remembered, however, that different types of organic matter mature at different rates. As alginite matures at a faster rate than vitrinite it is conceivable that it has yielded oil.

If significant hydrocarbon generation and primary migration occurred then petroleum deposits could develop in the upper sand of the Murta Member. This is a thin sand which has been partly reworked and is relatively dirty. Its porosity and permeability would therefore be expected not to be ideal. Recent drilling in the Dullingari Murta Field, however, has proved that this sand is capable of acting as a reservoir rock. The sand is capped by relatively impermeable shales of the upper part of the Murta Member.

The coal seams at the base of the Murta Member in Dullingari North-1 have reflectances ranging from 0.32% $\bar{R}_o$ to 0.36 $\bar{R}_o$ Therefore it is unlikely that they could be the source for commercial gas deposits.

In summary a large proportion of the shales comprising the Murta Member contain sufficient d.o.m. of the right type to be classified as source rocks. The thin upper sand has been shown to be capable of performing the role of a petroleum reservoir rock. Unfortunately the source rocks are probably immature and the major mode of primary migration, pressure driven, discrete, hydrocarbon phase movement (Tissot and Welte, 1978), is not significant in the area of study. The discovery of the Dullingari Murta Field indicates that the source rocks do reach maturity elsewhere. Work by Mudge (1980) to the northwest indicates that the source rocks are widespread. Therefore it is suggested that future work should concentrate on delineating areas where the Murta Member is characterized by higher levels of maturity.

6.3 Transition Beds

The total d.o.m. content of the Transition Beds is generally lower than in the Murta Member. Dullingari North-1 and Wilpinnie-1 have total d.o.m. contents greater than 2.8%. Della-7, Della-8 and Nappacoongee-2 all contain intervals with total d.o.m. contents in the vicinity of this level. As in the Birkhead Formation the intervals over which these percentages are found are much shorter than in the Murta Member.

Exinite and inertinite are the dominant macerals with vitrinite less important. The d.o.m. is terrestrial in nature. This is classed as Type-III kerogen by Tissot and Welte (1978). Again this indicates a low oil potential, a stand that is not shared by Kantsler, et al. (in press).

The mean vitrinite reflectances, $\bar{R}_o$, in the Transition Beds range from 0.32% in Dullingari North-1 to 0.42% in other wells. This indicates that the source rocks of the Transition Beds are immature.

In summary, the petroleum potential of the Transition Beds is low.

CONCLUSIONS

1. The total d.o.m. content is found to vary in all three sampled units. This may result from

   (a) Variations in the rate of sedimentation.

   (b) Variation in grain size of sediments allowing varying degrees of oxidation and so preservation of organic matter.

   or a combination of the two.

2. The Birkhead Formation was probably deposited in a lacustrine environment with associated forest swamps and to a lesser extent open marsh swamps and exposed swamps.

3. A barrier coastline environment may be responsible for deposition of the Murta Member.

4. The Transition Beds were deposited in a shallow marine environment which may have been subject to periodic transgressions and regressions.

5. Vitrinite reflectance studies indicate that rank and geothermal gradients vary in a complex fashion along the line of section. This is the result of

   (a) Varying depth of burial.
   (b) Variable thermal input from different parts of the basement.
   (c) Thickness of the Pre Jurassic sedimentary sequence.

6. A large proportion of the shales comprising the Murta Member are high quality source rocks containing Type-I and Type-II kerogen. Their hydrocarbon potential is therefore high. The petroleum potential of the Birkhead Formation and Transition Beds which contain Type-III kerogen is low.

(a) Tellocollinite; the structureless variety of vitrinite (D7-38).

(b) Longitudinal section of the algae *Botryococcus braunii* set in shale under UV light. Displays tubes and chambers (DN-14).

(c) Longitudinal and radial sections of *Botryococcus braunii* (DN-10).

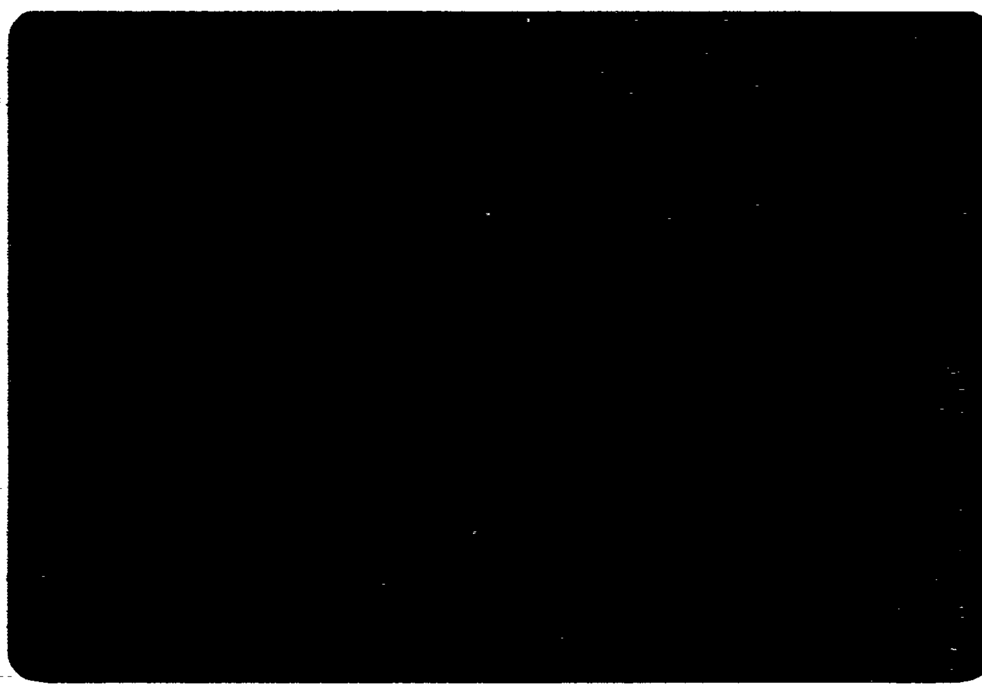
L - Longitudinal

R - Radial

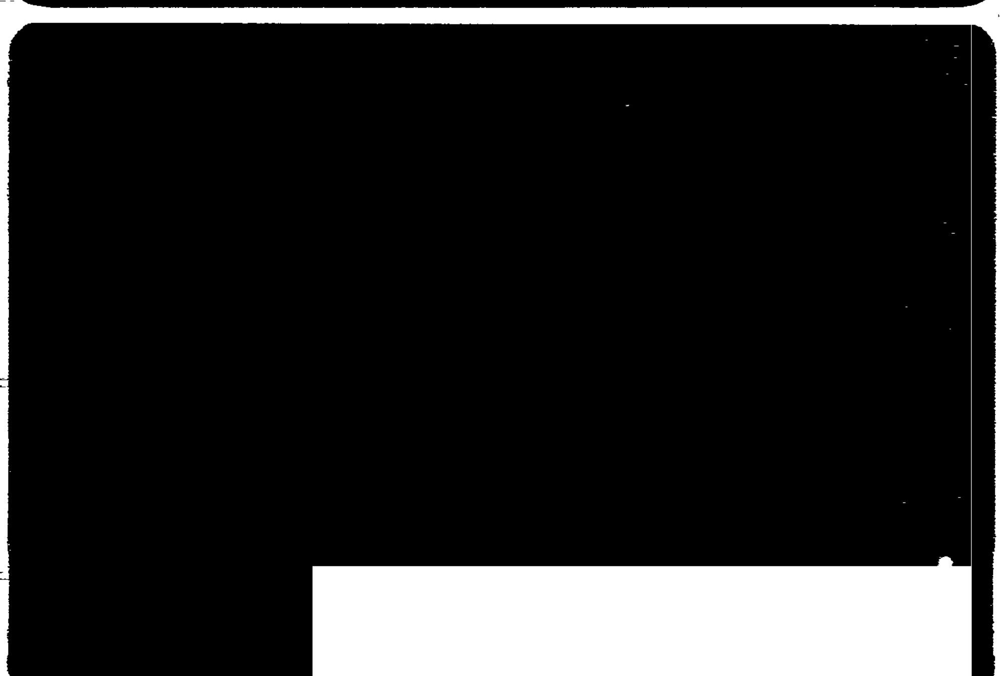
(Field of view is 0·43 mm across)

PLATE 1

a



b



c

PLATE 2

(a) Clarite rich in sporinite and resinite (D8-15). The exinite macerals are dark grey whilst the vitrinite is light grey.

(b) Clarite rich in alginite and cutinite (DN-50).

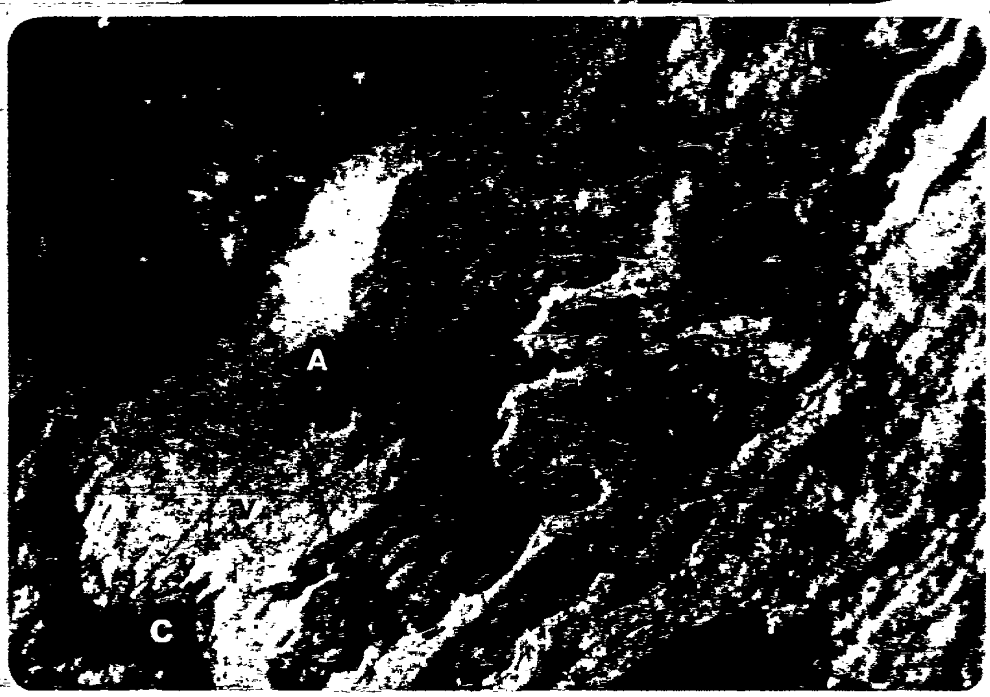
V - Vitrinite (Desmocollinite)
A - Alginite
C - Cutinite

(c) The same field of view as for (b) under UV light (DN-50).

