School of Applied Geology

PETROLOGY OF PERMIAN COAL, VASSE SHELF, PERTH BASIN, WESTERN AUSTRALIA

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ABSTRACT

The Early Permian coal samples for the study were obtained from the Vasse Shelf, southern Perth Basin, located approximately 200 km south-west of Perth. The selected coal samples for the study were also obtained from the Premier Sub-basin of the Collie Basin and the Irwin Sub-basin of the Perth Basin. The Early Permian coal measures are described as the Sue Coal Measures from the Vasse Shelf, the Ewington Coal Measures from the Premier Sub-basin and the coal measures from the Irwin Sub-basin are described as the Irwin River Coal Measures.

The Vasse Shelf coal is finely banded and the dominant lithotypes are dull and dull banded types, followed by bright banded and banded types, with minor bright types. The variation of dull and bright lithotypes represents fluctuating conditions of water table level during the growth of peat in the swamp. The maceral composition of the coal is predominantly composed of inertinite, followed by vitrinite and minor exinite and mineral matter. The coal is characterized by very low to medium semifusinite ratio and medium to high vitrinite content, supporting the deposition in anaerobic wet conditions with some degree of oxidation. The coal is classified as sub-bituminous to high volatile bituminous of the Australian classification. In terms of microlithotype group, the predominance of inertite over vitrite suggests the coal was formed under drier conditions with high degree of oxidation during its deposition. On the basis of the interpretations of lithotypes, macerals, microlithotypes and trace elements, the depositional environment of the coal is braided and meandering deltaic-river system without any brackish or marine influence.

The maceral composition of the Collie coal predominantly consists of inertinite and vitrinite, with low exinite and mineral matter. The very low to low semifusinite ratio and low to medium vitrinite content of the coal indicate that the coal was formed under aerobic dry to wet conditions with some degree of oxidation. The coal is categorized as sub-bituminous according to the Australian classification. The domination of inertite and durite over vitrite and clarite contents in the coal reflects the deposition under drier conditions with fluctuations in the water table. On the basis of the interpretations of macerals, microlithotypes and trace elements distribution, the depositional environment of the coal is lacustrine, braided to meandering fluvial system, without the influence of any marine influx.

The maceral composition of the Irwin River coal consists predominantly of vitrinite and inertinite, and minor exinite and mineral matter. The coal has very low semifusinite ratio and medium to high vitrinite content, suggesting the coal was deposited in anaerobic wet conditions with some degree of oxidation. The coal is classified as sub-bituminous of the Australian classification. The predominance of vitrite and clarite over inertite and durite contents in the coal indicates that the coal was formed in wetter conditions and in high water covers with a low degree of oxidation. Based on macerals and microlithotypes contents, the depositional environment of the coal is braided fluvial to deltaic, which is in accordance with the interpreted non-marine and mixed marine environment of deposition in the sub-basin.

The petrological comparisons of Vasse Shelf, Collie and Irwin River coals show that the average vitrinite content of the Irwin River coal is highest (49.1%) and of the Collie coal is lowest (37.3%) of the three. The inertinite content is highest in Collie coal (49.1%), followed by Vasse Shelf (46.4%) and Irwin River (39.2%) coals. The exinite content is low in Irwin River coal

(6.3%) as compared with Vasse Shelf (9.0%) and Collie (8.3%) coals. The mineral matter content is relatively low for all the three coals. The rank of the Vasse Shelf coal is high as compared with the Collie and Irwin River coals, either due to tectonic uplift after the deposition in post-Permian in the southern Perth Basin, or due to the average depth of burial over Vasse Shelf which is much greater than that of Collie and Irwin River coals.

The comparisons of the coal from Western Australia with the selected Gondwana coals show that the predominance of inertinite over vitrinite occurs in the Western Australian coals (Vasse Shelf and Collie Basin). On the other hand, the Brazilian, eastern Australian, Indian and Western Australian (Irwin Sub-basin) coals are dominated by vitrinite over inertinite. The exinite content is highest in the Indian coals and lowest in the eastern Australian coals. The mineral matter content is highest in the Brazilian and Indian coals, and lowest in Western Australian (Vasse Shelf) and eastern Australian (Sydney Basin) coals. The rank of the coals ranges from sub-bituminous to medium volatile bituminous according to the Australian classification.

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This thesis consists of original research work carried out by the author, except where indicated. This work has not previously been submitted for higher degree to any other university or such institution.

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CHAPTER 1. INTRODUCTION

1.1. Introduction

The coal samples for petrological study were obtained from the drill holes drilled in the Vasse Shelf of south-western Australia, located approximately 200 km south-west of Perth. The shelf is a part of the Perth Basin, a step faulted block lying between the Busselton Fault to the east and the Dunsborough Fault to the west (Figure 1.1). The selected coal samples for the study were also obtained from Premier Sub-basin of the Collie Basin and the Irwin Sub-basin of the Perth Basin, Western Australia (Figure 1.1).

The coal seams of economic significance are restricted to a stratigraphic interval of Early Permian age in the Vasse Shelf, southern Perth Basin, Western Australia. The presence of Early Permian coal in the area was first discovered in 1967 by the Geological Survey of Western Australia during the hydrological drilling in the Busselton area, Probert (1968). More recent discoveries of economic significance were made by extensive drilling undertaken by CRAE, and the deposits have been evaluated for subsurface mining.

Kristensen and Wilson (1986) and Le Blanc Smith (1990) reported that the coal-bearing sediments in the Vasse Shelf (described as the Sue Coal Measures) are present in the subsurface over a length of 17 km, and at depths between 180 m and 1,000 m. The coal measures are a sequence of interbedded sandstones, carbonaceous siltstone and claystone and coal, Cockbain (1990). The post-Permian overburden has a range between 85 m and 246 m.

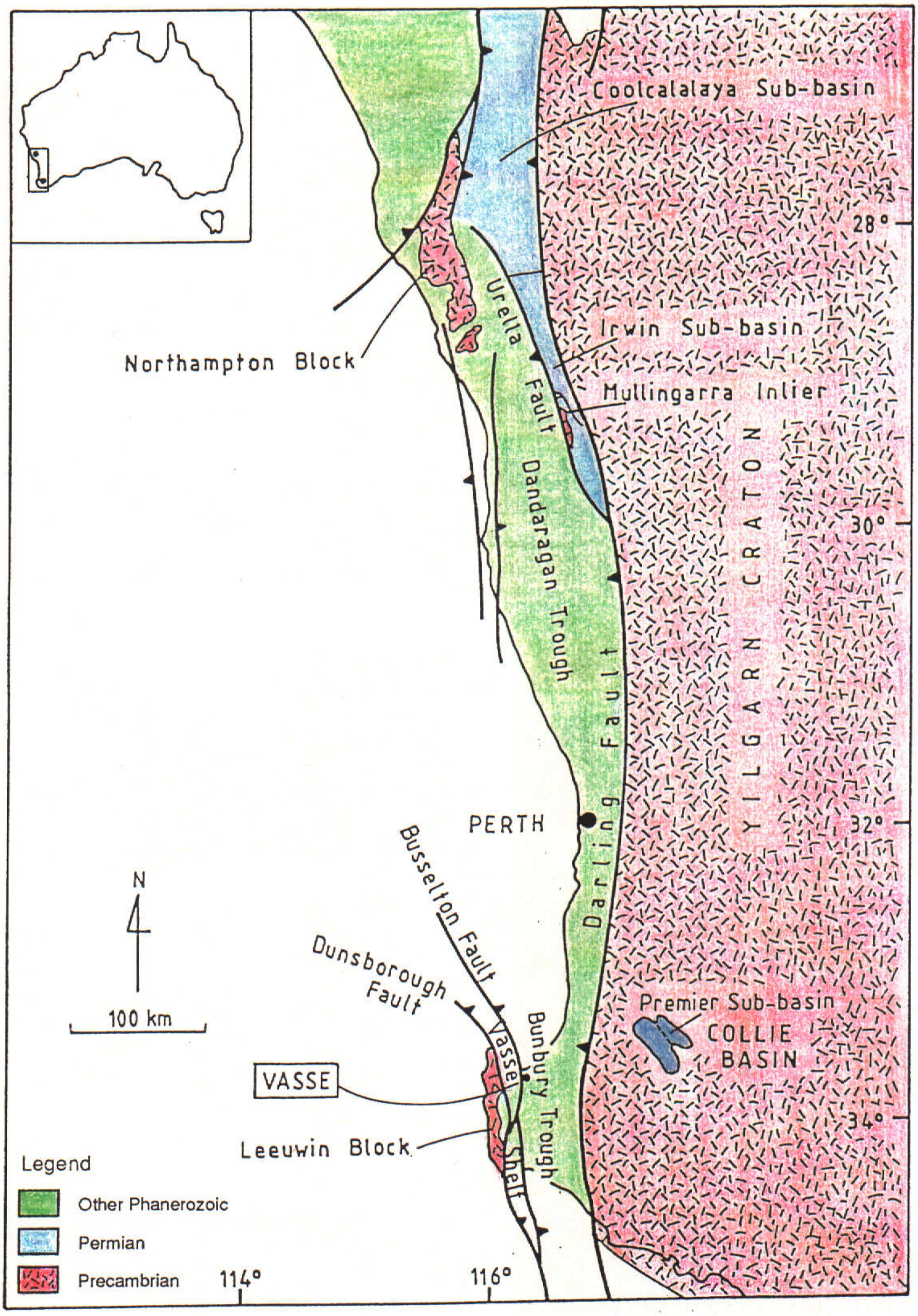


Figure 1.1. Regional setting and locality plan of the Vasse Shelf, Collie Basin and the Irwin Sub-basin (modified from Cockbain, 1990).

According to Le Blanc Smith (1993), the Collie Group of the Collie Basin, also of Permian age, is stratigraphically correlated with the Sue Coal Measures. The Collie group is cyclic in nature, and in ascending order consists of cross-bedded sandstone, siltstone, claystone and coal. This description applies equally to the Permian Sue Coal Measures of the Vasse Shelf and the thickness of the coal measures varies between 960 m to 1,120 m.

According to Kristensen and Wilson (1986), Cockbain (1990) and Le Blanc Smith (1990), the coal-bearing sediments described as the Irwin River Coal Measures from the Irwin Sub-basin are a sequence of interbedded sandstone with claystone, siltstone, shale (frequently carbonaceous) and coal. The north-south extent of the coal measures is approximately 40 km with the thickness ranging from 60 m to 120 m.

1.2. Aim and Objectives

The major aim of the project was to establish the petrology of the coal in terms of lithotypes, macerals, microlithotypes and mineral matter and trace element geochemistry for the selected coal seams from the Vasse Shelf area, and to establish petrological variations of the coal in the area.

The specific objectives of the project were :

. to review the literature,

. to develop methods and techniques,

. to establish petrology in terms of lithotypes, macerals and microlithotypes,

. to establish the distribution of mineral matter and trace elements in the coal,

. to compare the petrology of the coals from the Vasse Shelf, Premier Sub-basin (Collie Basin) and the Irwin Sub-basin of Western Australia and

. to model the depositional environments of the coals.

The above aim and the objectives of the thesis have been met by an integrated petrological study presented in the thesis. The author is solely responsible for the preparation of the coal samples and collection of petrological data.

1.3. Structure of the Thesis

The thesis consists of nine chapters, references and one appendix.

Chapter one is an introduction describing the aim and objectives, structure of the thesis and previous work.

Chapter two describes the geological setting of Vasse Shelf, Irwin Sub-basin and the Premier Sub-basin (Collie Basin). The rank, quality and the resources are also included in this chapter.

Chapter three contains the methods and terminology used in collection of petrological and geochemical data (trace elements).

Chapter four includes the petrological description of the coals in terms of lithotypes, macerals and mineral matter and microlithotypes. The reflectance measurements of vitrinite to determine the rank variation with the coal are included in this chapter.

Chapter five emphasizes the nature and distribution of mineral matter in the coal, and the minerals identified under the microscope and SEM.

Chapter six contains the comparative petrology of the Early Permian coal from Western Australia with the selected Early Permian Gondwana coals in terms of macerals and microlithotypes.

Chapter seven contains trace elements distribution in the coal. The trace elements determination were undertaken to study their concentrations and associations with organic and inorganic components of the coal.

Chapter eight describes the depositional environment of the coal interpreted on the basis of lithotypes, macerals, microlithotypes and the trace elements.

Chapter nine includes the conclusions of the study inclusive of geological setting, petrology, geochemistry and depositional environment of the coal.

Appendix I includes petrological data of the Vasse Shelf coal. The data on Collie and Irwin River coals are included in the main text.

1.4. Previous Works

The earlier published work on the geology and petrology of Permian coal of Perth Basin consists of Cook (1975), Cook and Kantsler (1979), Kantsler and Cook (1979), Kristensen and Wilson (1986), Mishra (1986), Lord (1990), Le Blanc Smith (1990) and Sappal and Santoso (1993).

Cook (1975) provided an overview of type and rank of coal from Western Australian basins, however, Collie Basin was not included in his study, and the rank of coal is sub-bituminous based on vitrinite reflectance. Sappal (1982, 1986) undertook the first detailed petrographic study of coal from the Collie Basin.

Kantsler and Cook (1979) analysed selected coal samples from oil wells drilled in the Perth Basin. They described the type and content of organic matter in Permian coals and associated sediments, and reported that coal of the Irwin River Coal Measures contains 45-55% vitrinite, 35-45% inertinite and 3-8% exinite. Selected samples from Sue Coal Measures of the Bunbury Trough, southern Perth Basin showed similarity in petrology to the Irwin River coal. Cook and Kantsler (1979) described the rank variation of coal in the Perth Basin and suggested that a Permian to Early Jurassic thermal event associated with the initiation of rifting may be the controlling factor of rank variation in the Perth Basin.

Mishra (1986) concentrated on type and rank variation in coals from the Indian basins (Damodar Valley, Son-Mahanadi Valley and Pench-Kanhan Valley Basins) and compared them with the Western Australian basins (Collie, Perth and Canning Basins). He indicated that the Permian coals of India and Western Australia are petrologically and geologically similar.

Kristensen and Wilson (1986) published a review of the coal resources of Western Australia, and stated that the Early Permian coals of the Perth Basin are present in the subsurface of the basin, and occur at mineable depths in the Vasse Shelf and the Irwin Sub-basin. The Vasse Shelf coal seams with the best economic potential occur near the base of the Permian sequence and these are of Artinskian age and possibly equivalent to the Ewington Coal Measures of the Collie Basin. There are eight groups of seams in the shelf over a vertical interval of 120 m, four of which are considered to have economic potential between depths of 180 m and 450 m over a strike length of 17 km. The thickness of the post-Permian overburden varies between 85 m and 246 m on the shelf. The coal is inertinite-rich, non-coking, high volatile and of bituminous "B" rank in the ASTM classification.

According to Lord (1990) the most important occurrences of Permian coal in the Perth Basin are located at Eradu, Irwin River and the Vasse Shelf. At Eradu (in the northern Perth Basin), the coal seam is present in the Wagina Sandstone of Late Permian age. The seam is 5.35 m thick, lenticular with high ash and moisture contents and it is considered to be of no economic significance. In the Irwin River Area, the coal seams are thin and lenticular, and the coal has a high ash and moisture contents and it appears to be of no economic significance.

Le Blanc Smith (1990) reported that the Sue Coal Measures of the Vasse Shelf range in age from Early to Late Permian, occur in a step-faulted block between the Leeuwin Block and the Busselton Fault (Figure 1.1). The coal measures consist of a sequence of sediments and coal up to 1,800 m in thickness, and overlie unconformably on an irregular Precambrian basement. The sequence contains interbedded sandstone, carbonaceous siltstone and claystone and coal. The coal-bearing strata do not outcrop, and in the shallowest areas the strata lie at a depth of 80 m and are unconformably overlain by the Early Cretaceous rocks, with a thickness up to 250 m. The Early Permian coal measures are equivalent to the Ewington Coal Measures of the Collie and Wilga Basins. Sappal and Santoso (1993) reported preliminary studies in petrology, geochemistry and depositional environment of the Early Permian Vasse Shelf coal from Western Australia.

This thesis represents the first detailed petrological investigation on the coal samples from the Vasse Shelf. The petrology includes lithotypes, macerals and microlithotypes analyses, distribution of mineral matter and trace elements in the coal. The geological, petrological and geochemical data are used to interpret depositional environment of the coal. The comparisons are also established with the coal from Irwin Sub-basin, Premier Sub-basin (a subdivision of the Collie Basin) and the selected Early Permian basins of eastern Australia, India, South Africa and Brazil.

CHAPTER 2. GEOLOGICAL SETTING

2.1. Introduction

The Perth Basin in Western Australia contains coal ranging in age from Early to Late Permian, but the thickest and most extensive seams are found in the Early Permian rocks. The Early Permian coal is present in the subsurface of the basin; however, coal only occurs at mineable depths in two structural subdivisions, namely the Vasse Shelf in the southern Perth Basin and the Irwin Sub-basin in the north. The Early Permian coal measures are described as the Sue Coal Measures from the Vasse Shelf, the Irwin River Coal Measures of the Irwin Sub-basin and the coal measures of the intracratonic Collie Basin are described as the Ewington Coal Measures, Figure 2.3.

A brief description of the geological setting of Vasse Shelf, Irwin Sub-basin and the Collie Basin is summarized from earlier publications.

2.2. Perth Basin

The Vasse Shelf and the Irwin Sub-basin are sub-divisions of the Perth Basin which was first named by Andrews (1938). The basin is a deep linear trough of sedimentary rocks extending from the Murchison River in the north to the south coast of Western Australia, a distance of approximately 1,000 km. The basin is defined to the east by the Darling Fault, a major tectonic feature, and to the north by the Northampton Block (Figure 1.1). Its western and southern offshore limits have not been clearly defined, they probably lie under the continental shelf.

The basin covers an area of about 45,000 km^2 onshore and a similar area offshore, and contains up to 15,000 m of Phanerozoic sediments ranging in age from Silurian to Quaternary. The basement rocks adjoining and underlying the basin comprise Archaean and Proterozoic rocks.

The dominant structural element of the Perth Basin is the Darling Fault, a growth fault which defines its eastern boundary. Its maximum west block throw exceeds 15,000 m. The fault probably developed during Silurian, with the greatest movements occurring from Middle Triassic to Early Cretaceous. The Basin is divided into several major structural subdivisions, separated by basement inliers and shallow basement ridges (Figure 1.1), these include Vasse Shelf and the Irwin Sub-basin.

The tectonic style of the Perth Basin is characterized by normal faulting, and there is no evidence of compressional tectonism. The faulting is the result of draping and differential compaction over basement ridges, considered to be positive features throughout the Phanerozoic, Playford, Cockbain and Low (1976). Studies of coal rank/deformation relationships particularly on the Vasse Shelf suggest that some of these features may have been tectonically emergent in post-Permian and even post-Jurassic time, Kristensen and Wilson (1986). The Perth Basin is a polycyclic basin and contains Silurian to Quaternary sequence.

2.2.1. Vasse Shelf

The Vasse Shelf is a faulted block where Precambrian basement lies at depths intermediate between the Leeuwin Block adjoining to the west and the Bunbury Trough to the east. Its onshore extent is approximately 400 km^2, but its northern boundary is not well defined. It is bounded to the east by the Busselton Fault which has a throw of up to 5,000 m, and to the west by the Dunsborough Fault which has a throw of at least 1,000 m. These faults converge to the south, Le Blanc Smith (1990). Figures 2.1 and 2.2 depict the geology, tectonic setting and a cross section of the Vasse Shelf.

The Vasse Shelf contains a Permian sequence up to 1,800 m thick overlying unconformably on an irregular Precambrian basement, and unconformably overlain by Early Cretaceous rocks of the Leederville Formation. The sequence is correlated to with Sue Coal Measures of the Bunbury Trough (Figure 2.3). The coal measures are unconformably overlain by Early Cretaceous rocks ranging in thickness between 80 m and 250 m. Where basement is shallowest, the Early Cretaceous sequence rests directly on Early Permian coal measures, and these areas have the best economic potential for coal. The most extensively explored area is the southern part of the shelf, where the coal deposit has been drilled at 2 km intervals by the CRAE. Here, the Early Permian coal seams are truncated by the unconformity along a north-northwest trending structural high, Kristensen and Wilson (1986). The coal seams in the Vasse Shelf with the best economic potential lie near the base of the Permian sequence, and these are of Early Permian age and possibly equivalent to the Ewington Coal Measures of the Collie Basin. The coal measures consist of sixteen coal seams and carbonaceous shale units in a cyclic sequence of point bar deposits. The thickness of the individual seams varies from 20 cm to 195 cm.

An example showing a sequence of coal seams A to J in the drill hole RBCH 5 is shown as lithology log in Figure 2.4, and the location of the drill hole RBCH 5 is given in Figure 3.1. The lithology is dominated by sandstone, followed by shale and coal with minor conglomerate and

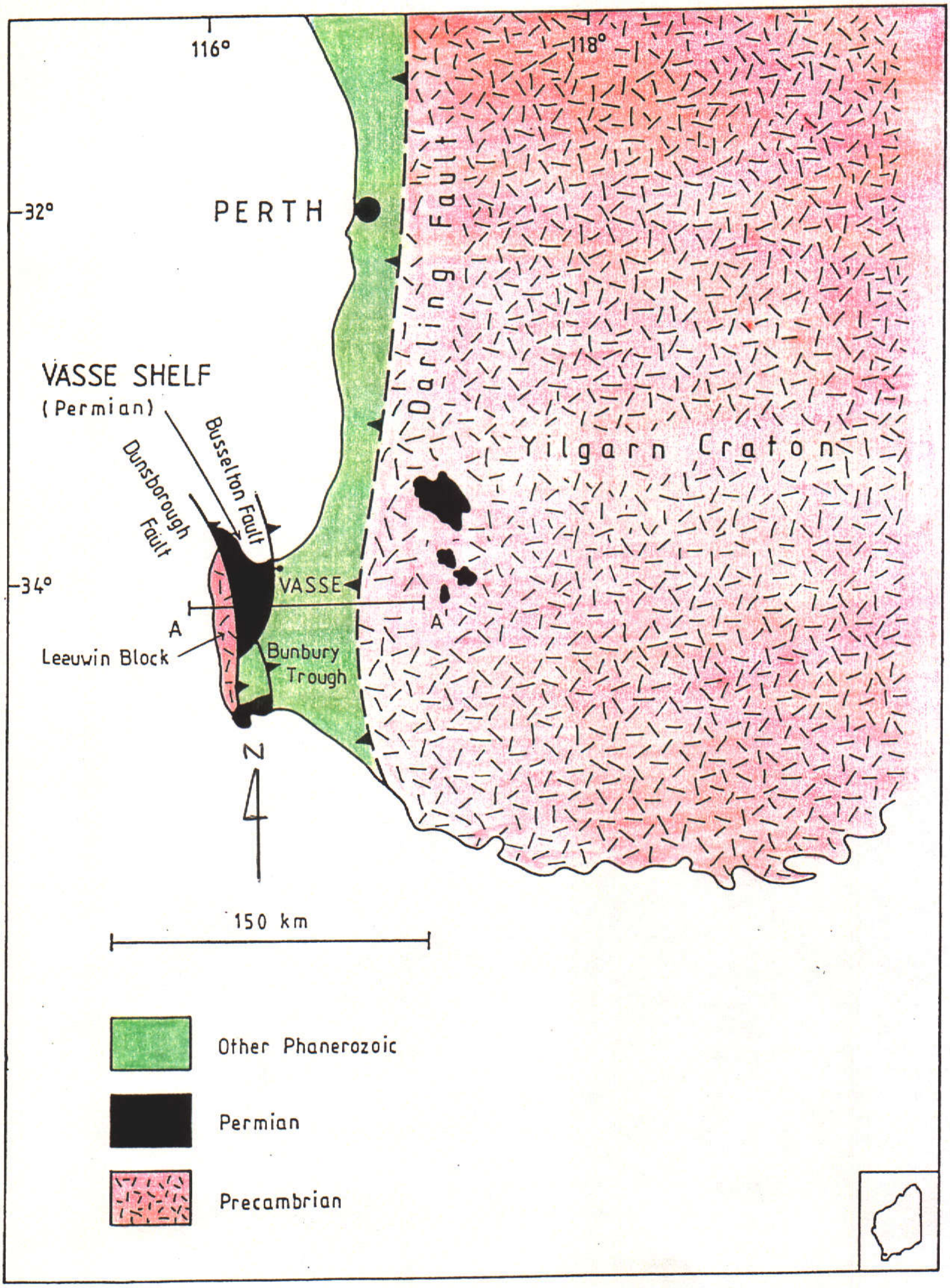


Figure 2.1. Geology and tectonic setting of the Vasse Shelf, south-western Australia (modified from Le Blanc Smith, 1990).

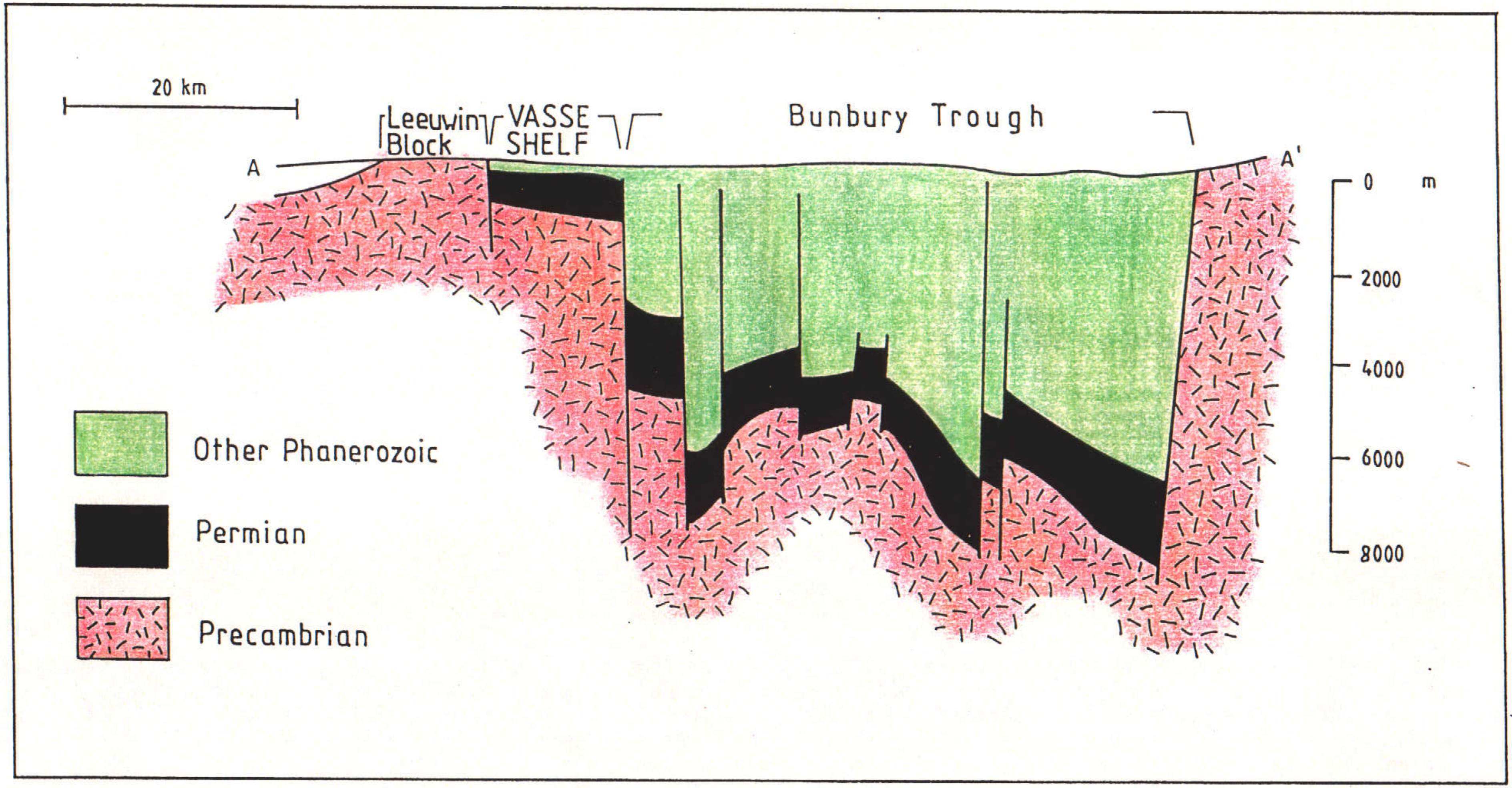


Figure 2.2. Cross-section (A-A') of the Vasse Shelf, south-western Australia (modified from Le Blanc Smith, 1990).

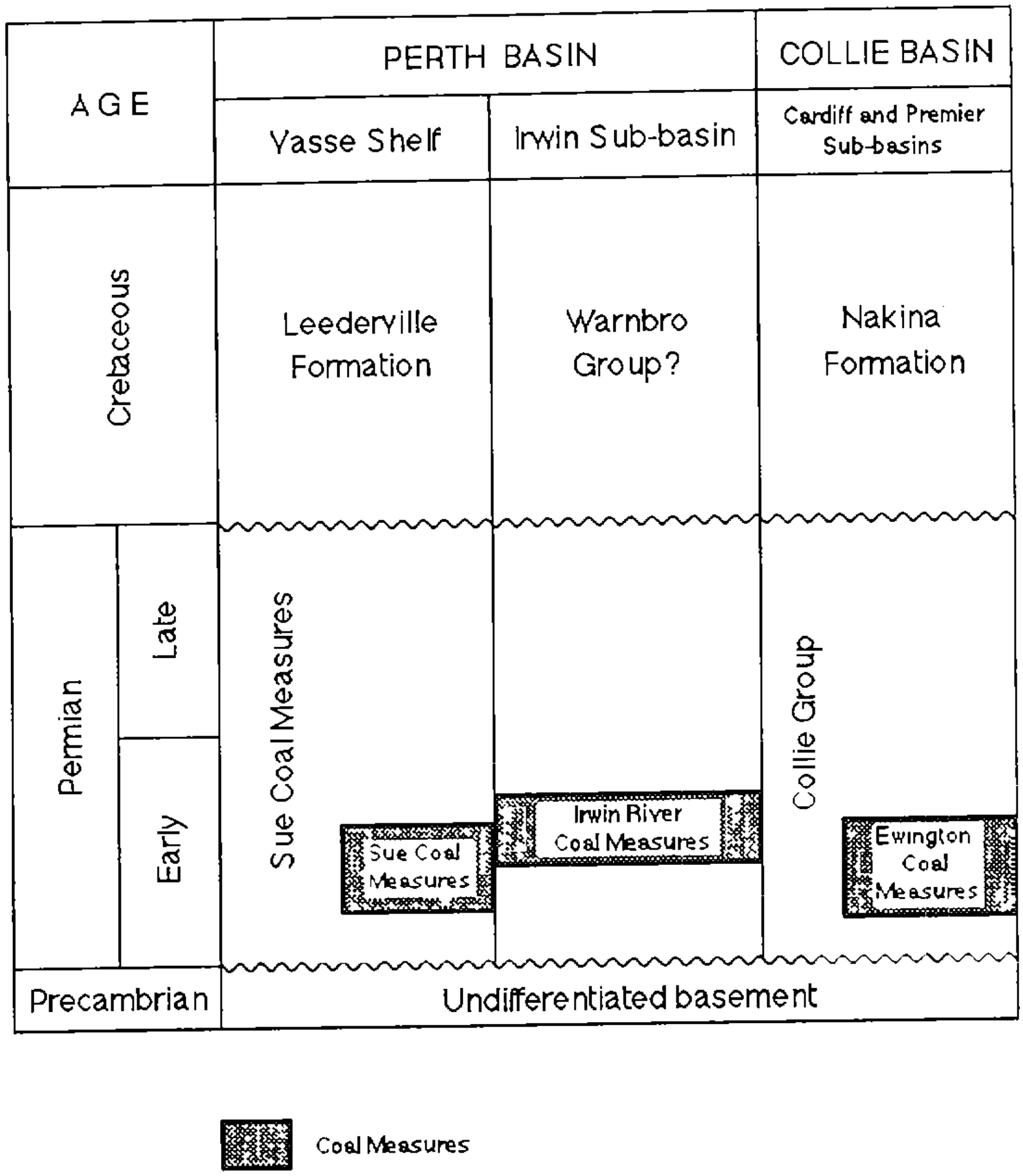


Figure 2.3. Stratigraphy of Early Permian coal measures in the Perth and Collie Basins, Western Australia (modified from Le Blanc Smith, 1993).

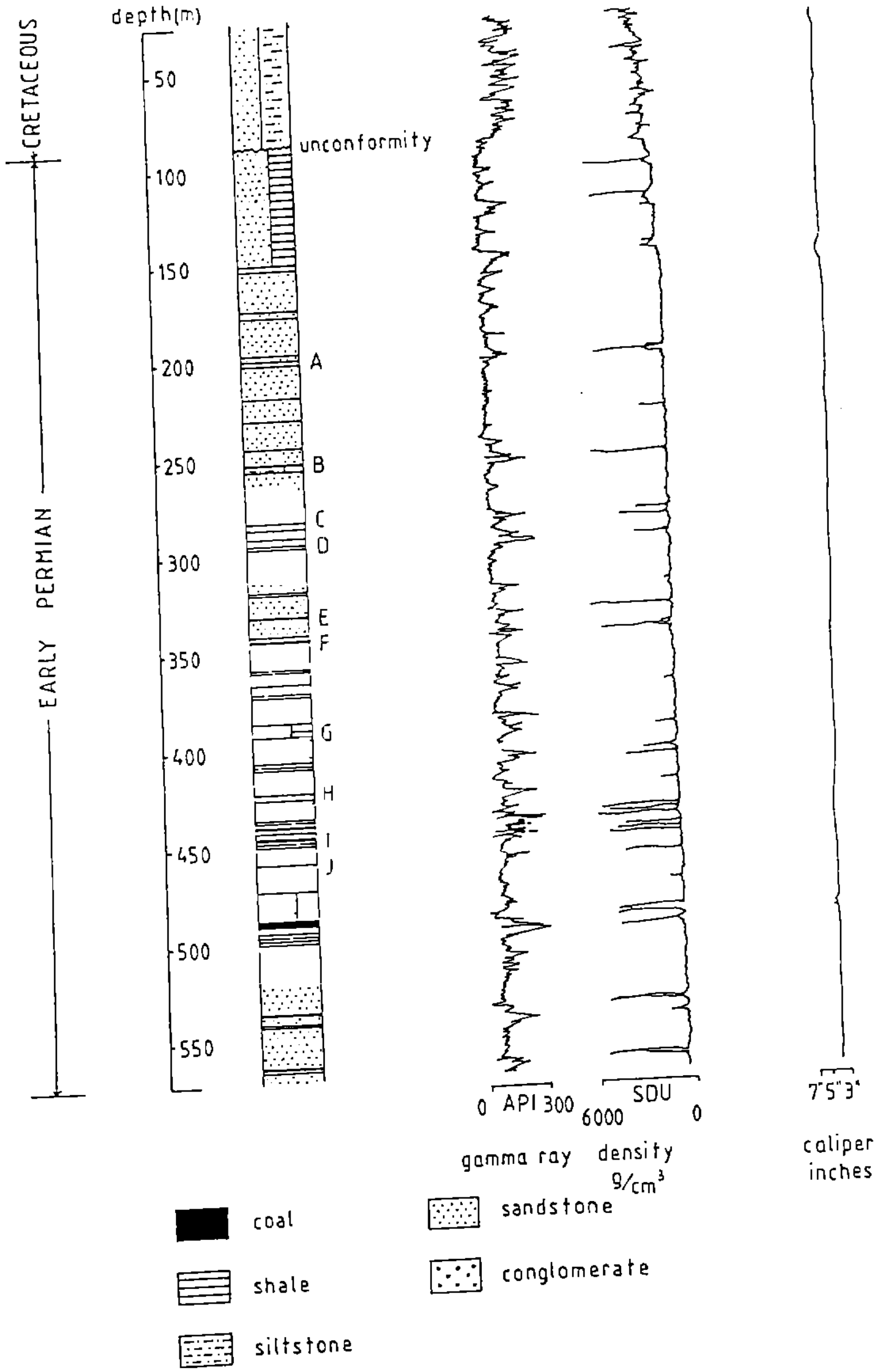


Figure 2.4. Lithology log of RBCH 5, A to J coal seams, Vasse Shelf, Western Australia (after CRAE, 1984).

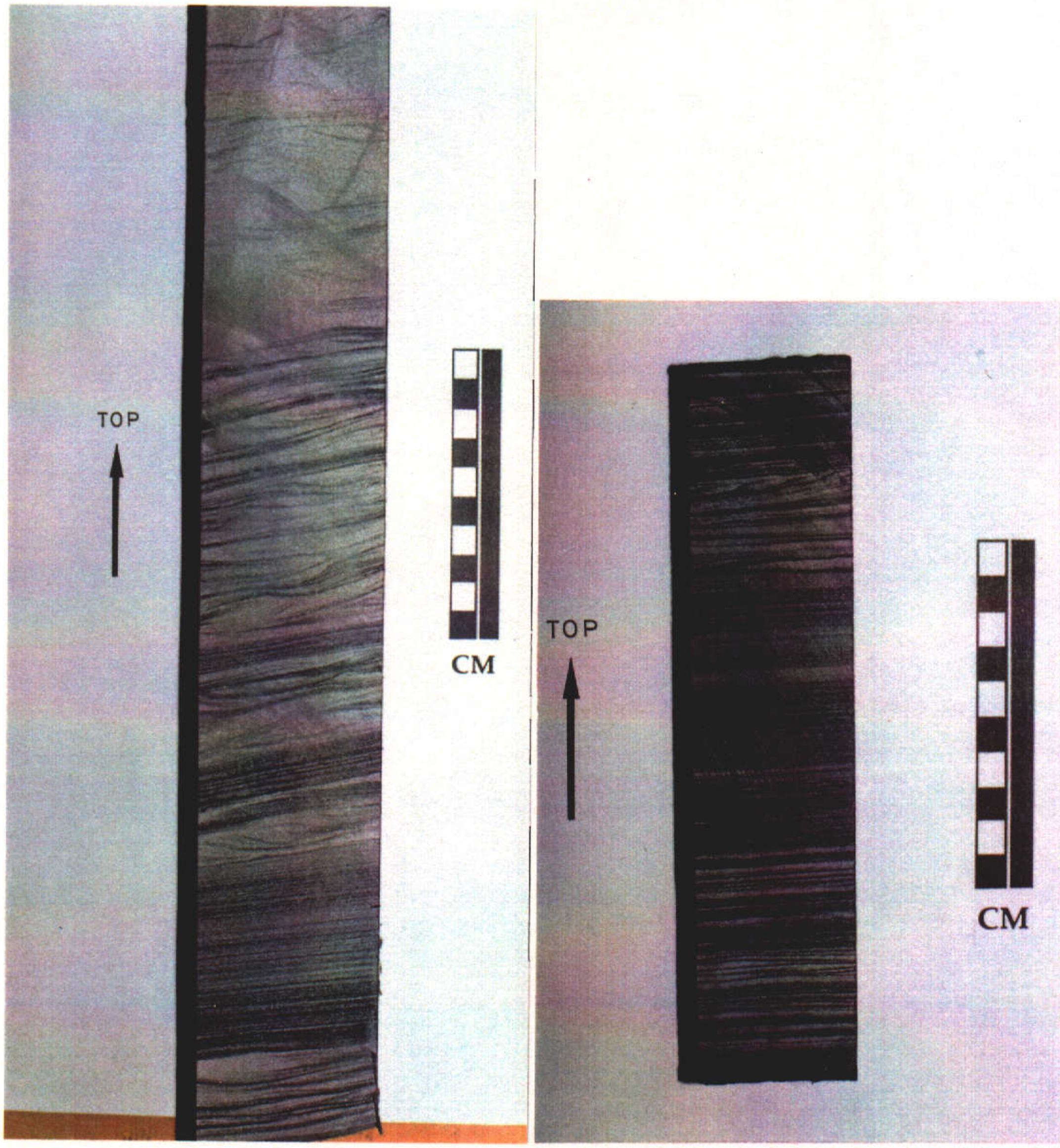
siltstone. The massive, parallel lamination structures and cross laminations dominate the sandstone, examples of which are shown in Figures 2.5.a and 2.5.b. The coal seams A to J are easily recognized by the geophysical log (gamma ray and density) because the coal seams are characterized by the longer kicks compared with the other sedimentary rocks. The lithology logs of other four drill holes (RBCH 6, RB 3, CRCH 1 and CRCH 2) are given in Appendix I.1. The presence of massive, parallel and cross laminations in the sequence of the log (Figure 2.4) suggests that the sediments were deposited in variable low to high energy conditions in the point bar environment, as described by Kristensen and Wilson (1986).

2.2.2. Irwin Sub-basin

The Irwin Sub-basin located 350 km north of Perth, covers an area of approximately 8,000 km^2. The Early Permian coal measures subcrop in the sub-basin, which is delineated to the east by the Darling Fault and to the west by the Urella Fault (Figures 2.6 and 2.7).

The publications on geology of the Irwin Sub-basin include Gregory and Gregory (1846), Woodward (1896, 1907), Maitland (1900, 1903, 1921), Campbell (1910), Blatchford (1927,1928, 1929), Johnson, De La Hunty and Gleeson (1954), Kristensen and Wilson (1986) and Cockbain (1990). Santoso (1990) undertook preliminary study on the petrology of selected coal from the north Irwin River area of the sub-basin.

In contrast to the continental sequence in the southern Perth Basin, the Permian sequence in the northern Perth Basin is mixed marine and continental. The Early Permian marine fluvio-glacial sequence below the coal measures overlies Silurian and Proterozoic sediments. The Irwin River



a

b

Figure 2.5.a. Very fine to fine sandstone with cross and parallel laminations (270.00m-270.37m), RBCH 5, Vasse Shelf, Western Australia.

Figure 2.5.b. Interbedded sandstone and carbonaceous shale with parallel and cross laminations (189.00m-189.25m), RBCH 5, Vasse Shelf, Western Australia.

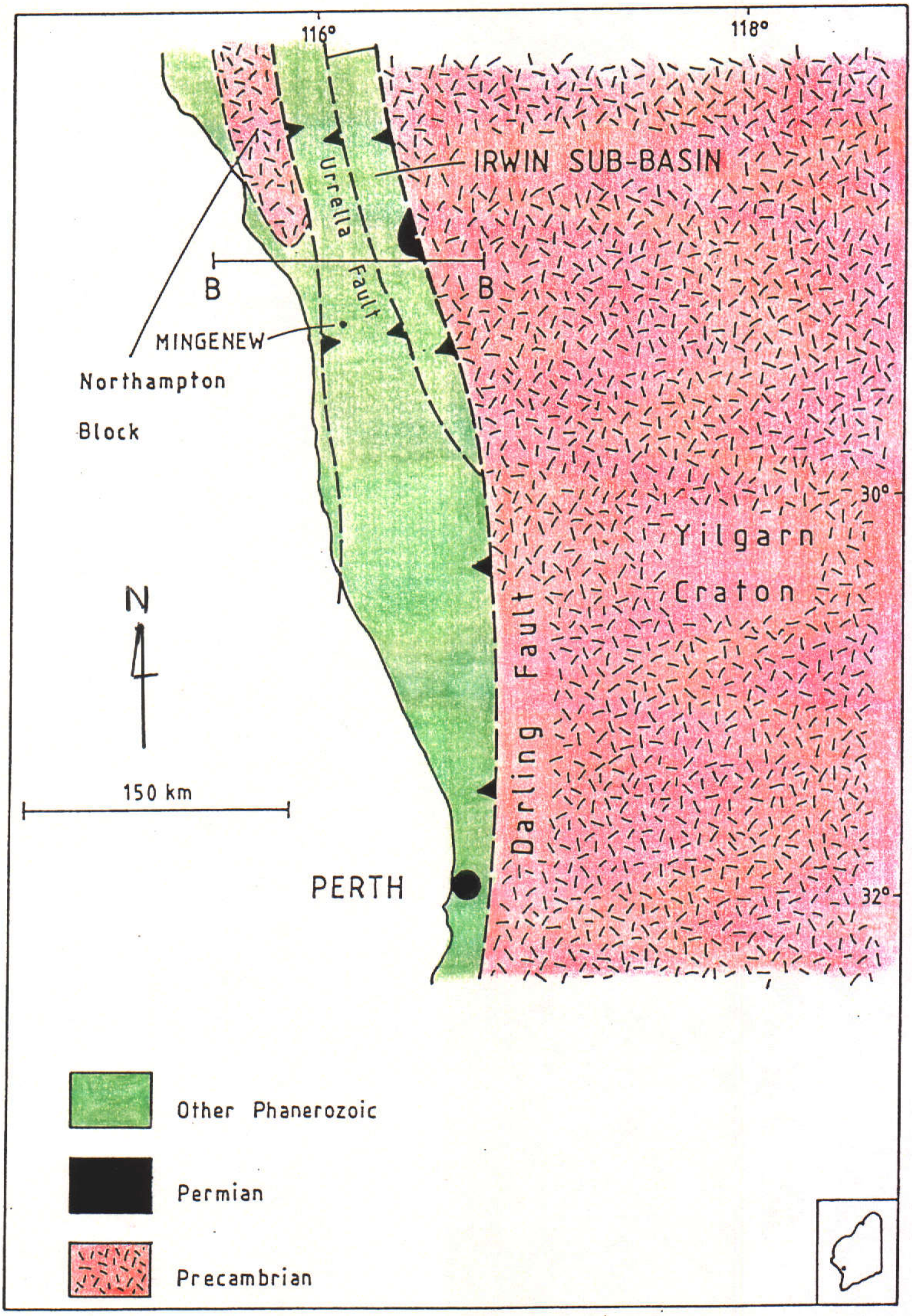


Figure 2.6. Geology and tectonic setting of the Irwin Sub-basin, northern Perth Basin, Western Australia (modified from Le Blanc Smith, 1990).

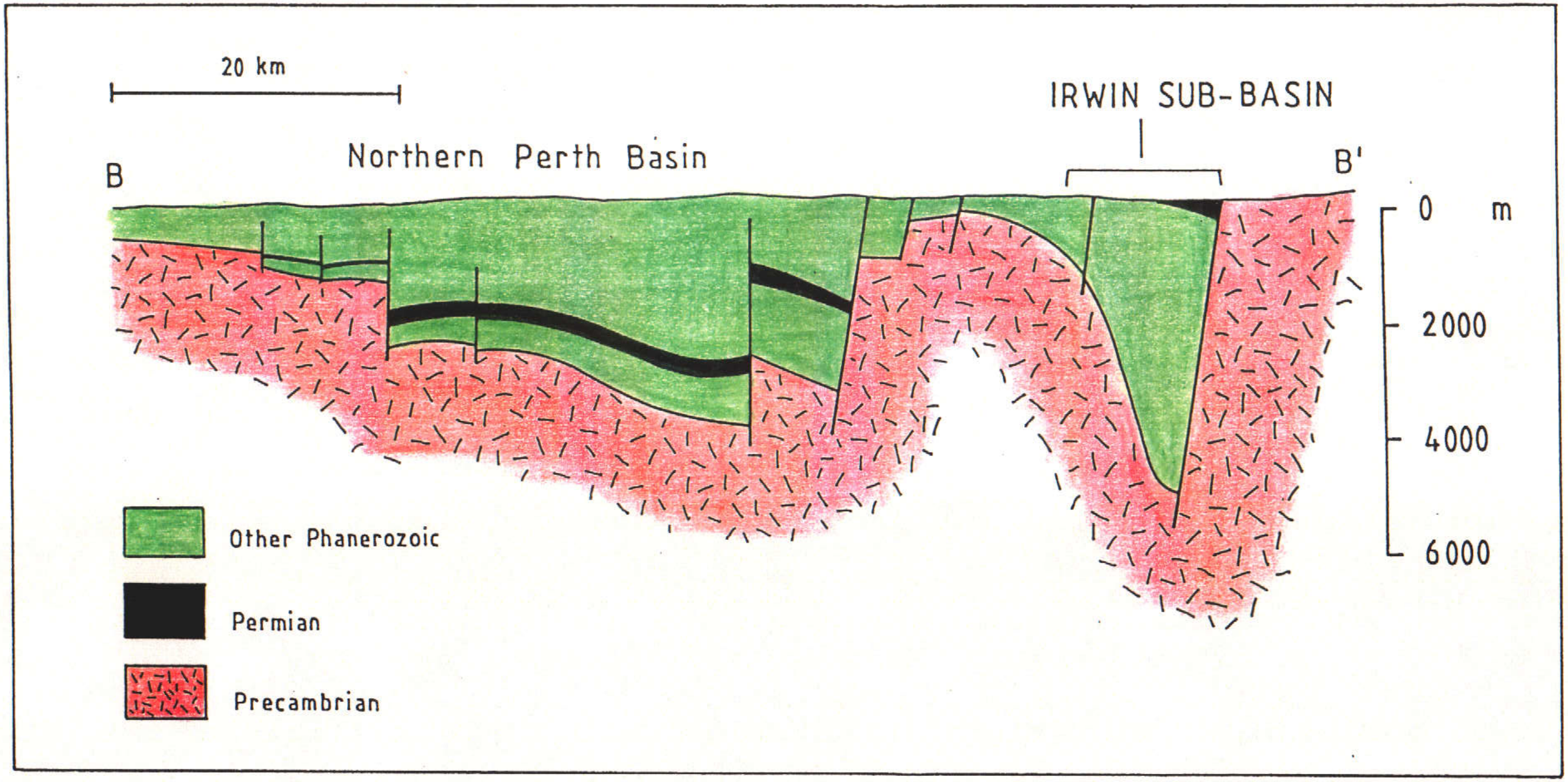


Figure 2.7. Cross-section (B-B') of the Irwin Sub-basin, northern Perth Basin, Western Australia (modified from Le Blanc Smith, 1990).

Coal Measures represent an upper deltaic progradation in a dominantly marine and paralic sequence, Kristensen and Wilson (1986) and Le Blanc Smith (1990).

The known extent of the Irwin River Coal Measures in the Irwin Sub-basin is approximately 40 km from north to south. The coal measures vary in thickness from 60 m in the north and 120 m in the south. The CRAE exploratory drilling revealed that the best area of seam development lies in the central sub-basin. Here, the coal measures contain up to 10 m cumulative thickness of coal in nine seams over a stratigraphic interval of 50 m. The coal seams range between 0.5 m and 6 m in thickness.

2.3. Collie Basin

The Collie Basin covers an area of about 230 km^2, located 160 km south-southeast of Perth. The basin is intracratonic and bilobate, probably a fault-controlled northwest-trending depression within a basement complex of Archaean granite and gneiss (Figure 2.8).

The published contributions to the geology of the basin include Woodward (1890), Robertson (1894), Maitland (1898), Jack (1905), Herman (1931), Wilson (1944), Balme (1952), Lord (1952, 1975, 1990), Low (1958), Lowry (1976), Wilde and Walker (1978), Wilde (1981), Park (1982), Kristensen and Wilson (1986), Sappal (1982, 1986), Wilson (1990), Backhouse (1990, 1991) and Le Blanc Smith (1993).

Balme (1952) applied biostratigraphy with a comprehensive analysis of the palynomorphs in the basin. Recently, Backhouse (1990, 1991) sequentially subdivided the Permian succession at Collie using a series of cryptic

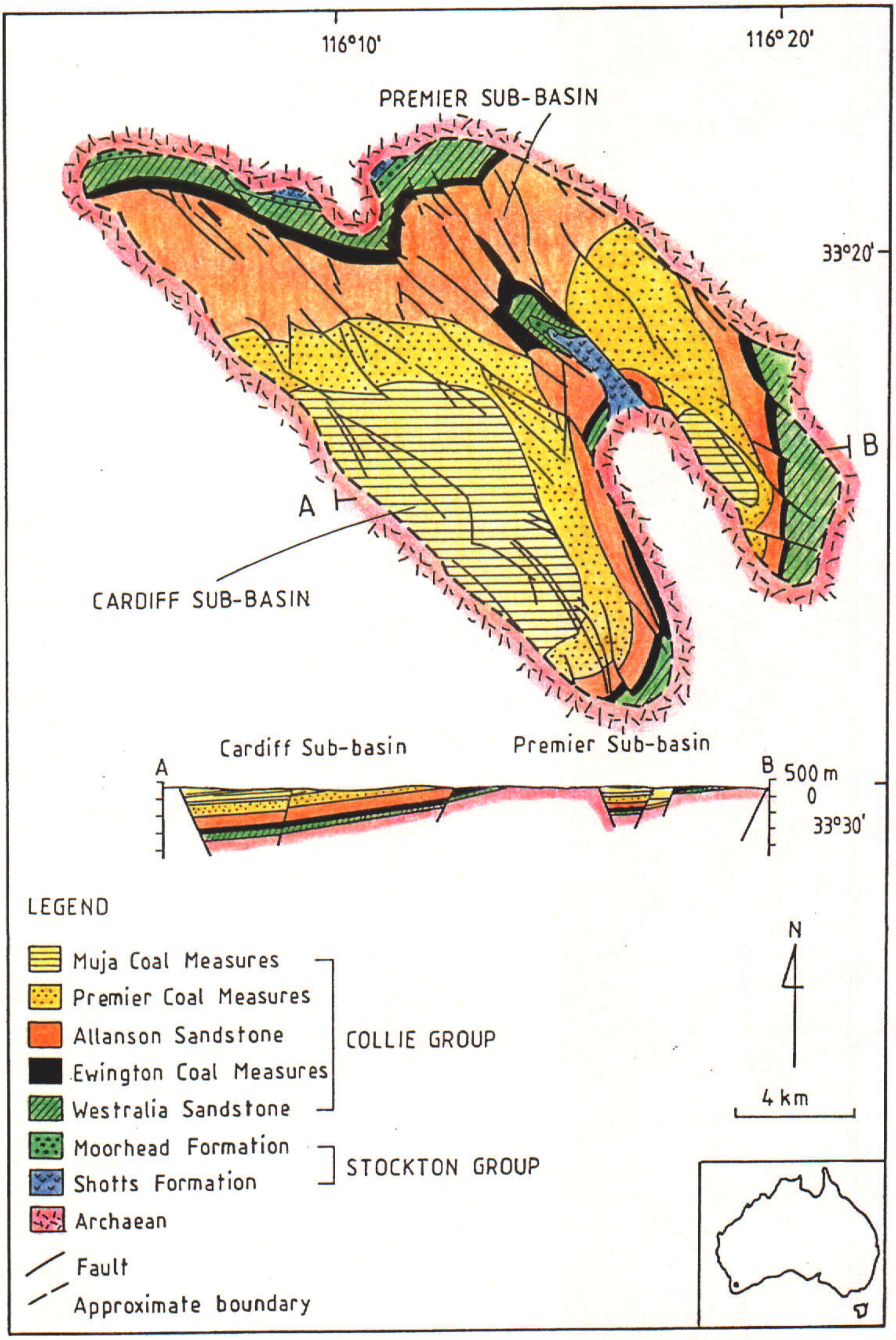


Figure 2.8. Subcrop distribution of the Collie and Stockton Groups, faults and cross-section A-B across the Collie Basin (after Le Blanc Smith, 1993).

biohorizons on the basis of first appearances of selected spore and pollen taxa.

The Collie Basin has been subdivided into two unequal units, named Cardiff and Premier Sub-basins (formerly Muja and Shotts Sub-basins), Figure 2.8. The Cardiff Sub-basin is the deepest containing at least 1,100 m of Permian sediments. The Premier Sub-basin contains 850 m and 580 m of Permian sediments in the Muja area and the Shotts area, respectively.

The stratigraphy of the Collie Basin consists of two groups, namely the Stockton and Collie Groups, overlying Archaean basement. At the base, the earliest Permian (Sakmarian) Stockton Group (formerly Stockton Formation) is conformably overlain by the Early to Late Permian Collie Group (Formerly Collie Coal Measures), which are unconformably overlain by the Cretaceous Nakina Formation (Figure 2.9). The Stockton Group consists of Moorhead Formation and the Shotts Formation. The Collie Group consists of five formations which are Muja Coal Measures, Premier Coal Measures, Allanson Sandstone, Ewington Coal Measures and the Westralia Sandstone. The Nakina Formation of Cretaceous age unconformably overlies the Permian sediments over the basin. Lowry (1976) and Park (1982) stated that the deposition of the coal measures was due to braided rivers and streams in the basin. According to Kristensen and Wilson (1986) the coal measures sedimentation occurred in an extensive fluvial basin which extended well beyond the present confines of the Collie Basin.

2.4. Coal Quality and Resources

Early Permian coal measures occur as shallow as 80 m in the Vasse Shelf,

AGE	GROUP	FORMATION
CRETACEOUS		Nakina Formation
PERMIAN	Collie Group	Muja Coal Measures
		Premier Coal Measures
		Allanson Sandstone
		Ewington Coal Measures
		Westralia Sandstone
	Stockton Group	Moorhead Formation
		Shotts Formation
ARCHAEAN	Undifferentiated Basement	

Figure 2.9. Stratigraphic units of the Collie Basin (after Le Blanc Smith, 1993).

and the coal has a rank of sub-bituminous to bituminous. This is stratigraphically equivalent to coal at depths exceeding 2,700 m in the Bunbury Trough, because the block faulting of the sequence has been uplifted in the Vasse Shelf, Kristensen and Wilson (1986).

The similarity of the Permian sequences at Collie, Bunbury Trough and Vasse Shelf shows that the coal measures were deposited over a wide area during a time when the Darling Fault and subsidiary structures (the Busselton and Dunsborough Faults) were less prominent features. The block-faulting during Mesozoic resulted in coal measures west of the Darling Fault being buried to depths exceeding 15 km, probably until Early Cretaceous time when tectonic activity resulted in the uplift of the Leeuwin Block and the adjoining Vasse Shelf. The activity was probably associated with the extrusion of the Bunbury Basalt and the intrusion of dolerite sills and dykes which have been intersected in the Bunbury Trough. The seismic and magnetic evidence also shows occurrence of igneous intrusions along some fault zones which separate fault blocks, Le Blanc Smith (1990).

The Vasse Shelf coal is non-coking and sub-bituminous to bituminous in rank as per the Australian Classification. The ash content in the coal ranges from 7% to 20% and specific energy varies from 17 to 31 MJ/kg on a dry basis. The bed moisture has a range of 6% to 20%, sulphur content varies between 0.5% and 1.4% and the volatile matter is about 23%. The coal is suitable for power generation.

The Collie coal is of sub-bituminous rank and non-coking, with an average ash content of 6%, bed moisture content of 25%, volatile matter of 24%, sulphur content of 0.4% and the specific energy of 20 MJ/kg on a dry basis.

Like the Vasse Shelf coal, the coal is suitable for power generation.

The Irwin River coal is also of sub-bituminous rank and non-coking and has an average ash content of 21%, bed moisture content of 16% to 25%, volatile matter of 25%, sulphur content of 0.6% and the specific energy of 16 MJ/kg on a dry basis.

The insitu resources of the shelf, basin and the sub-basin coals are:

.Vasse Shelf	=	480 Mt (inferred)
		290 Mt (measured)
.Collie Basin	=	804 Mt (inferred)
		526 Mt (measured)
.Irwin Sub-basin	=	1,100 Mt (inferred)

CHAPTER 3. COAL SAMPLES, METHODS, TERMINOLOGY AND TECHNIQUES

3.1. Introduction

The coal samples for this study were collected from the five drill holes drilled by the CRAE in the Vasse Shelf, Perth Basin, Western Australia. Additional coal samples were also obtained from Premier Sub-basin of the Collie Basin and the Irwin Sub-basin of the Perth Basin. The samples for petrology were available from minor coal seams because the major seams had already been removed for chemical analysis. The location of coal samples from the Vasse Shelf, Irwin Sub-basin and the Premier Sub-basin is given in Figures 3.1, 3.2 and 3.3. The procedures, preparation, terminology and techniques used for the study are according to the following Australian Standards:

AS K 149 *Glossary of terms for coal and coke.*

AS K 183 *Graphical representation of coal seams.*

AS 1038 (part 3) Methods for the analysis and testing of coal and coke: proximate analysis of hard coal.

AS 1038 (part 16) Methods for the analysis and testing of coal and coke: reporting of results.

AS 2061 *Code of practice for preparation of hard coal samples for microscopical examination by reflected light.*

AS 2418 (part 5) Terms relating to the petrographic analysis of bituminous coal and anthracite (hard coal).

AS 2486 *Microscopical determination of the reflectance of coal macerals.*

AS 2515 *Determination of the maceral group composition of*

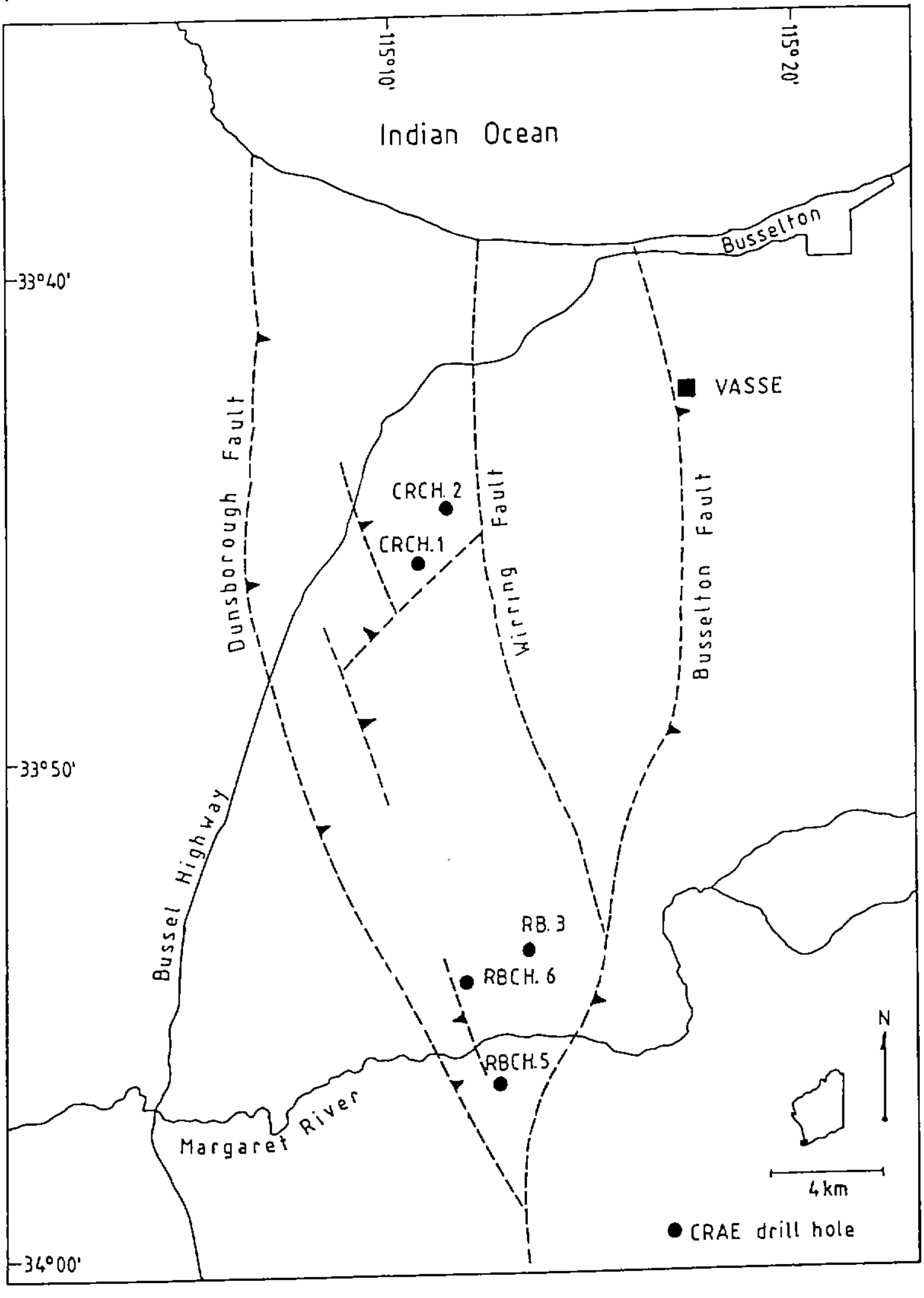


Figure 3.1. Location of the drill holes and coal samples, Vasse Shelf, Perth Basin.

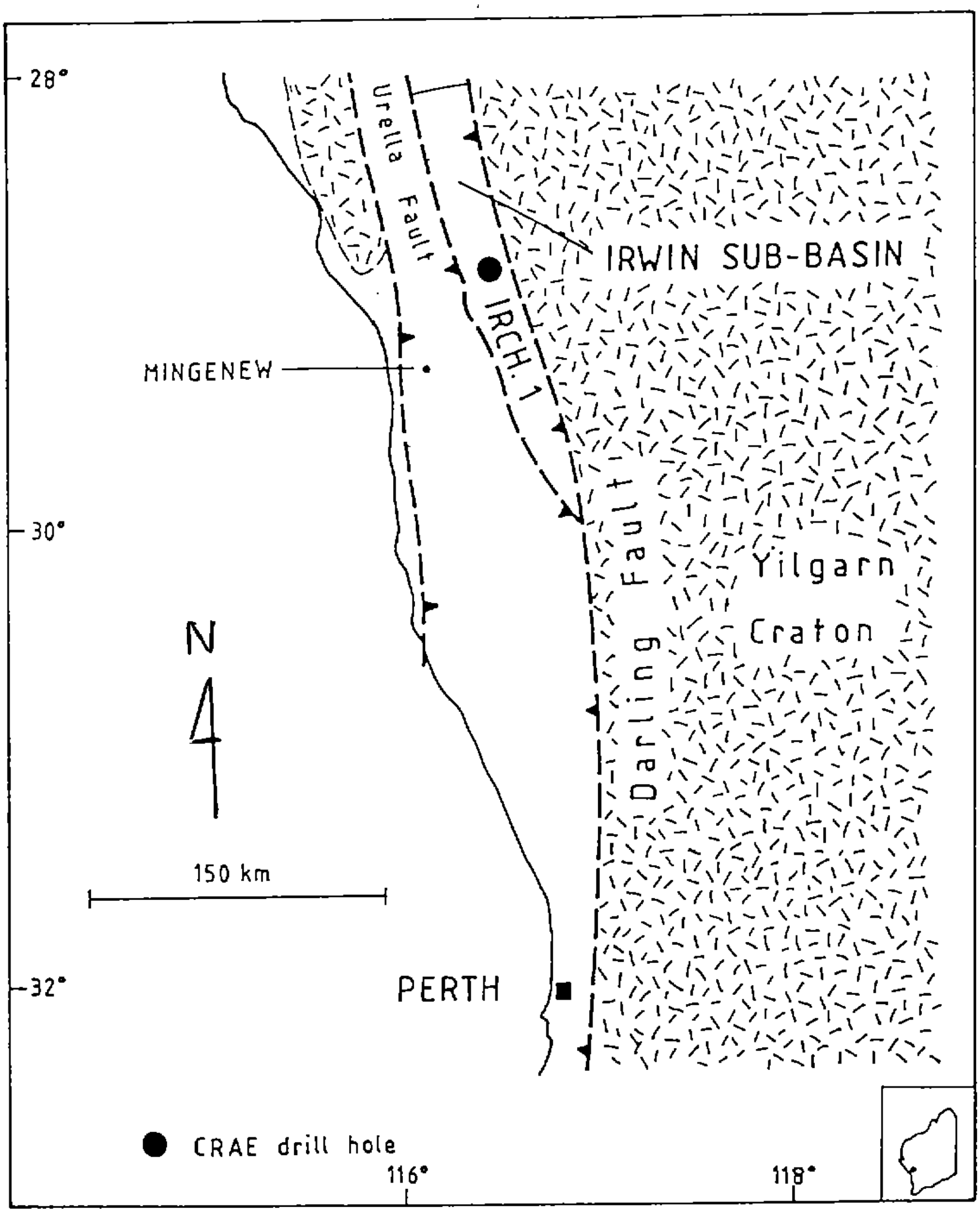


Figure 3.2. Location of the drill hole and coal samples, Irwin Sub-basin, Perth Basin.

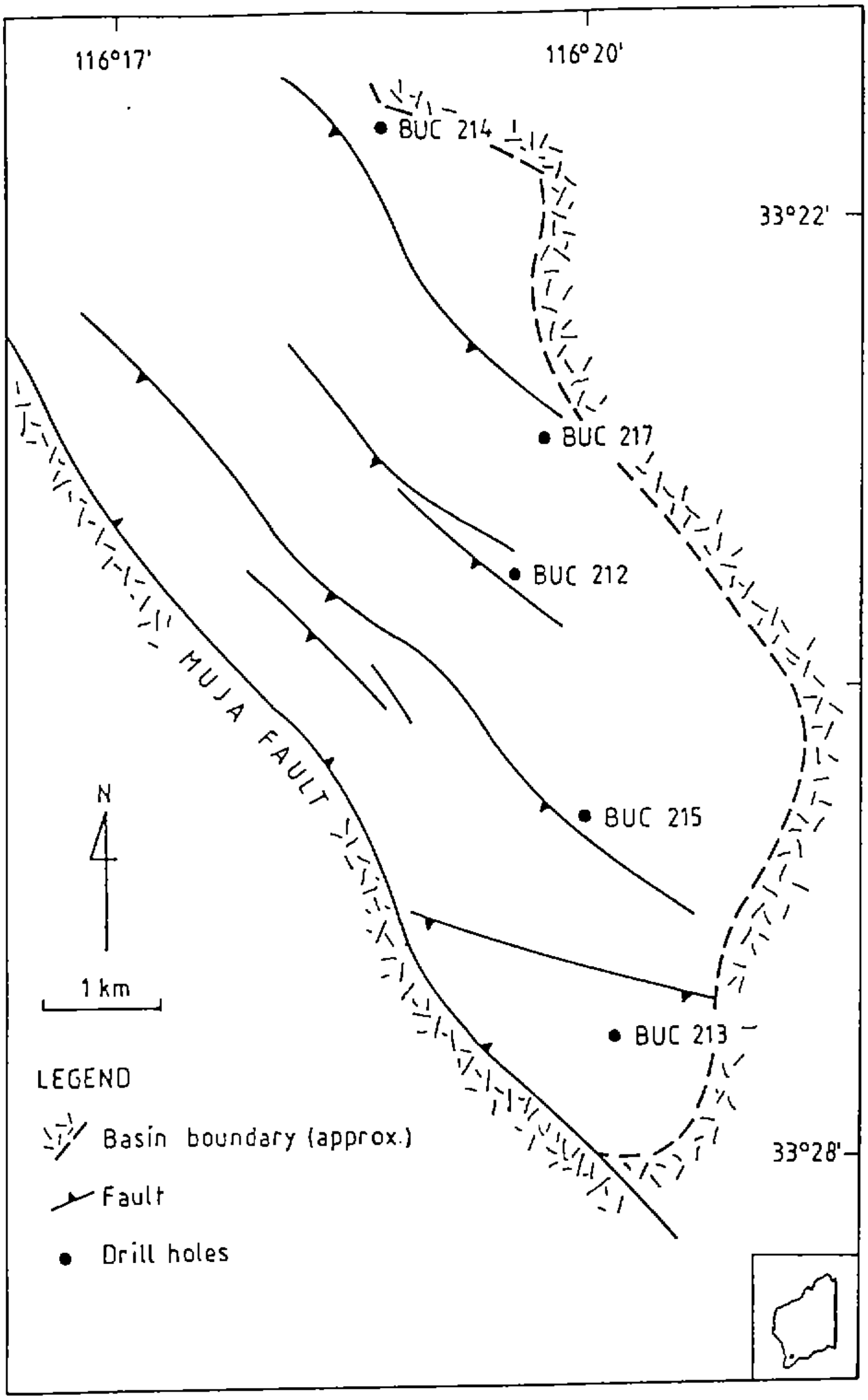


Figure 3.3. Location of the drill holes and coal samples, Premier Sub-basin, Collie Basin.

bituminous coal and anthracite (hard coal).

AS 2617 *Guide for taking of samples from hard coal seams insitu.*

AS 2856 *Coal maceral analysis.*

3.2. Sampling

The coal seams from eleven drill cores of the shelf and sub-basins were sampled by splitting the core remnants in halves. The samples were mainly from portions of minor coal seams in case of Vasse Shelf, because the major identified seams had already been removed earlier for chemical analyses. 375 coal samples from the Vasse Shelf, 31 coal samples from the Premier Sub-basin and 7 coal samples from the Irwin Sub-basin were prepared for petrographic examination according to the techniques developed in the laboratory.

3.3. Preparations

The cores of the individual seams were logged in the laboratory based on lithotypes according to the description shown in Figure 3.4. A minimum of 5 mm width was used for each lithotype, and a graphical representation in the form of a lithotype profile was prepared after compilation of the lithotype log. On the basis of lithotype characteristics and distinct shale partings, the individual seam was subdivided into a number of subsections. For the convenience of crushing, a maximum length of about half a metre was used for each subsection of the seam. The individual lithotype samples in each block were mixed to form a cumulative sample for crushing.

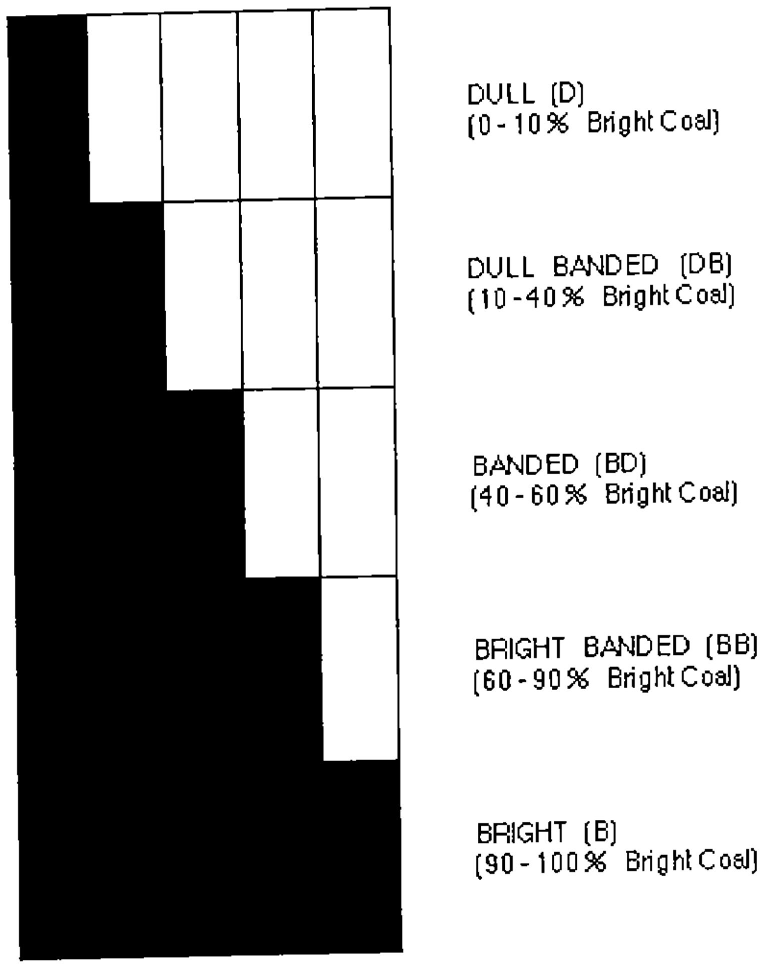


Figure 3.4. Macroscopic (lithotype) description of coal.

3.3.1. Crushing

A jaw crusher was used to crush the coal in each subsection to approximately less than 5 mm. It must be noted that the crusher was thoroughly cleaned to avoid contamination of the subsequent subsection. The samples were crushed in a coffee mill to 1 mm size for preparation of polished blocks. The polished blocks were prepared for representative samples of -1 mm size fractions, and for the size fractions of +4 mm, 4x2 mm, 2x1 mm, 1x1/2 mm, 1/2x1/4 mm and -1/4 mm (Figure 3.5).

3.3.2. Embedding

A sample splitter was used to obtain a representative sample of each of the size fractions. For each of the -1 mm, 1x1/2 mm, 1/2x1/4 mm and -1/4 size fractions, approximately 20 grams of coal was required, 40 grams for the 2x1 mm size fraction and 120 grams for the +4 mm and 4x2 mm size fractions. The samples of 20 grams each were individually placed into labelled plastic vials. The embedding medium used was an epoxy resin "araldite K 79" (3 parts) and hardener (1 part). In order to avoid the formation of bubbles, the sample and resin was evacuated in a vacuum chamber for approximately 30 minutes, and left overnight in a fume cupboard to set.

3.3.3. Grinding

The embedded coal within the plastic vial was cut vertically in halves by a diamond saw. The blocks were labelled after removing the plastic from the halves. One block was prepared and polished for microscopic examination and petrographic analysis and the other one was kept for reference. The

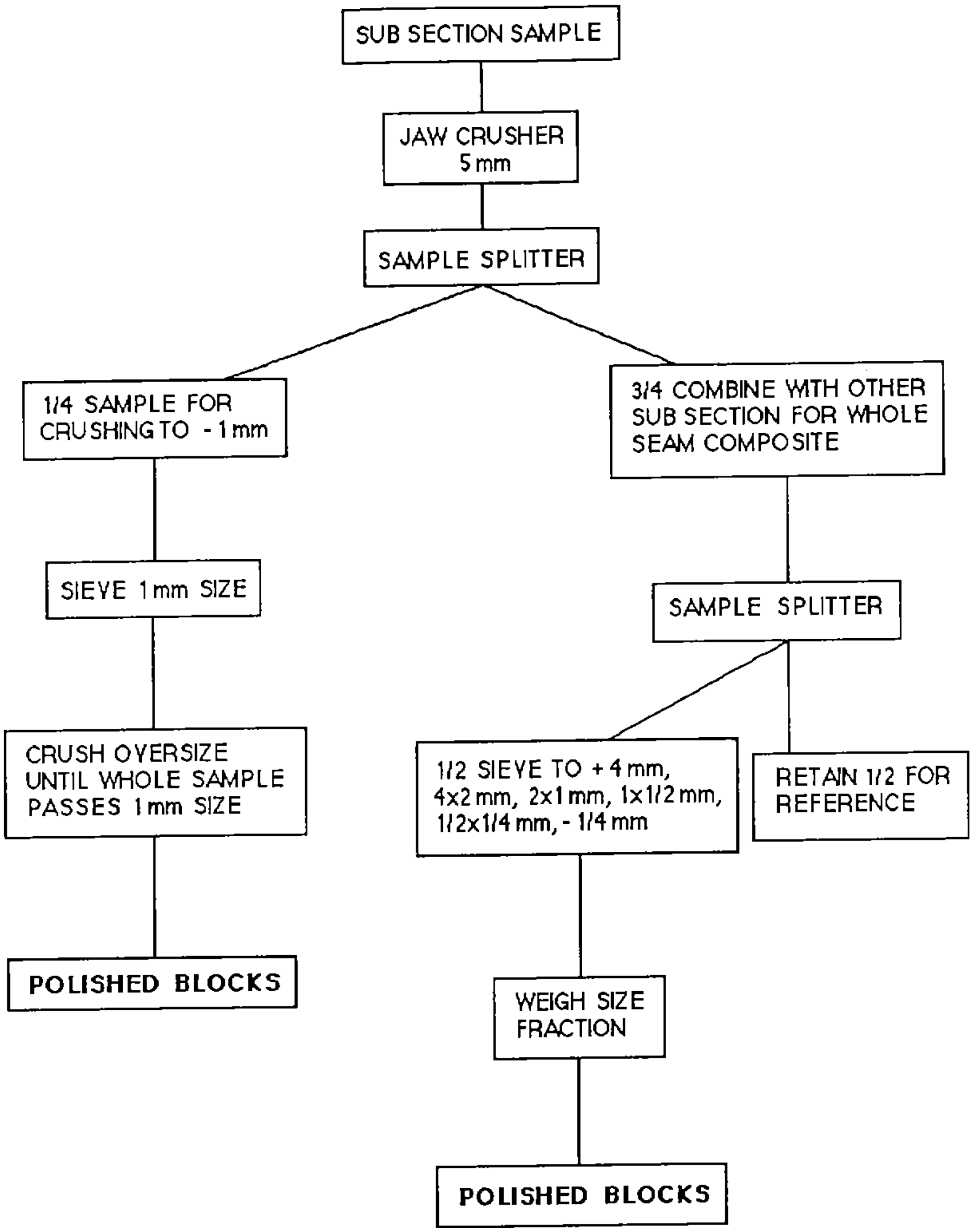


Figure 3.5. Flowchart for crushing coal samples.

individual block was ground on wet durite papers of 160, 220, 400, 600, 800, 1000 and 1200 grades, and cleaned in the ultrasonic bath prior to polishing.