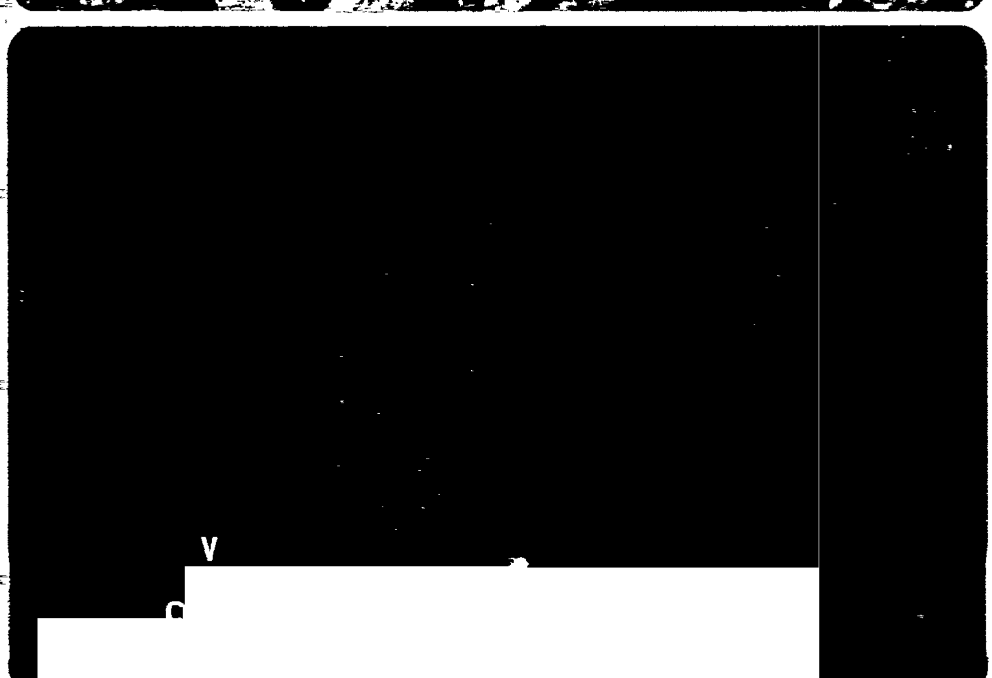
F. V. = 0·43 mm

PLATE 2

a



b



c

PLATE 3

(a) Duroclarite; consists of desmocollinite matrix with inertodetrinite and sporinite as inclusions (D8-10).

V - Vitrinite (Desmocollinite)

I - Inertodetrinite

(b) The same field of view as for (a) under UV light. The sporinite can now be picked out because it fluoresces (D8-10).

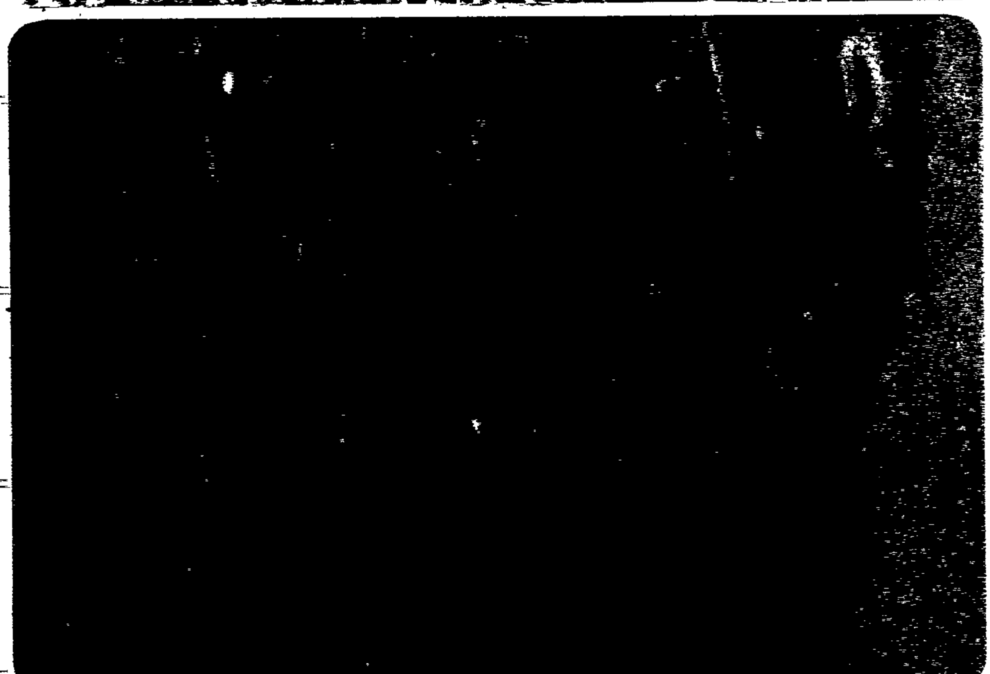
(c) Fusite and Clarite (DN-16).

F - Fusite

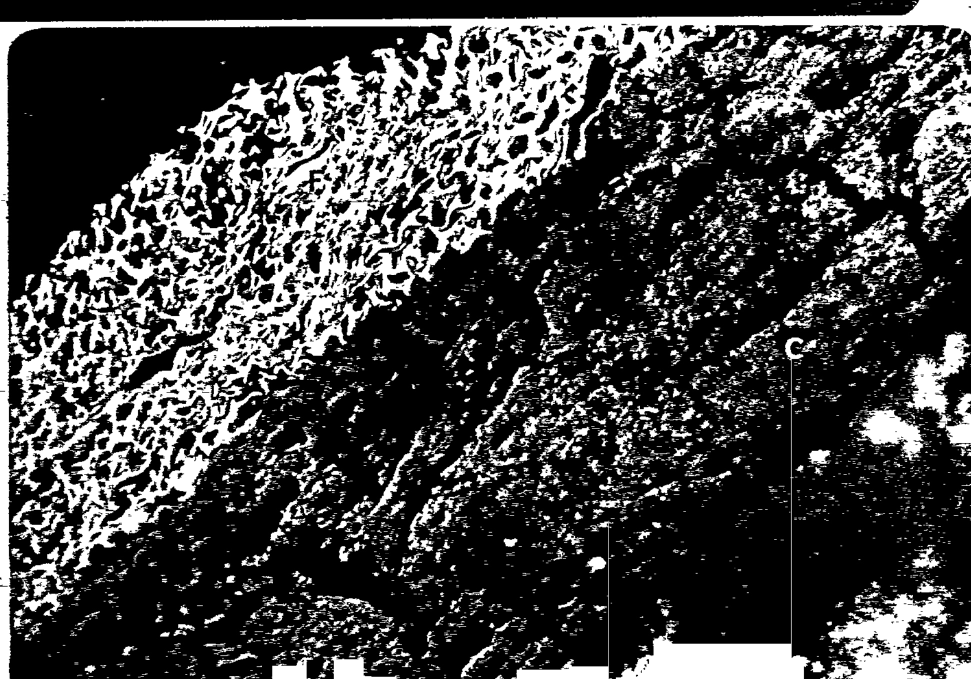
C - Clarite

F.V.= 0·43 mm

a



b



c

(a) Megaspore set in shale (D8-3).

M - Megaspore

(b) The same megaspore under UV light (D8-3).

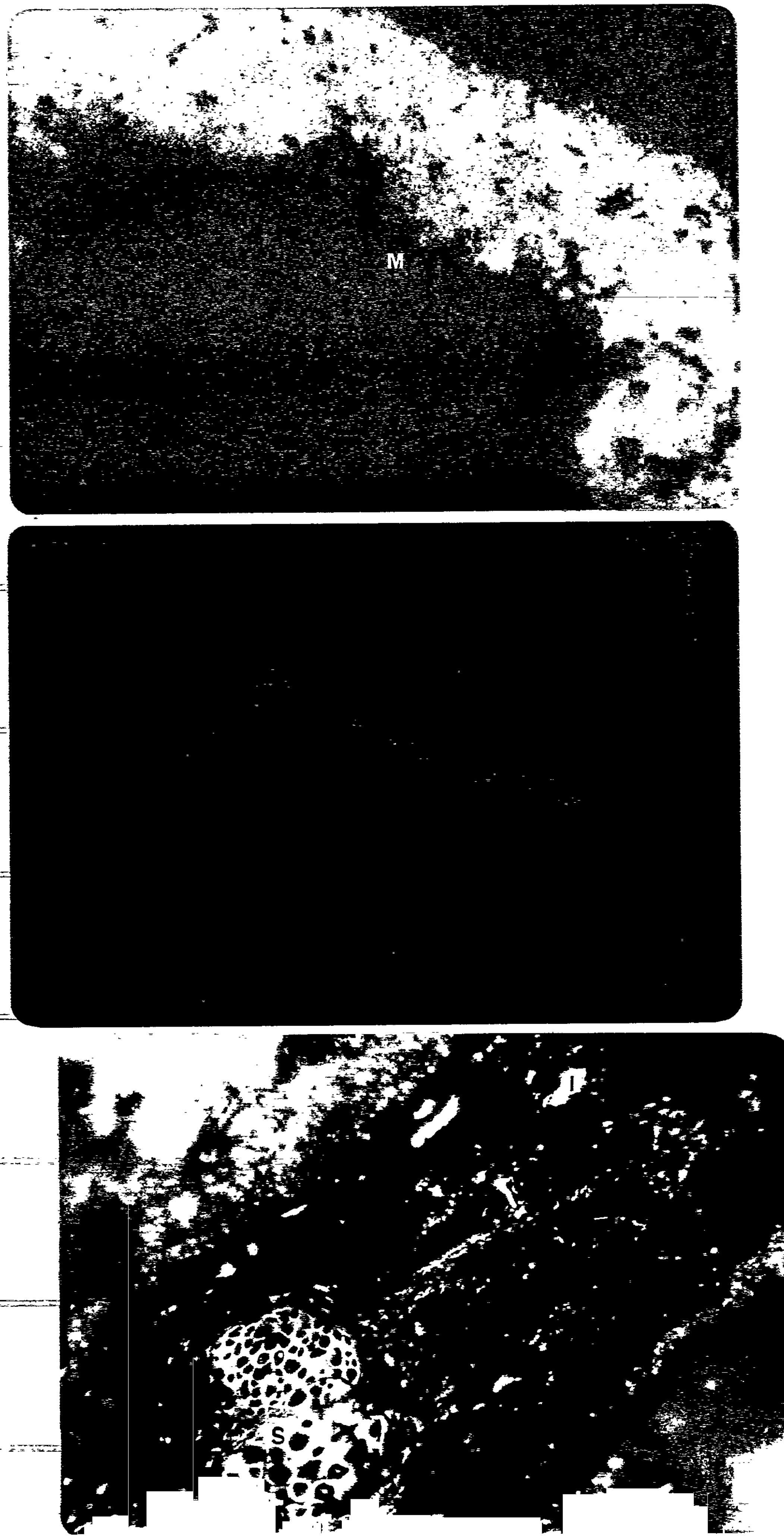
(c) Sclerotinite set in shale (D8-50).

S - Sclerotinite

I - Inertodetrinite

F.V. = 0·43 mm

PLATE 4



a

b

c

(a) Resinite and sporinite set in shale (D8-15).

R - Resinite

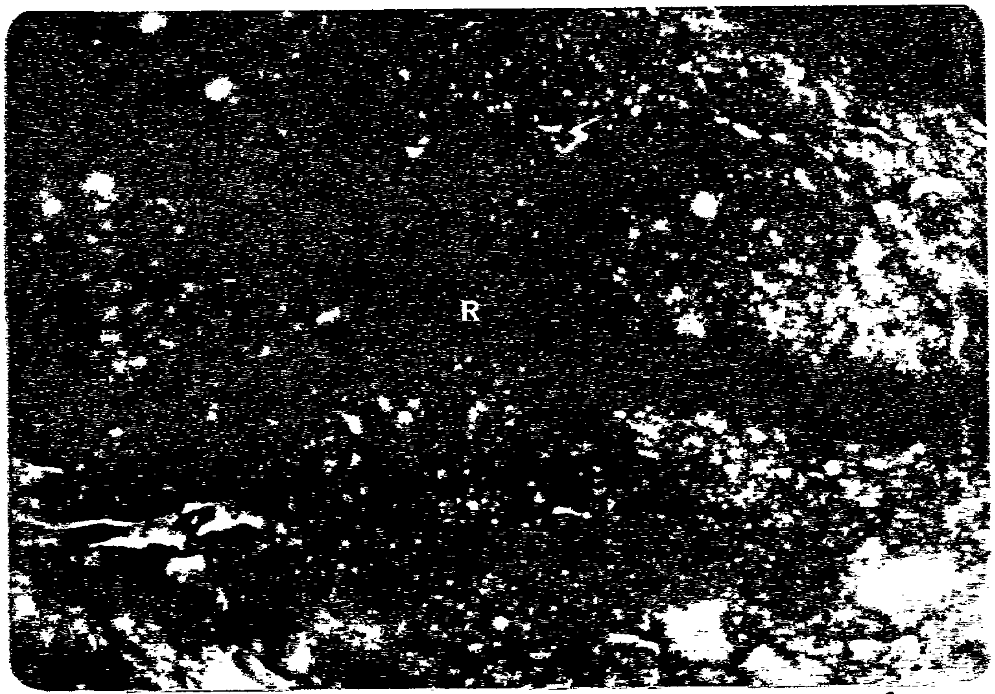
(b) The same field of view as for (a) under UV light. The sporinite can now be picked out because it fluoresces (D8-15).