3.3.4. Polishing

Polishing on ground, scratch free-blocks was undertaken by using "colloidal silica polishing suspension-Buehler Mastermet" slurry on a rotating disc covered with a silk cloth. The polishing was done at a speed of 125 for 3 minutes and later continued by a speed of 250 for 25 minutes. The blocks were thoroughly washed and cleaned in the ultrasonic bath and dried for microscopic examination and petrographic analysis. Figure 3.6 shows the flow diagram for the sample preparation developed in the laboratory.

3.4. Terminology

The type of peat-forming flora and depositional environments produce coal of different types. Different floral communities provide different assemblages of plant detritus which result in significant variations between peat deposits. Coal type can be determined either on macroscopic or microscopic scale. In Australia, macroscopic description of coal in terms of bright and dull components is routinely carried out during exploration. Predicting the microscopic composition of coal from macroscopic component is difficult, because of the presence of finely disseminated mineral matter in coal and several "dull" coals are found to be rich in vitrinite, Diessel (1965).

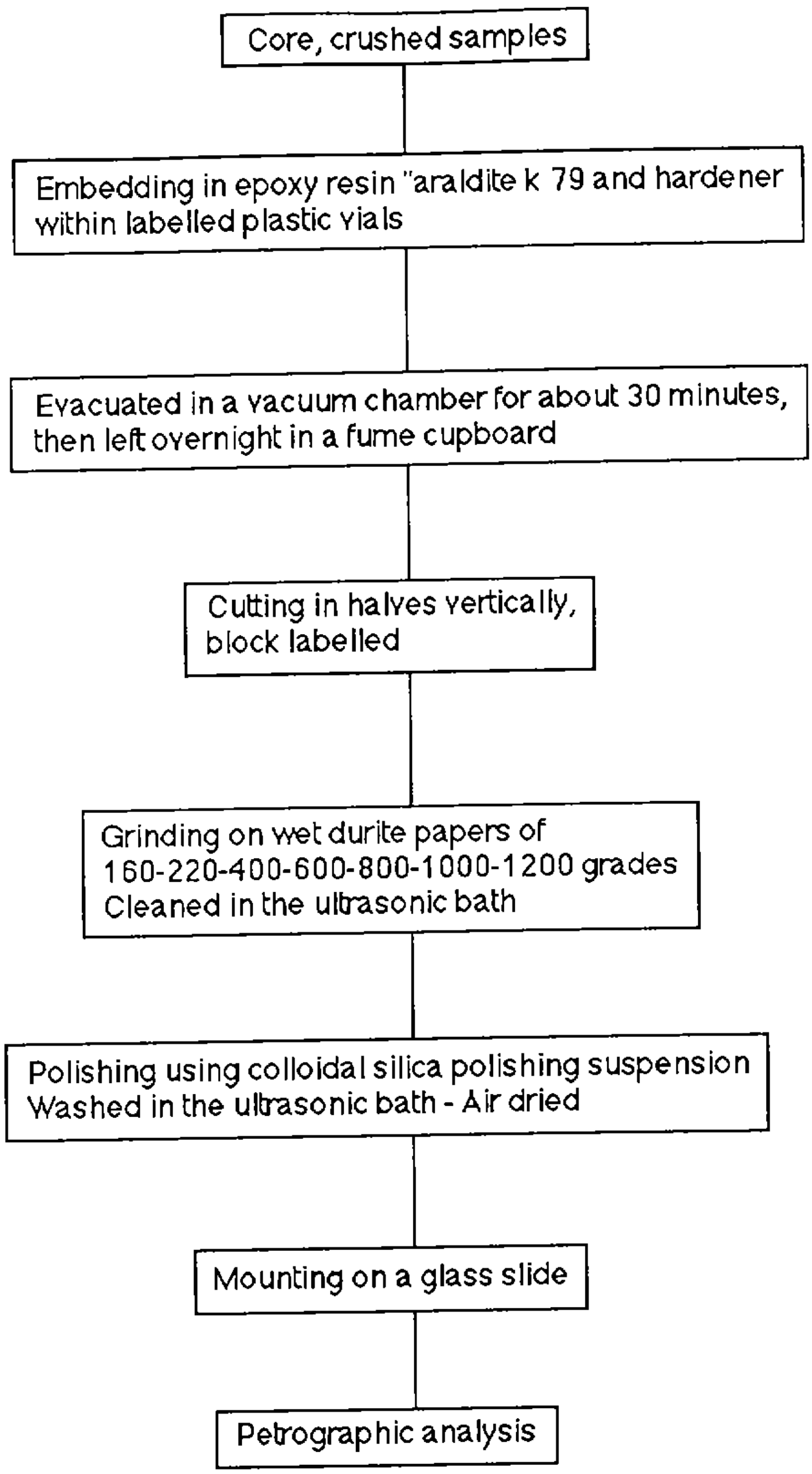


Figure 3.6. Flow diagram showing the coal sample preparation.

3.4.1. Lithotypes

The term lithotype was proposed by Seyler in 1954, ICCP (1963) to designate the macroscopically distinguishable bands of humic coals, which Stopes (1919) had previously described as vitrain, clarain, durain and fusain. Because of the finely-banded nature of many coal seams, Schopf (1960), Diessel (1965) and Cameron (1978) further subdivided the banded lithotype clarain, in order to fully describe the variations in seam profiles.

On the basis of lustre, namely bright against dull, fracture pattern and type of laminations, macroscopic bands of coal are distinguished and logged as lithotypes. In Europe, the minimum band width for individual lithotype, is designated as 1 cm. However, because of the finer laminations in Australian coals, a smaller unit of a 5 mm minimum is used. In the present study, the terms of Diessel (1965) applied for macroscopic description of lithotypes are used for the preparation of lithotype profiles (Figure 3.4). The lithotype terms are :

. *Dull Coal (D)* - *0-10 % Bright Coal*

. *Dull Banded Coal (DB)* - *10-40 % Bright Coal*

. *Banded Coal (BD)* - *40-60 % Bright Coal*

. *Bright Banded Coal (BB)* - *60-90 % Bright Coal*

. *Bright Coal (B)* - *90-100 % Bright Coal*

The presence of fusain and carbonaceous shale has also been recorded in the log.

3.4.2. Macerals

Macerals are defined as the microscopically recognizable organic constituents of coal which are predominantly defined by morphology, optical property and colour. Macerals have the suffix "inite" and at a basic level they are classified into three maceral groups, namely: vitrinite, inertinite and exinite. Table 3.1 shows the nomenclature and classification of the macerals applied in this study. The classification is summarized from ICCP (1963, 1971, 1975), Stach *et al.* (1982) and Australian Standard 2856 (1986).

The maceral group inertinite consists of coal components which have high carbon content. Because of this, the macerals of the group except semifusinite remain inert during carbonization in comparison to the other two maceral groups namely vitrinite and exinite. The macerals of inertinite group have strong reflectance in incident light microscopy. The macerals of exinite group are weakly reflecting and macerals of vitrinite group range between inertinite and exinite groups for their reflectance.

3.4.3. Microlithotypes

Seyler (1954) introduced the term microlithotypes to designate the typical association of macerals, in the form of microscopically fine layers with a minimum width of 50µ, ICCP (1963). This means that microlithotype analyses can only be determined, if in a polished surface perpendicular to the bedding plane, the band covers a minimum surface of 50x50 µ. Table 3.2 and Figure 3.7 show a summary of microlithotype classification, ICCP (1963) and Stach *et al.* (1982).

The microlithotypes may be contaminated with mineral matter, and associations of coal and minerals are called carbominerites, Stach *et al.* (1982). Table 3.3 shows coal-mineral associations. In the present study,

MACERAL GROUP	ORIGIN	PROPERTIES	MACERALS
Vitrinite	Humified wood or leaf tissue	Reflectance range small and lying between exinite and inertinite. Fluorescence weak to absent	Telocollinite* Telinite* Desmocollinite* Corpocollinite* Gelocollinite Vitrodetrinite*
Exinite or Liptinite	Sporopollenin, cutin, suberin, resins, waxes, oils, algal	Reflectance below that of vitrinite. Fluorescence distinct to intense.	Sporinite* Cutinite* Suberinite Resinite* Fluorinite Alginite* Exsudatinite (secondary resins) Liptodetrinite* Bituminite
Inertinite	Thermally or biochemically altered tissues	Reflectance above that of vitrinite. No fluorescence.	Fusinite* Semifusinite* Inertodetrinite* Macrinite* Micrinite* Sclerotinite*

*macerals present in the coal and included in the analysis

Table 3.1. Summary of maceral classification (after ICCP, 1963, 1971, 1975; Stach et al., 1982; Australian Standard 2856, 1986).

MICROLITHOTYPES	MACERALS	COMPOSITION	GROUP
Vitrite	Vitrinite (V)	>95% V	Monomaceralic
Liptite	Exinite (E)	>95% E	Monomaceralic
Inertite	Inertinite (I)	>95% I	Monomaceralic
Clarite	Vitrinite+Exinite	>95% V+E	Bimaceralic
Durite	Inertinite+Exinite	>95% I+E	Bimaceralic
Vitrinertite	Vitrinite+Inertinite	>95% V+I	Bimaceralic
Duroclarite	Vitrinite+Exinite+Inertinite	V, E, I each >5%, V>IE	Trimaceralic
Vitrinertoliptite	Vitrinite+Exinite+Inertinite	V, E, I each >5%, E>IV	Trimaceralic
Clarodurite	Vitrinite+Exinite+Inertinite	V, E, I, each >5%, I>VE	Trimaceralic

Table 3.2. Summary of microlithotypes (ICCP Handbook, 1963 and Stach *et al.*, 1982).

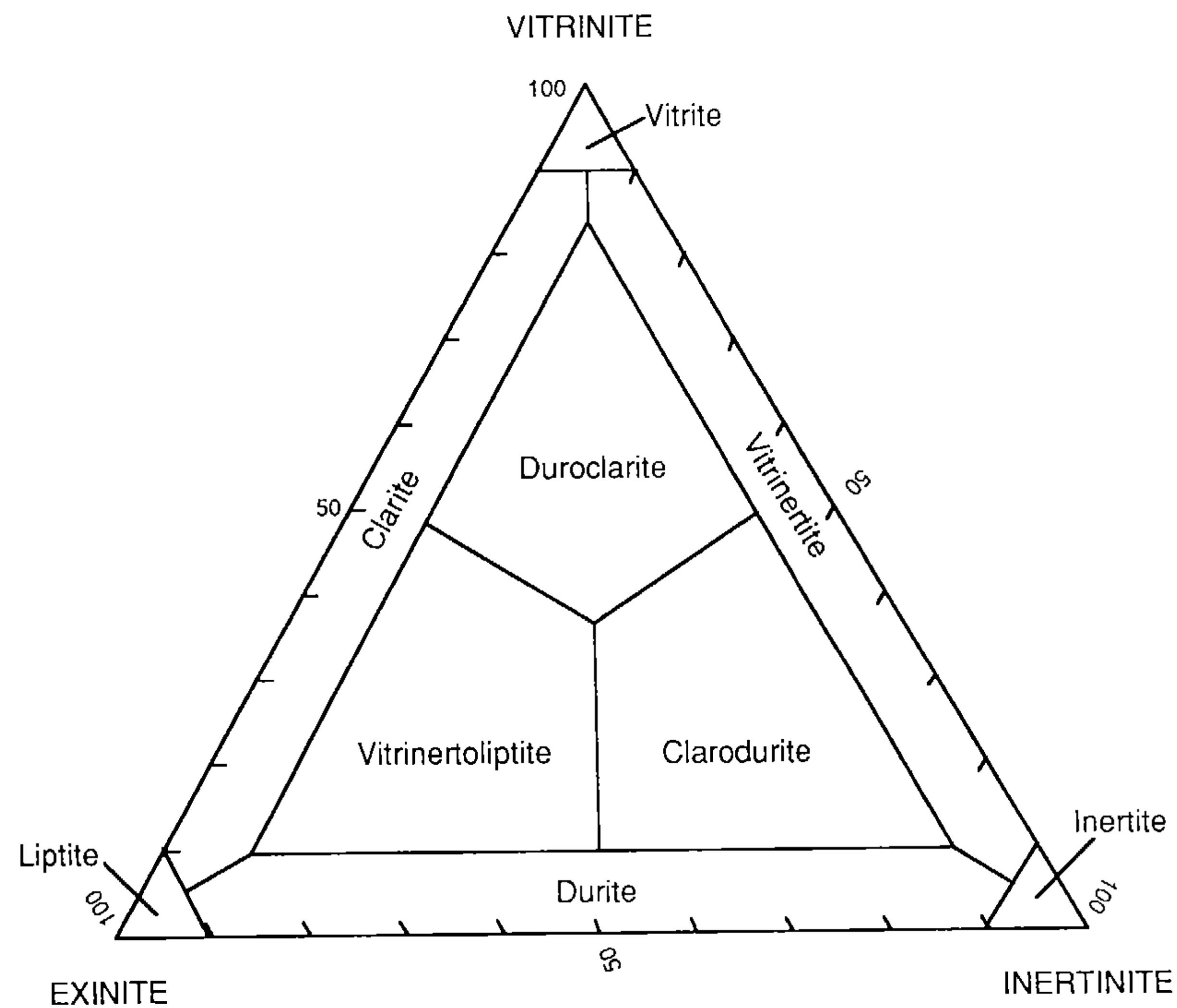


Figure 3.7. Microlithotype classification diagram (ICCP, 1963 and Stach *et al.*, 1982).

COAL INTERGROWN WITH A CERTAIN MINERAL OR A MINERAL GROUP	COMPOSITION	COLLECTIVE NAME FOR ANY ASSOCIATION OF COAL AND MINERALS
Carbargilite	coal + 20-60 % by volume of clay minerals	Carbominerite
Carbopyrite	coal + 5-20 % by volume of sulphide minerals	
Carbankerite	coal + 20-60 % by volume carbonate minerals	
Carbosilicate	coal + 20-60 % by volume of quartz	
Carbopolyminerite	coal + 20-60 % by volume* of various minerals	

*the lower limit can be reduced to 5%, depending on the content of pyrite.

Table 3.3. Classification of carbominerites (Stach *et al.*, 1982).

carbargilite, carbopyrite and minor carbosilicate are the dominant carbominerites in the coal.

3.5. Analytical Techniques

3.5.1. Lithotype Examination

Prior to microscopic examination, the cores of the coal seams A to P from the Vasse Shelf were macroscopically logged in order to obtain a lithotype profile. The core was cleaned and split in order to obtain a fresh surface for macroscopic examination and thickness of individual lithotype was recorded, using a minimum width of 5 mm. The thickness of sandstone, shale and siltstone, if present, was also recorded. After completion of the lithotype log, a graphical representation in the form of a lithotype profile was prepared, as shown in Figure 3.8. On the basis of lithotype characteristics, the core was subdivided into a number of subsections for analytical examination.

According to Warbrooke (1981), the lithotypes express the characteristics of the zone in which they are formed, and the coal-forming swamps may be divided into three zones, depending on water levels, which are:

. *Open water (limnic moor)*
Little vegetation with the exception of algae grows in this zone, so most vegetable matter present is transported into the area. During transportation, it undergoes partial decomposition after passing through oxygenated water and becomes inertinite and semi-inertinite-rich coal. Detrital clastic material also finds its way into this zone, and the resulting coals are usually dull to banded and often very shaly.

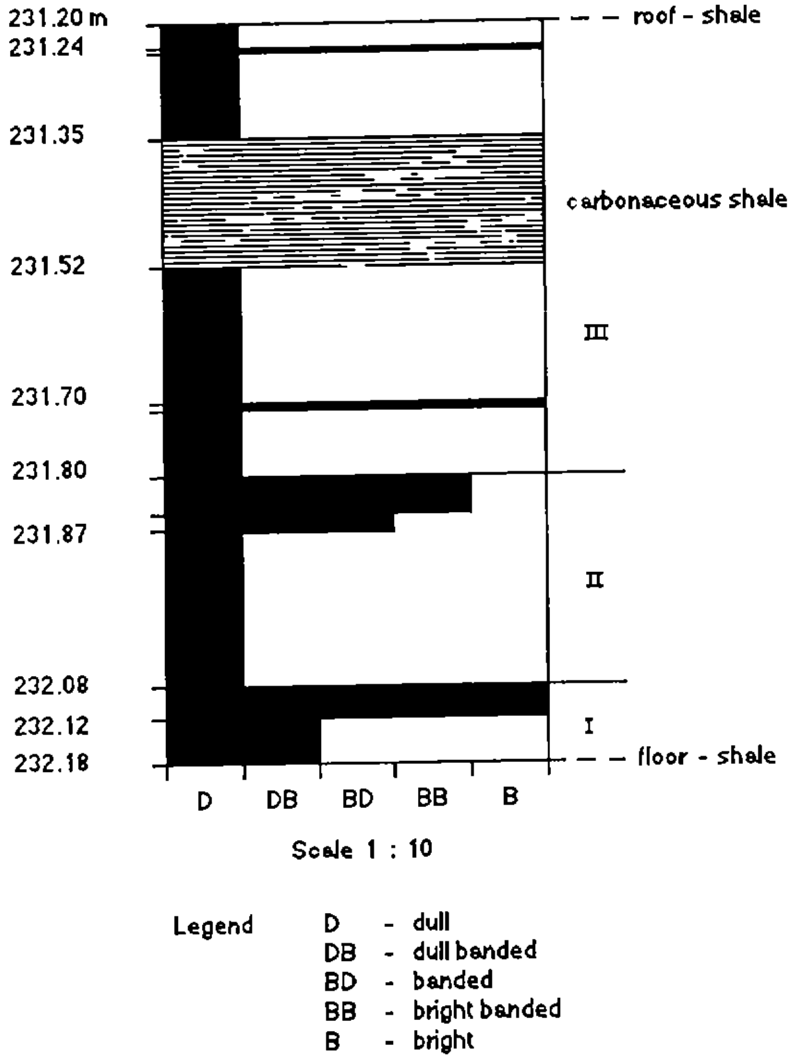


Figure 3.8. Lithotype profile of seam G, RB 3, Vasse Shelf, Western Australia.

. Wet swamp (limno-telmatic and telmatic zones)

This zone is usually covered with shallow water or is water logged. Vegetation grows in situ and is deposited quickly beneath the water in reducing conditions. These conditions favour the formation of vitrinite resulting in banded to bright coals.

. Dry swamp (terrestrial moor)

Vegetation is initially deposited in oxidizing conditions above the water table and is subject to partial decomposition before being influenced by reducing conditions below the water table. Inertinite and semi-inertinite macerals tend to predominate in this zone and detrital mineral matter is less, although inherent mineral matter increases. Resulting coals are dull to dull banded.

In addition, Diessel (1982 a) pointed out that "dullness" in coals may either be due to macerals ascribed to dry conditions (structured inertinites and groundmass macrinite) where oxidation of vegetation is due to subaerial exposure, or due to "wet" macerals (inertodetrinite, discrete macrinite, sporinite and alginite) and mineral matter, indicative of high water levels and transport of maceral precursors. Therefore, coal lithotypes may be related to the environment in which they are formed. In open water, coals deposited are dull and usually shaly, whereas in the wet swamp, coals deposited are bright. In addition, dull coal can also result from above the water table.

3.5.2. Microscopy (Macerals and Microlithotypes)

The microscopic examination of polished sections was undertaken, using a reflected light Leitz Orthoplan microscope fitted with a fluorescence mode.

The microscope was fitted with oil immersion objectives of x32 and x50, and x10 eyepieces, connected to Swift Automatic Point Counter for quantitative work, as shown in Figure 3.9.

By using the same microscope with the aid of a 100 W mercury lamp and ultraviolet excitation, fluorescence mode examination was undertaken in conjunction with reflected light. A filter system consisting of a TK dichroic beam-splitting mirror, a K 470 or K 490 barrier filter was used. During visual observation, the splitter was placed in the vertical illuminator of the microscope, and the barrier filter was used for cutting excitation light. The fluorescence-mode examination was carried out in order to provide supplementary evidence concerning identification and abundance of exinite group of macerals and it was used as an aid to distinguish between exinite macerals and clay minerals. According to Bustin *et al.* (1989) the exinite group of macerals show auto-fluorescence when irradiated with blue light or ultraviolet light, because of the presence of hydrogen in unsaturated bonds. Table 3.4 shows fluorescence colours and intensities for the maceral groups in different ranks of coal, using blue-light excitation, ICCP (1975). It can be seen that fluorescence colours and intensities of the macerals decrease with the increase in rank of coal. Exinites display high fluorescence intensities in peat and low rank coal. Some of the low to medium rank vitrinites also fluoresce in low rank coals, and inertinites do not fluoresce in any rank of coal.

The photomicrographs of macerals and mineral matter in the coal were obtained using a Wild Leitz MPS 46 photoautomat camera fitted to the Leitz Orthoplan microscope, as shown in Figure 3.10. Fujicolor Super HR 400 ASA film was used for all photomicrographs presented in the thesis.

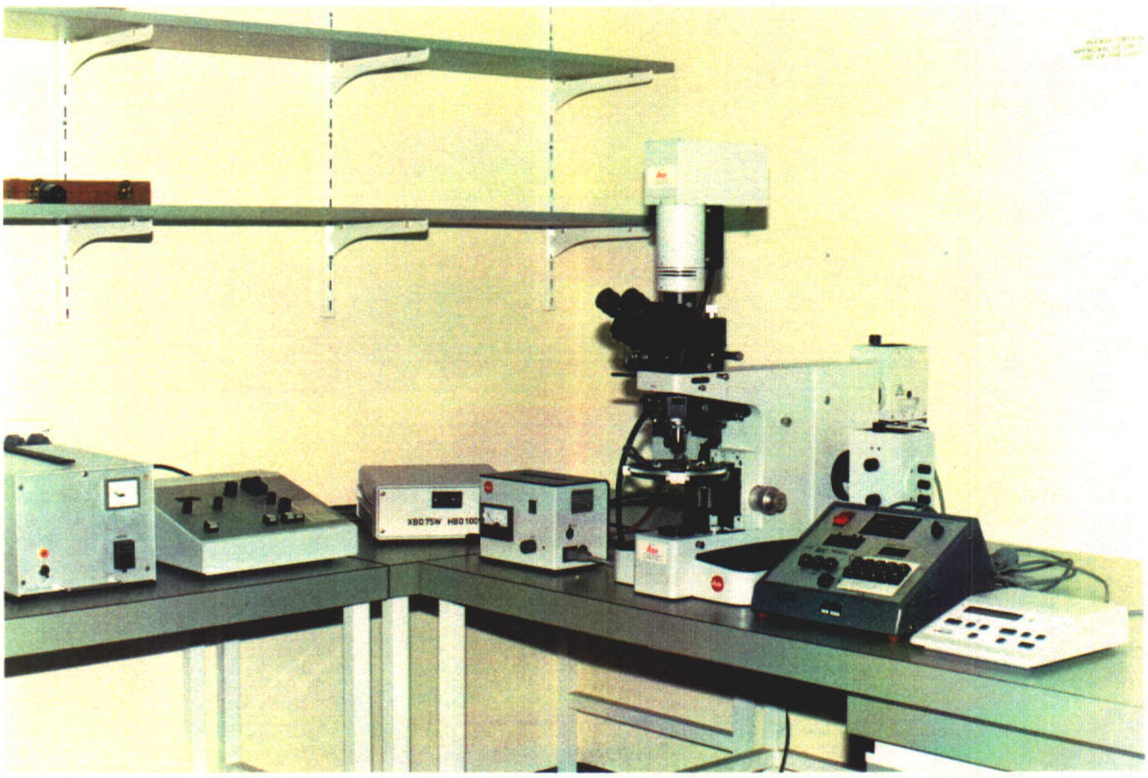


Figure 3.9. Equipment used for petrographic analysis.

MACERAL	SOFT BROWN COAL (LIGNITE)	HARD BROWN COAL (LIGNITE)	LOW-RANK BITUMINOUS COAL	HIGH-RANK BITUMINOUS COAL
Exinite	strong; green, yellow, orange, and brown	strong to moderate; greenish yellow, yellow-orange, and brown	strong to weak; yellow, orange, and brown	no fluorescence
Vitrinite	strong to weak; yellow and brown; or no fluorescence	very weak; brown; or no fluorescence	very weak; brown; or no fluorescence	no fluorescence
Inertinite	no fluorescence	no fluorescence	no fluorescence	no fluorescence

Table 3.4. Fluorescence colours and intensities of the maceral groups (ICCP, 1975).

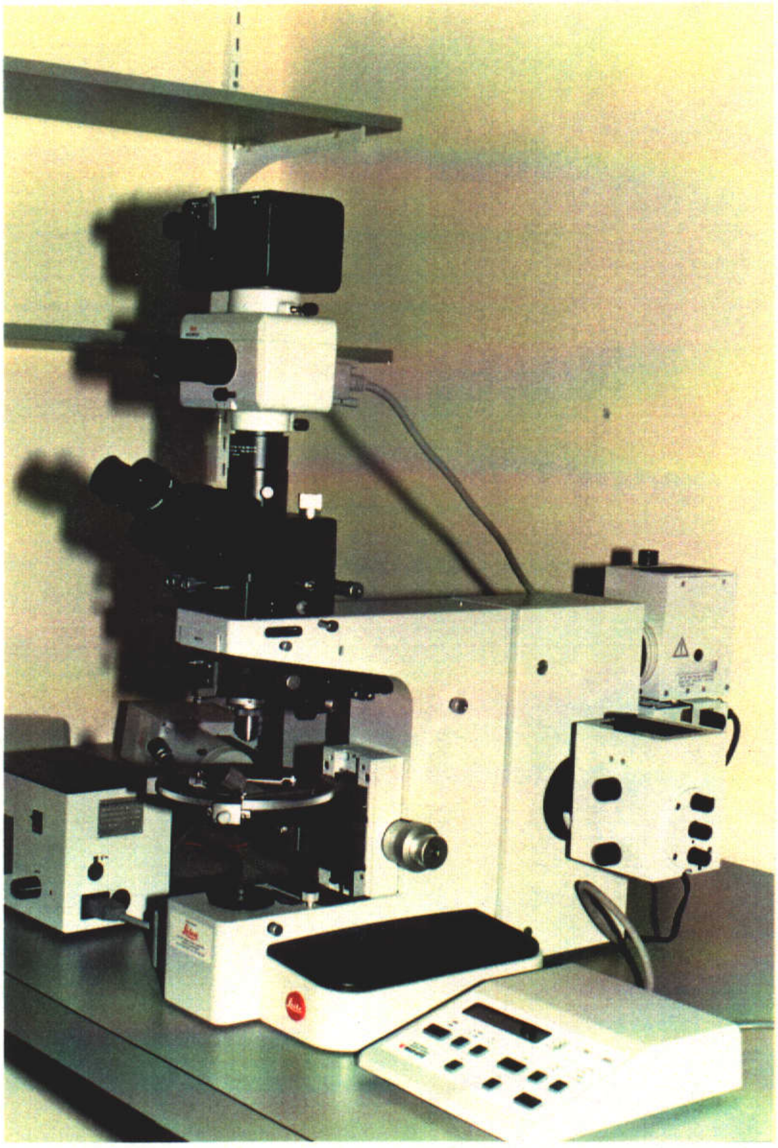


Figure 3.10. Photomicrographic equipment.

3.5.2.1. Maceral Analysis

The maceral analysis is based on counting of 500 points using the Swift Automatic Point Counter attached to the microscope. Traverses are made from top to the bottom of block, perpendicular to laminations. Step lengths and traverse spacing are altered relative to size fractions of the sample in order to obtain representative counts. For instance, the step length of 0.5 mm is used for a sample with the particle size of 1 mm. One block is required for the size fractions of -1 mm, 1x1/2 mm, 1/2x1/4 mm, and -1/4 mm, two blocks for the 2x1 mm size fraction, four blocks for the +4 mm and 4x2 mm size fractions, to obtain a count of 500 points.

Based on 500 point counts, volume percentage for each maceral and mineral is calculated. The maceral data are calculated as:

.mineral matter counted:
% vitrinite + exinite + inertinite + mineral matter = 100
.mineral matter free basis:
% vitrinite + exinite + inertinite = 100

The mineral matter associated with macerals is recorded for each sample, and the majority of mineral matter is clay and pyrite associated with vitrinite and inertinite. Quartz is also recorded in minor amounts. Details of the mineral matter are also examined using the SEM (section 3.5.2.4).

The importance of maceral analysis and diagnostic macerals in the interpretation of depositional environment of coal is described by Diessel (1982 a, 1986) modified by Lamberson, Bustin and Kalkreuth (1991) and Hunt, Brakel and Smyth (1986).

Diessel (1982a, 1986) applied maceral analysis as palaeoenvironmental indicators, and he designated that the presence of alginite is indicative of limnic or lacustrine conditions during the deposition of coal. The precursor of alginite is algae which flourish in ponds, lakes, lagoons, estuaries and other aqueous environments ranging from fresh to hypersaline waters. In many parts of the swamp, spores and pollens may be produced, but most are preserved among reeds of the limnotelmatic zone. Cutinite, a coalification product of mostly leaf cuticles is usually associated with wood-derived vitrinite, therefore it is preserved in forest moor and thus indicator of depositional environment. The presence of resinite may be indicative of a forest moor environment, where it is associated with telinite.

Telinite and telocollinite are derived mainly from incompletely gelified xylem and cortex tissues of plants and their presence commonly indicate a palaeoenvironment involving wood-producing plants under moist conditions. Root and leaf tissues of plants can also be preserved as the gelified xylem and the cortex tissues. Desmocollinite originates from intensely-decomposed and gelified attritus. Corpocollinite, vitrodetrinite and desmocollinite have low diagnostic value with regard to depositional environments.

The presence of inertinite group of macerals, except micrinite, indicates partial oxidation during the peat stage, and is commonly interpreted as indicating dry conditions. Fusinite and semifusinite are commonly indicated as the products of terrestrial forest moors, either by way of charcoal formation or as a result of attack of wood by fungi and bacteria under slightly oxidizing conditions. The inertodetrinite in coal consisting of fragmented cell walls of fusinite and semifusinite is formed under dry and slightly oxidizing conditions or terrestrial forest moor, and this type of inertodetrinite, although initially formed in a relatively dry forest moor, is more likely to be the result of transportation and redeposition in a subaqueous environment.

In this study, the facies triangles of Diessel (1982 a) have been used to interpret the depositional environment of the coal (Figures 3.11 and 3.12). In the triangle showing dispersed, woody and remaining macerals (DWR), the macerals considered to be facies diagnostic are contrasted to the remaining ones (Figure 3.11). The DWR macerals in the triangle consist of:

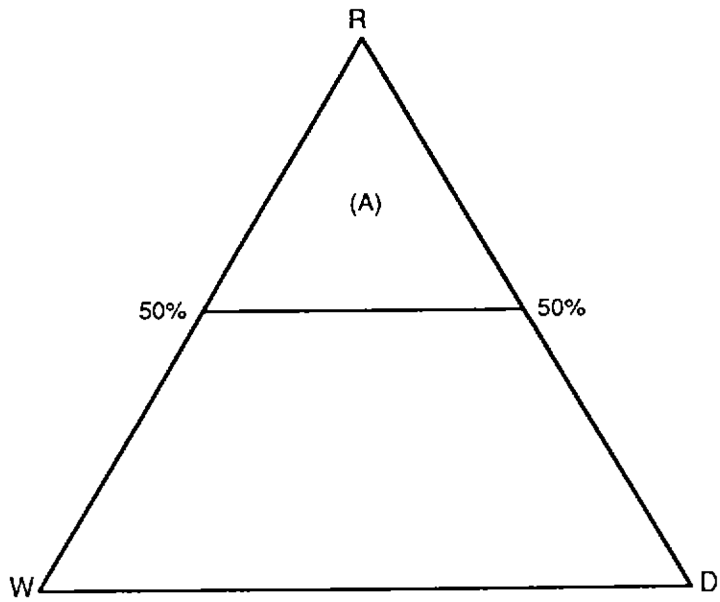
D (dispersed) = alginite + sporinite + inertodetrinite
W (woody) = telinite + telocollinite + semifusinite + fusinite
R (remainder)= other macerals (principally desmocollinite)

Apex D represents the dispersed macerals of the open moor. Apex W represents the wood-derived macerals of the forest moor. The remaining macerals represent apex R.

The triangle is divided into two sections by the lateral 50% line. Coals plotting in the upper field contain less than 50% diagnostic macerals and probably have resulted from a rather mixed coal-forming environment, without a strong tendency towards either forest moor or limnic conditions. On the other hand, coals plotting in the lower half contain sufficiently large numbers of diagnostic macerals to warrant further analysis.

In the DTF triangle showed in the Figure 3.12, the macerals are:

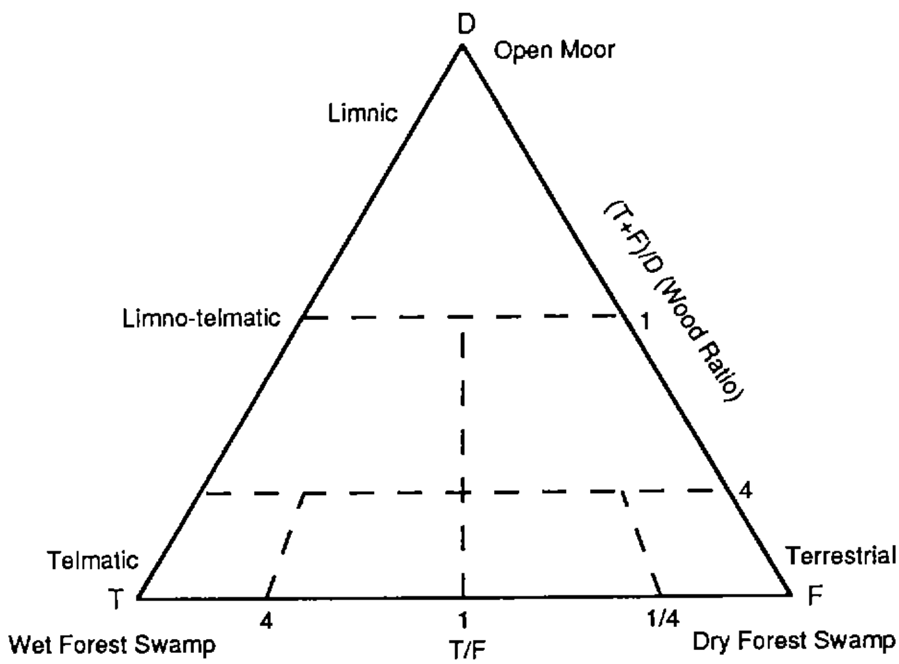
D (dispersed) = inertodetrinite + sporinite + alginite
T (telinite) = telinite + telocollinite



(A) : mixed environment without a strong tendency towards either forest moor or limnic conditions.

D (dispersed) : alginite, sporinite and inertodetrinite
W (woody) : telinite, telocollinite, semifusinite and fusinite
R (remainder) : other macerals (principally desmocollinite)

Figure 3.11. DWR facies triangle diagram (after Diessel, 1982 a).



D : inertodetrinite, sporinite and alginite
T : telinite and telocollinite
F : fusinite and semifusinite

Figure 3.12. DTF facies triangle diagram (after Diessel, 1982 a).

F (fusinite) = *fusinite + semifusinite*

The D representing inertodetrinite+sporinite+alginite is in the upper apex, T representing telinite+telocollinite in the left apex, F representing fusinite+ semifusinite in the right apex of the triangle. According to the facies triangle, if the ratio of

$$\frac{(telinite+telocollinite) + (fusinite+semifusinite)}{(inertodetrinite+sporinite+alginite)} \quad or \quad \frac{T+F}{D}$$

is less than 1, then coal was formed mainly under limnotelmatic, reed moor or limnic conditions with little input from forests. If the ratio is greater than 1, more than 50% of the diagnostic macerals may be assumed to have been formed from wood tissues in a forest moor. In the forest moor, the dryness or wetness is given by the ratio of

$$\frac{(telinite+telocollinite)}{(fusinite+semifusinite)} \quad or \quad \frac{T}{F}$$

The ratio having values greater than 1 indicates high moisture condition; on the other hand a ratio of less than 1 shows a drier environment. However, the amount of inertodetrinite+sporinite+alginite may still be high enough to suggest incomplete cover by forests and substantial contributions to the peat from an open-moor environment.

If (T+F)/D ratio exceeds 4, wood-derived material is dominant in the coal. A four-fold separation of wood derivatives ranges from highly gelified material at +4 to highly fusinised matter at -1/4. The differing ratios reflect changes from wet, limnotelmatic forest moors at high ratios to relative dry, terrestrial forests at low ratios.

Further, Diessel (1986) related the above coal facies indicators to the environment of coal formation (Figure 3.13) and used a gelification index (GI) and a tissue preservation index (TPI) in the interpretation of

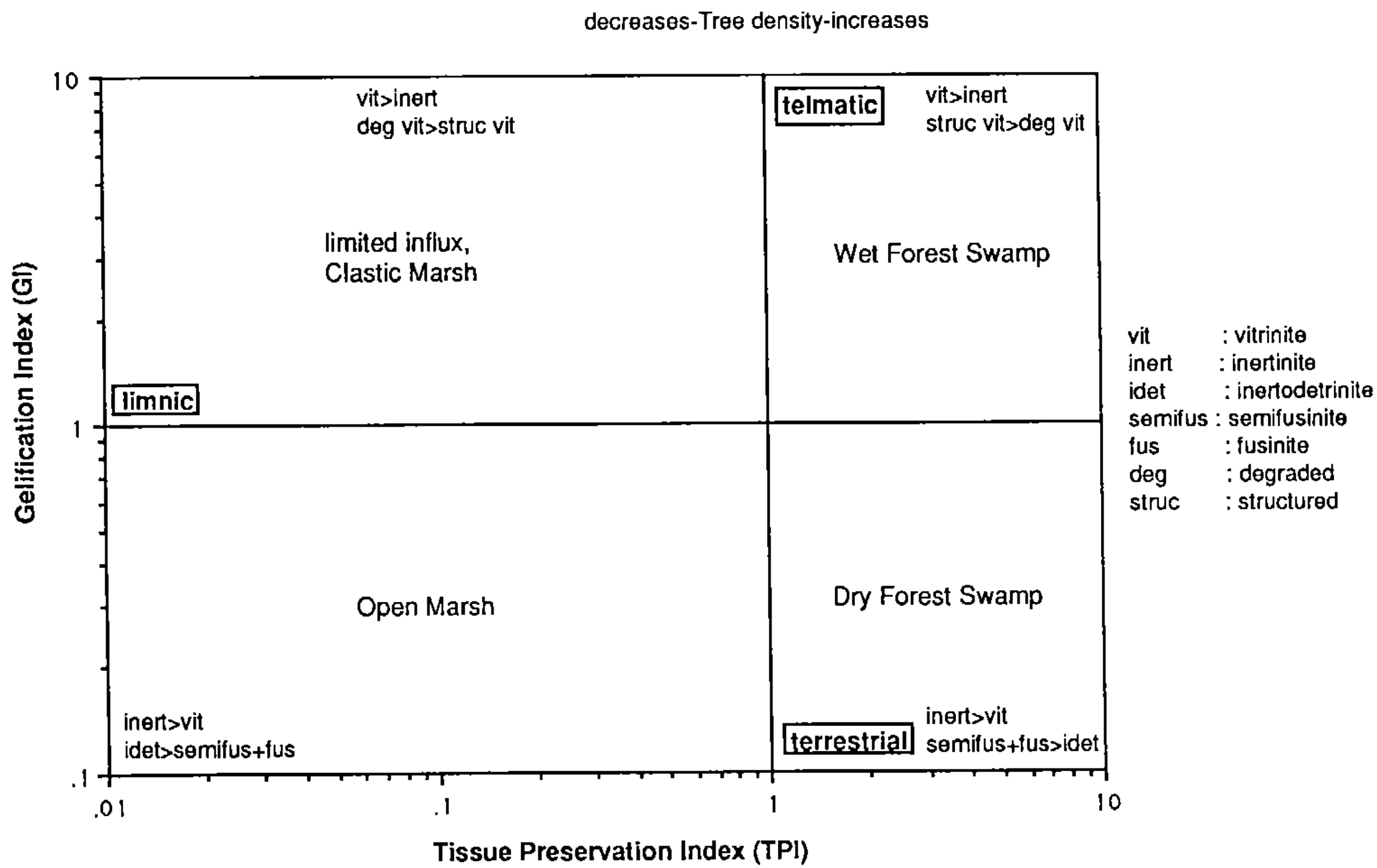


Figure 3.13. TPI-GI facies diagram (Diessel, 1986, Lamberson, Bustin and Kalkreuth, 1991).

environment of coal. The GI and the TPI are defined as :

$$GI = \frac{(vitrinite+macrinite)}{(fusinite+semifusinite+inertodetrinite)}$$

$$TPI = \frac{(telinite+telocollinite+fusinite+semifusinite)}{(desmocollinite+macrinite+inertodetrinite)}$$

The fields within the facies diagram correspond to the hydrologic and decomposition of vegetation characteristics of common wetland environments. According to Lamberson, Bustin and Kalkreuth (1991), the hydrologic regime is divided on the basis of water level into:

. *terrestrial* : *above water level, dry condition (dry forest swamp)*

. *telmatic* : *between high and low water (wet forest swamp)*

. *limnic* : *subaqueous (limited influx, clastic marsh)*

The vegetation type in the diagram corresponds to marsh (primarily herbaceous vegetation) or a swamp (primarily arboreal vegetation).

The term marsh covers all-peat forming regions which are predominantly herbaceous. All marsh peats with their low lignin/cellulose ratio, are characterized by variable GI, but low (<1) TPI. The clastic marsh is characterized by high GI, but low TPI. The vitrinite content is higher than the inertinite, and the degraded vitrinite is greater than the structured vitrinite. The open marsh has a low GI and TPI. The inertinite content is higher than the vitrinite, and the inertodetrinite is greater than the structured inertinite. The wet forest swamp is characterized by the predominance of structured over unstructured vitrinite, and vitrinite over inertinite. The dry forest swamp has a consistently lower water table which allows for the concentration of inertinite through preferential destruction of humic material. The boundary between the environments is gradational.

In this study, the GI and TPI ratios for the coal samples are plotted in order to indicate relationship between coal facies indicators and environment of coal deposition.

Hunt, Brakel and Smyth (1986) described the petrographic composition of coal in terms of "semifusinite ratio" of inertinite and "vitrinite content" on mineral matter free basis. The semifusinite ratio is the ratio of structured (fusinite and semifusinite) to unstructured (inertodetrinite) inertinite. The vitrinite content includes exinite in coal. The semifusinite ratio is described as high (0.8-1.0), medium (0.6-0.8), low (0.4-0.6) and very low (0.0-0.4). The vitrinite content is described as high (0.6-1.0), medium (0.4-0.6) and low (0.0-0.4) as shown in Figure 3.14. The coal with low semifusinite ratio is interpreted to be deposited in a slightly oxidizing environment, and the high semifusinite ratio of coal is assumed to be formed in a highly oxidizing environment due to drying out of the peat surface. The low vitrinite content coal is interpreted to be deposited in an anaerobic condition, low subsidence and slightly wet environment, and the high vitrinite content coal is interpreted to be formed in an anaerobic condition, high subsidence and wet environment. In this study, the semifusinite ratios and the vitrinite contents of the coal are used to compare depositional environments of the Vasse Shelf with Irwin River and the Collie coals.

3.5.2.2. Microlithotype Analysis

A reflected-light microscope fitted with a 32x oil immersion objective was used to undertake microlithotype analysis of the coal. Like the maceral analysis, the coal was carefully crushed to minus 1 mm size and polished for the examination. The effective area observed on the polished surface of coal must be 50μ in each direction, as per ICCP (1963). The analysis was

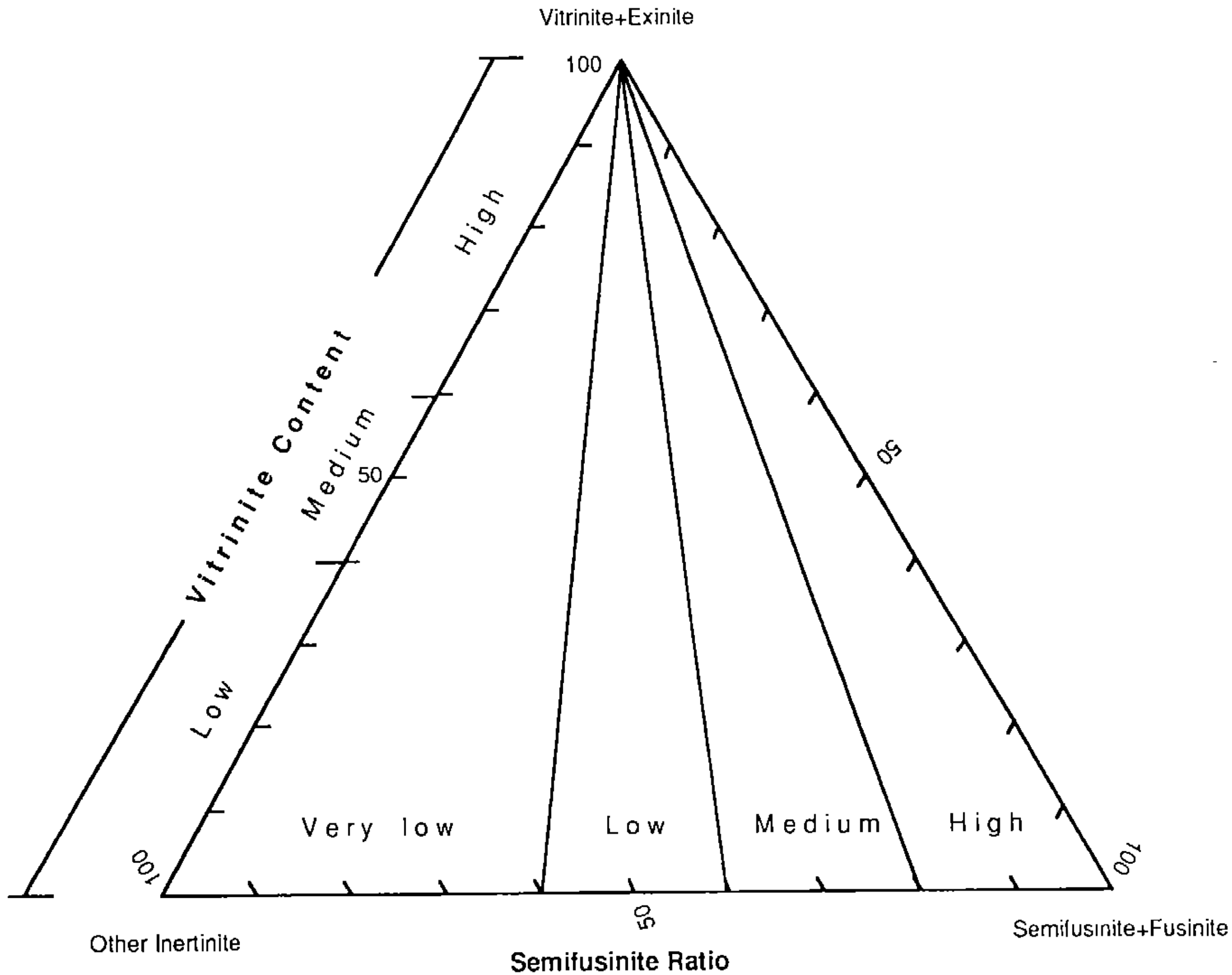


Figure 3.14. Maceral composition diagram showing 'vitrinite content' and 'semifusinite ratio' (Hunt, Brakel and Smyth, 1986).

based on counting of 500 points and traverses were made from top to the bottom, perpendicular to the settling direction of coal particulates in the polished blocks.

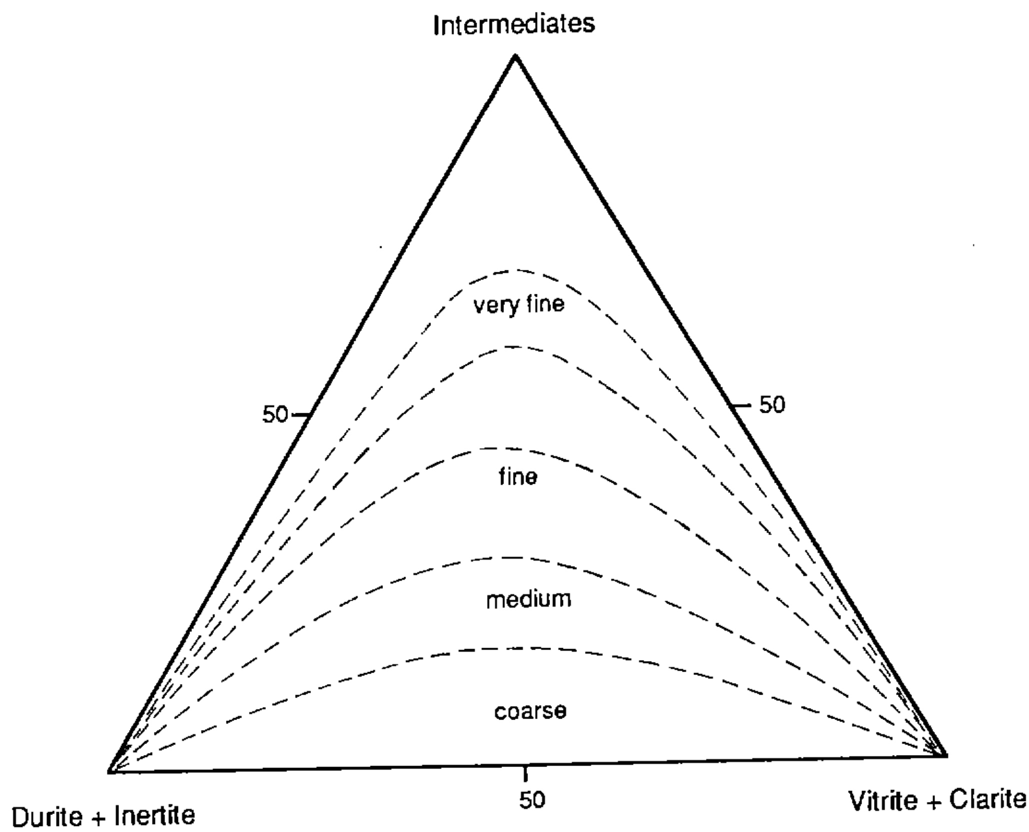
On the basis of the 500 point counts, volume percentage for each microlithotype was calculated. The data are expressed as percentage of monomaceral, bimaceral, trimaceral and carbominerite microlithotypes.

The microlithotype analysis for the interpretation of depositional environment of coal is described by Hunt and Hobday (1984) and Smyth (1979, 1989). Hunt and Hobday schemed a relationship between the microlithotype compositions and environmental types for coal formation on the basis of curves of relative bandwidth, as displayed in Figure 3.15. The microlithotype facies triangle is subdivided into:

. braided fluvial (alluvial fans) : medium banded
. meandering fluvial : very finely banded
. upper delta plain : finely banded
. lower delta plain : medium banded

Smyth (1979, 1989) reported that microlithotypes are related to the depositional environments prevailing at the time of peat accumulation and the microlithotype analyses are used in the interpretation of depositional environment of coal. Figure 3.16 shows the depositional environment of coal, namely:

. lacustrine (A): lower coastal plain, plus area dominated by coal swamps
. fluvial (B)
. brackish water (C): channel belt plus large lake
. upper deltaic (D): upper coastal plain



braided fluvial (alluvial fans)	: medium banded
meandering fluvial	: very finely banded
upper delta plain	: finely banded
lower delta plain	: medium banded

Figure 3.15. Bandwidth curves of microlithotype facies of coal (Hunt and Hobday, 1984).

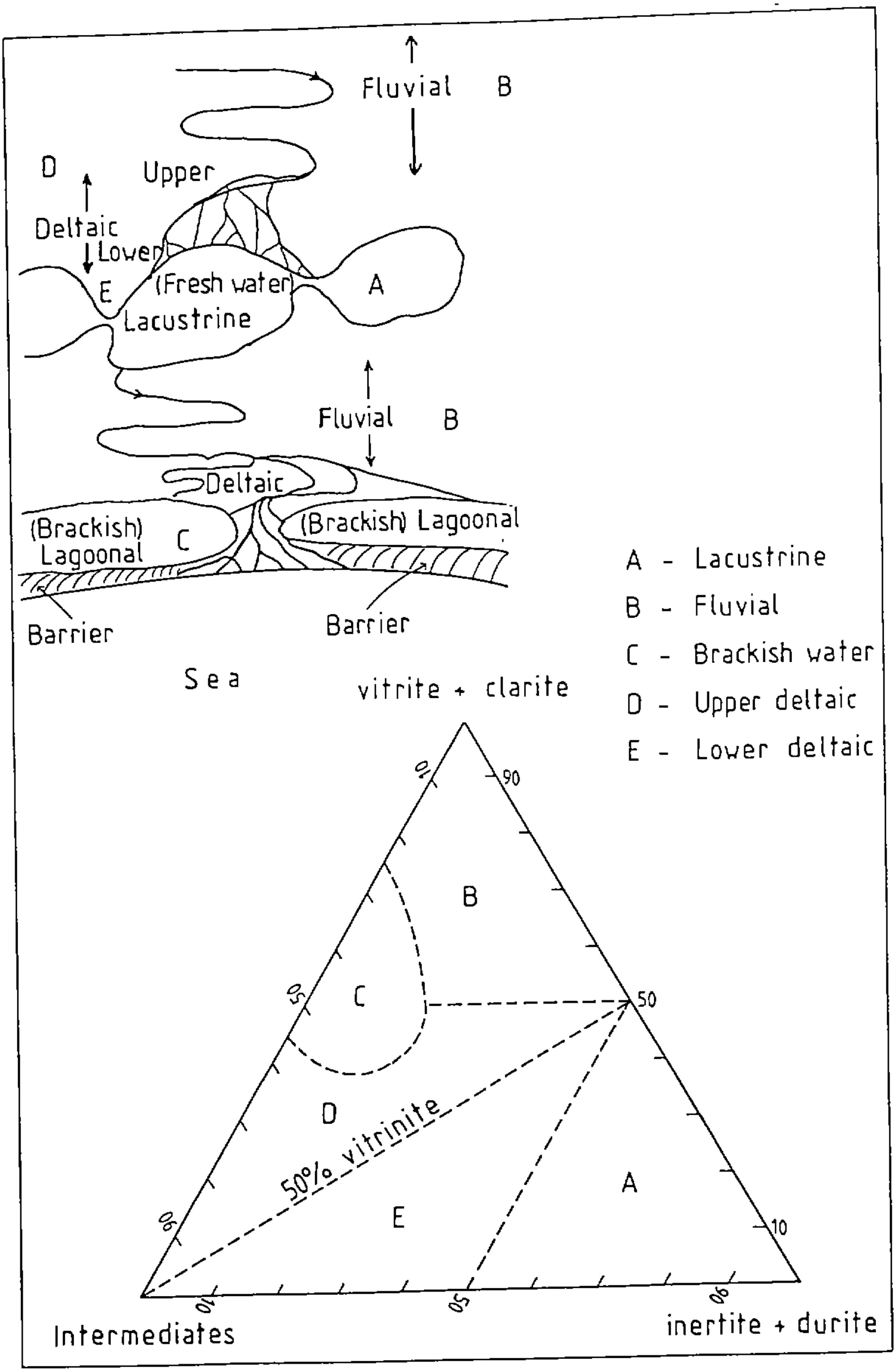


Figure 3.16. Environment of coal deposition related to microlithotype compositions (Smyth, 1979, 1989).

. *lower deltaic (E): area dominated by channel deposits, plus (minor) upper coastal plain*

For Australian Early Permian coals, braided fluvial environment is rich in vitrinite and vitrite, meandering river and upper coastal plain is inertite-rich and lower coastal plain is inertite and durite-rich. In the present study, the microlithotype analyses have been used to interpret depositional environments of the coals from the Vasse Shelf, Irwin Sub-basin and the Premier Sub-basin, described in chapter 8.

3.5.2.3. Reflectance Measurements

The measurements on vitrinite reflectance were carried out based on the Australian Standard As 2486-1981 Microscopical Determination of the Reflectance of Coal Macerals. The polished blocks containing vitrinite free from scratches were selected for the measurements.

The vitrinite reflectance measurements were undertaken using a Leitz Orthoplan microscope fitted with a Leitz MPV photometer, a 32x oil immersion objective and x10 eyepieces, as shown in Figure 3.9. The photometer was calibrated against a set of glass standards ranging in reflectance from 0.32% to 1.67%. A standard of 0.576% reflectance was used for calibration. Random (ROrnd) and maximum (ROmax) reflectance measurements were performed using reflected light. The ROrnd measurements were undertaken using non-polarized light, whilst the ROmax were made using polarized light, in which the polarizer was set at 45° and a Berek prism was used, Australian Standard 2486 (1981).

A 100 measurements were obtained on each sample from which the mean

ROrnd and the standard deviation (s) were calculated. In addition, a total of 30 measurements were taken on each sample from which the mean ROmax and deviation (s) were also calculated. The ROmax can also be calculated using the formula as described by Diessel (1982 b) :

ROmax = ROrnd x 1.07 - 0.01

ROmax - mean maximum reflectance in oil

ROrnd - mean random reflectance in oil

In the present study, the ROmax was calculated from the mean of the 30 measurements of maximum reflectance on vitrinite of the coal samples.

3.5.2.4. Scanning Electron Microscopy (SEM)

In the present work, coal samples were selected for qualitative examination of macerals and mineral matter using the SEM Jeol 4000. The examinations were performed at the Electron Microscopy Centre, a joint facility of Curtin University of Technology, Murdoch University and the University of Western Australia, Perth, Western Australia. The polished blocks prepared for the SEM examination were the same as that for the reflected light microscopy. The SEM analysis on selected polished blocks was focused on examining clay minerals, pyrite and quartz, to supplement optical microscopy.

The SEM supplemented by x-ray analysis is currently a routine procedure for the examination of coal samples. The instrument is analogous to an optical microscope and the electron source is equivalent to the light source and the glass lenses are replaced by electromagnetic lenses. Measurements from the samples are collected and displayed on a viewing screen for visual interpretation, Griffin and van Riessen (1991). The SEM consists of two modes of imaging, namely secondary electron (SE) and backscatter (BS) modes. The SE mode essentially relates to surface topography. The BS mode is useful, because it responds to average atomic number of density, and thus is related to mineral matter composition. The most important component in SEM is the accelerating voltage. For the BS mode, contrast increases with accelerating voltages (15-20 kV) and for the SE mode, better images are obtained at lower accelerating voltage (less than 15 kV).

For SEM examination, the coal samples were polished carefully with respect to surface relief, and too much relief was avoided because strong topography can affect the BS image at high magnification. The samples were coated by carbon or gold. A coating of carbon, as thin as possible, is necessary for best results for the BS image, because carbon is the best coating material for BS work due to its low atomic number. Gold is ideal for SE work because of its high atomic number, so it is useful for highlighting surface relief. Table 3.5 shows the identification of macerals and mineral matter using the SEM as described by Hamilton and Salehi (1986).

3.5.2.5. Trace Element Analysis

Twenty-nine coal samples were selected for trace element analysis in order to establish distribution of trace elements and their association with organic and inorganic component of the coal. In this study, the trace elements are used in the interpretation of the depositional environment of the coal. The trace elements determined in the coal are *B, Be, Co, Cr, Cu, Ga, Ge, Mn, Mo, Ni, Pb, Sb, Sn, Sr, Ti, U, V, Zn and Zr.*

MACERAL GROUP	MACERAL	MORPHOLOGY	BS GREY LEVEL	POLISHING RELIEF IN SE MODE
Vitrinite	desmocollinite	groundmass	intermediate	low
	telocollinite	distinct layers	intermediate	low
	gelocollinite	distinct ovoid boundaries, structureless	low-intermediate	low
Inertinite	fusinite	cell structure	bright-intermediate	very high
	semifusinite	cell structure	bright-intermediate	high
	macrinite	structureless, but with disticnt boundaries	bright-intermediate	high
	inertodetrinite	fragmental	bright-intermediate	high
	sclerotinite	fungal structure	bright-intermediate	high
Exinite	sporinite	spore shaped (ovoid to lenticular with central cavity)	low	high
	cutinite	elongated, laminar or serriate	low	high
	resinite	mainly ovoid, homogenous	low	moderate
	alginite	ovoid and inhomogenous	low	moderate to low
	exsudatinite	secondary cavity filling	low	low
Mineral Matter	–	varied	very bright	moderate to very high

Tabel 3.5. Identification of macerals and mineral matter using SEM (Hamilton and Salehi, 1986).

The samples for trace element analysis were ground to pass through a 250 μ sieve and ashed at 815° C in an electric furnace with controlled flow of air for oxidation. The ashes obtained from individual samples were sent to ANALABS for the trace element analyses. The Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES), the Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) and the X-ray Fluorescence Spectroscopy (XRF) techniques were used for the analysis.

CHAPTER 4. PETROLOGY OF COAL

4.1. Introduction

Coal is a heterogenous sedimentary rock characterized by many variations in its petrological, chemical and physical properties, and consists of various organic and inorganic constituents. The heterogenous nature of coal is macroscopically visible in terms of bright and dull bands, and details of these are only seen by microscopic examination under high magnifications. The petrographic analyses in terms of lithotypes, macerals and microlithotypes and mineral matter were completed on the coal, which are presented in this chapter. For interest of presentation and interpretation, the petrographic data are included in the text. The details of the mineral matter present in the coal are described in chapter 5.

The analyses were completed on coal from the sixteen seams of the Vasse Shelf area. The samples were supplied by CRAE from the five drill holes designated as: RBCH 5, RBCH 6, RB 3, CRCH 1 and CRCH 2. The locations of the drill holes are shown in Figure 3.1 (page 27).

The analyses were also completed on additional coal samples from Premier Sub-basin (Collie Basin) and the Irwin Sub-basin, supplied by Griffin Coal Mining Company Limited and the Geological Survey of Western Australia, respectively. The Collie coal samples were obtained from five drill holes labelled as: BUC 212, BUC 213, BUC 214, BUC 215 and BUC 217. The locations of the drill holes are given in Figure 3.2 (page 28). The coal samples from the Irwin Sub-basin were from the drill hole IRCH 1 located in the central part of the sub-basin (Figure 3.3, page 29).

4.2. The Vasse Shelf Coal

The coal samples for the analyses are from the seams A, B, C, D, E, F, G, H, I, J, K, L, M, N, O and P of the above mentioned five drill holes as shown in Figure 4.1. Thickness of the individual seams varies between 0.16 m to 1.95 m. The coal samples for petrology from a number of other seams of the shelf were unavailable, because of their prior removal for chemical analyses.

4.2.1. Lithotypes

The Vasse Shelf coal is finely banded and according to the terminology of Stopes (1919), the dominant proportion of the coal could be classified as clarain and durain. However, the terminology adopted in the present study is the one modified for Australian Permian coals, as given in Figure 3.4 (page 31). According to this terminology, the coal is of dull and dull banded lithotypes, with minor bright banded, banded and bright lithotypes.

A lithotype log provides a very useful basis for sampling and description of vertical variations in a seam. Furthermore, it can assist in seam correlation and elucidates lateral and vertical variations. It can also serve as a basis for an interpretation of the succession of mire conditions during formation of the seam.

4.2.1.1. Lithotype Profiles

The coal samples obtained from drill hole cores were individually logged in terms of lithotypes and partings of clastic bands. A lithotype profile was prepared from the lithotype log for each seam. The lithotype profiles for the

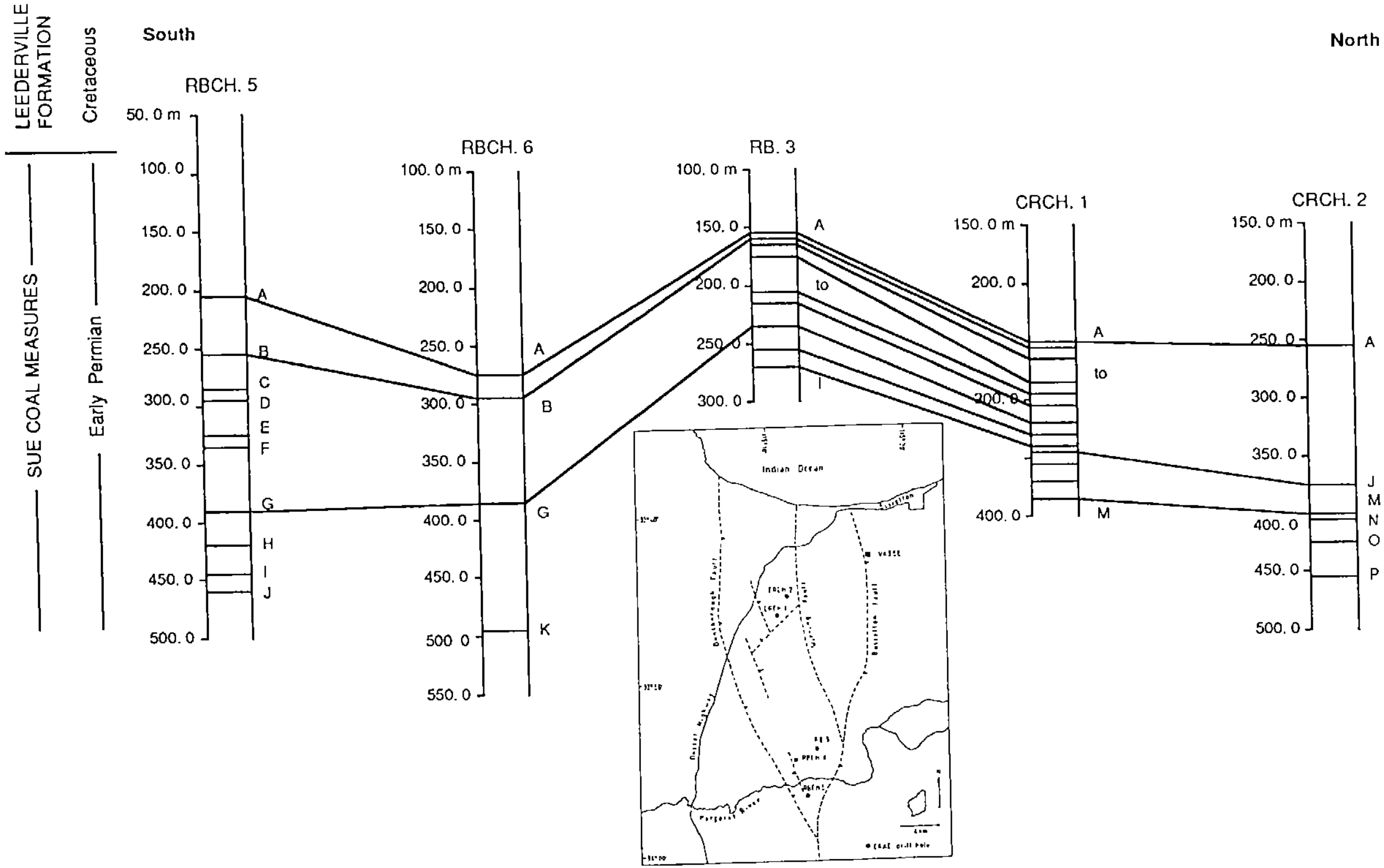


Figure 4.1. Stratigraphic succession of the coal seams, Vasse Shell, Perth Basin, Western Australia (after CRAE, 1984). Details of the lithology logs are in Appendix I.1.

individual seams are shown in Appendix I.2.

The formation of various lithotypes is mainly a result of the different rates of subsidence of swamp and peat growth. Fusain is formed at low rates of subsidence and under shallow water cover with frequent access to air. Bright and bright banded coals are indicative of flooding but only to a comparatively shallow depth. Dull coal is formed under somewhat deeper water cover. The formation of carbonaceous shale and shale requires complete submergence and wet conditions. Tasch (1960) related lithotypes to wet and dry conditions reflecting differing subsidence rates and fluctuating water table, with fusain representing the driest conditions and durain the wettest. The sequence of the conditions is as follows :

Dry *Fusain*
Bright coal and bright banded coal
Banded coal
Dull banded coal and dull coal
Carbonaceous shale
Wet *Inorganic sediments*

The lithotype profiles give information about frequency of small scale changes in the water table which occurred during the peat deposition. The thickness of individual lithotypes indicates the relative duration of either the submergence or emergence of the peat. This is in response to tectonic events, differential compaction and building up and breaking of banks and bars or other sedimentological control.

An example of a lithotype profile is given in Figure 4.2 for the G seam of the drill hole CRCH 1. The profile clearly shows an abundance of the dull and

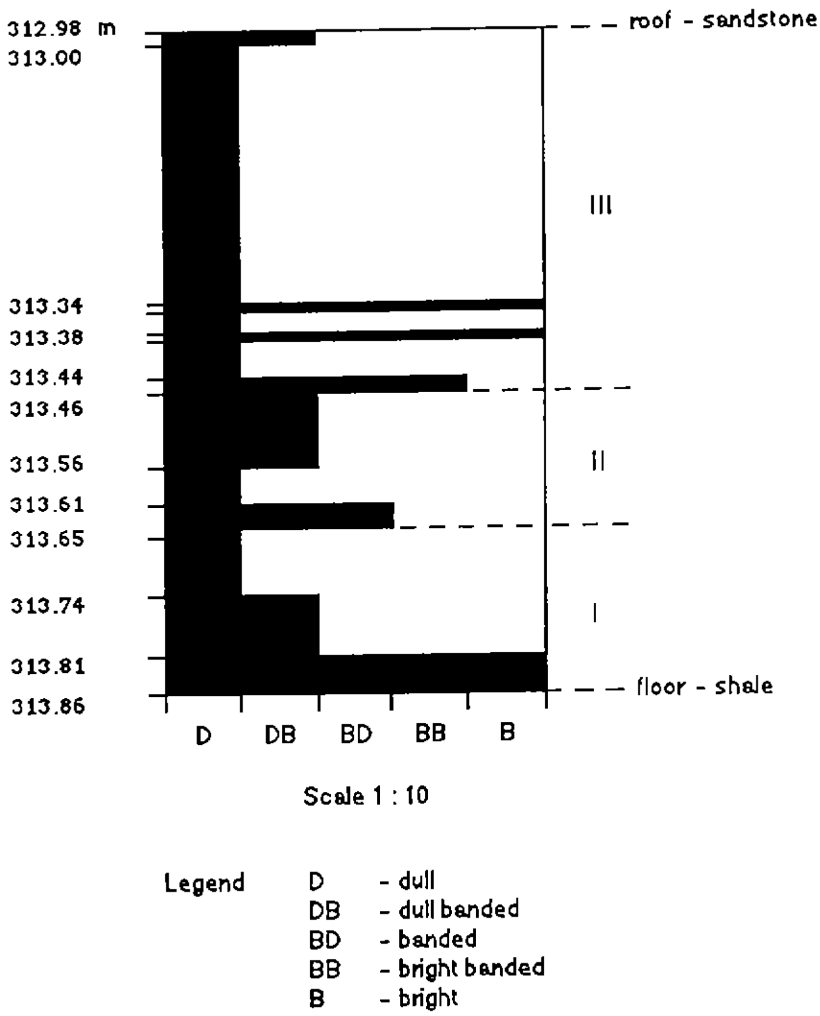


Figure 4.2. Lithotype profile of seam G, CRCH 1, Vasse Shelf, Western Australia.

dull banded lithotypes, with minor bright, banded and bright banded lithotypes. There is a transition of bright and dull banded lithotypes upward into dull lithotype (313.86 m to 313.65 m), and thus representing a transition of dry condition to relatively wetter condition. Somewhat similar trend is repeated three times in the G seam. This characteristic is also evident in other seams of the shelf, as shown in Appendix I.2.

4.2.1.2. Lithotype Variation

The proportions of lithotypes vary from seam to seam and drill hole to drill hole, as given in Table 4.1 which includes the percentages of the aggregate thickness of each lithotype and clastic parting, calculated on their proportions. The lithotype content of the individual seams is also depicted in Figures 4.3.a and 4.3.b.

The coal is predominantly composed of dull lithotypes. The seams B, C and I (RBCH 5), seams A and K (RBCH 6), seams B, E, F, G, H and I (RB 3), seams B, C, G, H, J and L (CRCH 1) and the seams J and N (CRCH 2) contain more than 50% of dull lithotypes. More than 50% dull banded lithotype is present in seam B (RBCH 6), seams A, D, F and K (CRCH 1) and the seam P (CRCH 2). The banded, bright banded and bright lithotypes are less than 50% in all the seams, with the exception of seam M (CRCH 1) and seam G (RBCH 5) which contain 78.3% and 53.6% of bright banded lithotypes respectively.

The lithotypes content of the coal suggest that in general:

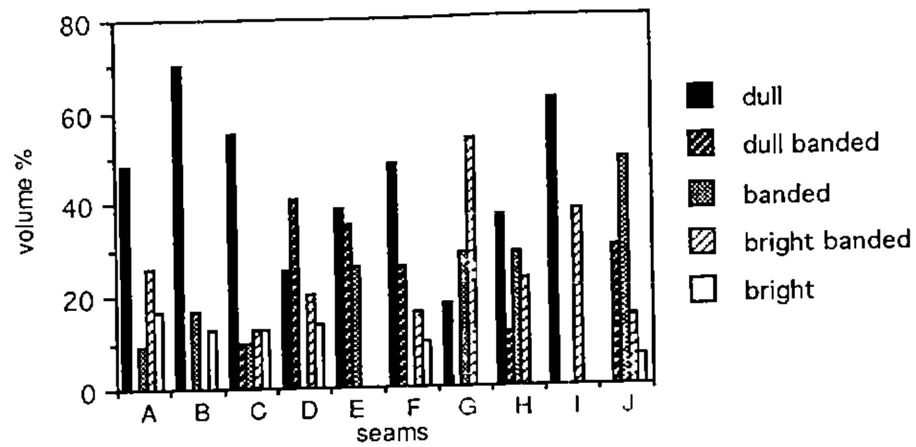
.The oscillations of dull and dull banded lithotypes with bright banded, banded and bright lithotypes were caused by the changes in the water table during the deposition of the peat in Early Permian time.

DRILL HOLES	SEAMS	THICKNESS (m)	CARBONACEOUS SHALE	DULL	DULL BANDED	BANDED	BRIGHT BANDED	BRIGHT
RBCH 5	A	0.54	–	48.1	–	9.3	25.9	16.7
	B	0.78	–	70.5	–	16.7	–	12.8
	C	0.40	–	55.0	10.0	10.0	12.5	12.5
	D	0.59	–	25.4	40.7	–	20.3	13.6
	E	0.85	–	38.8	35.3	25.9	–	–
	F	1.04	–	48.1	26.0	–	16.4	9.6
	G	0.28	–	17.9	–	28.6	53.6	–
	H	0.35	–	37.1	11.4	28.6	22.9	–
	I	0.45	–	62.2	–	–	37.8	–
	J	0.47	–	–	29.8	48.9	14.9	6.4
RBCH 6	A	0.67	–	85.1	4.5	–	–	10.5
	B	0.34	–	23.5	61.8	8.8	–	5.9
	G	0.22	–	22.7	45.5	31.8	–	–
	K	0.28	–	82.1	–	17.9	–	–
RB 3	A	0.18	–	16.7	38.9	16.7	–	27.8
	B	0.16	–	68.8	12.5	12.5	–	6.3
	C	0.60	–	23.3	41.7	11.7	20.0	3.3
	D	0.16	–	12.5	43.8	–	37.5	6.3
	E	1.00	–	54.0	5.0	39.0	–	2.0
	F	0.19	–	57.9	36.8	–	–	5.3
	G	0.98	17.4	63.3	6.1	2.0	5.1	6.1
	H	0.32	–	84.4	–	9.4	3.1	3.1
	I	1.95	–	82.1	4.6	7.2	2.1	4.1

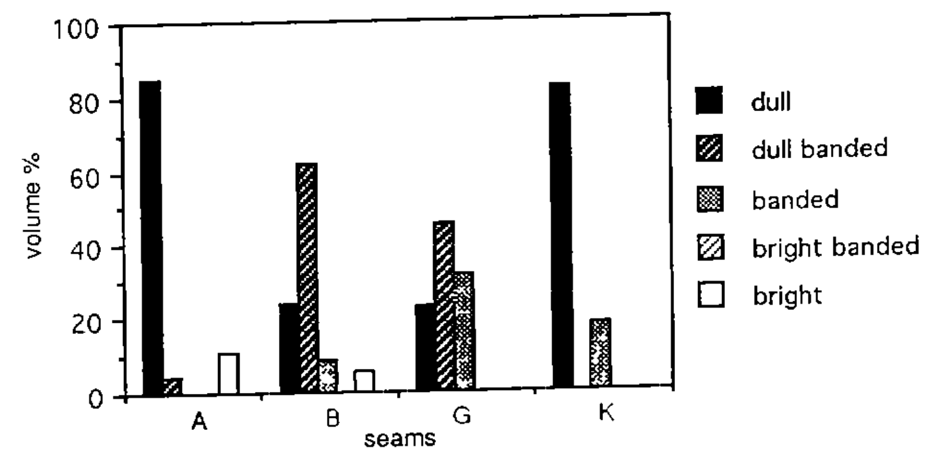
Table 4.1. Lithotype content (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.

DRILL HOLES	SEAMS	THICKNESS (m)	CARBONACEOUS SHALE	DULL	DULL BANDED	BANDED	BRIGHT BANDED	BRIGHT
CRCH 1	A	0.30	–	–	98.3	–	1.7	–
	B	0.35	–	96.3	–	–	3.7	–
	C	0.41	–	95.1	4.9	–	–	–
	D	0.41	–	22.0	56.1	–	22.0	–
	E	0.32	–	43.8	40.6	–	15.6	–
	F	0.90	–	12.2	53.3	–	21.1	13.3
	G	0.88	–	63.6	21 6	4.5	2.3	8.0
	H	1.00	–	58.0	37.0	–	4.0	1.0
	I	0.64	–	37.5	7.8	6.3	28 1	20.3
	J	0.80	–	81.3	5.0	13 8	–	–
	K	0.36	–	–	55.6	–	–	44 5
	L	0.95	–	54.7	32.6	–	6.3	6 3
	M	0.23	–	–	–	21.7	78.3	–
CRCH 2	A	0.26	–	–	42.3	23.1	19.2	15.4
	J	0.25	–	100 0	–	–	–	–
	M	0.22	–	40.9	22.7	27.3	–	9.1
	N	0.30	33.3	66.7	–	–	–	-
	O	0.25	–	28.0	24.0	28 0	20.0	–
	P	0.45	–	37.8	62.2	–	–	–

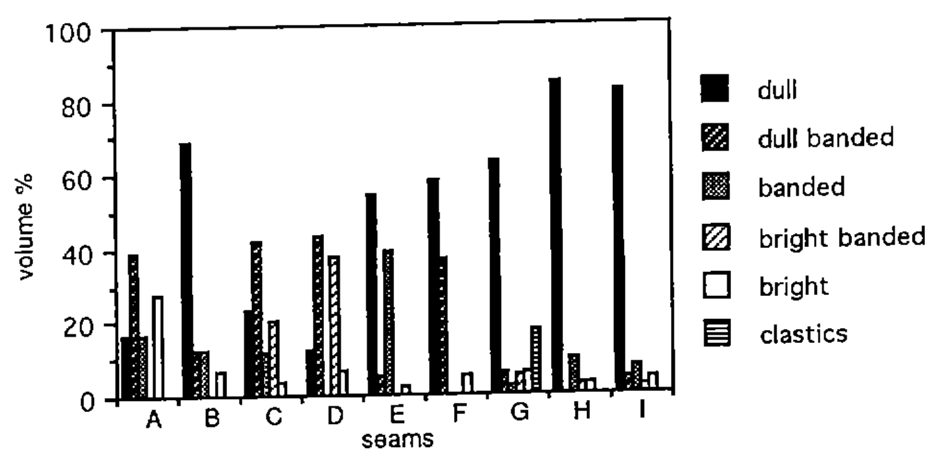
Table 4.1. Lithotype content (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.