(c) Elongate vitrinitic d.o.m. (D8-57).

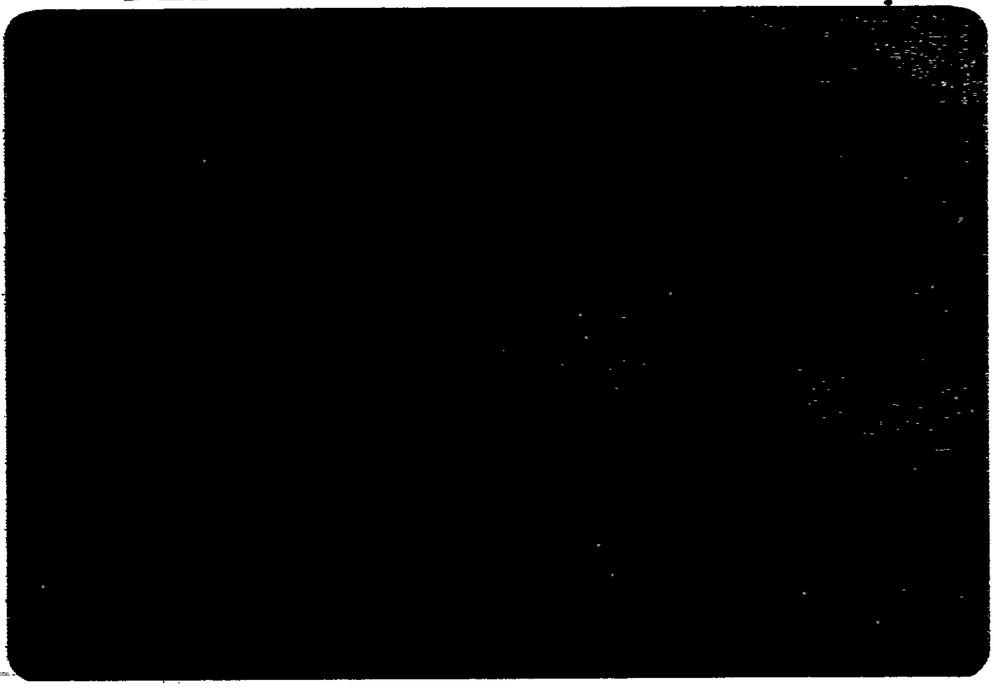
V - Vitrinite

F.V. = 0·43 mm

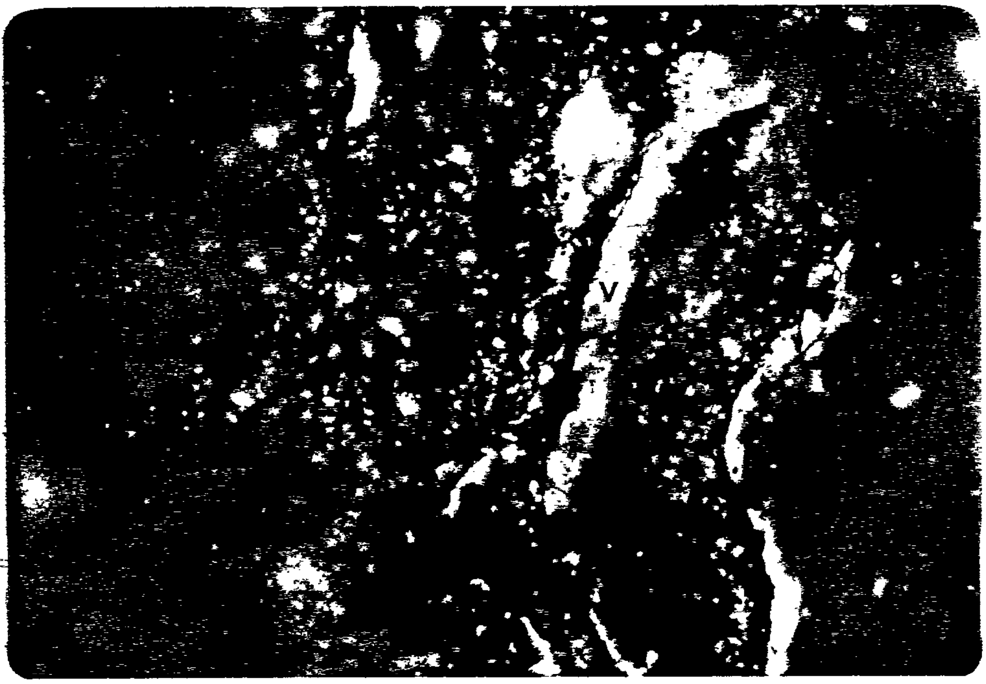
PLATE 5



a



b



c

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* * *

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APPENDIX I

SAMPLING AND SAMPLE PREPARATION

(a) Sampling

The Transition Beds, Murta Member and Birkhead Formation were sampled over their entire range in each of the five wells. These intervals were sampled because they are predominantly composed of shale and silt and as such are possible source rocks.

Samples were taken from rock cuttings only. The limited amount of core available was studied but not sampled.

Cuttings were available over intervals of 3.05 metres (10 feet). All cuttings were washed before being stored at the South Australian Department of Mines and Energy Core Library.

(b) Down Hole Caving

This results in contamination of lower intervals. It is most significant in samples with very low coal contents. It is possible that many samples only contained coal from higher levels. Caving results in anomalously low reflectance values and also casts doubts on the validity of coal maceral data determined for samples with low coal contents.

Caving was found to be a significant problem in the Murta Member and the Transition Beds. In most cases coal contents were very low within these units and are probably the result of caving from higher levels. Therefore data gathered in such instances should be interpreted in an appropriate manner.

(c) Sample Preparation

The 3.05 metre samples were usually combined to form representative samples over 9.15 metres (30 feet). This was done to enable the study of the complete range of the three units. Where an individual 3.05 metre interval was seen to contain greater than 10% coal it was not combined.

Samples were then mounted and polished. The polished sections were produced by three different techniques due to unavoidable circumstances. The method recommended by Eric Murray (pers. comm., 1980) from C.S.I.R.O., is described here.

The coal and shale is crushed to a size of less than 850 microns. The crushed particles are mixed well with the polyester resin and then placed in a square mold, 2½ cm on a side, where they are left to set. The sections are then ground on a diamond wheel until they are flat. This is followed by grinding on 400 and 600 silicon carbide wet and dry paper. They are cleaned under a high pressure jet of water rather than in an ultrasonic bath as this tended to break the shale fragments into tiny particles.

Polishing involved three stages. The first was with a one micron Al_2O_3 powder solution. Both of these stages were carried out on a mechanical lap rotating at approximately 400 r.p.m. The final stage of the polishing process involved polishing by hand with Buehler magomet on selvyt cloth. The sample is then given a short rub on clean selvyt cloth and water. The section was cleaned under a high pressure jet of water after each stage.

POSSIBLE ERROR IN TOTAL MACERAL TYPE CONTENT OF COAL DETERMINED FROM CUTTINGS

Lonergan (1979) reports a potential selective bias in the determination of vitrinite, inertine and exinite content of coals. Core samples were found to contain 15-30% more vitrinite than did cutting samples in close depth proximity. This observation introduces some error into the use of cuttings for maceral content determination. He goes on to say that the problem could be the result of the lower density of vitrinite compared to the other macerals (Stach, 1975) and its greater fracturing ability resulting in grains breaking up during drilling and being carried off during washing due to their fine size.

APPENDIX II

DETERMINATION OF MACERAL CONTENTS OF D.O.M. AND COAL

Point counts were made on all polished sections under ordinary light to determine the coal maceral and d.o.m. contents. Where the coal content of a sample was greater than 10% point counts were made to determine the coal microlithotype content. The sections were completely covered by points at ⅓ mm intervals in lines at 1 mm spacings. This resulted in approximately 1500 points of which between 500 and 1000 coincided with coal, d.o.m. or rock. This was the number of points suggested by Smyth (pers. comm., 1980). Maceral counts involved the use of a 60X magnification objective while microlithotype counts were made with a 25X magnification objective.

The point counts enabled the content of the various maceral types to be calculated. These are vitrinite, sporinite, cutinite, resinite, alginite, liptodetrinite, inertodetrinite, semifusinite and fusinite. In this study suberinite was classed as vitrinite.

It was difficult to identify the various forms of exinite in ordinary light. On some occasions exinite displays no morphology while on others what appears to be exinite is in fact not. This is shown in Plates A3,a and A3,b. The exinite content was checked by detailed observation of the sections under U.V. light.

The d.o.m. content is tabulated here (Tables A1-A5) in terms of the three maceral groups, vitrinite, inertinite and exinite as percentages of total d.o.m. and total rock. In the case of coal the three maceral groups are tabulated as percentages of total coal content. Microlithotype data is summarized in Tables A1-A5.

TABLE A1 - DULLINGARI NORTH-1

SAMPLE NO.	INTERVAL	T.O.M.	D.O.M.	D.O.M. AS % OF TOTAL D.O.M.			D.O.M. AS % OF TOTAL ROCK			COAL	COAL AS % OF TOTAL COAL		
				V	I	E	V	I	E		V	I	E
DN- 1	1307.6-1316.7	3.3	2.9	27	13	60	0.8	0.4	1.7	0.4	95	-	5
2	1325.9	2.2	2.2	27	18	55	0.6	0.4	1.2	-	-	-	-
3	1335	1.0	1.0	40	20	40	0.4	0.2	0.4	-	-	-	-
4	1344.2	1.4	1.4	29	29	42	0.4	0.4	0.6	0.1	100	-	Tr
5	1353.3	3.0	1.2	17	33	50	0.2	0.4	0.6	1.8	100	-	Tr
6	1362.5	2.4	1.0	11	26	63	0.1	0.3	0.6	1.4	96	4	Tr
7	1371.6	1.6	1.4	29	29	42	0.4	0.4	0.6	0.2	100	-	-
8	1380.7	1.8	1.8	22	34	44	0.4	0.6	0.8	-	-	-	-
9	1389.9	1.9	1.8	13	55	32	0.3	1.0	0.5	0.2	100	-	-
10	1399	3.6	3.3	14	38	48	0.4	1.3	1.6	0.3	100	-	Tr
11	1408.2	5.0	4.5	12	29	59	0.5	1.3	2.7	0.5	95	2	3
12	1417.3	6.4	4.5	13	48	39	0.5	2.2	1.8	1.9	85	10	5
13	1426.5	7.4	2.0	15	64	21	0.3	1.3	0.4	5.4	90	7	3
14	1435.6	5.7	4.5	17	35	48	0.7	1.6	2.2	1.2	100	-	Tr
15	1438.7	4.6	4.0	10	38	52	0.4	1.5	2.1	0.6	95	-	5
16	1441.7	12.9	3.7	19	33	48	0.7	1.2	1.8	9.2	89	7	4
17	1444.7	36.6	4.4	13	28	59	0.6	1.2	2.6	32.2	82	14	4
18	1447.8	27.4	3.0	22	28	50	0.7	0.8	1.5	24.4	85	10	5
19	1450.8	17.5	3.1	31	32	37	1.0	1.0	1.1	14.4	84	8	8
20	1453.9	13.6	1.2	43	29	28	0.5	0.4	0.3	12.4	88	4	8
49	1691.6-1700.8	2.1	1.7	67	11	22	1.1	0.2	0.4	0.4	90	5	5
50	1709.9	2.0	1.3	67	Tr	33	0.9	Tr	0.4	0.7	80	-	20