Lithotype distribution, RBCH 5

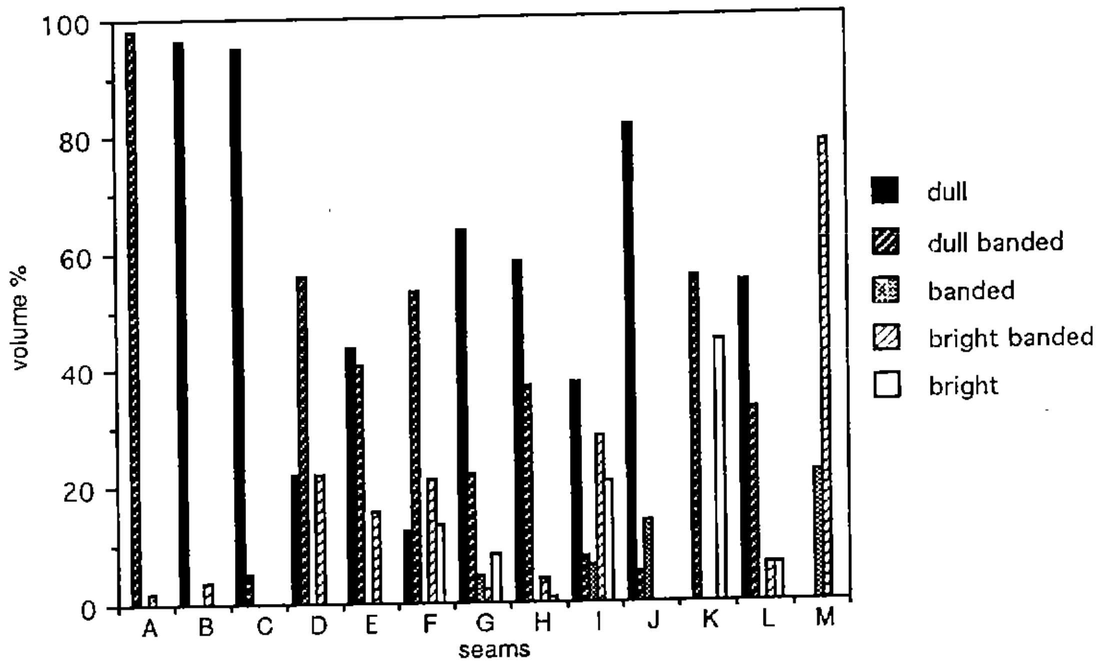


Lithotype distribution, RBCH 6

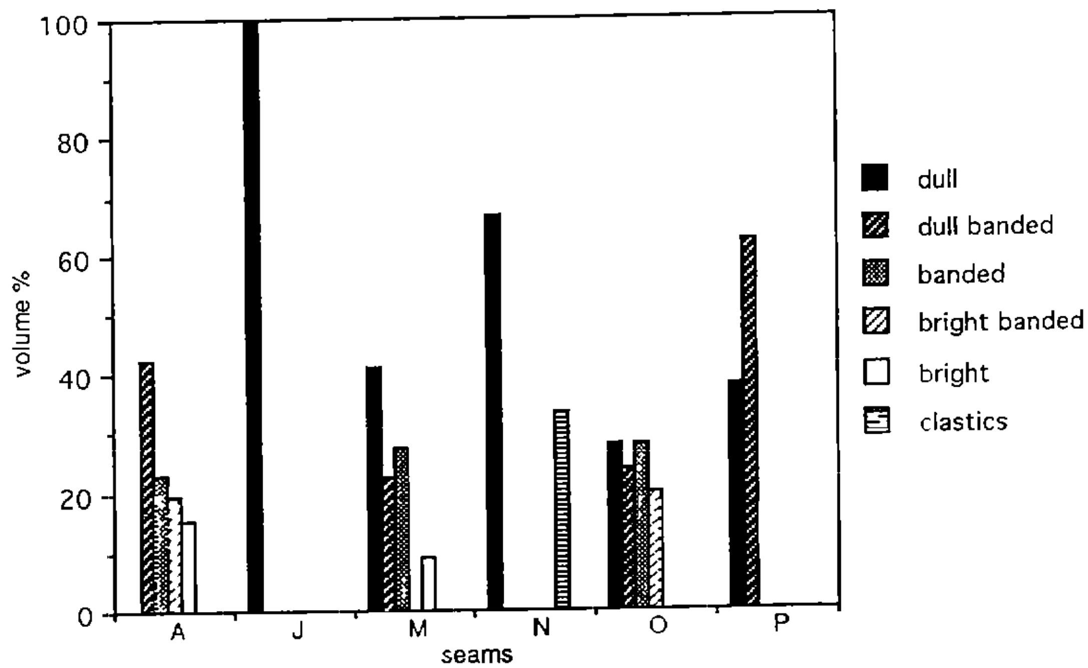


Lithotype and clastics distribution, RB 3

Figure 4.3.a. Lithotype and clastics distribution of the Vasse Shelf coal, drill holes RBCH 5, RBCH 6 and RB 3.



Lithotype distribution, CRCH 1



Lithotype and clastics distribution, CRCH 2

Figure 4.3.b. Lithotype and clastics distribution of the Vasse Shelf coal, drill holes CRCH 1 and CRCH 2.

.The formation of various lithotypes was mainly a result of the different rates of subsidence of the swamp and peat growth.

.The abundance of dull coals was formed under deeper water cover, and the bright coals were indicative of flooding, but only to a comparatively shallow water.

. The presence of carbonaceous shale suggests the peat was formed in wet conditions with fluctuating water table and in complete submergence.

The lateral variation of lithotypes in the Vasse Shelf coal can be observed within seams A to P from drill holes RBCH 5, RBCH 6, RB 3, CRCH 1 and CRCH 2, in south to north direction, as shown in Figure 4.4. In general, the dull and dull banded lithotypes predominate in all seams, however, there is a deviation occurring in seam M of CRCH 1, which is dominated by the bright banded lithotype, and this suggests that an increasing water table occurred during the deposition of the seam. The clastic partings occur in seams G of RB 3 and N of CRCH 2, and this reflects that the coal was formed under wetter conditions and complete submergence during its deposition. In the seams A to C, the lateral variation of lithotype content shows a marked trend which displays that the duller lithotype content increase to north (CRCH 1 and CRCH 2), which suggests that a decreasing water table occurred to north during the deposition of the seams. In the seams D to F, the lateral variation of lithotype content does not show a marked trend, the variation pattern is similar from south to north , which indicates that the deposition in all drill holes locations had similar conditions. Within the seams G and H, a marked trend occurs similar to the seams A to C, the duller lithotype content increase to the north (RB 3 and CRCH 1). It reflects that the water table increased to the north. However, in RB 3, clastic partings occur in the seam G, suggests the coal was formed in a complete submergence and wettest environment. In the seam I, the duller

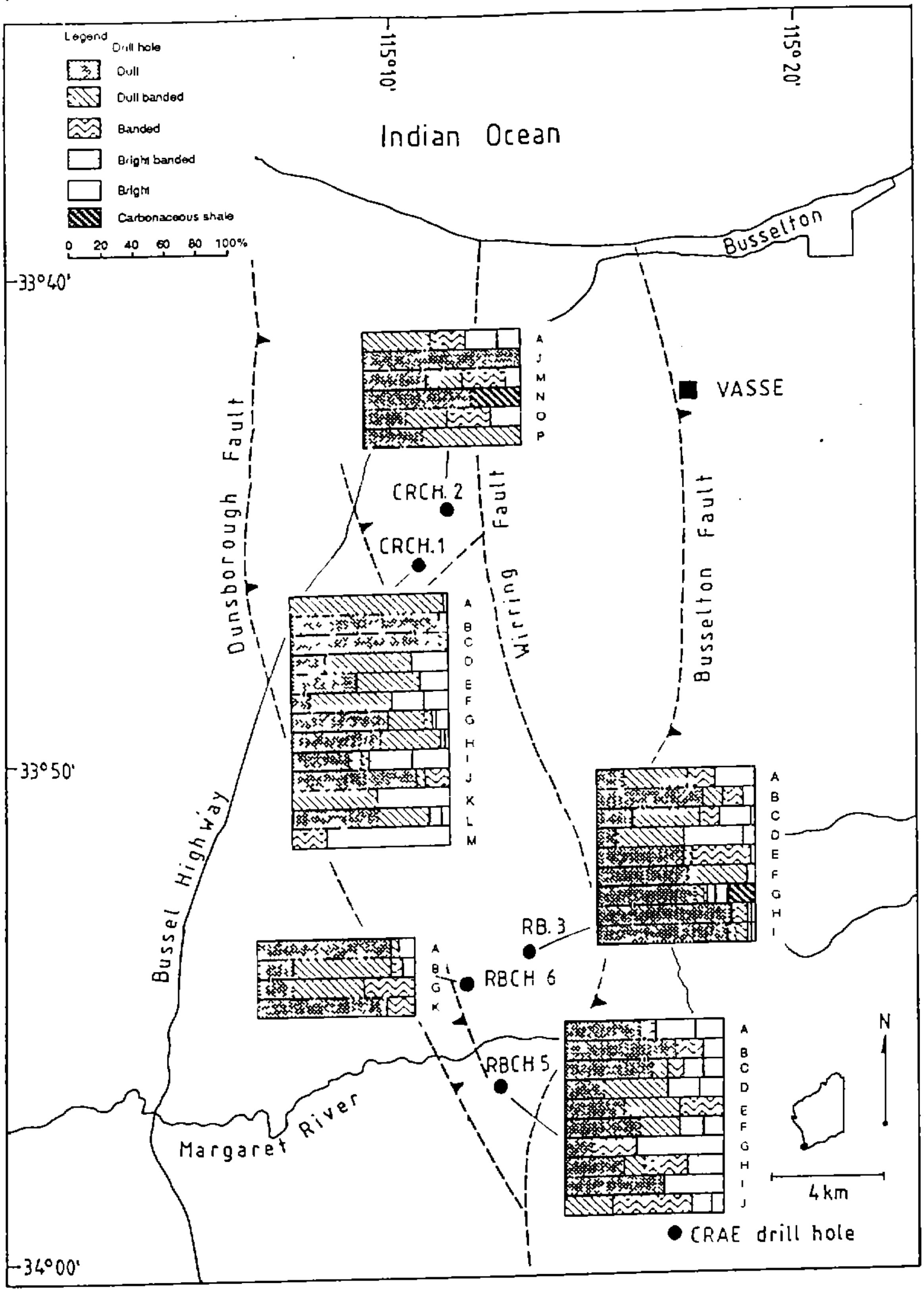


Figure 4.4. Variations of lithotypes of the Vasse Shelf coal, Perth Basin, Western Australia.

lithotype content is highest in RB 3 and lower in south (RBCH 5) and the north (CRCH 1) areas. This indicates that the coal in RB 3 was formed in the wettest environment. Within the seam J, the duller lithotype content increases to north areas (CRCH 1 and CRCH 2), and this indicates that an increasing water table occurred in the north areas. The duller lithotype content decreases to north (CRCH 1) within the seam K, and this suggests an increasing water table occurred in the south area (RBCH 6). The seam M of CRCH 1 is characterized by a high bright lithotype content which reflects that the coal was indicative of flooding, but only a comparatively shallow water. The seams L, N, O and P cannot be compared laterally due to their limited extent as coal lenses. In addition, the seam N of CRCH 2 contains clastic partings, which indicates that the coal was formed in a complete submergence and wettest environment. In summary, the coal in the northern area (CRCH 1, CRCH 2 and RB 3) was largely formed under wetter conditions and complete submergence with fluctuating water table, as compared with the southern area (RBCH 5 and RBCH 6).

4.2.2. Maceral Groups

As mentioned earlier, coal is heterogenous substance composed of organic and inorganic components. The microscopic organic entities of coal are described macerals derived from plant remains, which have undergone various degrees of decomposition in the peat swamps, and as well physical and chemical alteration after burial of plant material. Coal deposits are formed in peat swamp environments where different types of vegetation flourish. Evolution in the plant kingdom during geological time played an important part in the make-up of the plant source material in the swamps: which is reflected in the petrographic composition of coal. The detailed petrographic study of the Vasse Shelf coal was completed in this project, and the maceral groups and macerals identified in the coal are described, supported by the photomicrographs. The maceral groups present in the Vasse Shelf coal are given in Figure 4.5.

4.2.2.1. Vitrinite Group

The maceral group vitrinite identified in the Vasse Shelf coal consists mainly of desmocollinite and telocollinite, with minor vitrodetrinite, corpocollinite and telinite. The telocollinite and telinite are derived from xylem and cortex tissues, therefore indicating their origin from wood producing plants. Figures 4.6.a and 4.6.b show telocollinite and telinite filled with micrinite. The desmocollinite shows a thoroughly decomposed and gelified attritus of a variety of source materials. Figure 4.6.c shows desmocollinite associated with cutinite and inertodetrinite. The corpocollinite includes round or ovoid bodies which are homogeneous, massive, and similar to the surrounding vitrinite in reflectance. Corpocollinites are cell fillings and usually occur as isolated particles in a groundmass of desmocollinite as shown in Figure 4.6.d associated with desmocollinite and inertodetrinite. The vitrodetrinite occurs in the form of detritus. It mostly originates from plants or humic-peat particles which were degraded at an early stage.

4.2.2.2. Inertinite Group

The maceral group inertinite in the Vasse Shelf coal is mainly dominated by inertodetrinite, followed by fusinite and semifusinite, with minor micrinite, sclerotinite and macrinite. The macerals of the inertinite group are categorized as 'structured' and 'non-structured'. The structured macerals

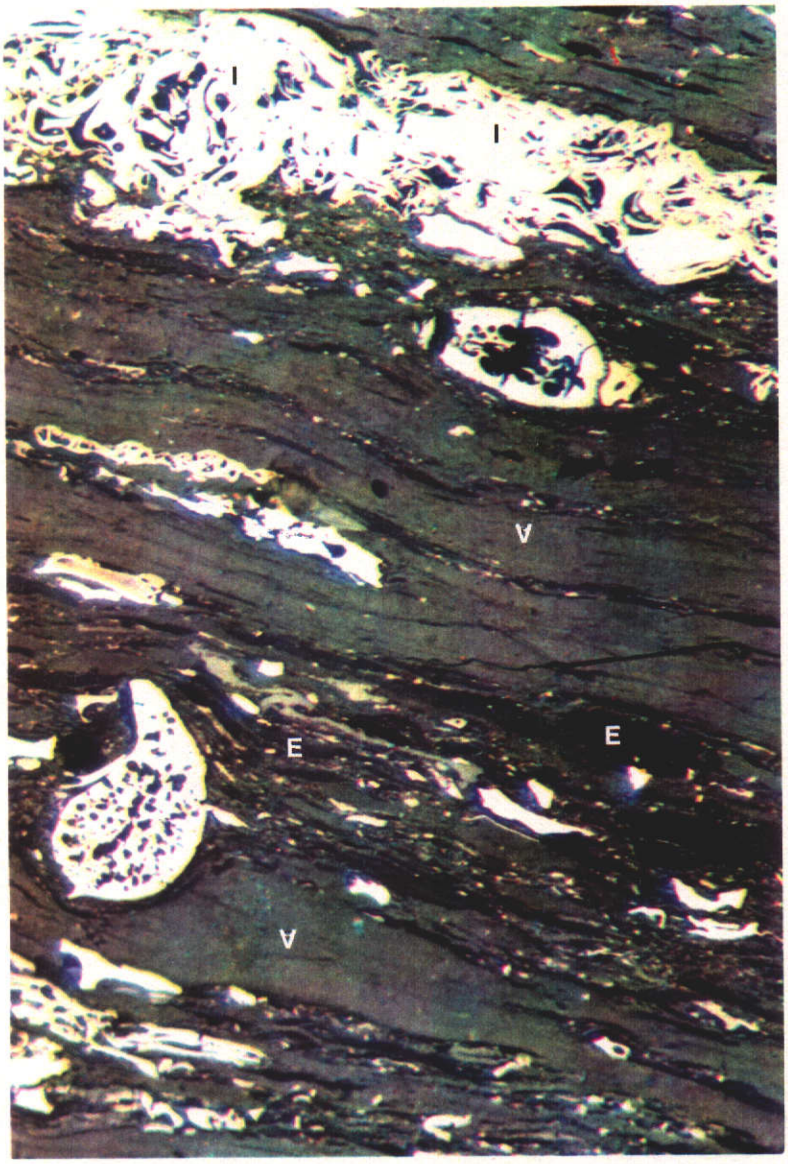
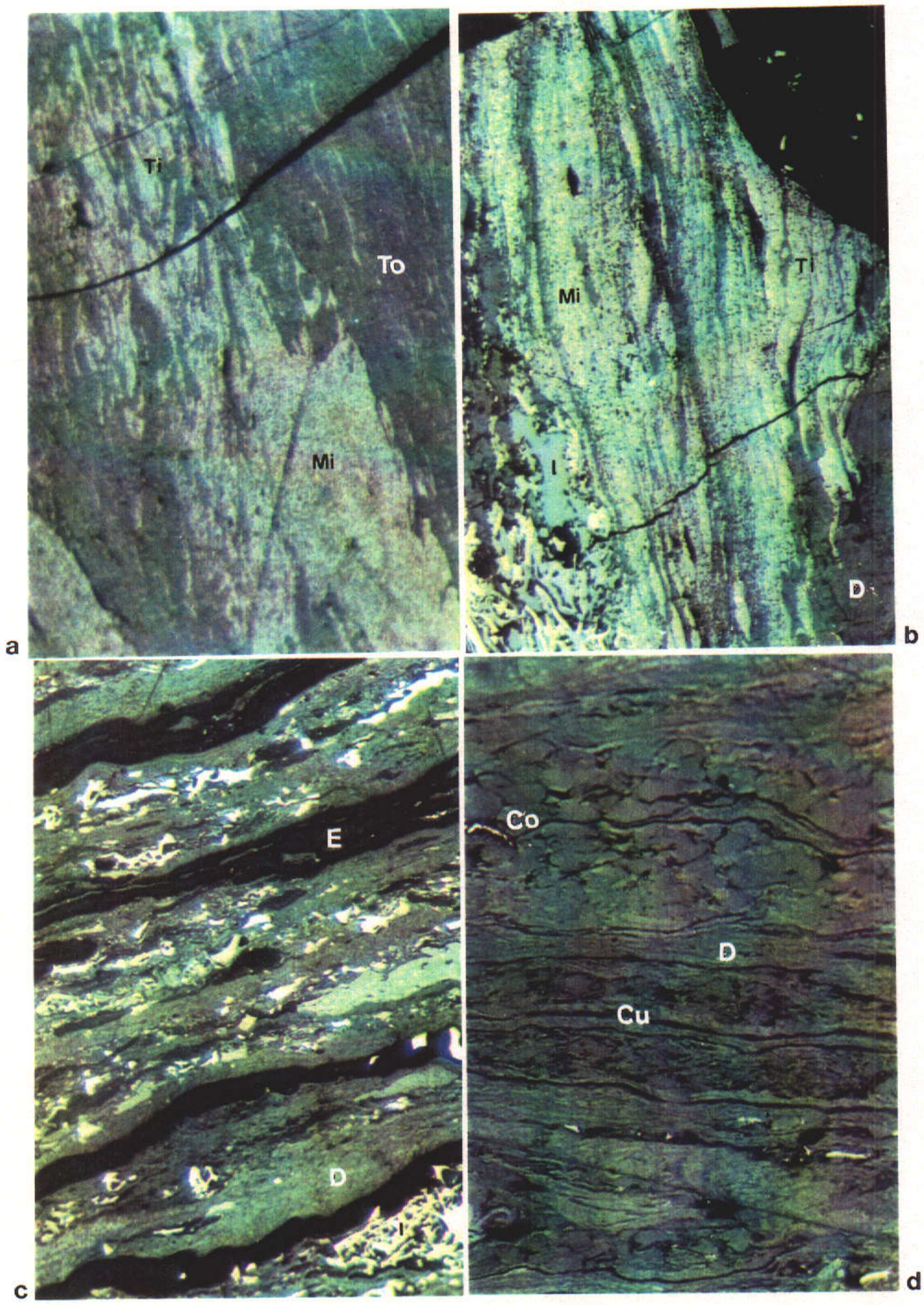


Figure 4.5. Maceral groups of the Vasse Shelf coal, vitrinite (V), inertinite (I) and exinite (E). B seam, IRCH 1, reflected light, oil immersion, x320.



Macerals of the vitrinite group, Vasse Shelf coal (reflected light, oil immersion, x320).

Figure 4.6.a. Telocollinite (To) and telinite (Ti) associated with micrinite (Mi). M seam, CRCH 1.

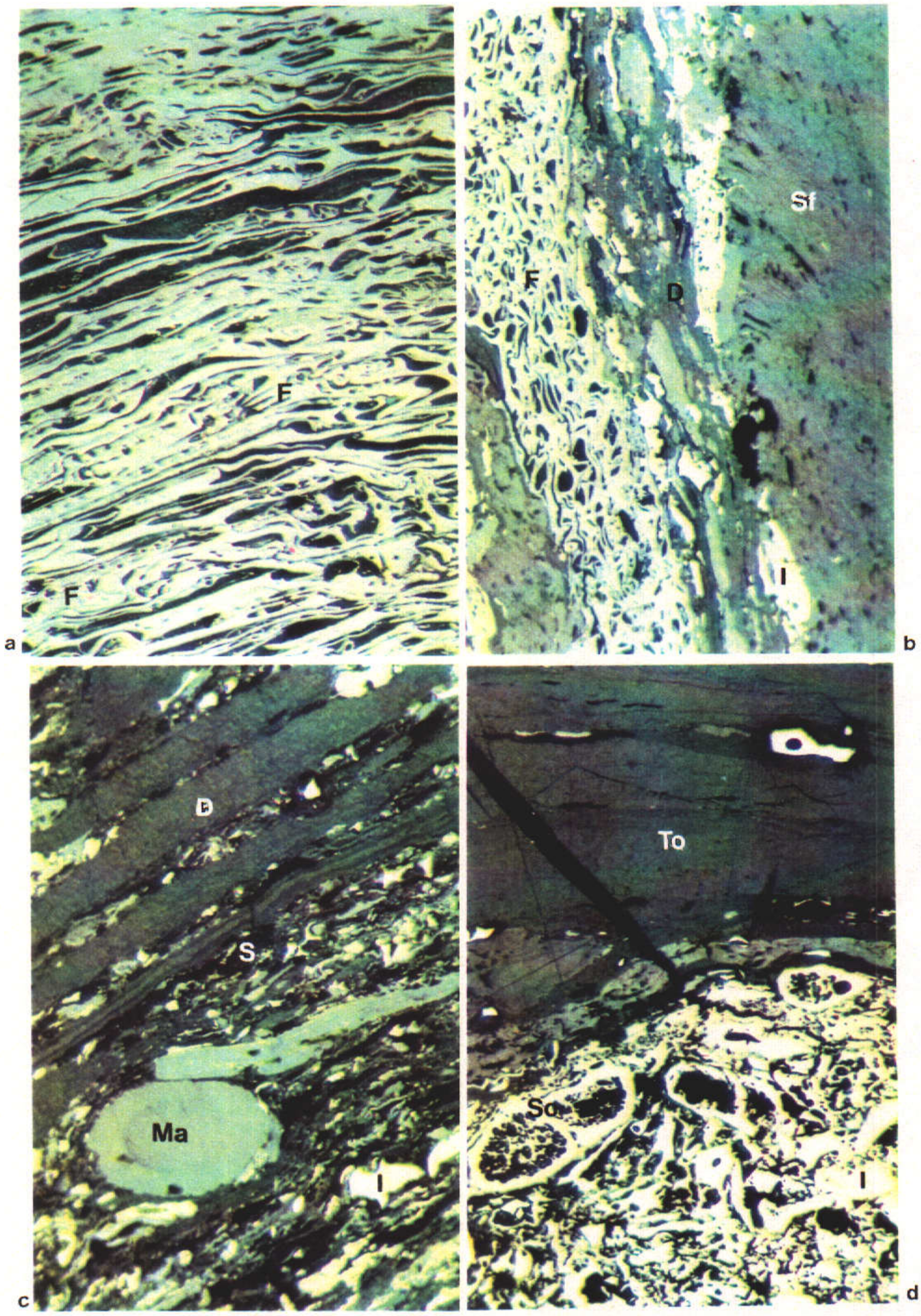
Figure 4.6.b. Telinite (Ti) associated with desmocollinite (D), inertodetrinite (I) and micrinite (Mi). F seam, RB 3.

Figure 4.6.c. Desmocollinite (D) associated with cutinite (Cu) and inertodetrinite (I). D seam, CRCH 1.

Figure 4.6.d. Corpocollinite (Co) associated with desmocollinite (D) and cutinite (Cu). K seam, RBCH 6.

consist of fusinite and semifusinite which are defined by the presence of botanical structure, and are considered to originate from lignin and cellulose of plants. According to Diessel (1982a), fusinite and semifusinite are commonly regarded as the products of terrestrial forest moors either by way of charcoal formation or as a result of attack on wood by fungi and bacteria under slightly oxidizing conditions. Figures 4.7.a and 4.7.b show cellular structure of fusinite with high reflectance of all macerals. The semifusinite shown in Figure 4.7.b is associated with fusinite and inertodetrinite.

The non-structured macerals comprise inertodetrinite, micrinite, sclerotinite, and macrinite as shown in Figures 4.7.c and 4.7.d. The inertodetrinite, the dominant inertinite in the Vasse Shelf coal is formed because of the physical breakdown of fusinite and semifusinite (Figures 4.8.a, 4.8.b, 4.8.c and 4.8.d), and it consists of fragmental cell walls. Although initially formed in dry terrestrial forest moor, it is transported and redeposited in a sub-aqueous environment, due to its frequent coexistence with sporinite and alginite. Figures 4.6.a and 4.6.b show micrinite which consists of grains of less than 1 μ associated with vitrinite. It is considered as a secondary maceral possibly formed from exinite source material and peatification of cell walls. The sclerotinite is generally considered to be fungal remains. Two specific forms of sclerotinite are recognized in the coal, one which consists of round or oval shaped bodies and the other consisting of plectenchyme tissue. The sclerotinite (oval shaped) is shown in Figure 4.7.d, associated with inertodetrinite and telocollinite. The macrinite occurs in the form of rounded bodies, elongated pieces and groundmass, and possesses practically no cellular structure as shown in Figure 4.7.c.



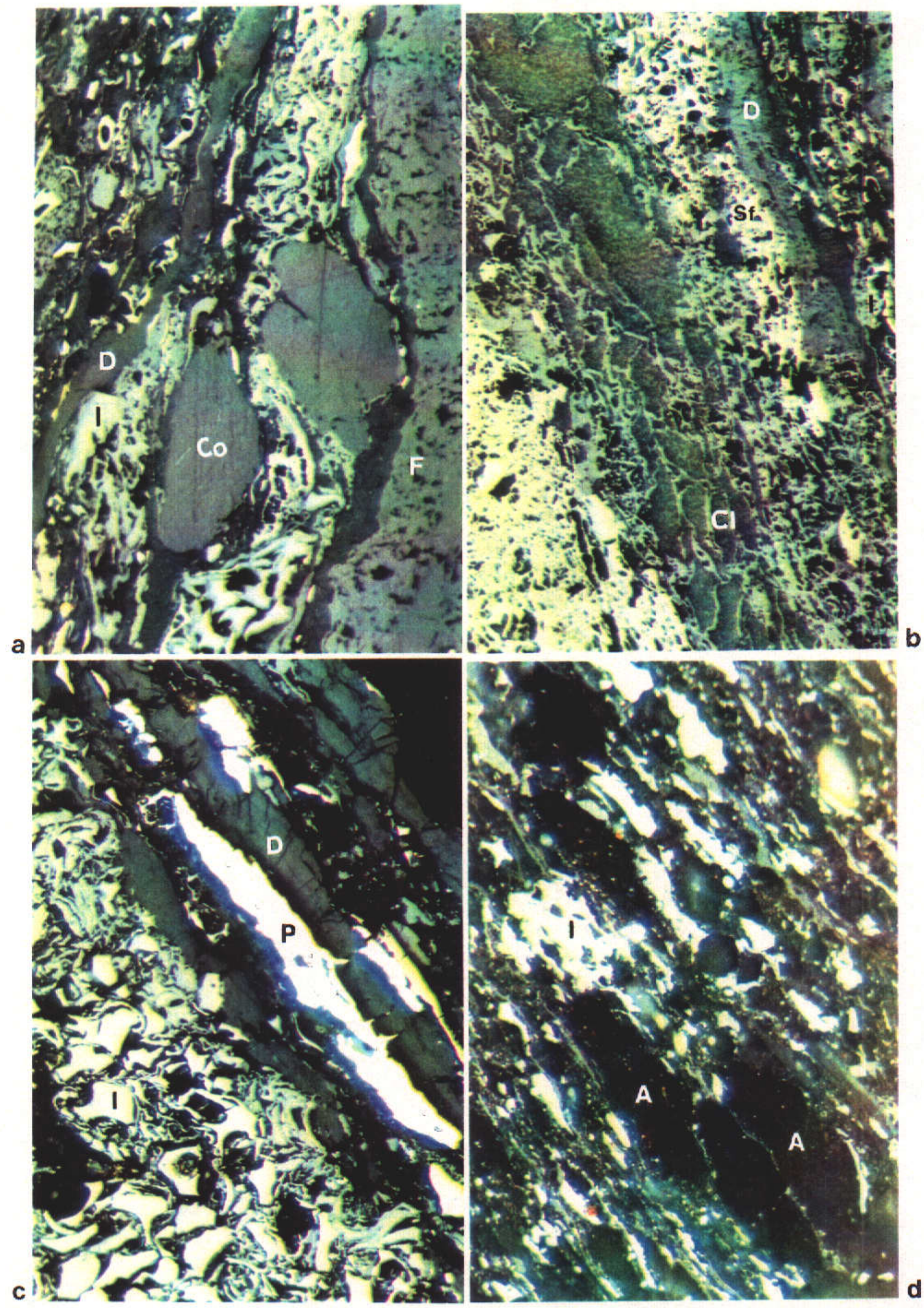
Macerals of the inertinite group, Vasse Shelf coal (reflected light, oil immersion, x320).

Figure 4.7.a. Fusinite (F) showing characteristic 'bogen structure'. H seam, RBCH 5.

Figure 4.7.b. Semifusinite (Sf) associated with fusinite (F), desmocollinite (D) and inertodetrinite (I). L seam, CRCH 1.

Figure 4.7.c. Macrinite (Ma) associated with desmocollinite (D), inertodetrinite (I) and sporinite (S). F seam, RB 3.

Figure 4.7.d. Sclerotinite (Sc) associated with inertodetrinite (I) and telocollinite (To). C seam, CRCH 1.



Macerals of the inertinite group, Vasse Shelf coal (reflected light, oil immersion, x320).

Figure 4.8.a. Inertodetrinite (I) associated with corpocollinite (Co), fusinite (F) and desmocollinite (D). A seam, RBCH 5.

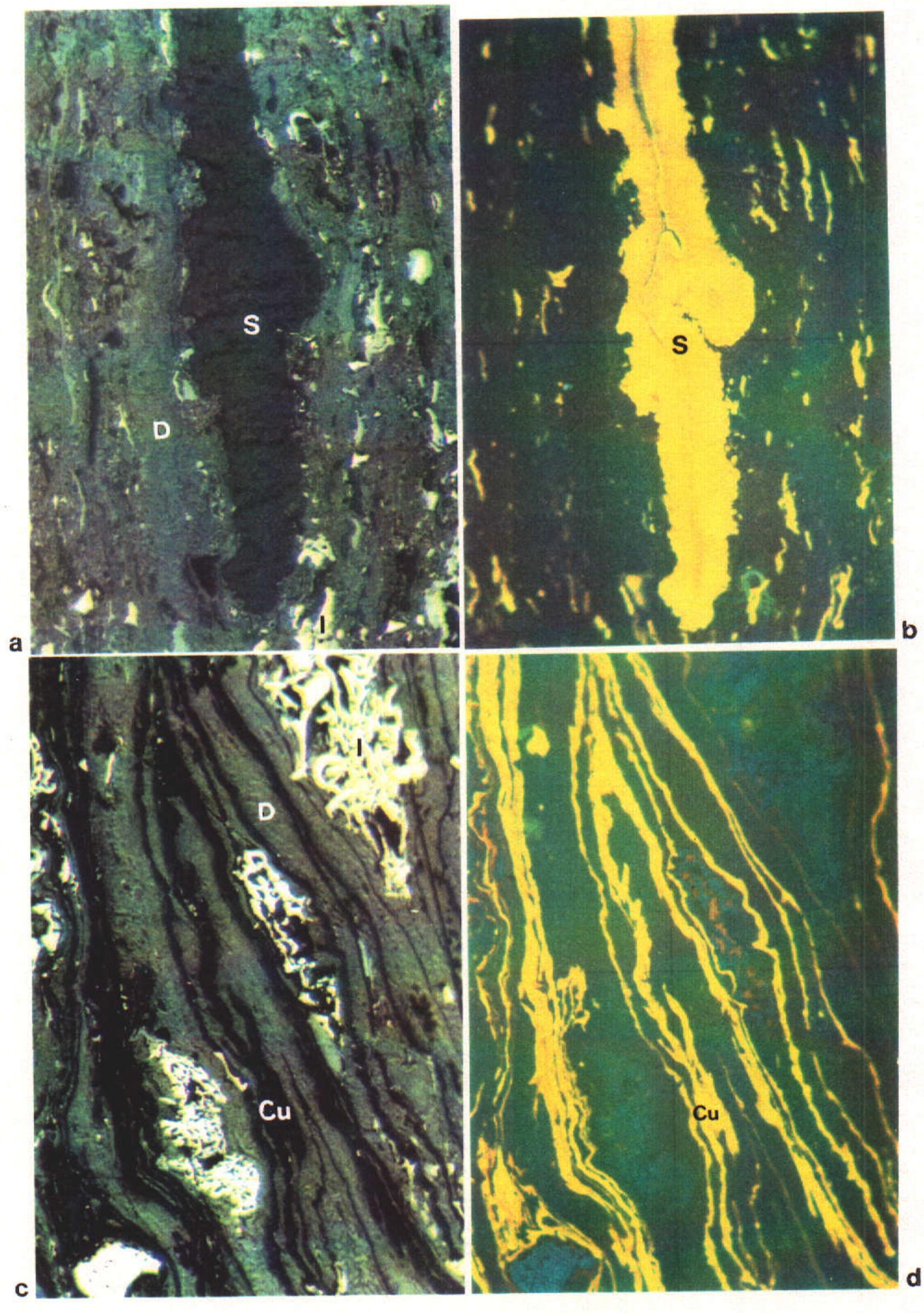
Figure 4.8.b. Inertodetrinite associated with desmocollinite (D), semifusinite (Sf) and clay (Cl). C seam, CRCH 1.

Figure 4.8.c. Inertodetrinite (I) associated with desmocollinite (D) and pyrite (P). M seam, CRCH 2.

Figure 4.8.d. Inertodetrinite (I) associated with alginite (A). J seam, CRCH 2.

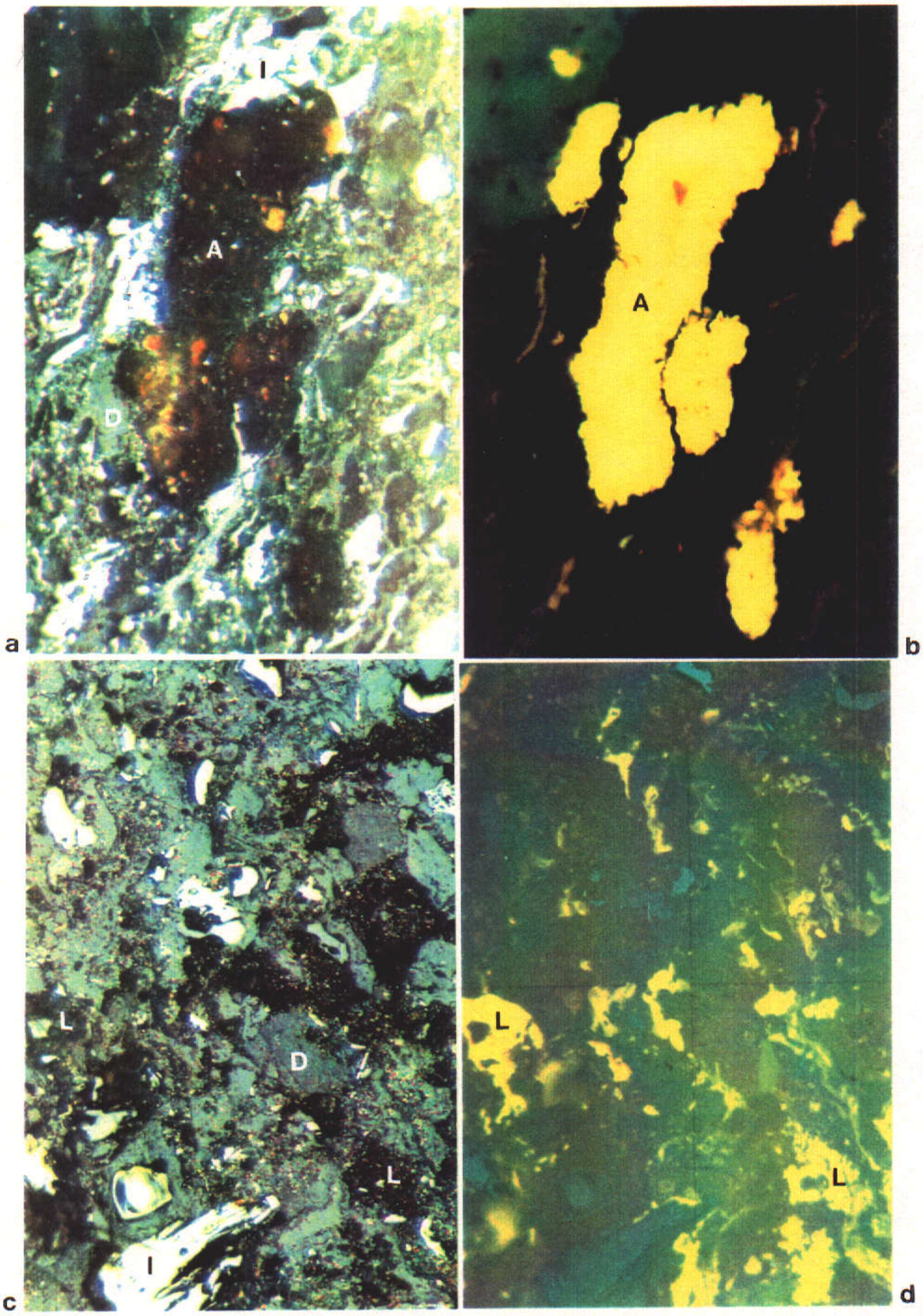
4.2.2.3. Exinite Group

The exinite group recognized in the Vasse Shelf coal consists of macerals: sporinite, cutinite, alginite, liptodetrinite and resinite. The sporinite, cutinite and alginite can be related to specific source material, and have considerable palaeo-environmental significance for the coal deposition. Spore exines are important constituents of the maceral sporinite. In incident light, sporinite appears dark grey, and under fluorescence microscopy, the fluorescence colour for sporinite is brownish yellow to yellow. Figures 4.9.a and 4.9.b show sporinites associated with vitrinite and inertinite. The maceral cutinite is derived from cuticle which is a waxy outer protective layer of leaves, shoots, roots, needles, stalks and thin stems. The cuticles of all plants are highly resistant to decay in comparison to the internal structures of leaves. In incident light, cutinite appears as dark wavy lines. Under fluorescence microscopy, cutinite displays yellow in the fluorescence colour. Figures 4.9.c, 4.9.d, 4.11.c and 4.11.d show cutinite in matrices of vitrinite and inertinite. The alginite comprises remnants of algae which flourish in lakes, lagoons and marine environments, and it appears dark in reflected light, and displays yellow fluorescence in ultraviolet light. Figures 4.10.a and 4.10.b show alginite associated with inertodetrinite. Resinite is a maceral which probably originates from a number of source materials, such as gums and resins which are extruded as waste products from barks of many trees. The resinite of the Vasse Shelf coal appears dark in reflected light and displays yellow fluorescence when examined in ultraviolet light as shown in Figures 4.11.a and 4.11.b. The liptodetrinite includes all shapes and forms of detrital exinitic maceral, and it appears dark in reflected light (Figure 4.10.c) and displays brownish yellow colour in ultraviolet light (Figure 4.10.d).