TABLE A2 - NAPPACOONGEE-2

SAMPLE NO.	INTERVAL	T.O.M.	D.O.M.	D.O.M. AS % OF TOTAL D.O.M.			D.O.M. AS % OF TOTAL ROCK			COAL	COAL AS % OF TOTAL COAL		
				V	I	E	V	I	E		V	I	E
N- 1	1127.8-1136.9	1.8	1.6	25	25	50	0.4	0.4	0.8	0.2	100	-	-
2	1146	1.6	1.6	25	37	38	0.4	0.6	0.6	-	-	-	-
3	1155.2	4.4	2.7	21	36	43	0.5	1.0	1.2	1.7	95	-	5
4	1164.3	2.2	1.0	40	20	40	0.4	0.2	0.4	1.2	85	-	15
5	1173.5	2.2	2.0	30	10	60	0.6	0.2	1.2	0.2	90	-	10
6	1182.6	2.9	1.9	20	30	50	0.3	0.6	1.0	1.0	95	-	5
7	1191.8	1.8	1.4	29	57	14	0.4	0.8	0.2	0.4	80	-	20
8	1200.9	2.7	2.1	36	28	36	0.8	0.5	0.8	0.6	80	10	10
9	1204	1.6	1.2	-	33	67	-	0.4	0.8	0.4	90	Tr	10
10	1207 -1216.2	3.9	2.7	7	29	64	0.2	0.8	1.7	1.2	67	33	Tr
11	1225.3	2.2	1.8	11	33	56	0.2	0.6	1.0	0.4	95	-	5
12	1240.5-1249.7	2.5	1.9	10	20	70	0.2	0.4	1.3	0.6	80	-	20
13	1258.8	4.1	3.3	10	31	59	0.4	1.0	1.9	0.8	100	-	Tr
14	1268	3.3	3.1	25	25	50	0.7	0.8	1.6	0.2	100	-	-
15	1271	2.5	2.5	15	31	54	0.3	0.8	1.4	-	-	-	-
44	1496.6-1502.7	3.1	2.3	50	8	42	1.2	0.2	0.9	0.8	80	10	10
45	1511.8	2.3	2.3	42	16	42	1.0	0.3	1.0	-	-	-	-
46	1521	4.6	2.7	43	14	43	1.2	0.3	1.2	1.9	75	5	20
47	1530.1	2.4	1.8	56	11	33	1.0	0.2	0.6	0.6	95	-	5
48	1539.2	2.4	2.0	50	-	50	1.0	-	1.0	0.4	100	-	-
49	1545.3-1554.5	2.0	1.0	20	-	80	0.2	-	0.8	1.0	100	-	Tr

TABLE A3 - WILPINNIE-1

SAMPLE NO.	INTERVAL	T.O.M.	D.O.M.	D.O.M. AS % OF TOTAL D.O.M.			D.O.M. AS % OF TOTAL ROCK			COAL	COAL AS % OF TOTAL COAL		
				V	I	E	V	I	E		V	I	E
W- 1	1255.8-1264.9	4.8	4.0	10	38	52	0.4	1.6	2.0	0.2	100	-	Tr
2	1274	1.2	1.2	17	33	50	0.2	0.4	0.6	0.8	75	15	10
3	1283.2	1.9	1.9	11	44	45	0.1	0.9	0.9	1.0	70	20	10
4	1292.2	2.7	2.3	25	42	33	0.5	1.0	0.8	0.4	100	-	-
5	1201.5	3.3	3.3	24	35	41	0.7	1.2	1.4	-	-	-	-
6	1310.6	1.2	1.2	33	17	50	0.4	0.2	0.6	-	-	-	-
7	1319.8	3.5	2.7	21	36	43	0.5	1.0	1.2	0.8	95	-	5
8	1322.8	6.5	4.1	32	41	27	1.3	1.7	1.1	2.4	92	8	Tr
9	1332	1.6	1.6	27	37	36	0.4	0.6	0.6	-	-	-	-
10	1341.1	2.7	2.7	7	36	57	0.2	1.0	1.5	-	-	-	-
11	1347.2	2.7	2.1	19	36	45	0.4	0.8	0.9	0.6	100	-	Tr
12	1356.4	2.2	1.8	23	31	46	0.4	0.6	0.8	0.4	100	-	-
13	1365.5	1.9	1.3	11	33	56	0.2	0.4	0.7	0.6	88	12	-
14	1374.6	2.6	1.4	Tr	63	37	Tr	0.9	0.5	1.2	100	-	Tr
15	1383.8	0.9	0.9	20	40	40	0.2	0.3	0.4	-	-	-	-
16	1392.9	3.2	3.1	21	9	70	0.7	0.2	2.2	0.1	100	-	-
17	1402.1	3.8	3.8	15	25	60	0.5	1.0	2.3	-	-	-	-
W-43	1630.7-1639.8	1.9	1.8	50	20	30	0.9	0.4	0.5	0.1	70	-	30
44	1649	1.4	1.4	11	33	56	0.1	0.5	0.8	-	80	-	20
45-46	1655.1	10.0	1.7	33	44	23	0.6	0.7	0.4	8.3	85	10	5
47	1664.2	2.6	1.7	45	19	36	0.8	0.3	0.6	0.9	100	-	-
48	1673.4	4.7	2.3	47	27	26	1.1	0.6	0.6	2.4	90	5	5
49	1682.5	4.1	4.1	60	15	25	2.5	0.6	1.0	-	-	-	-
50	1691.7	1.5	1.3	29	14	57	0.4	0.2	0.7	0.2	90	-	10

TABLE A4 - DELLA 8

SAMPLE NO.	INTERVAL	T.O.M.	D.O.M.	D.O.M. AS % OF TOTAL D.O.M.			D.O.M. AS % OF TOTAL ROCK			COAL	COAL AS % OF TOTAL COAL		
				V	I	E	V	I	E		V	I	E
D8- 1	1237.5-1246.6	2.0	1.8	25	25	50	0.5	0.4	0.9	0.2	100	-	-
2	1255-8	2.5	2.1	36	19	45	0.8	0.4	0.9	0.4	100	-	-
3-5	1264.9	4.0	2.7	21	29	50	0.5	0.8	1.4	1.3	96	-	4
6	1268	3.8	1.5	25	50	25	0.4	0.8	0.4	2.3	100	-	Tr
7	1271	4.6	2.1	19	54	27	0.4	1.1	0.6	2.5	96	-	4
8	1280.2	4.0	2.7	21	43	36	0.5	1.2	1.0	1.3	85	10	5
9	1289.3	4.4	2.3	25	42	33	0.5	1.0	0.8	2.1	96	Tr	4
10	2998.4	2.8	1.4	29	42	29	0.4	0.6	0.4	1.4	80	10	10
11	1307.6	2.9	2.1	19	54	27	0.4	1.1	0.6	0.8	100	-	Tr
12	1316.7	1.9	1.9	17	58	25	0.3	1.1	0.5	Tr	100	-	-
13	1325.9	4.0	2.8	46	27	27	1.3	0.8	0.7	1.2	95	-	5
14	1335	3.2	3.0	44	39	17	1.3	1.2	0.5	0.2	90	-	10
15-17	1344.2	8.8	5.2	35	35	30	1.8	1.8	1.6	3.6	95	-	5
18	1347.2	3.9	2.9	20	60	20	0.6	1.7	0.6	1.0	90	5	5
19	1356.4	2.5	2.1	27	37	36	0.5	0.8	0.8	0.4	100	-	Tr
20	1365.5	1.0	0.8	45	15	40	0.4	0.1	0.3	0.2	100	-	Tr
21	1368.6	3.7	1.2	17	33	50	0.2	0.4	0.6	2.5	85	5	10
22	1377.7	4.0	2.7	21	43	36	0.5	1.2	1.0	1.3	80	10	10
45	1578.9-1588	2.3	1.9	50	30	20	1.0	0.6	0.3	0.4	100	-	Tr
46	1591.1	1.4	1.0	95	Tr	5	0.9	Tr	0.1	0.4	95	5	-
47	1594.1	4.6	1.5	100	Tr	Tr	1.5	Tr	Tr	3.1	80	10	10
48	1597.2	2.3	0.5	67	-	33	0.3	-	0.2	1.8	95	-	5
49	1600.2	6.3	3.1	88	-	12	2.7	-	0.4	3.2	80	8	12
50	1603.2	12.6	2.8	73	7	20	2.0	0.2	0.6	9.8	86	4	10
51	1606.3	6.6	2.1	55	18	27	1.2	0.3	0.6	4.5	75	10	15
52-54	1609.4-1618.5	1.0	0.6	60	10	30	0.4	0.1	0.2	0.4	90	-	10
55	1621.5	2.5	1.5	100	Tr	Tr	1.5	Tr	Tr	1.0	90	6	4
56	1630.7	2.3	1.2	100	Tr	Tr	1.2	Tr	Tr	1.1	90	6	4
57-58	1636.8	4.4	3.1	88	6	6	2.7	0.2	0.2	1.3	95	-	5
59	1645.9	2.2	1.8	56	Tr	44	1.0	Tr	0.8	0.4	100	-	Tr

00447

TABLE A5 - DELLA 7

SAMPLE NO.	INTERVAL	T.O.M.	D.O.M.	D.O.M. AS % OF TOTAL D.O.M.			D.O.M. AS % OF TOTAL ROCK			COAL	COAL AS % OF TOTAL COAL		
				V	I	E	V	I	E		V	I	E
D7- 1	1261.9-1271	1.8	1.8	44	23	33	0.8	0.4	0.6	-	-	-	-
2	1280.2	2.7	2.5	7	62	31	0.2	1.6	0.7	0.2	100	-	-
3	1289.3	3.1	2.7	14	57	29	0.4	1.5	0.8	0.4	80	-	20
4	1298.4	8.6	1.5	24	38	38	0.3	0.6	0.6	7.1	76	12	12
5	1307.6	2.3	2.3	9	58	33	0.2	1.3	0.8	-	-	-	-
6	1316.7	3.1	2.5	16	46	38	0.4	1.2	0.9	0.6	100	-	-
7	1325.9	2.0	1.4	-	29	71	-	0.4	1.0	0.6	100	-	Tr
8	1335	1.8	1.8	11	56	33	0.2	1.0	0.6	-	-	-	-
9	1344.2	4.0	4.0	29	23	48	1.2	0.9	1.9	-	-	-	-
10	1353.3	2.9	2.9	13	40	47	0.3	1.2	1.4	-	-	-	-
11	1362.5	4.0	4.0	35	25	40	1.4	1.0	1.6	-	-	-	-
12	1371.6	2.7	2.7	29	21	50	0.8	0.5	1.4	-	-	-	-
13	1380.7	2.4	2.0	10	60	30	0.2	1.2	0.6	0.4	100	-	Tr
14	1389.9	2.3	2.1	9	27	64	0.2	0.6	1.3	0.2	90	-	10
15	1399	1.6	1.6	25	12	63	0.4	0.2	1.0	-	-	-	-
37	1609.3-1618.5	2.8	1.6	63	25	12	1.0	0.4	0.2	1.2	100	-	-
38	1627.6	2.4	1.4	43	28	29	0.6	0.4	0.4	1.0	40	60	-
39	1636.8	3.1	2.5	54	15	31	1.4	0.4	0.7	0.6	95	-	5
40	1645.9	4.1	3.1	25	37	38	0.8	1.1	1.2	1.0	95	-	5
41	1652	2.8	1.8	45	33	22	0.8	0.6	0.4	1.0	100	-	Tr
42	1655.1	16.6	2.8	59	24	17	1.7	0.7	0.4	13.8	90	5	5
43	1658.1	8.1	2.4	32	30	38	0.8	0.7	0.9	5.7	70	26	4
44	1667.3	1.2	1.2	33	50	17	0.4	0.6	0.2	-	-	-	-
45	1676.4	2.5	2.5	31	31	38	0.7	0.7	1.1	-	-	-	-
46	1685.5	2.0	1.8	33	44	22	0.6	0.8	0.4	0.2	100	-	-