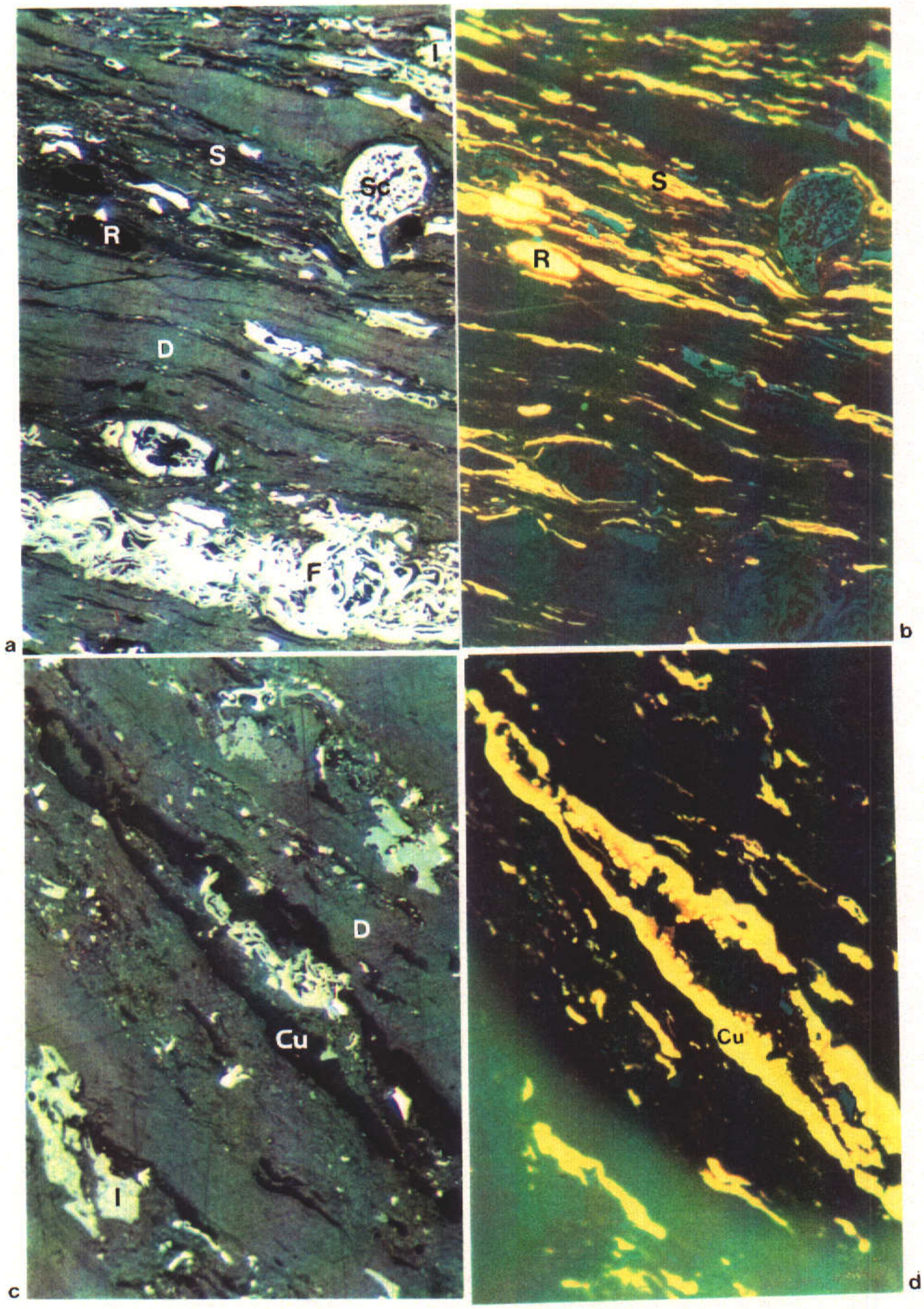
Macerals of the exinite group, Vasse Shelf coal (reflected light, oil immersion, x320).

Figure 4.9.a. Sporinite (S) associated with desmocollinite (D) and inertodetrinite (I). M seam, CRCH 1.
Figure 4.9.b. Same section after blue-light excitation, sporinite (S) displays greenish-yellowish fluorescence colours. M seam, CRCH 1.
Figure 4.9.c. Cutinite (Cu) associated with desmocollinite (D) and inertodetrinite (I). B seam, CRCH 1.
Figure 4.9.d. Same section after blue-light excitation, cutinite (Cu) displays brownish-yellowish fluorescence colours. B seam, CRCH 1.



Macerals of the exinite group, Vasse Shelf coal (reflected light, oil immersion, x320).

Figure 4.10.a. Alginite (A) associated with inertodetrinite (I) and desmocollinite (D). M seam, CRCH 1.
Figure 4.10.b. Same section after blue-light excitation, alginite (A) displays yellowish fluorescence colours. M seam, CRCH 1.
Figure 4.10.c. Liptodetrinite (L) associated with desmocollinite (D) and inertodetrinite (I). K seam, RBCH 6.
Figure 4.10.d. Same section after blue-light excitation, liptodetrinite (L) displays brownish-yellowish fluorescence colours. K seam, RBCH 6.



Macerals of the exinite group, Vasse Shelf coal (reflected light, oil immersion, x320).

Figure 4.11.a. Resinite (R) associated with sporinite (S), desmocollinite (D), sclerotinite (Sc), fusinite (F) and inertodetrinite (I). B seam, CRCH 1.

Figure 4.11.b. Same section after blue-light excitation, resinite (R) and sporinite (S) display yellowish and brownish fluorescence colours, respectively. B seam, CRCH 1.

Figure 4.11.c. Cutinite (Cu) associated with desmocollinite (D) and inertodetrinite (I). D seam, RB 3.

Figure 4.11.d. Same section after blue-light excitation, cutinite (Cu) displays yellowish fluorescence colour. D seam, RB 3.

4.2.3. Microlithotypes

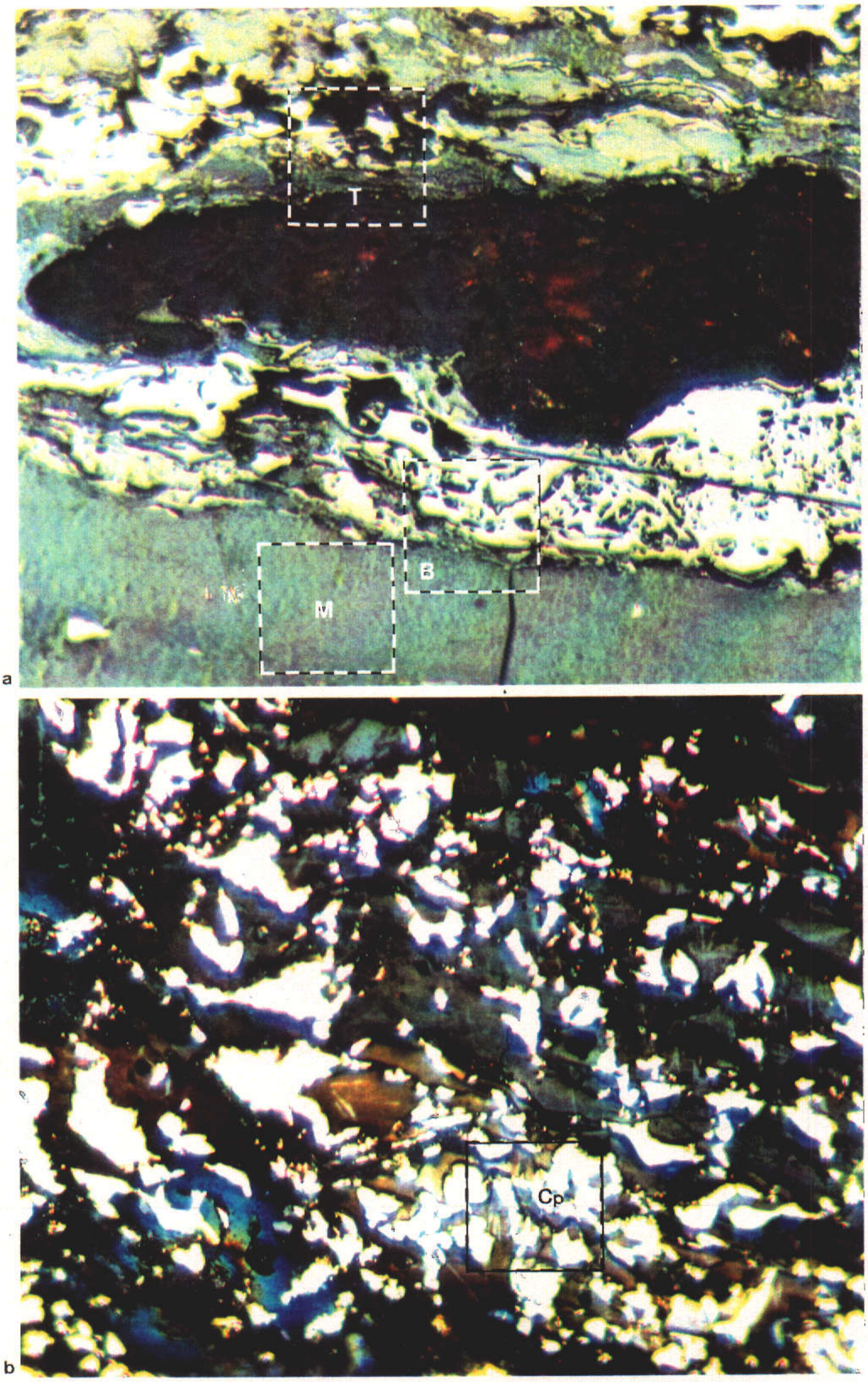
The microlithotype examination of the coal shows the presence of four microlithotypes, namely: monomaceral, bimaceral, trimaceral and carbominerite, as shown in Figures 4.12.a and 4.12.b.

4.2.3.1. Monomaceral

The monomaceral microlithotypes consist of vitrite, liptite and inertite (Figures 4.13.a, 4.13.b and 4.13.c). The vitrite in the Vasse Shelf coal occurs as microbands of vitrinite, liptite is a group of microlithotypes which occurs rarely, and it is predominantly composed of sporite and algite with low cutite. The inertite is mainly composed of fusite and semifusite. In the Vasse Shelf coal, inertite is more common than clarite.

4.2.3.2. Bimaceral

The bimaceral microlithotype consists of clarite, durite and vitrinertite, as shown in Figures 4.14.a, 4.14.b and 4.14.c. In the Vasse Shelf coal, durite is the most common constituent within this type, followed by vitrinertite and clarite. The clarite consists of vitrinite-rich clarite identified as clarite-V and exinite-rich clarite as clarite-E. The durite is composed of inertinite and exinite group of macerals, and it consists of inertinite-rich durite identified as durite-I and exinite-rich durite as durite-E. The vitrinertite is a combination of vitrinite and inertinite group of macerals, and it consists of vitrinite-rich vitrinertite identified as vitrinertite-V and inertinite-rich vitrinertite as vitrinertite-I.



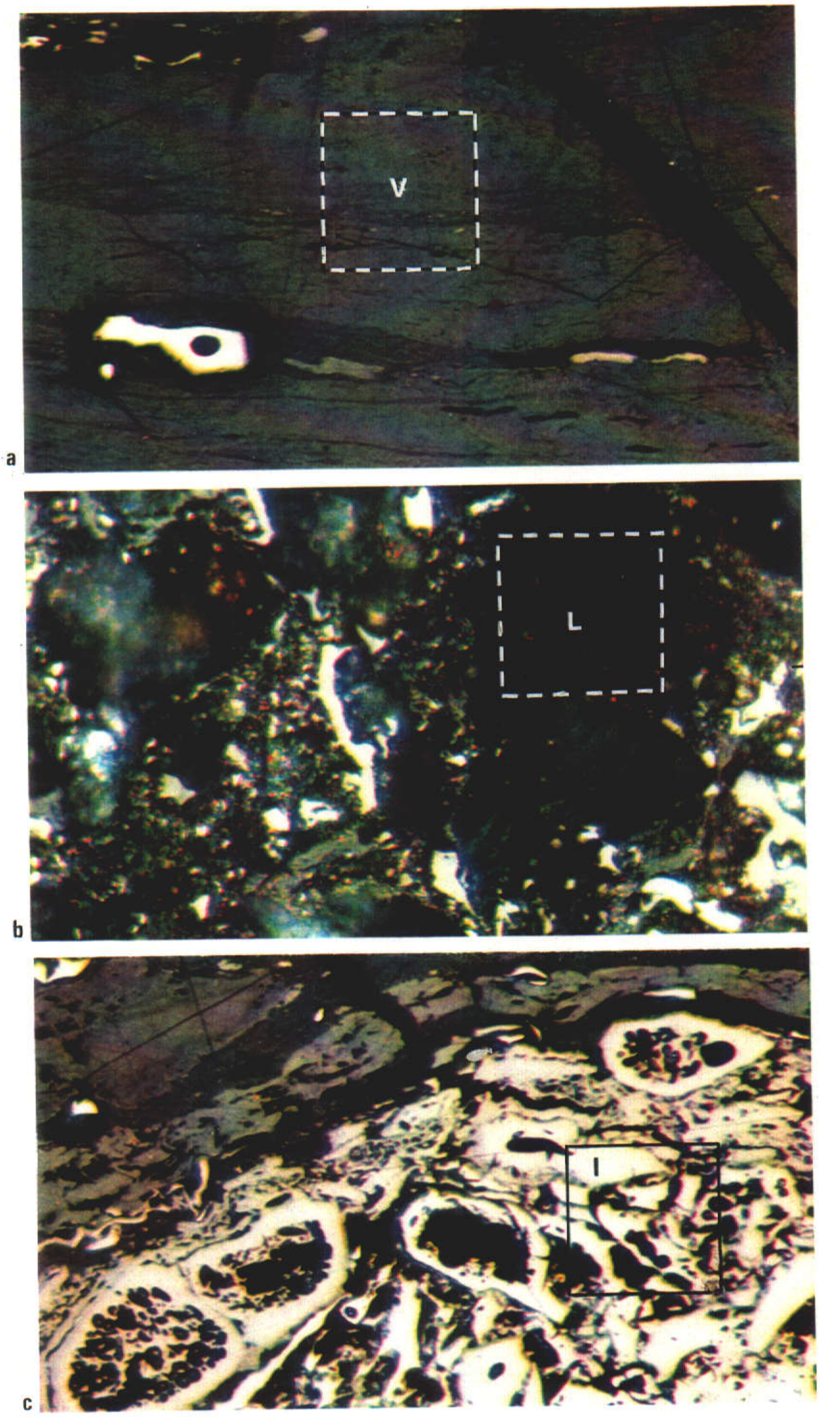
a

b

Microlithotypes of the Vasse Shelf coal (reflected light, oil immersion, x320).

Figure 4.12.a. Monomaceralic (M), bimaceralic (B) and trimaceralic (T) microlithotypes. A seam, CRCH 1.

Figure 4.12.b. Carbominerite: carbopyrite (Cp), D seam, RB 3.

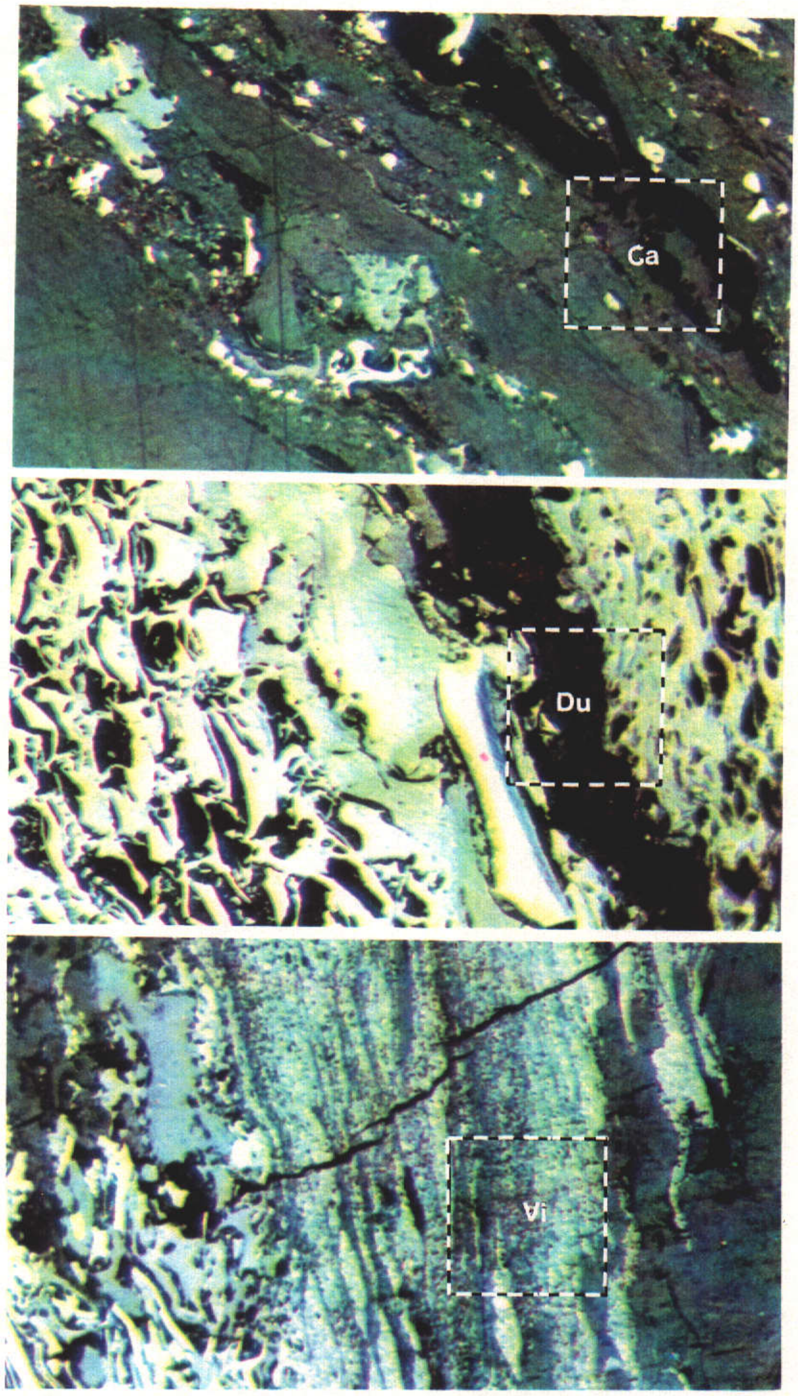


Monomaceralic microlithotypes of the Vasse Shelf coal (reflected light, oil immersion, x320).

Figure 4.13.a. Vitrite (V) occuring as microbands of vitrinite. C seam, CRCH 1.

Figure 4.13.b. Liptite (L) composed of alginite. M seam, CRCH 1.

Figure 4.13.c. Inertite (I) consisting of sclerotinite. C seam, CRCH 1.



Bimaceralic microlithotypes of the Vasse Shelf coal (reflected light, oil immersion, x320).

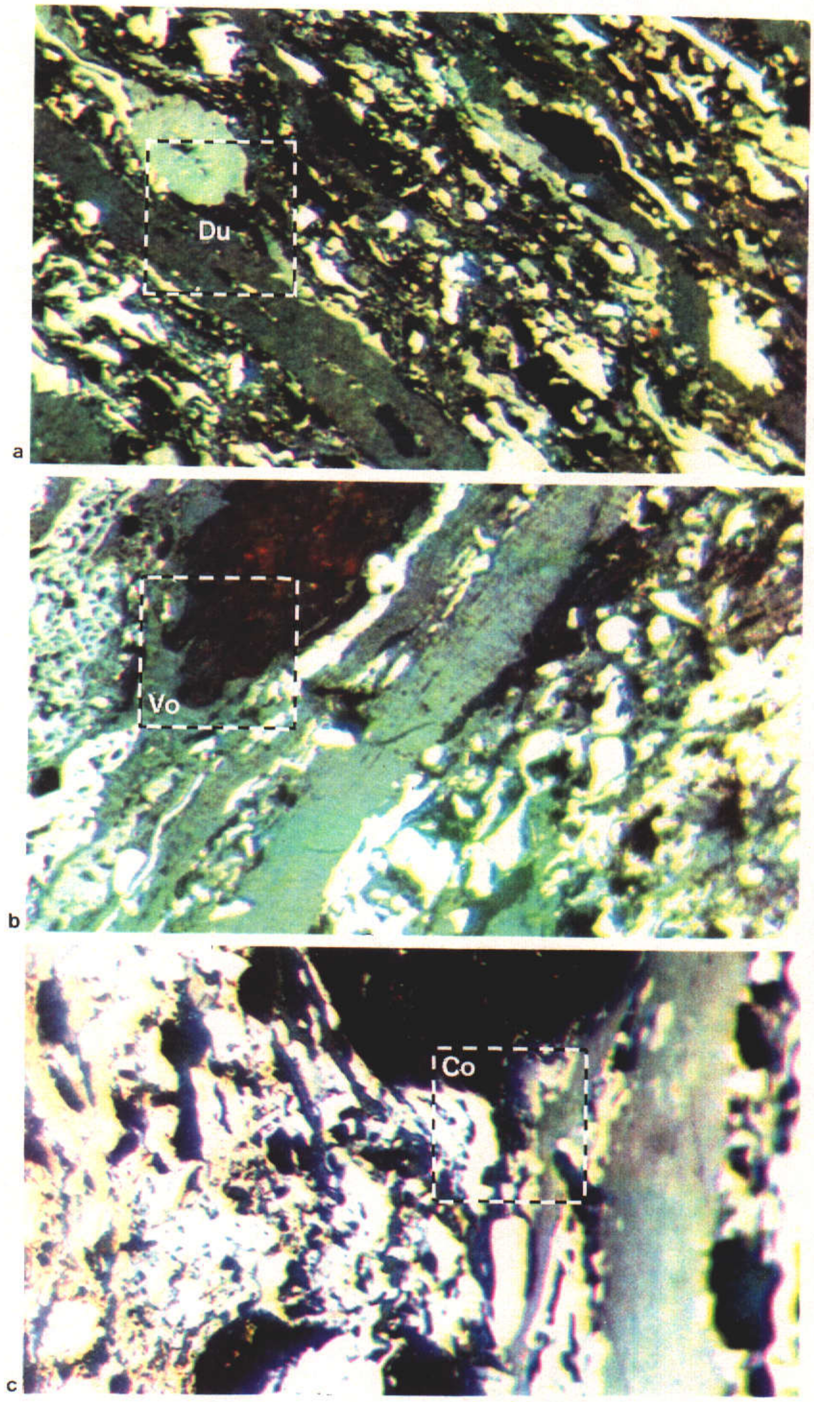
Figure 4.14.a. Clarite (Ca) consisting of vitrinite (desmocollinite) and exinite (cutinite). D seam, RB 3.
Figure 4.14.b. Durite (Du) composed of inertinite (inertodetrinite) and exinite (sporinite). B seam, RBCH 5.
Figure 4.14.c. Vitrinertite (Vi) showing inertinite-rich vitrinertite. F seam, RB 3.

4.2.3.3. Trimaceral

This microlithotype consists of duroclarite, vitrinertoliptite and clarodurite in which vitrinite, inertinite and exinite groups are present, as shown in Figures 4.15.a, 4.15.b and 4.15.c. Duroclarite is a combination of dominant vitrinite group plus a minor amount of inertinite and exinite groups. In the Vasse Shelf coal, this is commonly observed as telocollinite and desmocollinite with sporinite and alginite, associated with inertodetrinite. Vitrinertoliptite is an association of dominant exinite with a minor amount of inertinite and vitrinite groups. The exinite is present as alginite, sporinite and liptodetrinite, whereas the inertinite as inertodetrinite and the vitrinite as desmocollinite and telocollinite. Clarodurite is a combination of dominant inertinite with a minor amount of vitrinite and exinite groups, in which mineral matter is often found to be associated in this microlithotype. The inertinite is often present as inertodetrinite, the vitrinite as desmocollinite and telocollinite and the exinite as alginite and sporinite. In the Vasse Shelf coal, the duroclarite is the most common constituent, followed by the clarodurite with minor vitrinertoliptite.

4.2.3.4. Carbominerite

On the basis of the content of mineral matter associated with macerals, carbominerite group of the Vasse Shelf coal is sub-divided into carbargilite (Figure 4.16), carbopyrite (Figure 4.12.b) and carbosilicate. The carbargillite is composed of 20%-60% clay minerals in association with macerals. It is the most common constituent within this type, followed by carbopyrite and very low carbosilicate. The carbopyrite is a mixture of 5% to 20% pyrite and macerals, and the carbosilicate contains a mixture of 20% to 60% quartz and macerals.



Trimaceralic microlithotypes of the Vasse Shelf coal (reflected light, oil immersion, x320).

Figure 4.15.a. Duroclarite (Du) consisting of predominant vitrinite with inertinite and exinite. A seam, CRCH 2.

Figure 4.15.b. Vitrinertoliptite (Vo) composed of predominant exinite, vitrinite and inertinite. H seam, RB 3.

Figure 4.15.c. Clarodurite (Co) showing predominant inertinite, with vitrinite and exinite. B seam, RBCH 6.

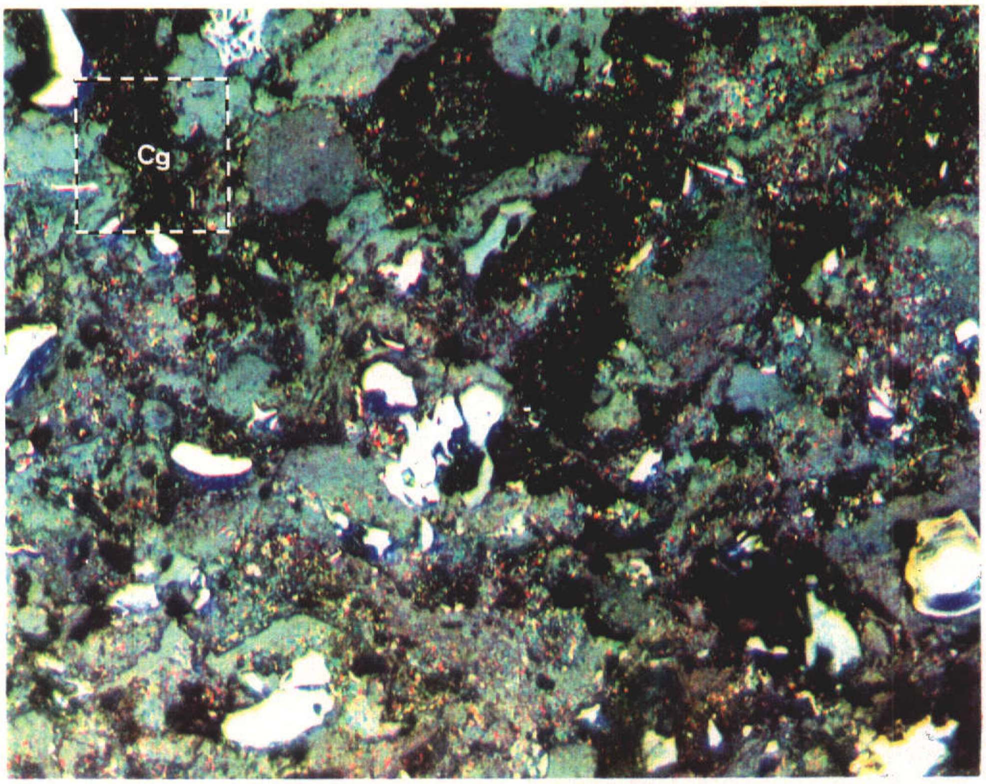


Figure 4.16. Carbominerite of the Vasse Shelf coal showing carbargilite (Cg) associated with vitrinite and inertinite. K seam, RBCH 6.

4.2.4. Maceral and Mineral Matter Analyses

The data on maceral and mineral matter analyses of the Vasse Shelf coal are presented for the drill holes RBCH 5, RBCH 6, RB 3, CRCH 1 and CRCH 2. The analyses were carried out to establish the distribution of macerals and mineral matter in the individual coal seams. The distribution of macerals and mineral matter in the individual coal seams is given in Table 4.2 and Figures 4.17.a and 4.17.b. The maceral compositions on a mineral matter free basis for individual seams are also depicted on a ternary diagram, as shown in Figure 4.18 which shows the dominance of inertinite over vitrinite and exinite.

The maceral and mineral matter analyses in Table 4.2 and Figures 4.17.a and 4.17.b show that in the coal seams A to P, the vitrinite content varies between 19.6% (seam M, CRCH 1) to 64.2% (seam M, CRCH 2), the inertinite content ranges from 14.8% (seam M, CRCH 2) to 63.0% (seam M, CRCH 1) and the exinite content is between 5.3% (seam L, CRCH 1) to 18% (seam M, CRCH 2). The mineral matter in the seams ranges between 1.6% (seam A, CRCH 2) to 8.2% (seam O, CRCH 2).

The inertinite group in the coal is mainly dominated by inertodetrinite with low fusinite and semifusinite and very low micrinite, sclerotinite and macrinite. Inertodetrinite, the highest inertinite content, is recorded in the seam J of CRCH 2 which contains 43.0%. However, there is a low inertodetrinite content (8.2%) in the seam K of CRCH 1. The fusinite and semifusinite are relatively low, with amounts of 2.0% in the seam M of CRCH 2 to 24.7% in the seam G of CRCH 1 and 0.0% in the seam J of CRCH 2 to 12.4% in the seam A of RB 3, respectively. The fusinite content is consistently higher than the semifusinite content. Probably, the fusinite

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
RBCH 5	Telinite	0.9	0.9	0 3	0.7	1.0	1.8	0.2	0.0	0.4	0.4						
	Telocollinite	5.7	8.7	11.7	10.9	12.1	11.1	16.2	1.6	11.8	9.6						
	Corpocollinite	4.7	1.0	3.0	0.2	1.2	0.9	1.6	0.2	0.0	2.6						
	Desmocollinite	27.9	29.6	26.1	29.6	24.5	21.5	29.0	32.0	29.4	30.9						
	Vitrodetrinite	1.6	1.7	1.5	3.2	2.3	2.5	1.4	3.2	3.8	0.7						
	Vitrinite Group	**40.8**	**41.9**	**42.6**	**44.6**	**41.1**	**37.9**	**48.4**	**37.0**	**45.4**	**44.2**						
	Fusinite	6.4	9.5	7.1	6.2	14.1	11.8	4.2	2.2	2.4	5.9						
	Semifusinite	5.5	3.4	1.6	1.0	2.3	2.0	2.6	0.2	1.4	3.3						
	Sclerotinite	0.9	1.1	0.7	1.1	1.3	1.5	1.0	1.0	1.0	0.9						
	Micrinite	1.3	1.7	2.3	2.0	2.3	2.9	3.2	2.4	4.2	3.3						
	Macrinite	0.3	0.3	0.1	0.1	0.4	0.3	0.0	0.0	0 2	0.0						
	Inertodetrinite	33.6	27.5	33.1	24.7	28.7	30.9	29.6	40.0	37.0	26.5						
	Inertinite Group	**48.0**	**43.5**	**44.9**	**35.1**	**49.1**	**49.5**	**40.6**	**45.8**	**46.2**	**39.9**						
	Sporinite	2.4	2.4	2.4	4.1	1.9	2.4	2.4	3.2	0.4	2.0						
	Cutinite	1.0	3.4	1.5	10.3	0.7	1.4	2 2	2.8	2.6	5.5						
	Resinite	0.6	0.6	0.7	0.4	0.8	0.4	0.2	0.4	0.2	0.7						
	Alginite	0.1	0.0	0.0	0.0	1.2	2.1	0.4	1.4	0.4	0.3						
	Liptodetrinite	1.3	2.7	3.2	2.5	1.0	2.2	3.4	3.8	1.8	2.5						
	Exinite Group	**5.4**	**9.1**	**7.8**	**17.3**	**5.6**	**8.5**	**8.6**	**11.6**	**5.4**	**11.0**						
	Clay	3.1	2.7	3.7	2.0	2.7	2.7	0.8	4.0	1.4	3.0						
	Pyrite	2.1	2.0	0.6	0.5	0.8	1.0	1.2	1.6	1.0	1.3						
	Quartz	0.6	0.8	0.4	0.5	0.7	0.4	0.4	0.0	0.6	0.6						
	Mineral Matter	**5.8**	**5.5**	**4.7**	**3.0**	**4.2**	**4.1**	**2.4**	**5.6**	**3.0**	**4.9**						

Table 4.2. Maceral and mineral matter contents (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
RBCH 6	Telinite	1.0	0.8					0.4				0.0					
	Telocollinite	14.0	7.8					6.0				3.8					
	Corpocollinite	0.8	0.0					0.0				0.6					
	Desmocollinite	23.6	31.0					33.0				31.2					
	Vitrodetrinite	2.4	1.2					4.2				2.0					
	Vitrinite Group	**41.8**	**40.8**					**43.6**				**37.6**					
	Fusinite	5.4	11.4					15.2				10.8					
	Semifusinite	2.3	3.2					4.0				2.6					
	Sclerotinite	1.3	0.8					1.0				0.6					
	Micrinite	1.7	1.0					1.4				2.8					
	Macrinite	0.4	0.2					0.2				0.0					
	Inertodetrinite	33.0	27.4					22.6				33.6					
	Inertinite Group	**44.1**	**44.0**					**44.4**				**50.4**					
	Sporinite	2.4	2.8					2.8				1.0					
	Cutinite	2.9	3.0					2.6				3.4					
	Resinite	1.3	1.2					0.4				0.6					
	Alginite	0.6	1.6					0.0				0.4					
	Liptodetrinite	3.1	2.2					2.4				2.2					
	Exinite Group	**10.3**	**10.8**					**8.2**				**7.6**					
	Clay	2.2	3.0					2.8				1.0					
	Pyrite	1.4	0.6					0.6				2.8					
	Quartz	0.2	0.8					0.4				0.6					
	Mineral Matter	**3.8**	**4.4**					**3.8**				**4.4**					

Table 4.2. Maceral and mineral matter contents (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
RB 3	Telinite	3.0	2.4	1.4	1.4	1.4	1.8	1.6	0.8	0 9							
	Telocollinite	17.0	15.8	12.2	19.4	14.8	10.4	11 9	14 8	15.1							
	Corpocollinite	2.6	1.2	1.0	2.4	2.0	2.6	1.9	0.2	1.4							
	Desmocollinite	15.6	19.4	16.6	20.2	16.4	19.0	16.2	14 6	15.2							
	Vitrodetrinite	1.0	1.4	1.9	1.2	1.6	2.4	2 8	2 6	1.4							
	Vitrinite Group	**39.2**	**40.2**	**33.1**	**44.6**	**36.2**	**36.2**	**34.3**	**33.0**	**33.9**							
	Fusinite	21.4	20.6	21.4	18.6	21.0	19.4	21.6	27.0	23.1							
	Semifusinite	12.4	8.8	11.1	8.8	4.1	5.8	3.8	3.8	3.3							
	Sclerotinite	0.2	0.4	0.9	0.4	0.0	0.6	0.8	0 6	1.4							
	Micrinite	2.2	3.0	3.1	0.6	2.5	2.2	3.3	2.0	3.1							
	Macrinite	0.2	0.0	1.2	0.8	0.5	1.0	1.0	1.2	0.6							
	Inertodetrinite	14.2	17.6	18.8	11.2	22.8	18.8	20.7	18.8	22.4							
	Inertinite Group	**50.6**	**50.4**	**56.5**	**40.4**	**50.9**	**47.8**	**51.1**	**53.4**	**53.8**							
	Sporinite	3.6	1.4	2.4	2.4	3.1	4 0	3.1	4.2	2.9							
	Cutinite	1.4	0.8	0.3	0.4	0.7	0.6	0.7	0.8	0.9							
	Resinite	0.4	0.0	0.6	0.0	0.5	2.6	2.0	2.4	2.5							
	Alginite	2 4	3.8	4.5	6.4	4.5	3.6	3.6	1.6	2.8							
	Liptodetrinite	0.0	0 0	0.1	0.0	0.0	0 6	0.5	0.8	0.7							
	Exinite Group	**7.8**	**6.0**	**7.9**	**9.2**	**8.8**	**11.4**	**9.9**	**9.8**	**9.7**							
	Clay	1.0	1.8	1.2	2.8	1.7	1.8	1.5	1.4	1.2							
	Pyrite	0.8	1.0	0.9	2.2	1.5	1 6	2.2	1.8	1.0							
	Quartz	0.6	0.6	0.4	0.8	0.9	1.2	0.9	0.6	0.5							
	Mineral Matter	**2.4**	**3.4**	**2.5**	**5.8**	**4.1**	**4.6**	**4.6**	**3.8**	**2.7**							

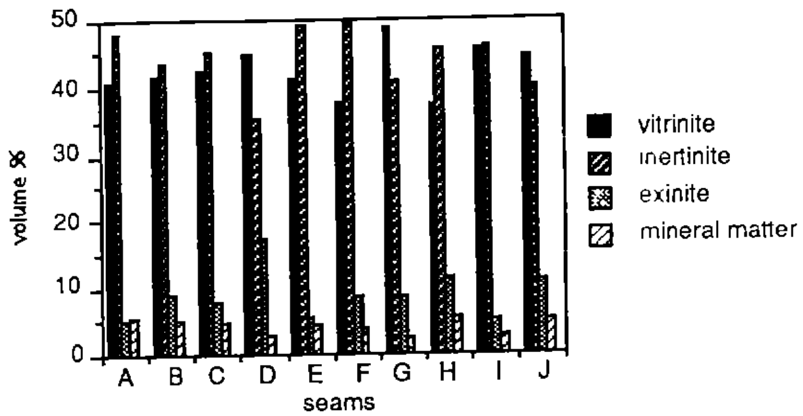
Table 4.2. Maceral and mineral matter contents (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
CRCH 1	Telinite	0.6	1 2	0.4	0.6	0.8	1.6	0.8	1.1	0.7	0.6	1.2	1 5	3.0			
	Telocollinite	14.4	13 0	10.0	21.8	16.0	29.5	20.1	20.9	33.4	19.4	33.6	29.2	2.8			
	Corpocollinite	1.0	1.6	2.6	1.2	2.0	3.9	0.0	1.2	1.6	3.1	3.8	1.2	1 4			
	Desmocollinite	23.2	21.8	15.8	12.6	11.8	12 4	15.3	19.0	16.7	13.0	13.2	9.5	10 8			
	Vitrodetrinite	1.6	2.0	2.8	0.8	3.4	0.8	0.3	0.3	0.3	0.2	0.0	0.4	1.6			
	Vitrinite Group	**40.8**	**39.6**	**31.6**	**37.0**	**34.0**	**48.2**	**36.5**	**42.6**	**52.7**	**36.3**	**51.8**	**41.7**	**19.6**			
	Fusinite	11.6	12.2	3.4	13.8	13.0	11.8	24.7	20.9	12.7	13.0	20.6	21.7	18.4			
	Semifusinite	4.0	7.0	3.0	4.6	3.2	3.5	5.5	7.7	8.1	3.7	8.4	10.9	2.6			
	Sclerotinite	0.8	3.2	1.8	1.6	0.8	0.9	1.2	1.9	1.1	1.3	0.0	0.9	0.8			
	Micrinite	2.6	2.2	3.2	2.2	2.8	1.8	1.5	2.5	1.1	1.6	0.2	1.1	1.6			
	Macrinite	0.6	0 4	0.6	0.6	0.4	0.6	0.6	0.6	1.0	0.8	0.4	0.8	1.8			
	Inertodetrinite	30.0	24.2	42.4	24.2	35.4	17.9	20.9	14.6	11.9	30.2	8.2	14.6	37.8			
	Inertinite Group	**49.6**	**49.2**	**54.4**	**47.0**	**55.6**	**36.5**	**54.4**	**48.3**	**35.9**	**50.6**	**37.8**	**49.9**	**63.0**			
	Sporinite	3.8	2.4	3.0	3.6	2.6	2.7	3.5	2.1	3.5	2.6	3.4	2.9	4.2			
	Cutinite	0.6	3.2	1.2	2.6	1.2	1.0	0.4	0.7	1.1	0.3	1.4	1.4	5.2			
	Resinite	0.2	0.4	1.0	1.0	0.6	0.5	0 5	0.5	0.3	0.2	0.4	0.5	0.0			
	Alginite	0.4	1.4	0.8	2.2	0.4	5.1	0.0	2.1	1.0	5.3	0.8	0.0	0.0			
	Liptodetrinite	1.6	1.4	1.6	1.0	1.0	1 1	1.2	1.3	1.6	0.4	2.2	0.5	2.6			
	Exinite Group	**6.6**	**8.8**	**7.6**	**10.4**	**5.8**	**10.4**	**5.6**	**6.6**	**7.5**	**8.8**	**8.2**	**5.3**	**12.0**			
	Clay	0.4	0.6	3.4	2.2	2.0	3 1	1.3	1.1	1.3	1.6	0.4	0.5	1.4			
	Pyrite	2.0	1.4	2.2	2.6	1.8	1.2	1.9	1.1	2.0	2.2	1.4	2.2	3.4			
	Quartz	0.6	0.4	0.8	0 8	0.8	0.6	0.3	0.3	0.6	0.5	0.4	0.4	0.6			
	Mineral Matter	**3.0**	**2.4**	**6.4**	**5.6**	**4.6**	**4.9**	**3.5**	**2.5**	**3.9**	**4.3**	**2.2**	**3.1**	**5.4**			

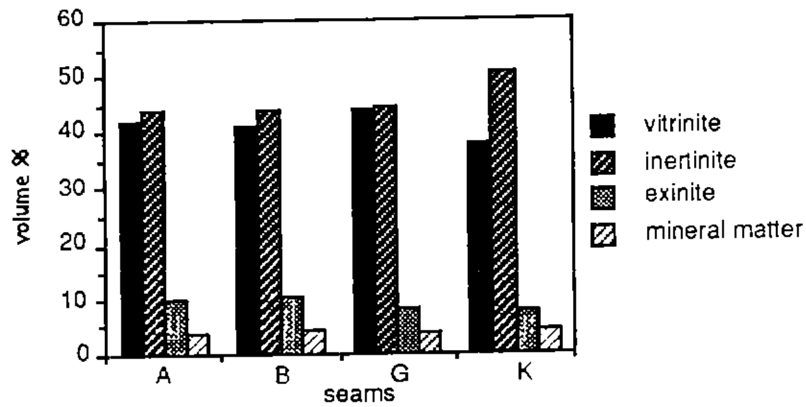
Table 4.2. Maceral and mineral matter contents (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
CRCH 2	Telinite	1.6									0.0			0.2	0.0	0.4	0.2
	Telocollinite	6.0									2.6			16.2	15.6	5.2	3.0
	Corpocollinite	0.0									0.0			0.0	0.0	0.8	0.4
	Desmocollinite	33.6									27.2			45.0	23.4	33.0	24.7
	Vitrodetrinite	1.0									2.8			2.8	3.2	5.0	2.6
	Vitrinite Group	**42.2**									**32.6**			**64.2**	**42.2**	**44.4**	**30.9**
	Fusinite	7.2									2.6			2.0	13.4	9.2	10.0
	Semifusinite	5.0									0.0			1.6	0.8	1.6	3.7
	Sclerotinite	0.8									0.6			0.0	1.0	1.4	1.7
	Micrinite	0.8									1.6			0.0	1.0	0.6	2.4
	Macrinite	0.0									0.0			0.0	0.2	0.0	0.7
	Inertodetrinite	29.4									43.0			11.2	28.8	25.6	36.7
	Inertinite Group	**43.2**									**47.8**			**14.8**	**45.2**	**38.4**	**55.2**
	Sporinite	3.6									0.2			10.8	1.8	1.6	1.8
	Cutinite	2.0									2.6			1.6	1.0	2.6	0.9
	Resinite	0.6									0.8			0.6	0.2	0.2	0.3
	Alginite	5.8									8.8			0.4	0.2	0.4	2.9
	Liptodetrinite	1.0									2.2			4.6	5.0	4.2	3.3
	Exinite Group	**13.0**									**14.6**			**18.0**	**8.2**	**9.0**	**9.1**
	Clay	0.2									3.8			1.6	3.4	5.0	2.2
	Pyrite	0.6									1.0			1.0	0.8	2.4	2.3
	Quartz	0.8									0.2			0.4	0.2	0.8	0.3
	Mineral Matter	**1.6**									**5.0**			**3.0**	**4.4**	**8.2**	**4.8**

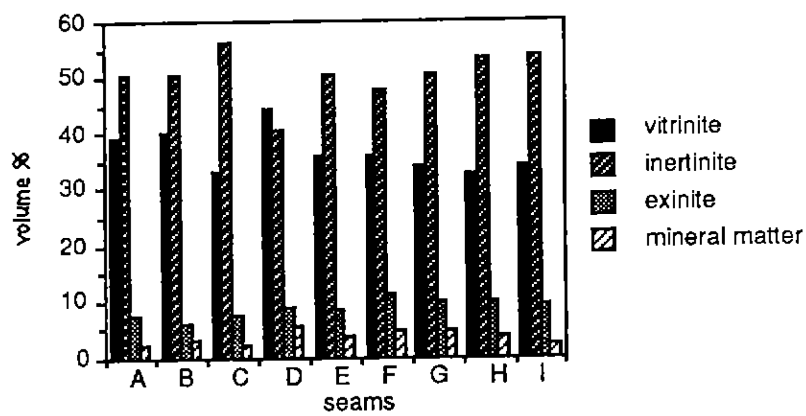
Table 4.2. Maceral and mineral matter contents (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.