00448

● DULLINGARI NORTH-1

■ NAPPACOONGEE-2

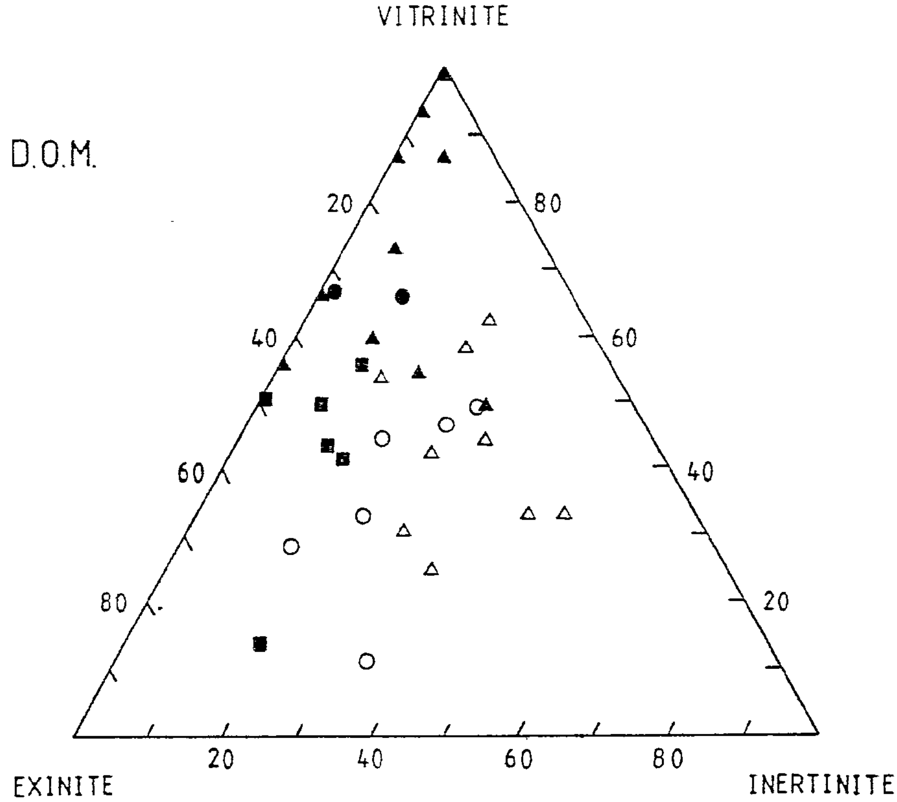
○ WILPINNIE-1

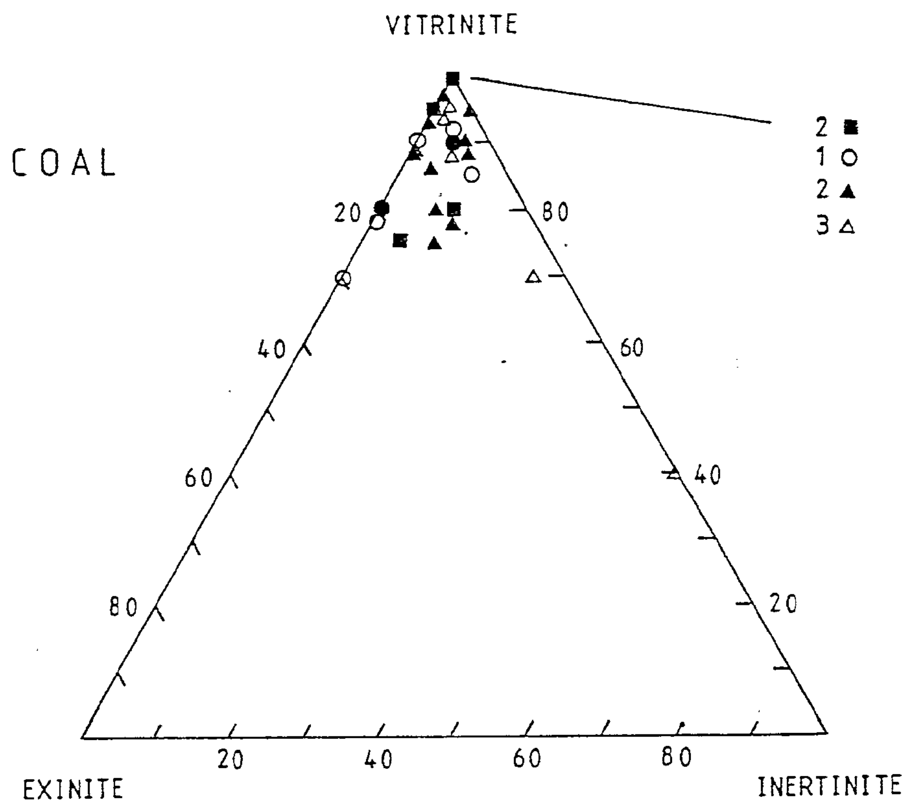
▲ DELLA-8

△ DELLA-7

BIRKHEAD FORMATION

FIGURE A1



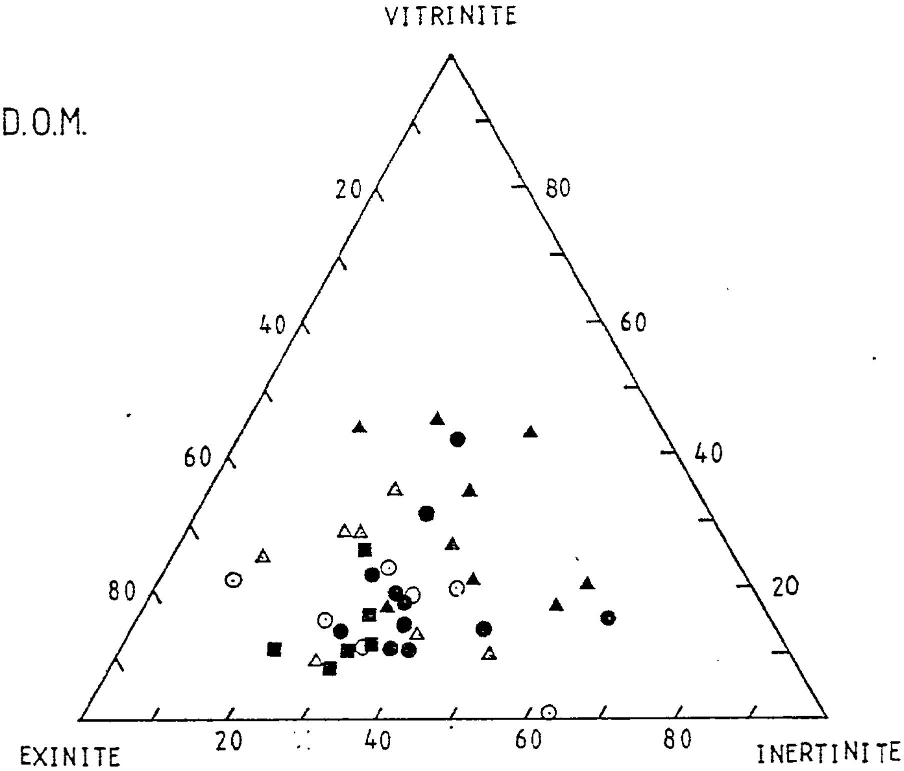


S.M.M. 80

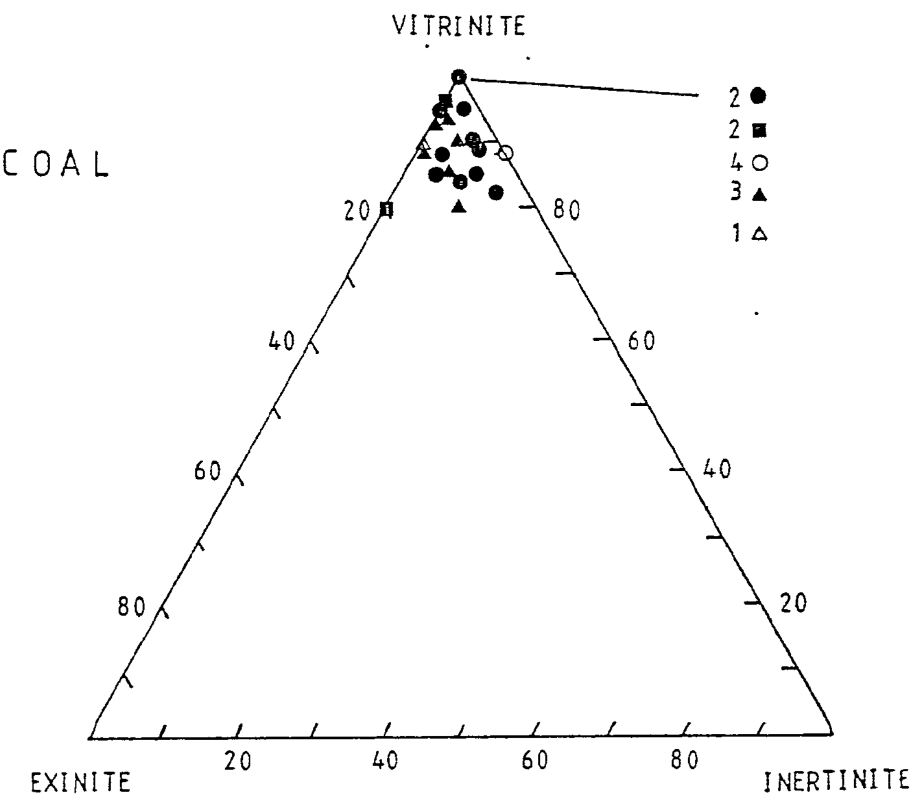
MURTA MEMBER

FIGURE A2

D.O.M.