Maceral and mineral matter distribution, RBCH 5

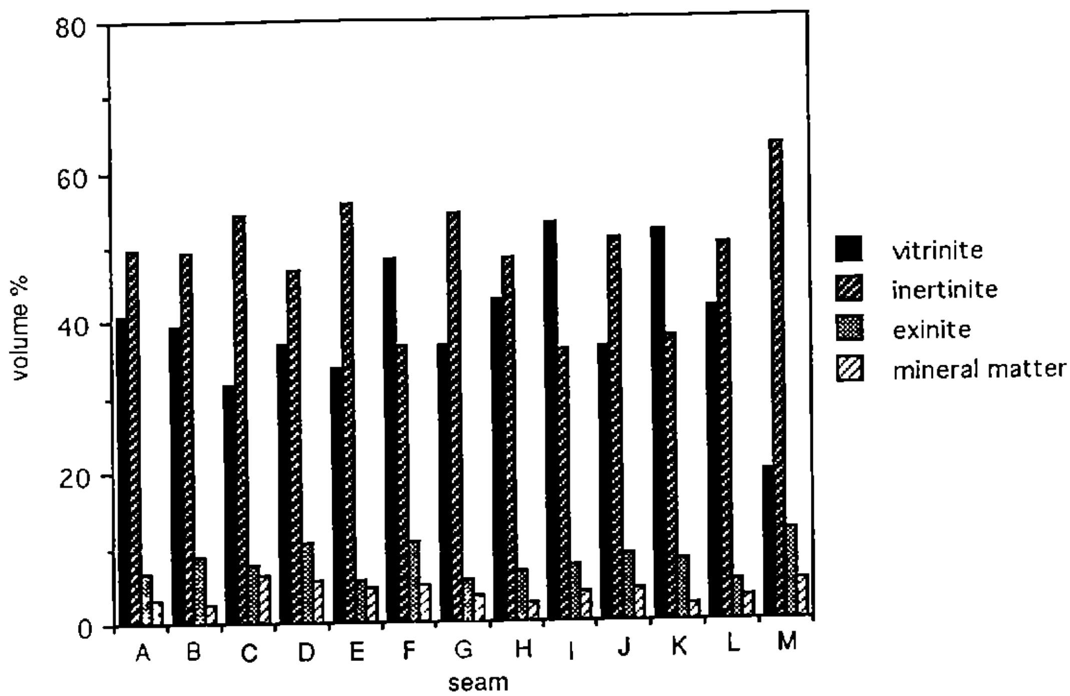


Maceral and mineral matter distribution, RBCH 6

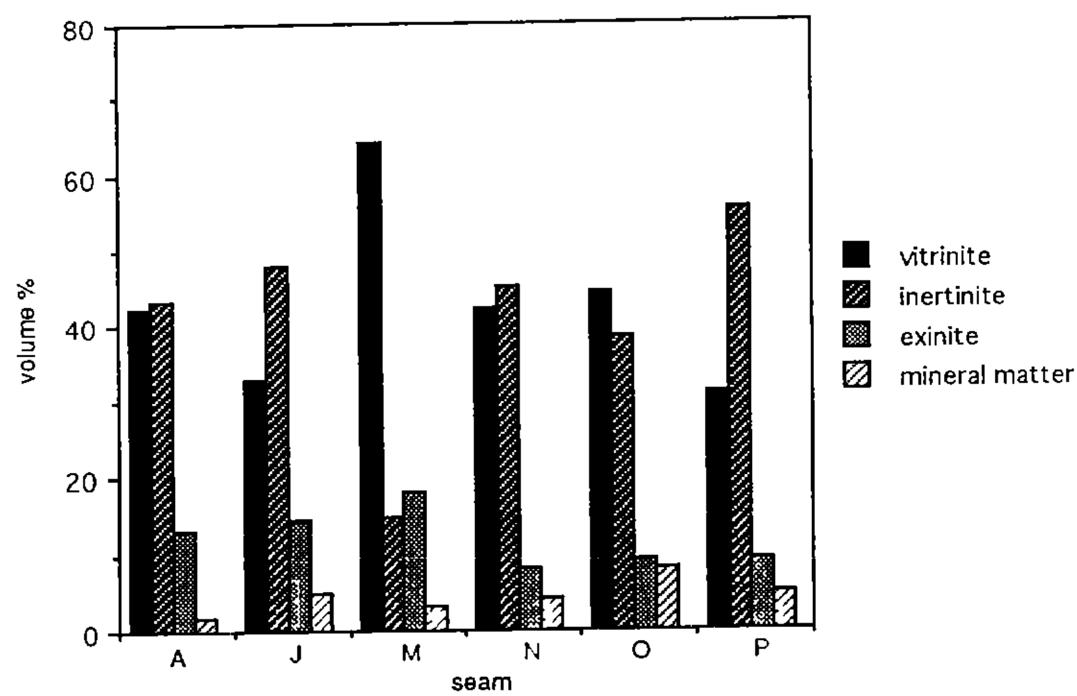


Maceral and mineral matter distribution, RB 3

Figure 4.17.a. Maceral and mineral matter distribution of the Vasse Shelf coal, drill holes RBCH 5, RBCH 6 and RB 3.



Maceral and mineral matter distribution, CRCH 1



Maceral and mineral matter distribution, CRCH 2

Figure 4.17.b. Maceral and mineral matter distribution of the Vasse Shelf coal, drill holes CRCH 1 and CRCH 2.

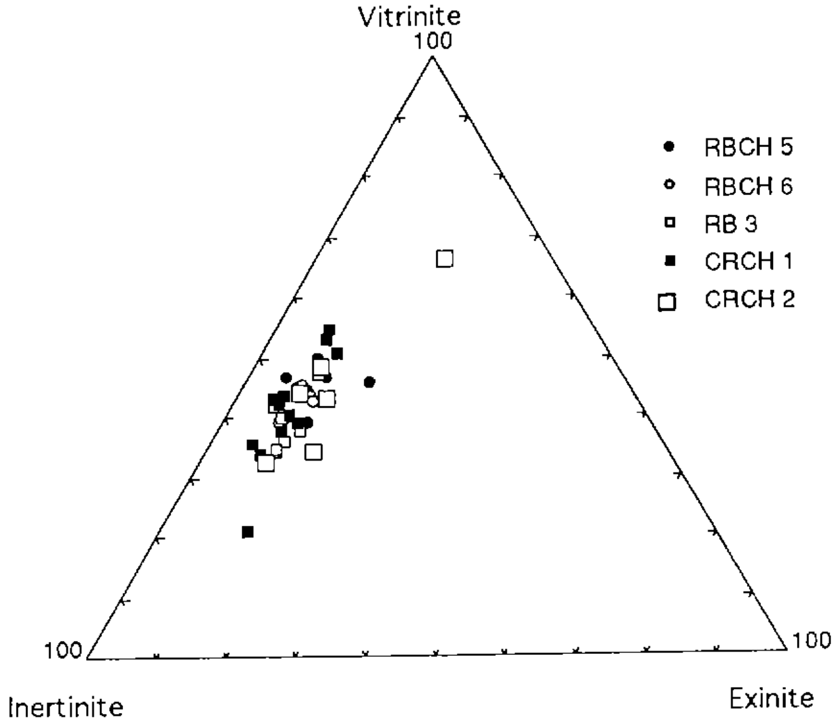


Figure 4.18. Maceral composition of the Vasse Shelf coal (mineral matter free).

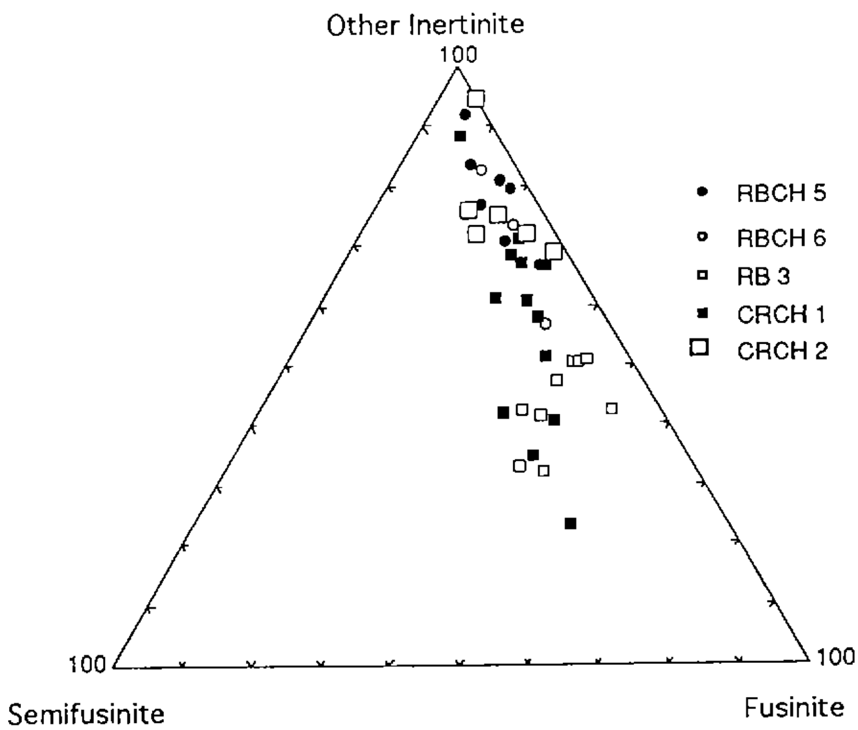


Figure 4.19. Composition of inertinite group of the Vasse Shelf coal.

and semifusinite were formed mainly from the degradation and oxidation process of humic substances. The micrinite shows a low range of 0.0% in the seam M of CRCH 2 to 4.2% in the seam I of RBCH 5, whereas sclerotinite and macrinite are very low constituents in the coal, containing 0.0% in the seam M of CRCH 2 to 3.2% in the seam B of CRCH 1 and 0.0% in seams G, H and J of RBCH 5 to 1.2% in the seams C and H of RB 3, respectively. Figure 4.19 depicts a ternary diagram of the inertinite composition for individual seams, in terms of semifusinite, fusinite and other inertinite (inertodetrinite, micrinite, sclerotinite and macrinite). The diagram shows that the other inertinite and fusinite macerals are dominant in the coal, in comparison to the semifusinite.

The macerals of the vitrinite group in the coal, in order of abundance are desmocollinite, telocollinite and vitrodetrinite. The desmocollinite content varies between 9.5% in the seam L of CRCH 1 to 45.0% in the seam M of CRCH 2, the telocollinite content is between 1.6% in the seam H of RBCH 5 to 33.6% in the seam K of CRCH 1 and the vitrodetrinite content is from 0.0% in the seam K to 5.0% in the seam O of CRCH 2. The corpocollinite and telinite occur in very low amounts and constitute 0.0% in the seam I of RBCH 5 and in the seams B and G of RBCH 6 to 4.7% in the seam A of RBCH 5 and 0.0% in the seam H of RBCH 5 and in the seam K of RBCH 6 to 3.0% in the seam A of RB 3, respectively. The ternary diagram illustrated in Figure 4.20, shows the composition of vitrinite macerals for individual seams on the basis of desmocollinite, telocollinite and other vitrinite (corpocollinite, telinite and vitrodetrinite). This figure shows that the vitrinite is predominated by desmocollinite.

The exinite macerals in the coal in order of abundance are sporinite, cutinite and liptodetrinite. The resinite and alginite occur in relatively low

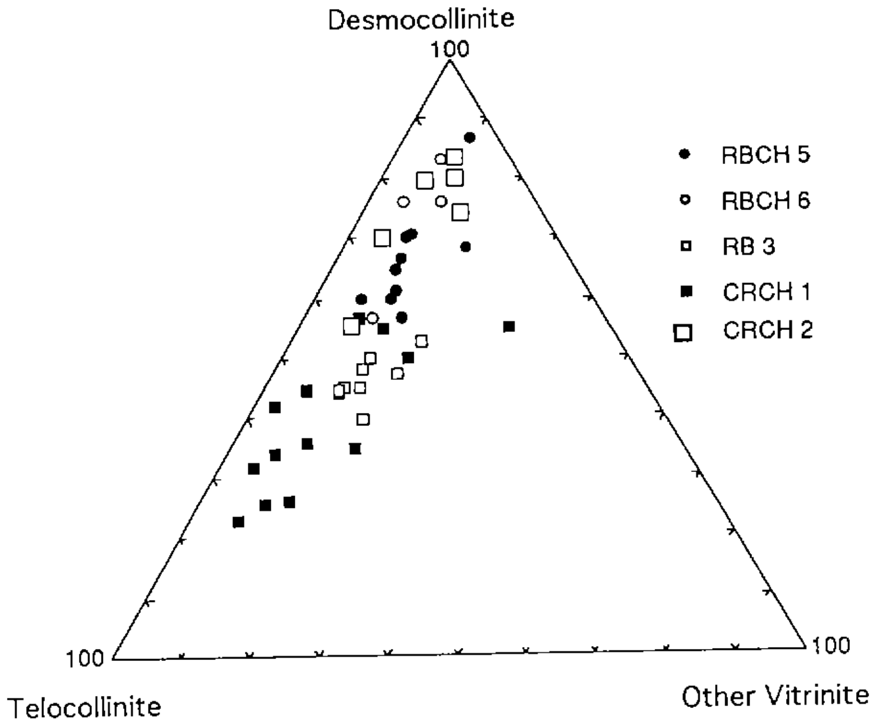


Figure 4.20. Composition of vitrinite group of the Vasse Shelf coal.

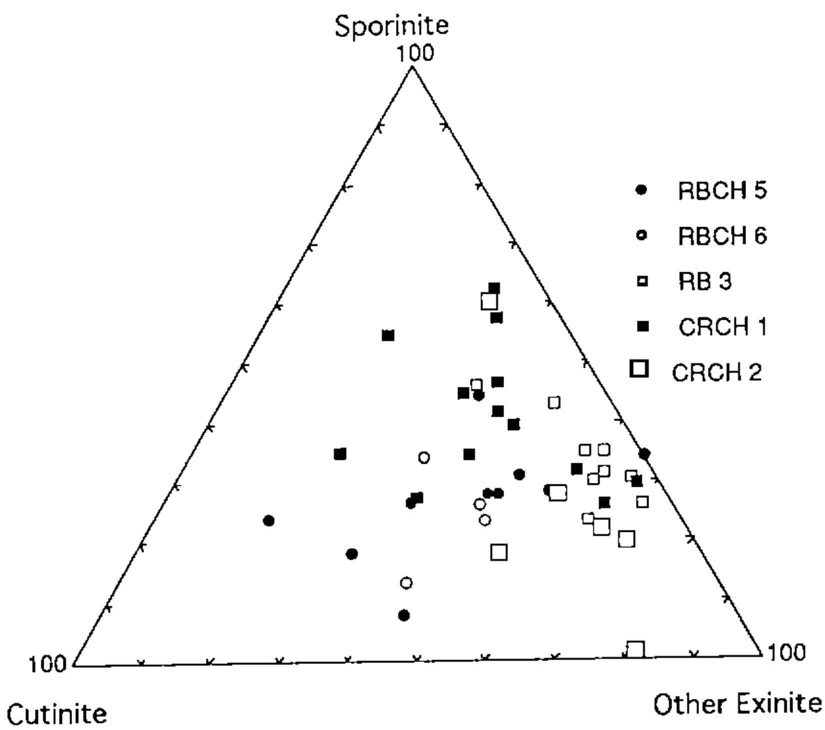


Figure 4.21. Composition of exinite group of the Vasse Shelf coal.

amounts. The sporinite, dominant maceral of the group, varies from 0.2% in the seam J of CRCH 2 to 10.8% in the seam M of CRCH 2. The cutinite has a range from 0.3% in the seam C of RB 3 and in the seam J of CRCH 1 to 10.3% in the seam D of RBCH 5, and the liptodetrinite is between 0.0% in the seams A, B, D and E of RB 3 to 5.0% in the seam N of CRCH 2. The resinite and alginite contents range between 0.0% in the seams B and D of RB 3 to 2.6% in the seam F of RB 3 and 0.0% in the seams B, C and D of RBCH 5 to 8.8% in the seam J of CRCH 2, respectively. Figure 4.21 depicts a ternary diagram of the exinite composition for individual seams, in terms of sporinite, cutinite and other exinite (liptodetrinite, alginite and resinite), the other exinite macerals are dominant in comparison to sporinite and cutinite.

Very low semifusinite ratio for the coal is present in RBCH 5, RBCH 6, CRCH 1 and CRCH 2 and low to medium in RB 3 and CRCH 1, whereas the coal in RBCH 6 and RB 3 has a medium value of vitrinite content and the coal in RBCH 5, CRCH 1 and CRCH 2 has a medium to high vitrinite content, as shown in Figure 4.22. The coal is characterized by very low to medium semifusinite ratio and medium to high vitrinite content, which suggests on the basis of the vitrinite content, that vitrinite in the coal was formed in an anaerobic condition, medium to high subsidence and wet environment, and based on the very low semifusinite values, the inertinite group in the coal was deposited in a slightly oxidizing environment. Overall the coal could be interpreted to be formed in an anaerobic wet environment with some degree of oxidation during its deposition.

The vertical and lateral variations of maceral and mineral matter contents in the Vasse Shelf coal within the individual seams from the drill holes RBCH 5, RBCH 6, RB 3, CRCH 1 and CRCH 2, are shown in Figure 4.23.

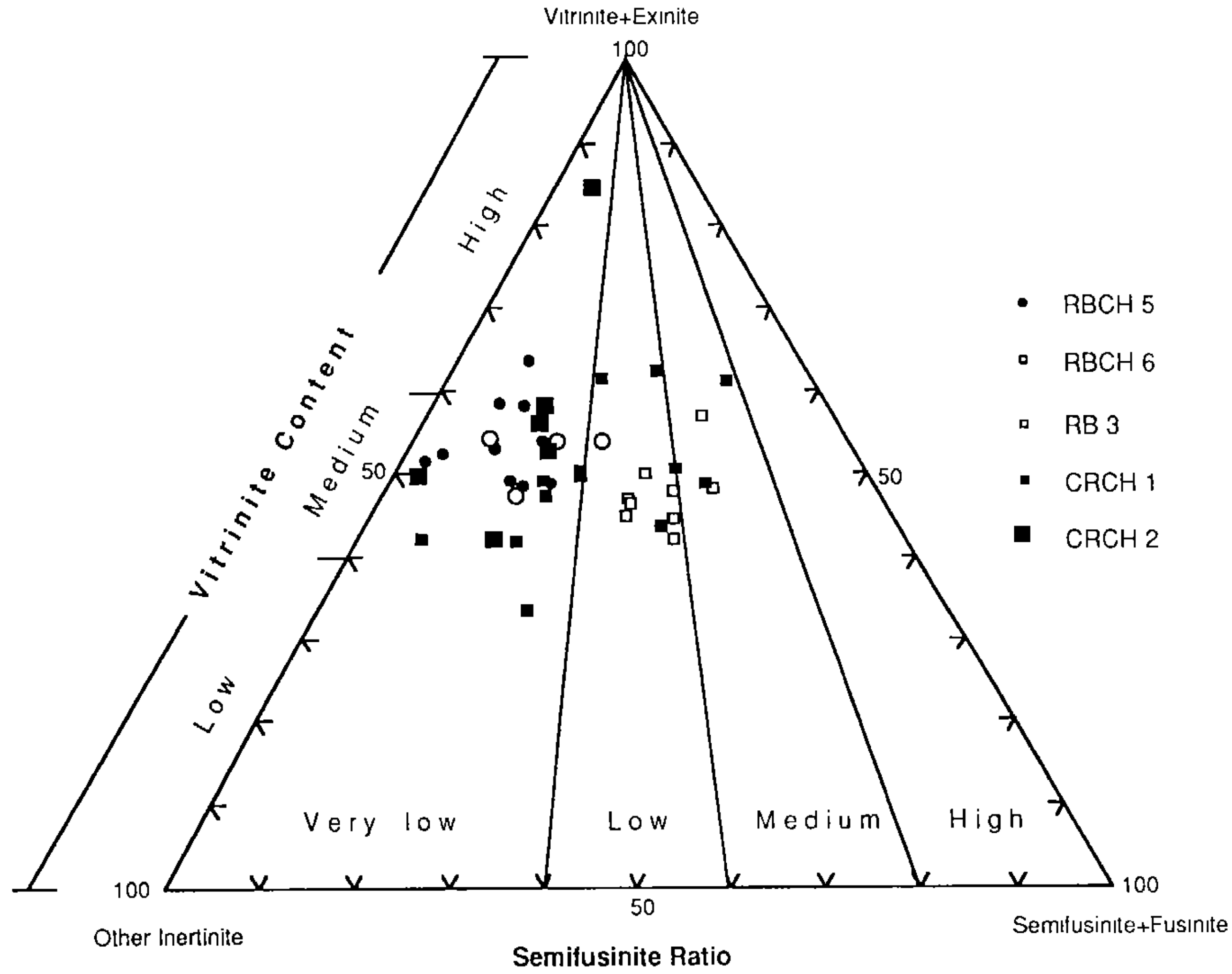


Figure 4.22. Maceral composition of the Vasse Shelf coal, showing 'vitrinite content' and 'semifusinite ratio'.

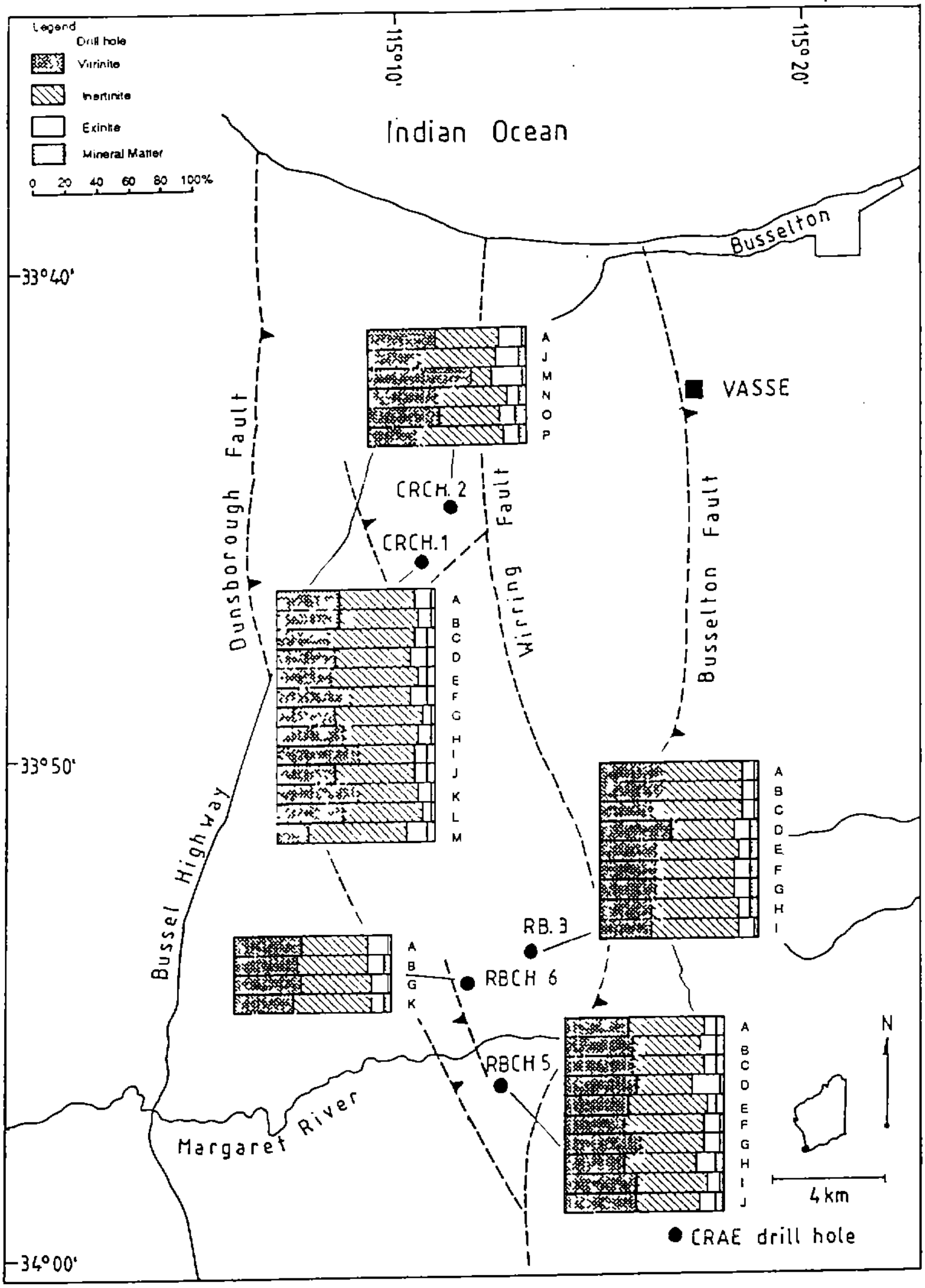


Figure 4.23. Variations of maceral and mineral matter of the Vasse Shelf coal, Perth Basin, Western Australia.

Vertically, the vitrinite content in the coal is variable in all the drill holes, however, its content decreases downwards in the drill hole RB 3, with the exception of the seam D in which the vitrinite content shows an increase. On the other hand, the inertinite content in the drill hole displays a reverse trend to the vitrinite content, with the exception of the seam D. The exinite content shows no remarkable variation from one seam to another. The mineral matter content in the drill holes RB 3 and RBCH 5 decreases downwards (except within the seam A, B and C and H, I and J, respectively). The variations in proportion of vitrinite and inertinite reflect frequent fluctuations in water table.

The lateral variation of maceral groups in the coal is also shown in the figure within the individual seams of all the drill holes, from south to north. The abundance of each maceral group and mineral matter in the individual seams, generally varies to a limited extent.

4.2.5. Maceral and Mineral Matter Distribution in Coal Size Fractions

In order to establish distribution of macerals and mineral matter in the size fractions, a composite coal sample of individual seam was crushed and sieved in size fractions of +4 mm, 4x2 mm, 2x1 mm, 1x1/2 mm, 1/2x1/4 mm and -1/4 mm. The polished blocks of the individual coal samples were prepared for microscopic examination. The proportions of macerals and minerals for the individual size fractions were calculated from the point counts made on the polished blocks under the reflected light microscope. The petrographic data on size fractions of the seams A to P are listed in Tables 4.3.a to 4.3.e, and depicted in Figures 4.24.a, 4.24.b, 4.25.a, 4.25.b, 4.26.a, 4.26.b, 4.27.a, 4.27.b, 4.28.a and 4.28.b.

SEAMS	SIZE FRACTION (mm)	VITRINITE	INERTINITE	EXINITE	MM
A	>4	26.6	60.4	8.0	5.0
	4x2	29.8	59.8	3.8	6.6
	2x1	38.2	52.2	3.8	5.8
	1x1/2	42.0	47.0	4.2	6.8
	1/2x1/4	43.2	47.2	2.0	7.6
	<1/4	42.4	44.6	5.6	7.4
B	>4	35.0	44.6	13.4	7.0
	4x2	39.8	47.8	7.4	5.0
	2x1	39.0	45.0	10.0	6.0
	1x1/2	54.0	33.2	5.6	7.2
	1/2x1/4	52.0	37.6	3.4	7.0
	<1/4	50.0	36.8	5.2	8.0
C	>4	34.6	49.6	10.6	5.2
	4x2	40.8	48.0	5.6	5.6
	2x1	40.2	48.0	7.8	4.0
	1x1/2	38.8	49.8	5.0	6.4
	1/2x1/4	46.2	43.4	3.4	7.0
	<1/4	39.6	49.2	5.0	6.2
D	>4	40.6	34.8	20.8	3.8
	4x2	48.7	29.9	18.5	2.9
	2x1	50.2	32.1	13.6	4.1
	1x1/2	43.4	38.1	14.1	4.4
	1/2x1/4	52.4	30.8	12.8	4.0
	<1/4	54.6	32.2	9.4	3.8
E	>4	28.0	63.2	6.2	2.6
	4x2	35.0	57.2	3.6	4.2
	2x1	41.0	52.0	4.0	3.0
	1x1/2	36.8	53.6	4.0	5.6
	1/2x1/4	36.2	53.8	4.6	5.4
	<1/4	41.6	49.2	4.2	5.0
F	>4	24.0	61.4	8.8	5.8
	4x2	32.4	55.2	8.2	4.2
	2x1	32.6	53.6	8.2	5.6
	1x1/2	38.0	49.8	7.8	4.4
	1/2x1/4	40.6	47.2	6.2	6.0
	<1/4	42.4	46.2	5.6	5.8
G	>4	58.0	33.2	6.2	2.6
	4x2	59.6	31.8	5.4	3.2
	2x1	55.4	35.2	5.0	4.4
	1x1/2	51.0	41.4	4.0	3.6
	1/2x1/4	60.0	30.2	5.4	4.4
	<1/4	53.0	35.2	6.2	5.6
H	>4	28.4	54.0	12.2	5.4
	4x2	34.6	47.4	11.6	6.4
	2x1	22.2	59.0	11.2	7.6
	1x1/2	31.0	54.0	8.4	6.6
	1/2x1/4	37.4	45.8	10.0	6.8
	<1/4	33.2	44.4	14.0	8.4
I	>4	39.0	46.8	11.4	2.8
	4x2	29.4	57.4	9.4	3.8
	2x1	32.6	57.0	6.4	4.0
	1x1/2	43.4	48.2	4.2	4.2
	1/2x1/4	37.8	48.6	8.8	4.8
	<1/4	36.0	51.4	6.2	6.4
J	>4	48.4	33.2	13.2	5.2
	4x2	40.0	39.2	17.2	3.6
	2x1	51.4	36.2	7.8	4.6
	1x1/2	46.4	40.0	9.0	4.6
	1/2x1/4	41.0	43.2	11.4	4.4
	<1/4	46.8	41.4	6.2	5.6

Table 4.3.a. Maceral and mineral matter content (%) in size fractions of the coal, drill hole RBCH 5.

SEAMS	SIZE FRACTION (mm)	VITRINITE	INERTINITE	EXINITE	MM
	>4	35.2	39.2	19.0	6.6
	4x2	27.0	53.4	13.0	6.6
A	2x1	30.6	53.4	9.8	6.2
	1x1/2	28.2	55.2	9.8	6.8
	1/2x1/4	35.2	47.8	10.8	6.2
	<1/4	34.8	50.2	6.8	8.2
	>4	42.0	42.8	10.0	5.2
	4x2	34.2	50.8	9.2	5.8
B	2x1	45.4	38.2	11.4	5.0
	1x1/2	41.6	46.4	7.2	4.8
	1/2x1/4	43.8	43.2	8.0	5.0
	<1/4	40.2	45.2	8.6	6.0
	>4	36.4	46.6	13.2	3.8
	4x2	39.6	45.8	9.2	5.4
G	2x1	34.4	49.2	11.2	5.2
	1x1/2	36.0	47.6	11.4	5.0
	1/2x1/4	44.8	41.0	8.4	5.8
	<1/4	43.8	42.8	6.6	6.8
	>4	32.2	51.0	12.2	4 6
	4x2	27.8	58.0	10.8	3.4
K	2x1	30.0	55.2	10.0	4.8
	1x1/2	33.8	53.8	7.8	4.6
	1/2x1/4	37.6	50.8	6.0	5.6
	<1/4	35.6	50.4	7.4	6.6

Table 4.3.b. Maceral and mineral matter content (%) in size fractions of the coal, drill hole RBCH 6.

SEAMS	SIZE FRACTION (mm)	VITRINITE	INERTINITE	EXINITE	MM
A	>4	46.6	37.6	12.8	3.0
	4x2	45.4	39.0	13.2	2.4
	2x1	51.4	38.4	7.4	2.8
	1x1/2	46.8	38.4	11.8	3.0
	1/2x1/4	43.2	39.6	13.8	3.4
	<1/4	36.4	50.4	10.4	2.8
B	>4	38.8	46.2	11.2	3.8
	4x2	39.6	48.0	8.8	3.6
	2x1	39.0	47.8	9.8	3.4
	1x1/2	38.6	47.0	10.6	3.8
	1/2x1/4	36.4	51.4	8.4	3.8
	<1/4	42.6	47.6	6.4	3.4
C	>4	33.6	52.0	11.6	2.8
	4x2	44.4	46.2	7.2	2.2
	2x1	31.2	56.0	10.2	2.6
	1x1/2	41.6	48.8	7.0	2.6
	1/2x1/4	38.2	50.0	9.0	2.8
	<1/4	43.2	47.6	6.0	3.2
D	>4	42.8	39.8	12.0	5.4
	4x2	48.6	33.2	13.4	4.8
	2x1	44.6	38.2	12.6	4.6
	1x1/2	52.6	26.6	14.4	6.4
	1/2x1/4	50.6	31.6	13.0	4.8
	<1/4	49.2	35.0	9.0	6.8
E	>4	38.0	50.4	7.8	3.8
	4x2	38.2	50.0	8.4	3.4
	2x1	39.6	48.8	8.4	3.2
	1x1/2	36.2	50.8	9.6	3.4
	1/2x1/4	38.4	49.2	8.8	3.6
	<1/4	39.0	47.0	9.8	4.2
F	>4	31.8	51.8	12.0	4.4
	4x2	25.4	61.6	9.2	3.8
	2x1	27.8	55.0	13.0	4.2
	1x1/2	36.0	50.6	9.2	4.2
	1/2x1/4	34.4	50.8	10.0	4.8
	<1/4	31.6	54.0	9.6	4.8
G	>4	33.4	57.6	4.4	4.6
	4x2	33.2	53.6	7.8	5.4
	2x1	34.0	55.2	6.6	4.2
	1x1/2	34.2	55.6	6.0	4.2
	1/2x1/4	31.2	53.2	10.2	5.4
	<1/4	36.4	53.4	5.2	5.0
H	>4	37.0	51.6	7.4	4.0
	4x2	30.2	59.2	7.0	3.6
	2x1	25.2	63.4	7.6	3.8
	1x1/2	24.6	64.6	7.2	3.6
	1/2x1/4	31.6	56.0	8.2	4.2
	<1/4	32.8	53.8	9.0	4.4
I	>4	24.6	63.2	9.6	2.6
	4x2	20.6	64.8	11.0	3.6
	2x1	22.4	65.4	10.0	2.2
	1x1/2	21.6	65.8	10.2	2.4
	1/2x1/4	29.8	60.0	7.4	2.8
	<1/4	31.8	57.4	7.8	3.0

Table 4.3.c. Maceral and mineral matter content (%) in size fractions of the coal, drill hole RB 3.