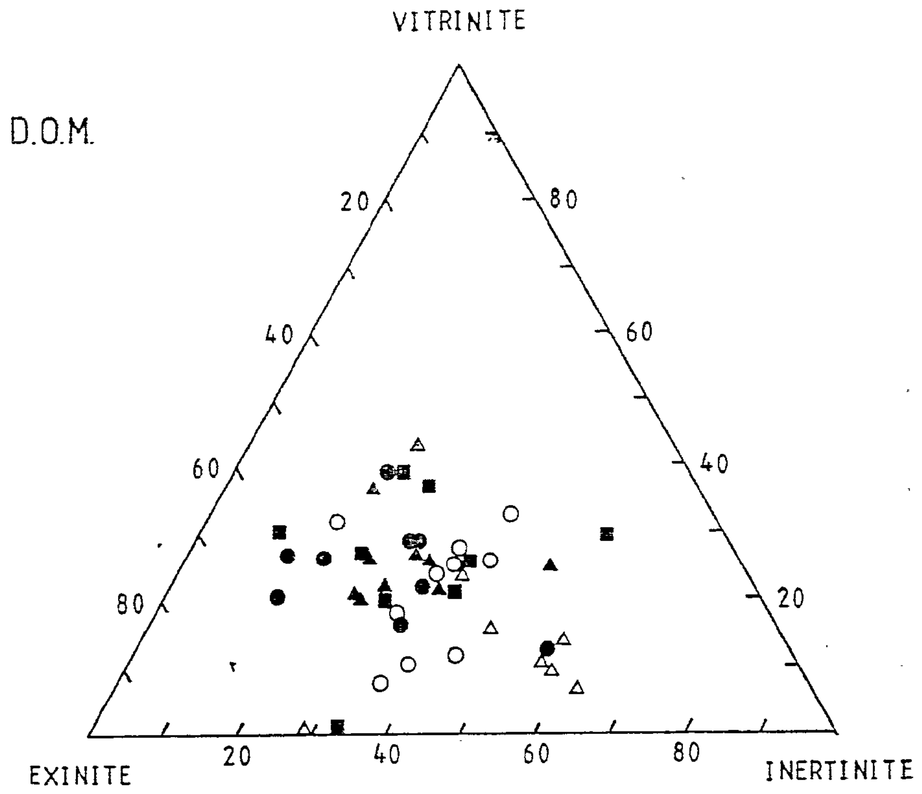
COAL

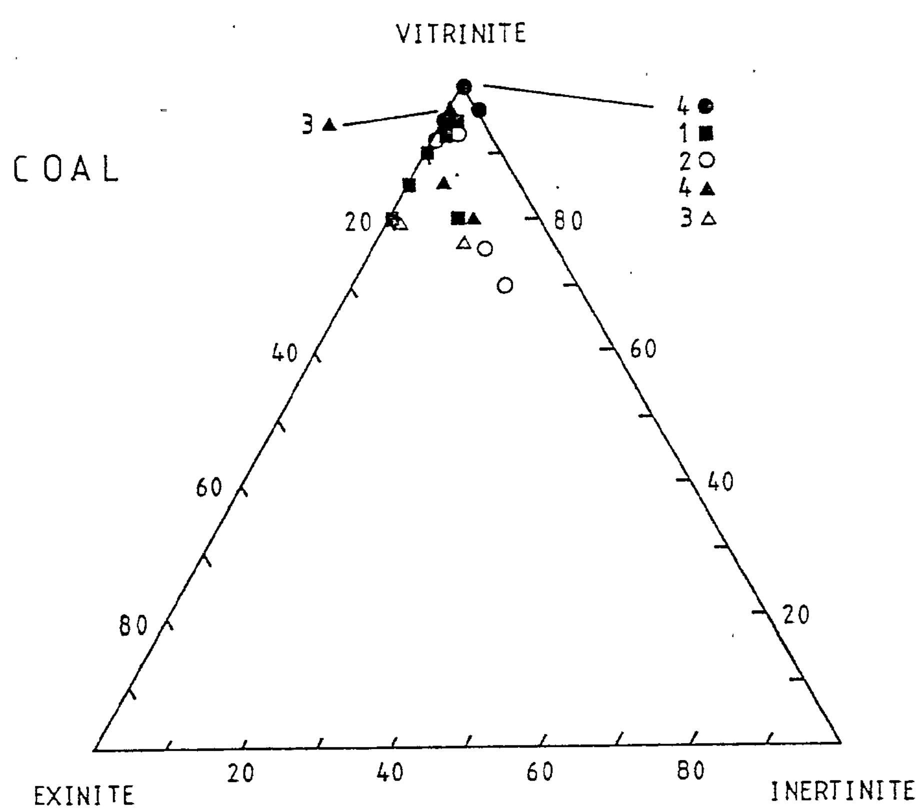


S.M.M. 80

TRANSITION BEDS

FIGURE A3





S.M.M.80

TABLE A6

Summary of the microlithotypes *

Maceral composition (mineral-free)		Microlithotype	Maceral-group composition (mineral-free)	Microlithotype group
Monomaceral				
Co	> 95 %	(Collite)*	V > 95 %	Vitrite
T	> 95 %	(Telite)*		
VD	> 95 %			
S	> 95 %	Sporite		
Cu	> 95 %	(Cutite)*		
R	> 95 %	(Resite)*	E (L) > 95 %	Liptite
A	> 95 %	Algite		
LD	> 95 %			
Sf	> 95 %	Semifusite		
F	> 95 %	Fusite	I > 95 %	Inertite
Sc	> 95 %	(Sclerotite)*		
ID	> 95 %	Inertodetrite		
M	> 95 %	(Macroite)*		
Bimaceral				
V + S	> 95 %	Sporoclarite		
V + Cu	> 95 %	Cuticoclarite	V + E (L) > 95 %	Clarite V, E(L)
V + R	> 95 %	(Resinoclarite)*		
V + LD	> 95 %			
V + M	> 95 %			
V + Sf	> 95 %			
V + F	> 95 %		V + I > 95 %	Vitrinertite V, I
V + Sc	> 95 %			
V + ID	> 95 %			
I + S	> 95 %	Sporodurite		
I + Cu	> 95 %	(Cuticodurite)*		
I + R	> 95 %	(Resinodurite)*	I + E (L) > 95 %	Durite I, E(L)
I + LD	> 95 %			
Trimaceral				
V, I, E	> 5 %	Duroclarite	V > I, E (L)	Trimacerite V, I, E(L)
		Vitrinertoliptite	E > I, V	
		Clarodurite	I > V, E (L)	

* The terms in parentheses are not at present in use.

Co = Collinite; T = Telinite; VD = Vitrodetrinite; S = Sporinite; Cu = Cutinite; R = Resinite; A = Alginite; LD = Liptodetrinite; M = Macrinite; Sf = Semifusinite; F = Fusinite; Sc = Sclerotinite; ID = Inertodetrinite; V = Vitrinite; F = Fusinite; L = Liptinite; I = Inertinite.

Stach (1975)

APPENDIX III

REFLECTANCE STUDIES

The reflectance of vitrinite is a measure of the rank of a coal, increasing with depth of burial in response to rising temperature and time of exposure. According to Kantsler, et al. (1978a) the mean vitrinite reflectance, $\bar{R}_o$, is one of the most reliable and sensitive indicators of rank.

Temperature and time also control petroleum genesis so that the various stages of petroleum maturation can be determined by vitrinite reflectances. Measurements may be made on coal seams associated with source rocks or the vitrinitic d.o.m. within the source rocks themselves.

Tellocollinite is the vitrinite maceral which is normally used in reflectance determinations (Stach, 1975). Many of the samples contain little or no coal so that measurements had to be made on vitrinitic d.o.m. As these inclusions often occur segregated from their like it is difficult to determine which vitrinite maceral they are. Therefore, reflectivities were recorded from all the different forms of vitrinite present. Each of these has its own characteristic reflectance. Because of this $\bar{R}_o$ values for individual samples could be expected to show greater variation than normally encountered.

Reflectance measurements were made using a Leitz Ortholux II Pol BK microscope. The microscope has three light sources. The observation light source is a standard tungsten light of variable intensity. An UV lamp allows the examination of samples under UV light. For reflectance measurements the measurement light is used. This is a tungsten lamp equipped with an extremely sensitive voltage stabilizer in order to maintain a constant light intensity.

The reflected light is received by a phototube which is linked to a photomultiplier with digital readout. The photomultiplier was set to make 100 individual measurements per second and to present the averaged value for each second to two decimal places. The photomultiplier was calibrated against a glass standard of 1.23% $\bar{R}_o$. By convention reflectance measurements were made in green light of 546 nm.

Measurements were made immediately following immersion of the polished surface in a Ziess non-fluorescing oil. A 32X magnification objective was used.

The samples were searched for fragments of coal containing vitrinite and vitrinitic d.o.m. under the observation light source. This prevents heating and consequent changes in the R.I. of the oil that results from extended exposure to the measurement light (Stevenson, pers. comm., 1980). Once a suitable subject is located the measurement light source is used and the subject is placed under the measurement spot.

The reflectivity of each polished section measured was calculated from 30-50 measurements on vitrinite and then averaged to give $\overline{R}_o$.

Factors which cause variations in $\overline{R}_o$ are

(1) Natural variation in reflectivity among the various vitrinite types.

(2) Statistical errors due to insufficient measurements for a true Gaussian distribution.

(3) Technical errors due to incorrect identification of macerals.

(4) Contamination from cavings.

(5) Reworking of older coals (Stach, 1975).

(6) Hot connate waters moving through aquifers (Lonergan, 1979).

The affect of factors (3), (4) and (5) can be minimized by carefully examining the collected data for a sample and excluding anomalous data from the calculations of $\overline{R}_o$.

There are some limitations to the use of vitrinite reflectance as an indicator of rank.

(1) Vitrinite is identified on the basis of its reflectance. Thus the reflectance is measured as an indicator of the maturity of the vitrinite particles which have been selected on the basis of their reflectance.

(2) Where vitrinite is not abundant as is the case in the Transition Beds and Murta Member.

SUMMARY OF VITRINITE REFLECTANCE DATA

DELLA-7

Depth (m)	% $\bar{R}_o$ Vit.
1290	0.42 ± 0.06
1373	0.44 ± 0.06
1652	0.71 ± 0.06
1656	0.74 ± 0.07

DELLA-8

Depth (m)	% $\bar{R}_o$ Vit.
1269	0.42 ± 0.04
1366	0.39 ± 0.04
1600	0.49 ± 0.04
1603	0.51 ± 0.12

WILPINNIE-1

Depth (m)	% $\bar{R}_o$ Vit.
1265	0.42 ± 0.05
1385	0.46 ± 0.08
1674	0.64 ± 0.08

NAPPACOONGEE-2

Depth (m)	% $\bar{R}_o$ Vit.
1146	0.42 ± 0.04
1251	0.45 ± 0.04
1546	0.59 ± 0.06

DULLINGARI NORTH-1

Depth (m)	% $\bar{R}_o$ Vit.
1254	0.32 ± 0.04
1445	0.32 ± 0.04
1449	0.36 ± 0.05
1702	0.59 ± 0.07

APPENDIX IV

REQUIREMENTS FOR HYDROCARBON DEPOSITS

For petroleum to be generated suitable source rocks are required. According to Tissot and Welte (1978) three factors must be considered in determining the quality of a petroleum source rock:

(1) The organic matter content.

(2) The type of organic matter present.

(3) The maturity of the source rocks.

The presence of insoluble dispersed organic matter, kerogen, is necessary for a bed to be an active or potential source rock. Percentage organic carbon is normally used to measure the organic matter content of a sediment. A potential source rock must have at least 0.5% organic carbon. In order to calculate the total organic matter content, the organic carbon content must be multiplied by a conversion factor to compensate for the other elements in the organic matter. Forsman and Hunt (1958) determined conversion factors ranging from 1.07 for metamorphosed rocks up to 1.40 for non metamorphosed organic matter rich in oxygen. Average values of organic carbon for shale type source rocks are in the vicinity of 2% (Tissot and Welte, 1978). This means that if rocks contain greater than 2.8% organic matter, as indicated by microscopic observation, they may be considered as source rocks.

The varying types of d.o.m. have differing hydrocarbon potentials so it is necessary to distinguish between them. Inertinite has a high initial carbon content and is chemically inert making it an unlikely source of hydrocarbons. Vitrinite is richer in hydrogen than inertinite. Its oil potential is only moderate although gas may be generated at depth. Exinite has a higher $^{H}/_{C}$ ratio and therefore has a good potential for oil and gas generation. Figure A4 plots the various types of d.o.m. on a plot of $^{O}/_{C}$ against $^{H}/_{C}$ and illustrates their relative potential as sources for hydrocarbons.

According to Tissot and Welte (1978) there are three types of kerogen. In Type-I kerogen the original $^{H}/_{C}$ ratio is high and therefore the potential for oil and gas is high. It consists of structured algal material. In Type-II kerogen the $^{H}/_{C}$ ratio and the oil and gas potential are lower than in the previous case although still significant. It consists of algae and land derived exinites such as sporinite. Type-III kerogen has a low $^{H}/_{C}$ ratio and the oil and gas potential are consequently low. Significant quantities of gas may be generated at depth. It consists of terrestrial material. Figure A5 plots the various kerogen types on a plot of $^{O}/_{C}$ against $^{H}/_{C}$.

The third consideration is the maturity of the source rocks. With subsidence d.o.m. is altered in response to temperature-time conditions. During this alteration process hydrocarbons may be generated. Mean vitrinite reflectance under oil immersion ($\overline{R}_o$) is used to define the maturity of source rocks. According to Tissot and Welte (1978) the following generalizations can be made:

(a) $\overline{R}_o$ < 0.5 to 0.7% : source rock is immature.

(b) 0.5 to 0.7% < $\overline{R}_o$ < 1.3% : main zone of oil generation.

(c) 1.3% < $\overline{R}_o$ < 2% : zone of wet gas and condensate.

(d) $\overline{R}_o$ < 2% : dry gas zone.

This can be seen in diagramatic form in Figure A6. There are no sharp boundaries as different types of organic matter have different compositions and different rates of transformation in response to temperature.

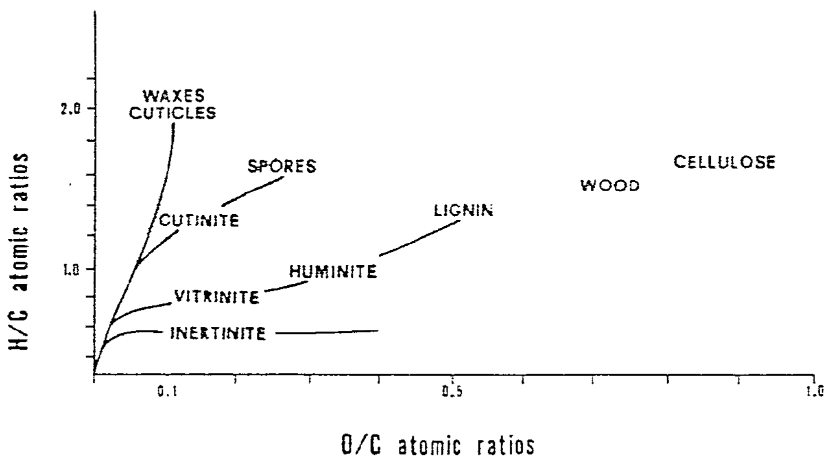
Once hydrocarbons are generated in the source rocks they must make their way to reservoirs for deposits to form. According to Tissot and Welte (1978) there are two forms of migration. Primary migration involves the generation of hydrocarbons from d.o.m. and its subsequent movement through the source rock. Once out of the source rock, secondary migration takes over with movement through the permeable and porous carrier rock to the reservoir rock where the hydrocarbons accumulate.

During the main phase of hydrocarbon generation the most important mode of primary migration is pressure driven, discrete hydrocarbon phase movement (Tissot and Welte, 1978). This is accomplished by microfracturing of relatively impermeable source rocks. This process results in migration over distances of the order of tens of metres. At depths of 1000 to 1500 metres, before the onset of the main phase of hydrocarbon generation, solution migration is more important. According to Powell, et al. (1978), the transition of smectite to vermiculite supplies the water involved in solution migration. Their work indicates that solution migration is not significant during the main phase of hydrocarbon generation as no clay dehydration reaction occurs at this stage. Solution migration would not be capable of producing major petroleum deposits.

Secondary migration leads to the accumulation of hydrocarbons in reservoir rocks which are associated with a trap. The driving forces are the buoyant rise of hydrocarbons and water flow (Tissot and Welte, 1978). A reservoir rock must be porous so that it can hold the hydrocarbons and permeable so they can pass into it. The quality of reservoir rocks is degraded by recrystallization and the proportion of fine material present. To be a reservoir the porous and permeable rock must be sealed by a relatively impermeable cap rock. Secondary migration ceases when the capillary pressures in narrow rock pores exceeds the driving force.

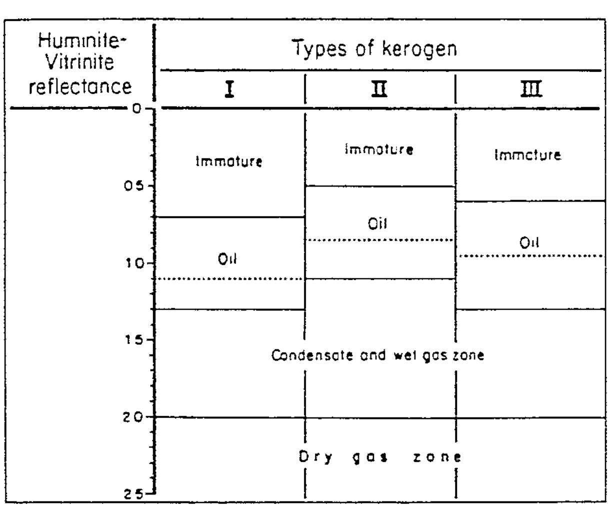
The generative potential of coal is for gas rather than oil. The coalification process results in the release of methane, carbon dioxide and water. The main phase of methane generation in coal is generally thought to begin in the range of 1.3 to 1.4% $\overline{R}_o$. Tissot and Welte (1978) claim that due to the high absorption capacity of coal, the sizeable microporosity and the fact that coal occurs as massive, continuous, solid organic phase liquid hydrocarbons generated are unable to escape.

FIGURE A4



Selected plant and coal materials and their respective position in the H/C-, O/C-diagram (van Krevelen-diagram)

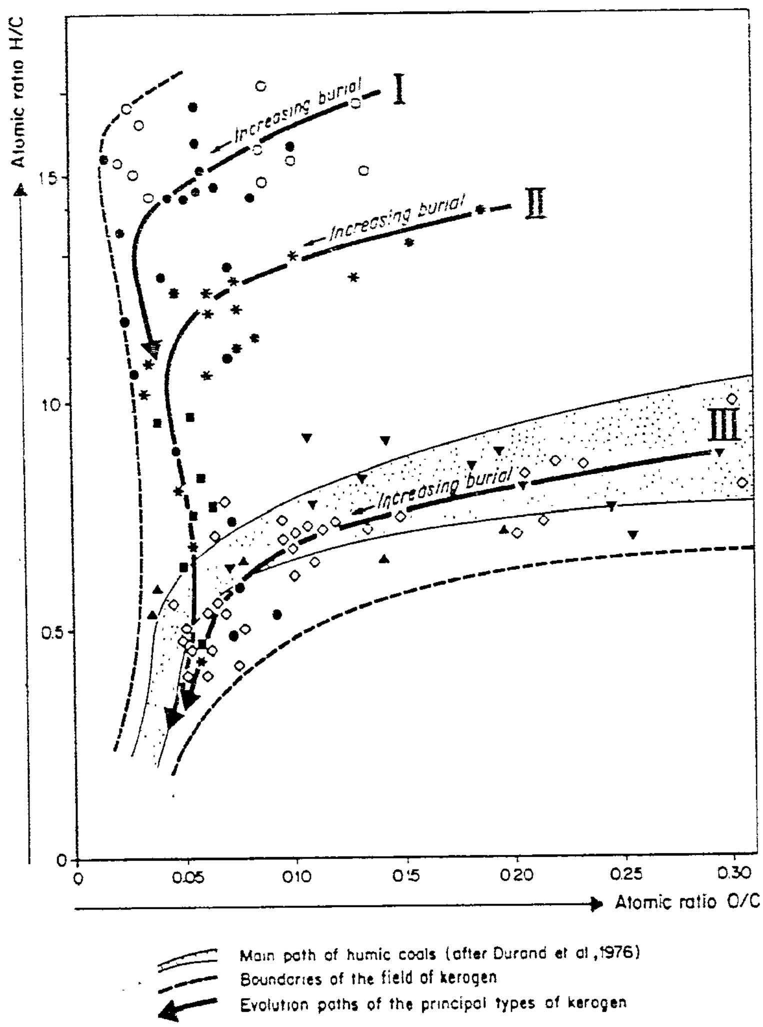
FIGURE A6



Approximate boundaries of the oil and gas zones in terms of vitrinite reflectance. Boundaries may change slightly according to the time–temperature relationship, and also to the mixing of various sources of organic matter

Tissot et al (1978)

FIGURE A5



Type	Age and /or formation	Basin, country	
I	Green River shales (Paleocene - Eocene)	Uinta, Utah, U.S.A	●
	Algal kerogens (Botryococcus, etc...). Various oil shales		○
II	Lower Toarcian shales	Paris, France, W Germany	*
	Silurian shales	Sahara, Algeria and Libya	■
	Various oil shales		●
III	Upper Cretaceous	Douala, Cameroon	◇
	Lower Mannville shales	Alberta, Canada	▲
	Lower Mannville shales (Mc Iver, 1967)	Alberta, Canada	▼

Principal types and evolution paths of kerogen: types I, II and III are most frequent. Kerogens of intermediate composition also occur. Evolution of kerogen composition with increasing burial is marked by an *arrow* along each evolution path I, II and III. We propose to name this type of diagram after van Krevelen

Tissot et al (1978)

(a) Duroclarite; consists of desmocollinite matrix with alginite and inertodetrinite as inclusions.

V - Vitrinite (Desmocollinite)
A - Alginite
I - Inertodetrinite

(b) The brown coal maceral porigellinite set in shale along with vitrinite, fusinite and inertodetrinite (D8-14).

P - Porigellinite
V - Vitrinite
F - Fusinite
I - Inertodetrinite

(c) A curved fragment of vitrinite and cutinite which may be structural or botanical in origin.

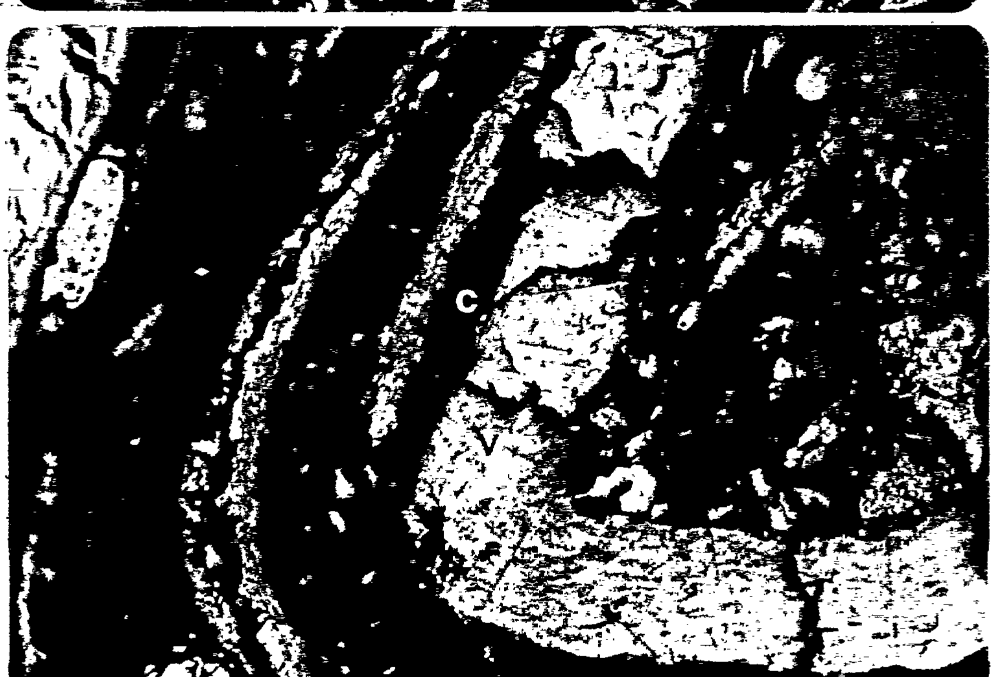
V - Vitrinite
C - Cutinite

F.V. = 0·43 mm

PLATE A1

a

b



c

(a) Pieces of alginite and sporinite set in shale under UV light (DN-14). The alginite fluoresces more intensely than the sporinite.

(b) Pieces of alginite set in shale under UV light (DN-14).

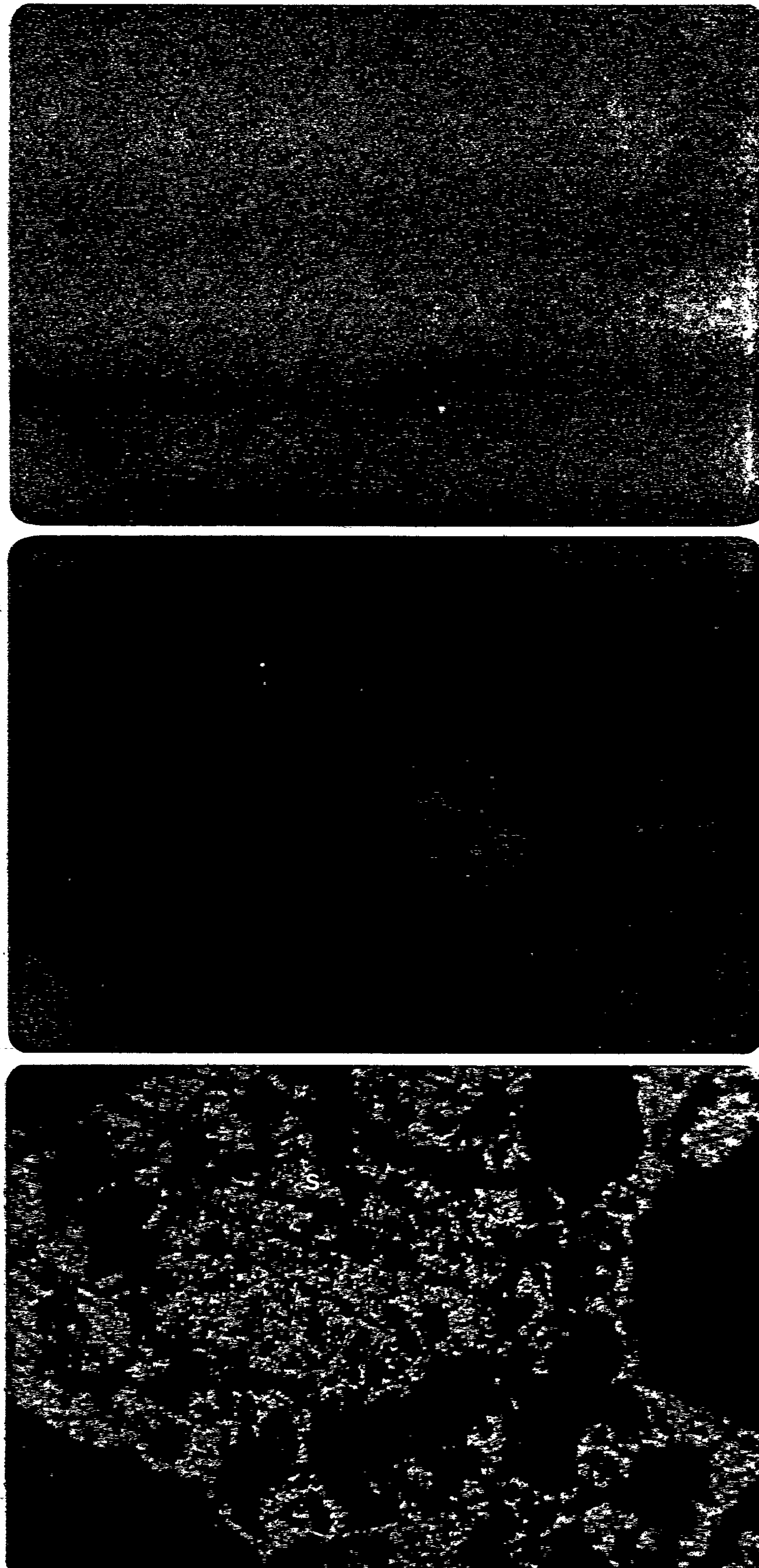
(c) Sulphides replacing original cellular structure defined by the discontinuous ring of resinite.

S - Sulphides

R - Resinite

F.V. = 0·43 mm

PLATE A2



a

b

c

(a) The three macerals as d.o.m. within the same fragment of shale. Inertodetrinite, vitrinite and sporinite are dominant (D8-15).

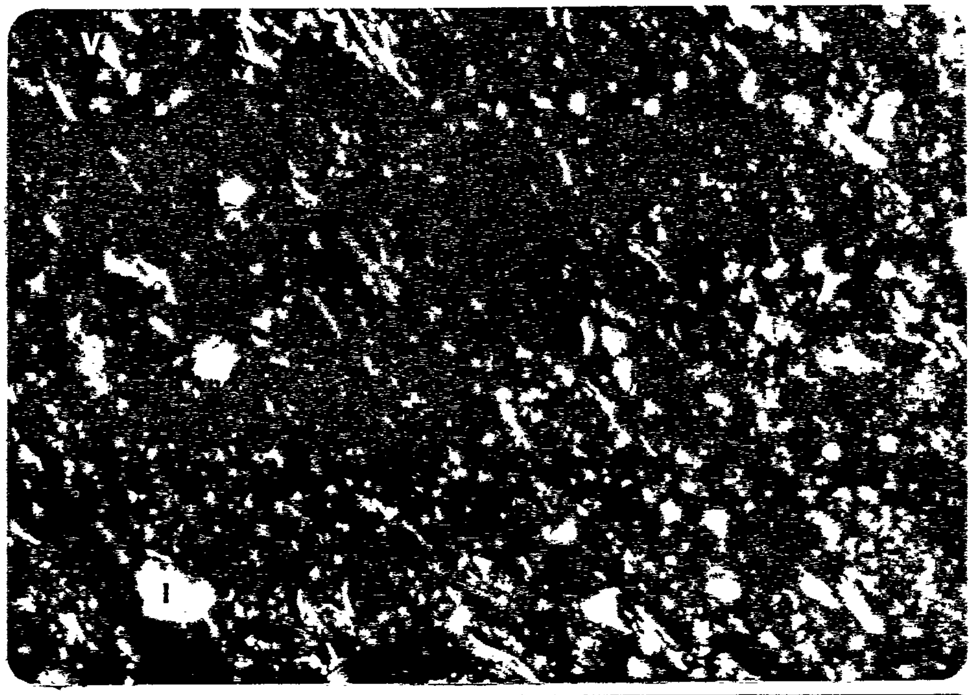
Inertodetrinite - white
Vitrinite - grey

(b) The same field of view as for (a) under UV light. The sporinite can now be picked out because it fluoresces.

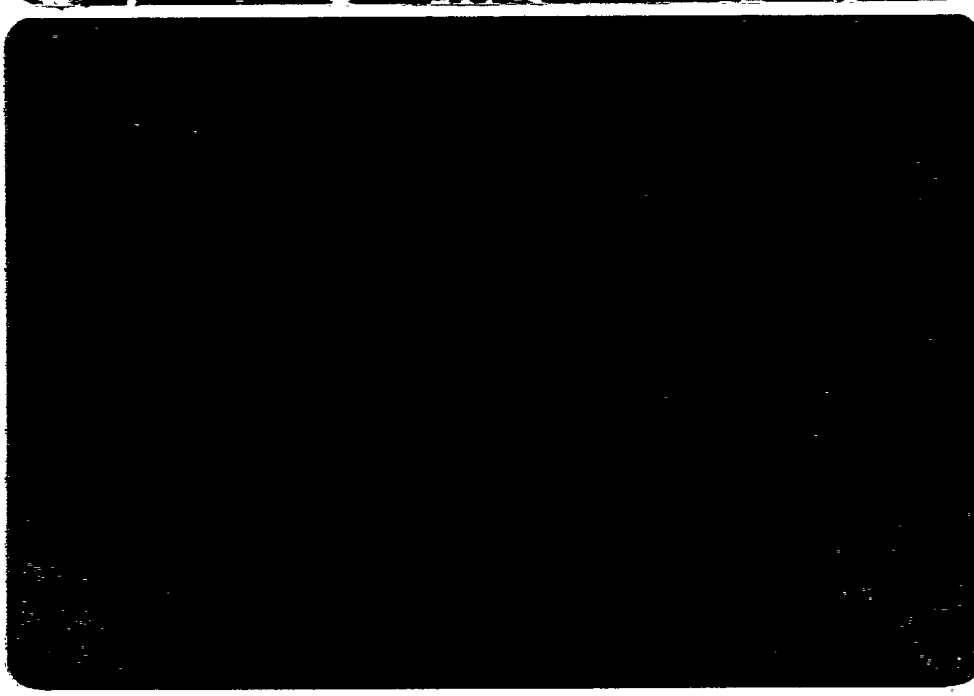
(c) Two separate fragments of shale within the same sample having vastly different d.o.m. contents and types.

F.V. = 0·43 mm

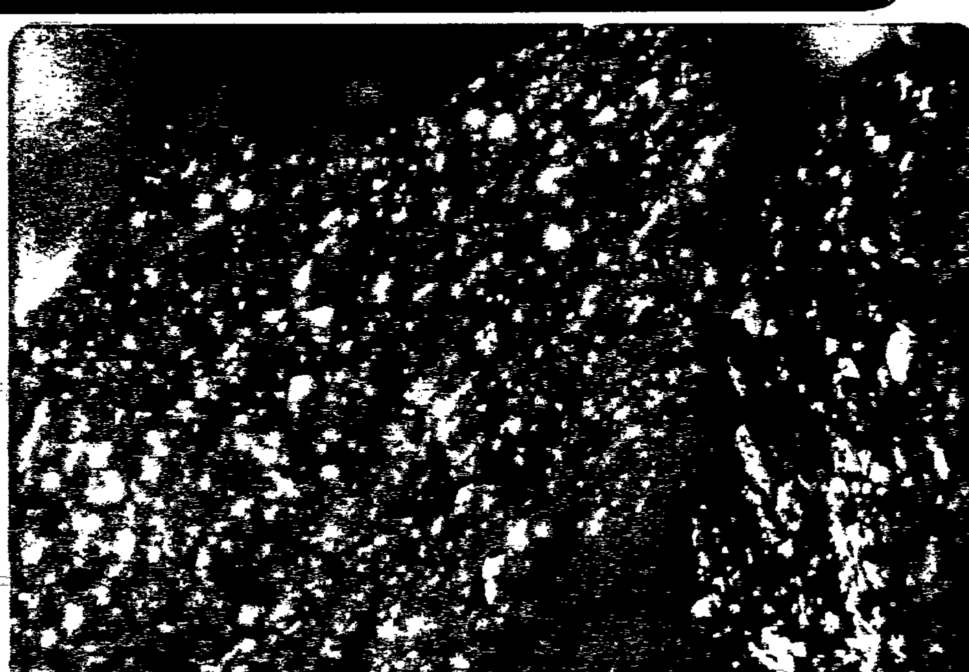
PLATE A3



a



b



c