SEAMS	SIZE FRACTION (mm)	VITRINITE	INERTINITE	EXINITE	MM
A	>4	28.2	60.0	9.0	2.8
	4x2	36.4	51.2	9.4	3.0
	2x1	36.6	52.0	7.8	3.6
	1x1/2	40.2	48.2	9.2	2.4
	1/2x1/4	41.2	48.6	7.2	3.0
	<1/4	38.6	49.2	8.8	3.4
B	>4	38.2	50.4	8.8	2.6
	4x2	37.6	51.0	9.0	2.4
	2x1	38.4	49.8	8.8	3.0
	1x1/2	43.2	45.6	8.4	2.8
	1/2x1/4	44.2	45.0	8.4	2.4
	<1/4	37.8	50.6	8.8	2.8
C	>4	25.6	58.2	10.0	6.2
	4x2	26.6	58.0	9.6	5.8
	2x1	30.2	56.8	7.6	5.4
	1x1/2	29.0	54.8	9.6	6.6
	1/2x1/4	32.0	52.0	9.8	6.2
	<1/4	27.6	55.4	10.2	6.8
D	>4	48.0	35.2	11.2	5.6
	4x2	41.8	42.6	9.8	5.8
	2x1	40.2	43.8	10.8	5.2
	1x1/2	40.2	44.6	10.2	5.0
	1/2x1/4	42.4	42.6	9.2	5.8
	<1/4	40.6	44.2	10.4	4.8
E	>4	33.8	55.6	6.8	3.8
	4x2	34.2	54.0	7.0	4.8
	2x1	34.8	55.2	5.6	4.4
	1x1/2	37.2	52.0	6.6	4.2
	1/2x1/4	40.6	47.0	7.2	5.2
	<1/4	34.4	54.4	6.6	4.6
F	>4	42.8	40.4	10.4	6.4
	4x2	44.0	38.8	11.0	6.2
	2x1	46.4	37.6	10.8	5.2
	1x1/2	49.0	32.4	11.8	6.8
	1/2x1/4	50.4	34.2	9.8	5.6
	<1/4	45.8	38.6	10.2	5.4
G	>4	35.8	56.2	5.4	2.6
	4x2	37.0	54.2	5.8	3.0
	2x1	37.0	54.8	5.2	3.0
	1x1/2	38.0	53.2	5.6	3.2
	1/2x1/4	42.0	49.4	5.6	3.0
	<1/4	43.2	47.8	6.2	2.8
H	>4	35.2	52.4	9.0	3.4
	4x2	49.6	9.4	2.8	45.0
	2x1	45.0	43.8	8.0	3.2
	1x1/2	46.8	40.6	9.0	3.6
	1/2x1/4	44.4	43.8	8.8	3.0
	<1/4	41.2	47.0	9.2	2.6

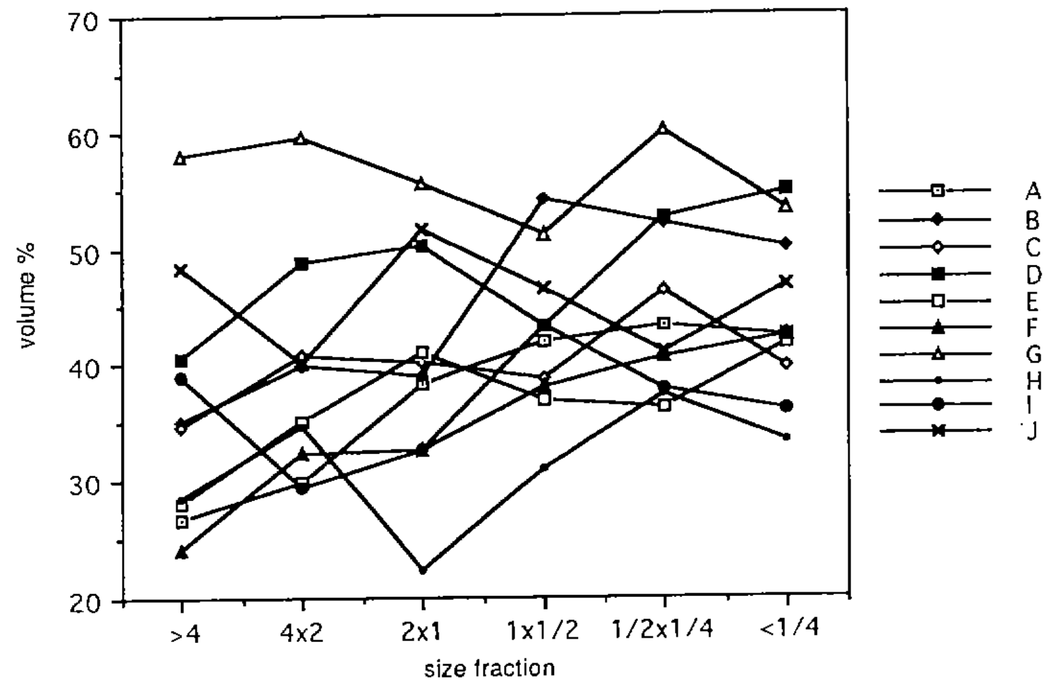
Table 4.3.d. Maceral and mineral matter content (%) in size fractions of the coal, drill hole CRCH 1.

SEAMS	SIZE FRACTION (mm)	VITRINITE	INERTINITE	EXINITE	MM
I	>4	49.2	36.2	9.8	4.8
	4x2	45.8	41.4	8.4	4.4
	2x1	45.2	43.4	7.4	4.0
	1x1/2	47.6	40.4	8.4	3.6
	1/2x1/4	49.6	38.2	7.6	4.6
	<1/4	45.8	42.6	7.4	4.2
J	>4	43.2	37.8	11.6	7.4
	4x2	39.8	44.0	10.8	5.4
	2x1	37.6	44.0	12.6	5.8
	1x1/2	41.6	42.8	10.6	5.0
	1/2x1/4	44.2	40.6	10.6	4.6
	<1/4	40.2	45.8	9.2	4.8
K	>4	39.6	46.8	10.8	2.8
	4x2	42.8	45.2	9 6	2.4
	2x1	46.8	39.6	10.4	3.2
	1x1/2	49.8	38.0	9.4	2.8
	1/2x1/4	54.6	32.4	9.6	3.4
	<1/4	49.6	38.4	9.4	2.6
L	>4	37.8	52.2	5.8	4.2
	4x2	38.8	51.6	5.8	3.8
	2x1	41.6	50.0	5.6	2.8
	1x1/2	44.2	46.6	5.4	3.8
	1/2x1/4	38.4	53.4	4.6	3.6
	<1/4	41.8	50.6	4.2	3.4
M	>4	19.4	58.2	14.4	8.0
	4x2	20.6	66.4	7.2	5.8
	2x1	25.4	61.6	7.8	5.2
	1x1/2	23.6	62.8	7.4	6.2
	1/2x1/4	20.2	66.0	7.2	6.6
	<1/4	19.8	67.0	7.6	5.6

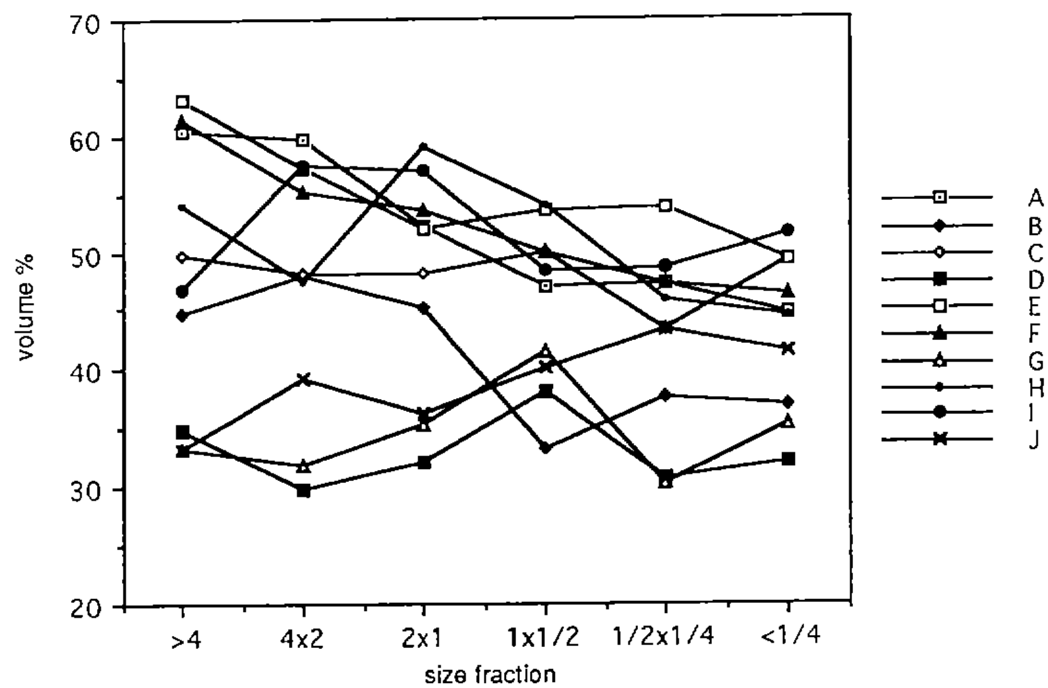
Table 4.3.d. Maceral and mineral matter content (%) in size fractions of the coal, drill hole CRCH 1.

SEAMS	SIZE FRACTION (mm)	VITRINITE	INERTINITE	EXINITE	MM
A	>4	33.6	45.0	19.0	2.4
	4x2	37.4	45.6	14.8	2.2
	2x1	39.6	44.0	13.8	2.6
	1x1/2	37.2	46.4	12.4	4.0
	1/2x1/4	38.0	41.6	17.2	3.2
	<1/4	39.8	48.0	8.4	3.8
J	>4	36.8	44.8	13.2	5.2
	4x2	36.6	41.4	15.8	6.2
	2x1	32.8	45.0	17.2	5.0
	1x1/2	35.8	44.0	14.4	5.8
	1/2x1/4	32.6	49.2	12.8	5.4
	<1/4	41.0	43 2	8 8	7 0
M	>4	69.6	11.6	16.6	2.2
	4x2	70.2	9.2	18.2	2.4
	2x1	67.0	15.4	15.0	2.6
	1x1/2	60.8	15.4	20.4	3.4
	1/2x1/4	60.8	18.4	17.2	3.6
	<1/4	71.2	12.6	12.4	3.8
N	>4	43.4	42.4	9.2	5.0
	4x2	43.8	39.4	10.0	6.8
	2x1	42.6	40.8	10.8	5.8
	1x1/2	47.4	39.4	9.0	4.2
	1/2x1/4	46.4	40.2	8.4	5.0
	<1/4	50.0	37.0	6.8	6.2
O	>4	48.4	32.8	10.6	8.2
	4x2	49.4	32.2	10.2	8.2
	2x1	54.2	24.0	13.0	8.8
	1x1/2	55.0	25.0	12.6	7.4
	1/2x1/4	55.2	25.0	11.2	8.6
	<1/4	58.8	25.0	3.8	12.4
P	>4	25.6	56.2	11.4	6.8
	4x2	26.0	56.6	10.8	6.6
	2x1	30.8	55.6	7.4	6.2
	1x1/2	22.2	58.6	12.8	6.4
	1/2x1/4	26.8	59.4	8.2	5.6
	<1/4	32.0	53.4	7.4	7.2

Table 4.3.e. Maceral and mineral matter content (%) in size fractions of the coal, drill hole CRCH 2.

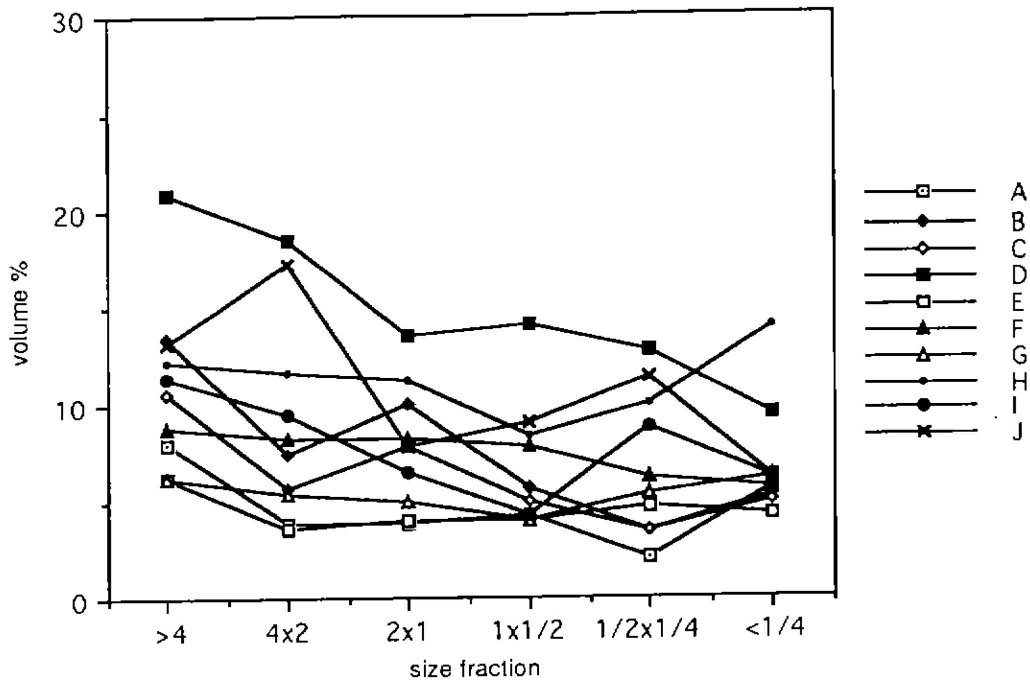


Vitrinite content of size fractions, seams A to J, drill hole RBCH 5

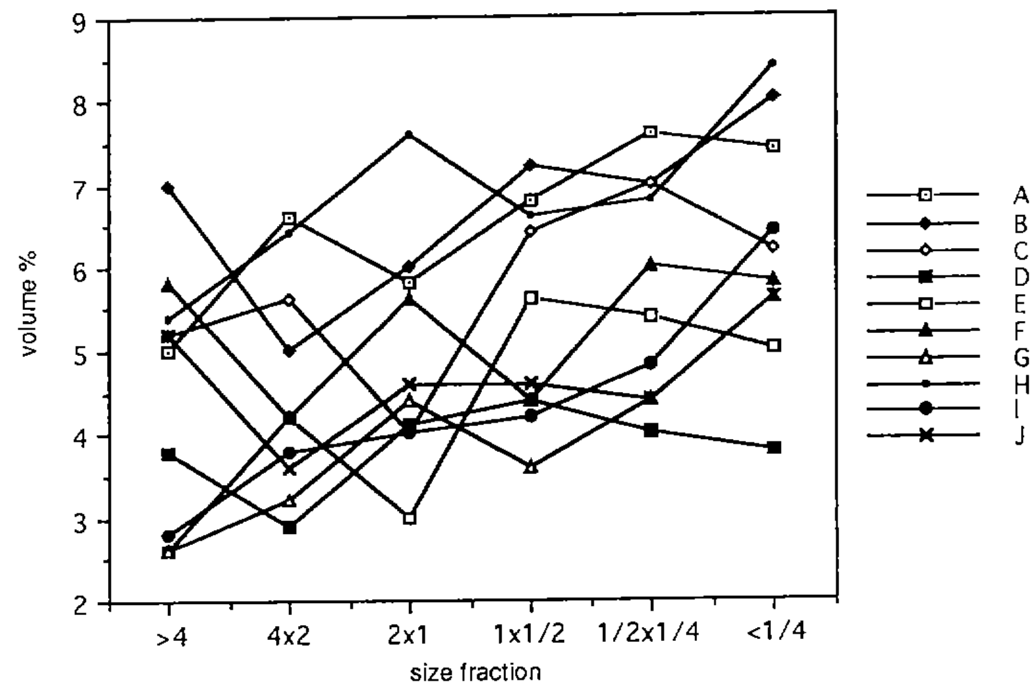


Inertinite content of size fractions, seams A to J, drill hole RBCH 5

Figure 4.24.a. Vitrinite and inertinite content variations of the size fractions, seams A to J, drill hole RBCH 5, Vasse Shelf, Perth Basin.

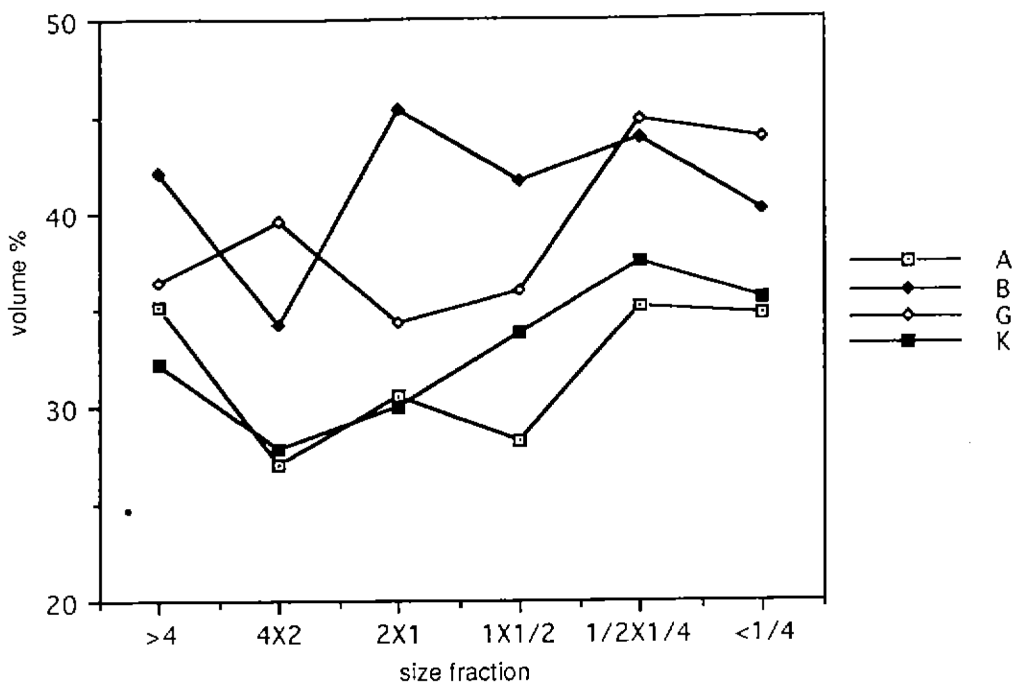


Exinite content of size fractions, seams A to J, drill hole RBCH 5

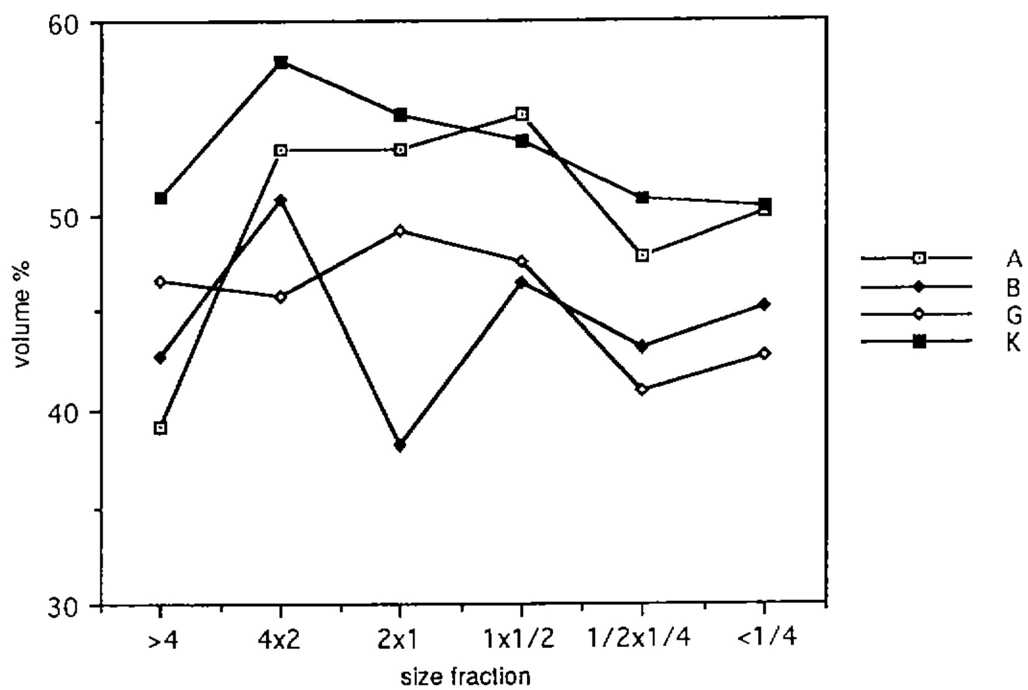


Mineral matter content of size fractions, seams A to J, drill hole RBCH 5

Figure 4.24.b. Exinite and mineral matter content variations of the size fractions, seams A to J, drill hole RBCH 5, Vasse Shelf, Perth Basin.

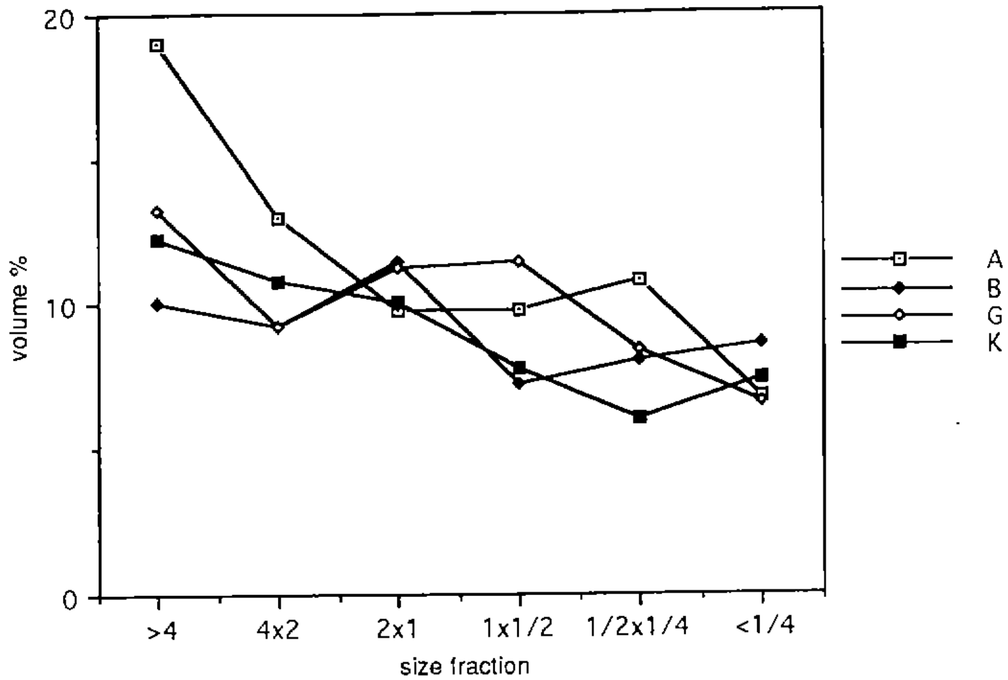


Vitrinite content of size fractions, seams A, B, G and K, drill hole RBCH 6

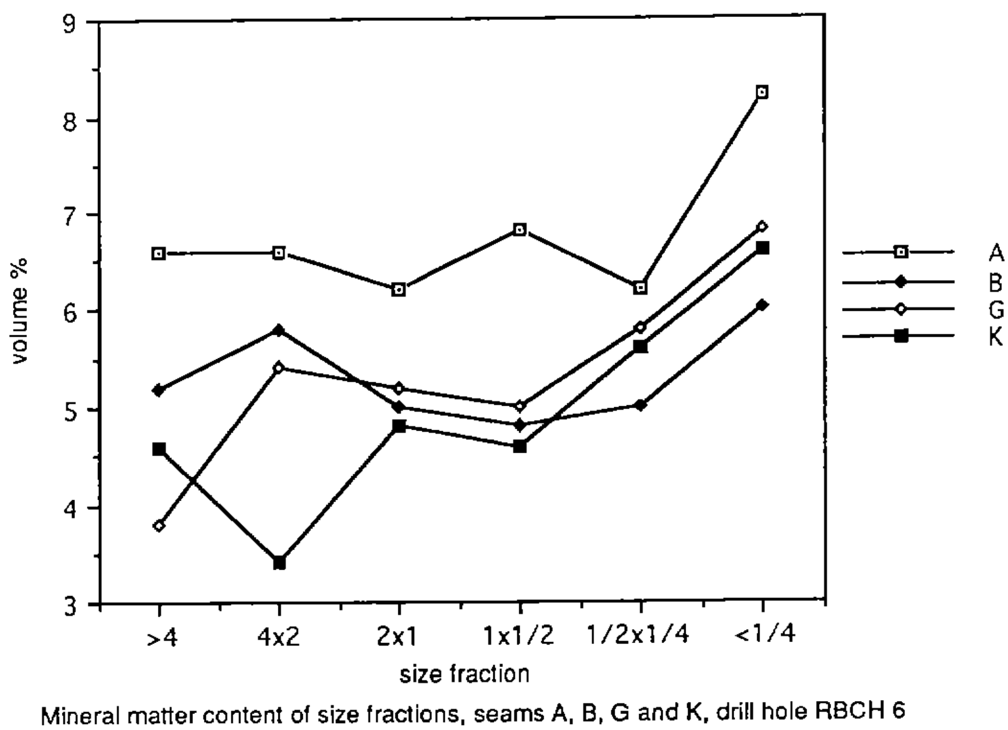


Inertinite content of size fractions, seams A, B, G and K, drill hole RBCH 6

Figure 4.25.a. Vitrinite and inertinite content variations of the size fractions, seams A, B, G and K, drill hole RBCH 6, Vasse Shelf, Perth Basin.

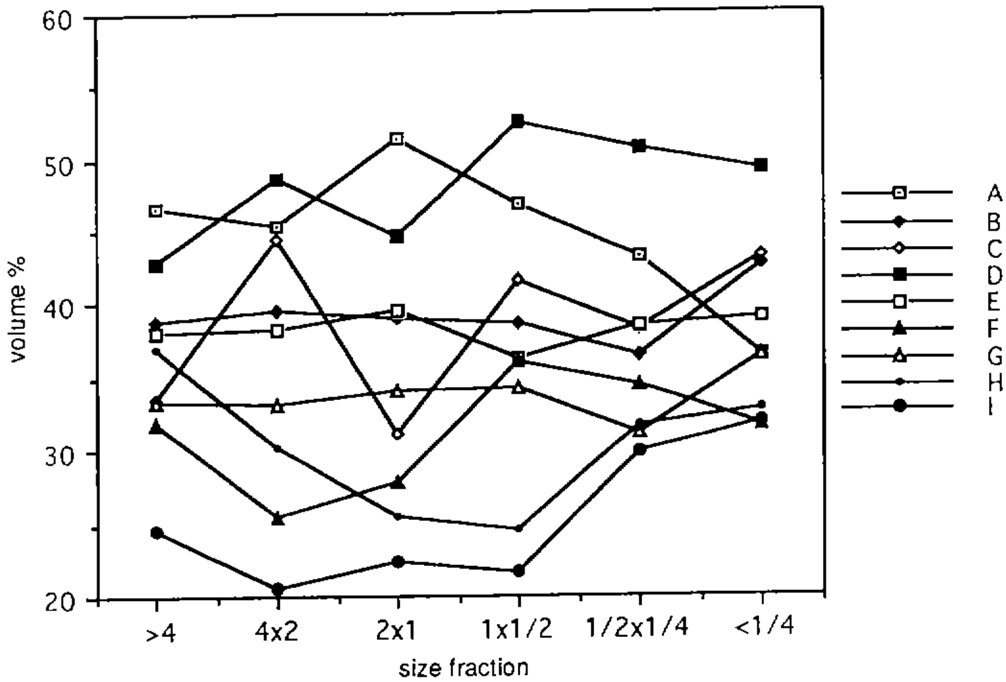


Exinite content of size fractions, seams A, B, G and K, drill hole RBCH 6

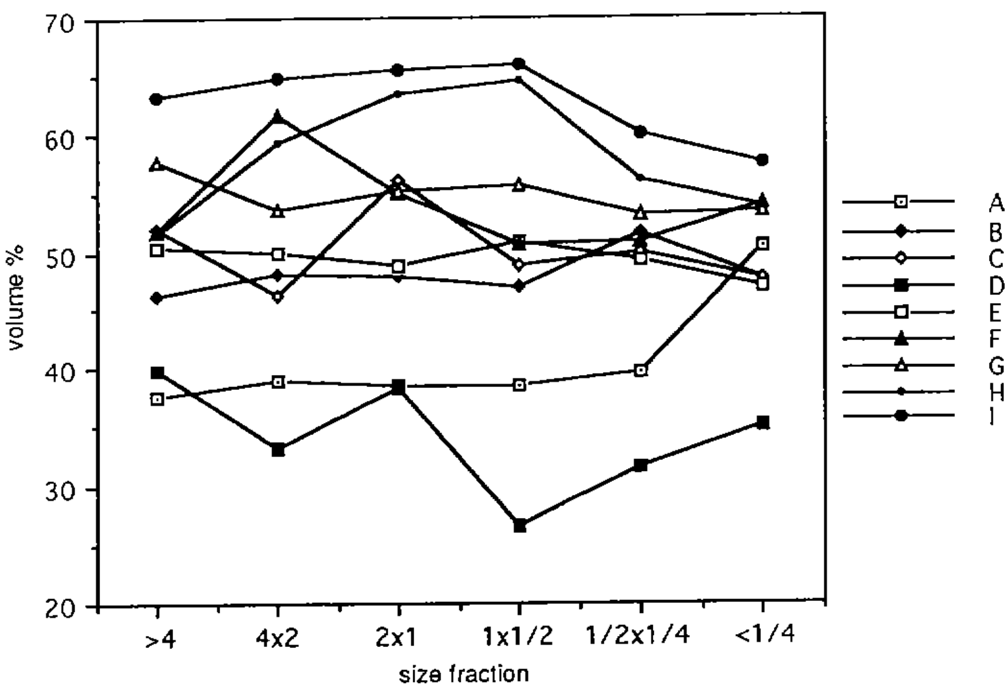


Mineral matter content of size fractions, seams A, B, G and K, drill hole RBCH 6

Figure 4.25.b. Exinite and mineral matter content variations of the size fractions, seams A, B, G and K, drill hole RBCH 6, Vasse Shelf, Perth Basin.

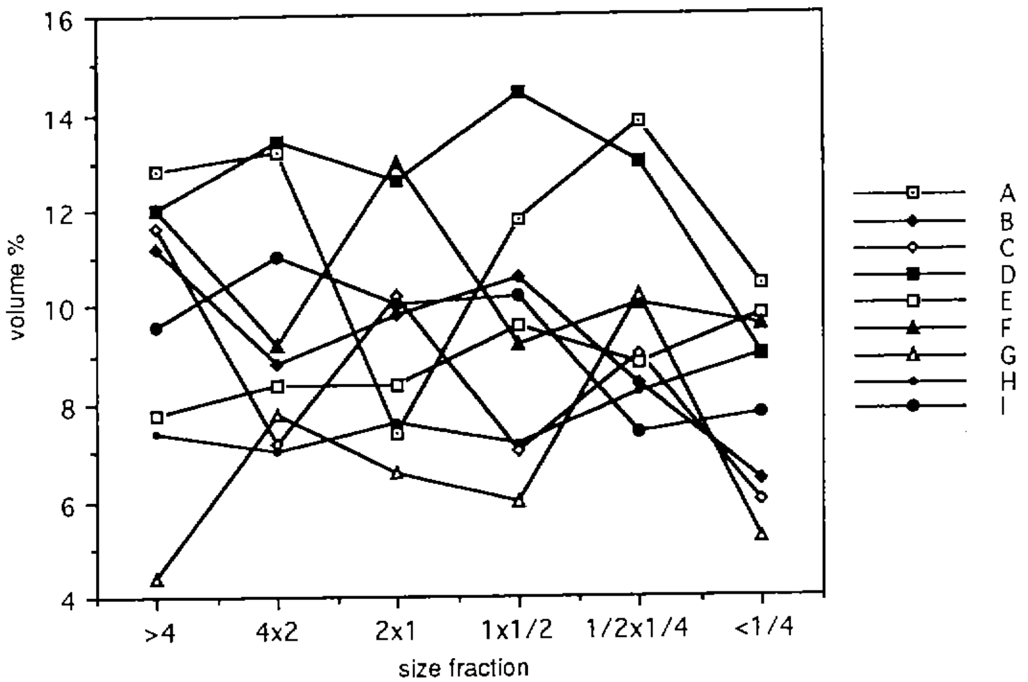


Vitrinite content of size fractions, seams A to I, drill hole RB 3

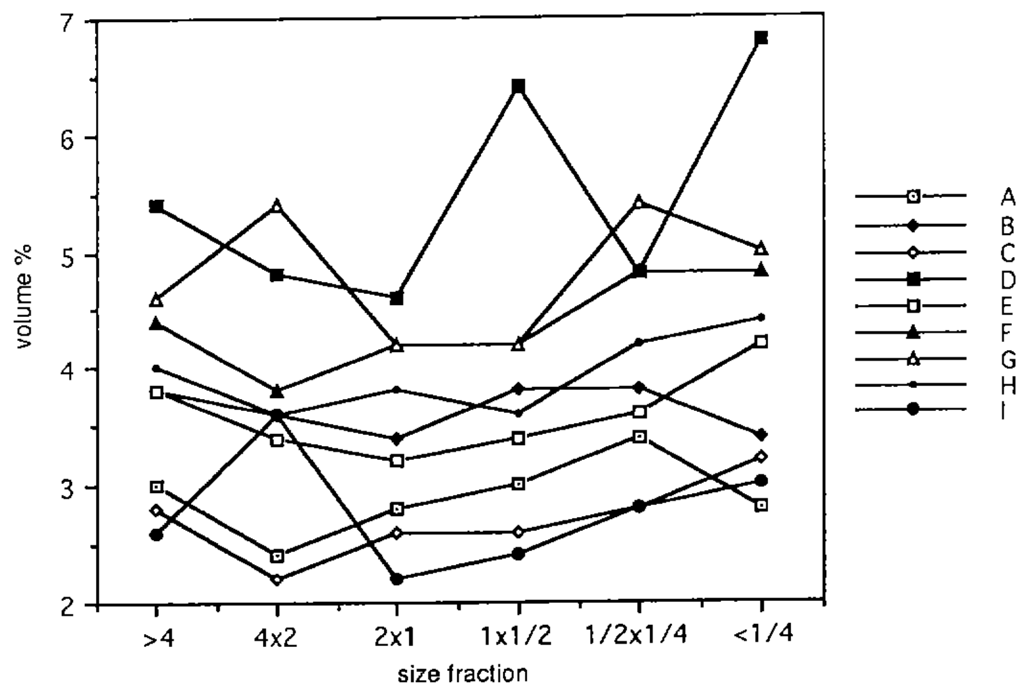


Inertinite content of size fractions, seams A to I, drill hole RB 3

Figure 4.26.a. Vitrinite and inertinite content variations of the size fractions, seams A to I, drill hole RB 3, Vasse Shelf, Perth Basin.

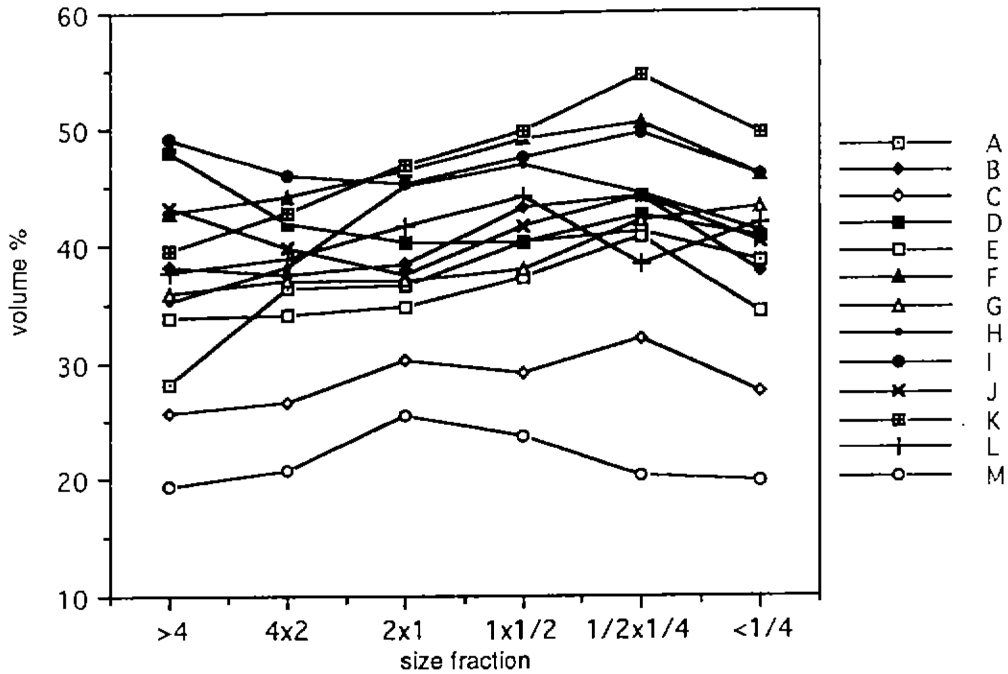


Exinite content of size fractions, seams A to I, drill hole RB 3

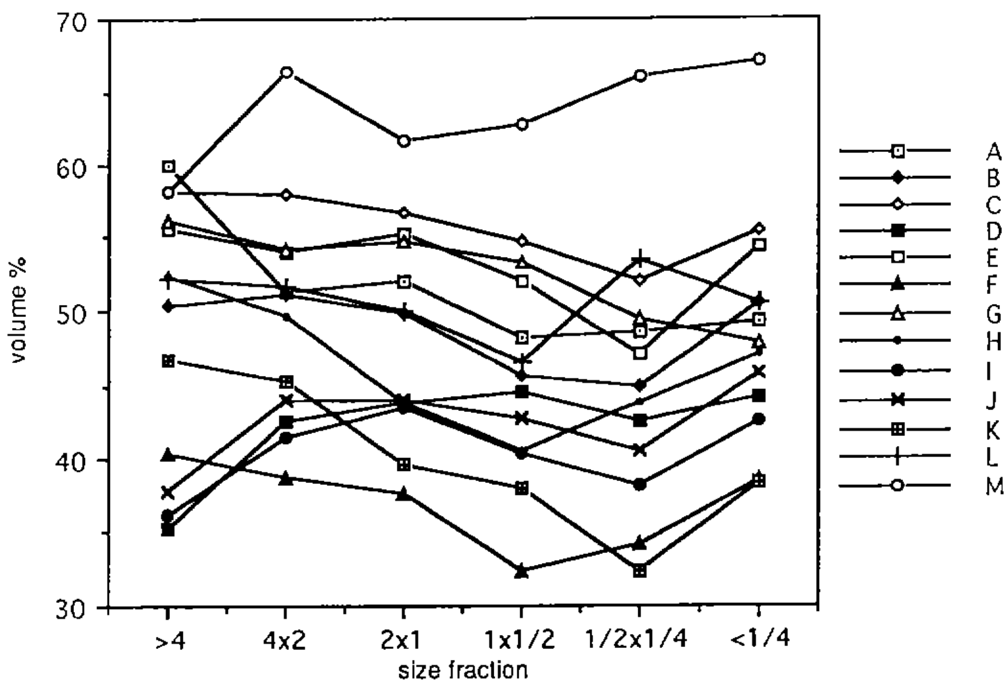


Mineral matter content of size fractions, seams A to I, drill hole RB 3

Figure 4.26.b. Exinite and mineral matter content variations of the size fractions, seams A to I, drill hole RB 3, Vasse Shelf, Perth Basin.

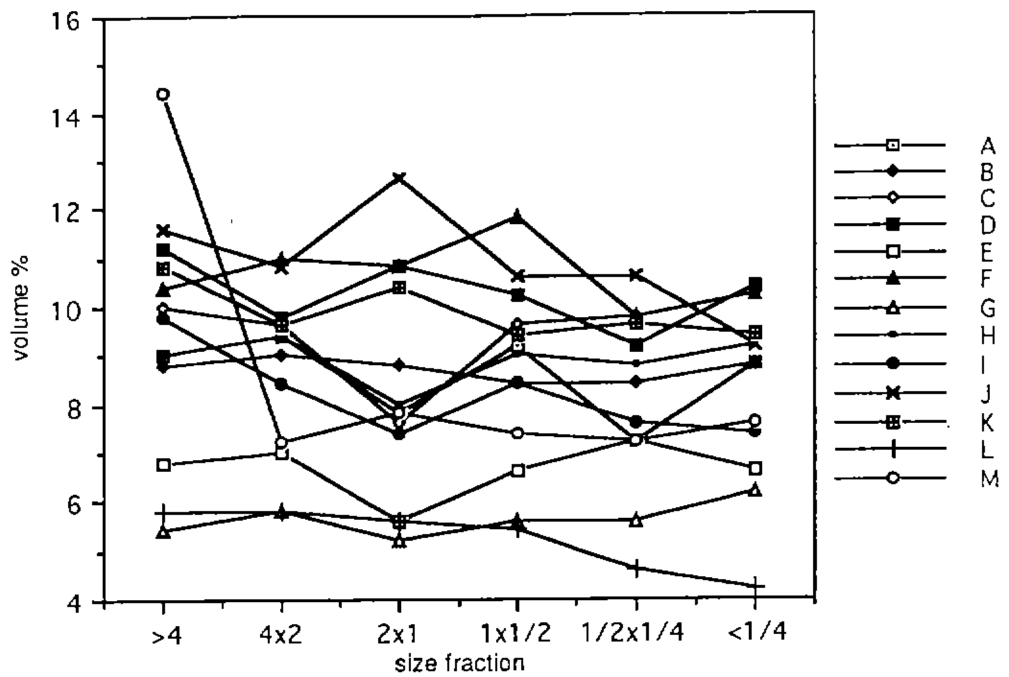


Vitrinite content of size fractions, seams A to M, drill hole CRCH 1

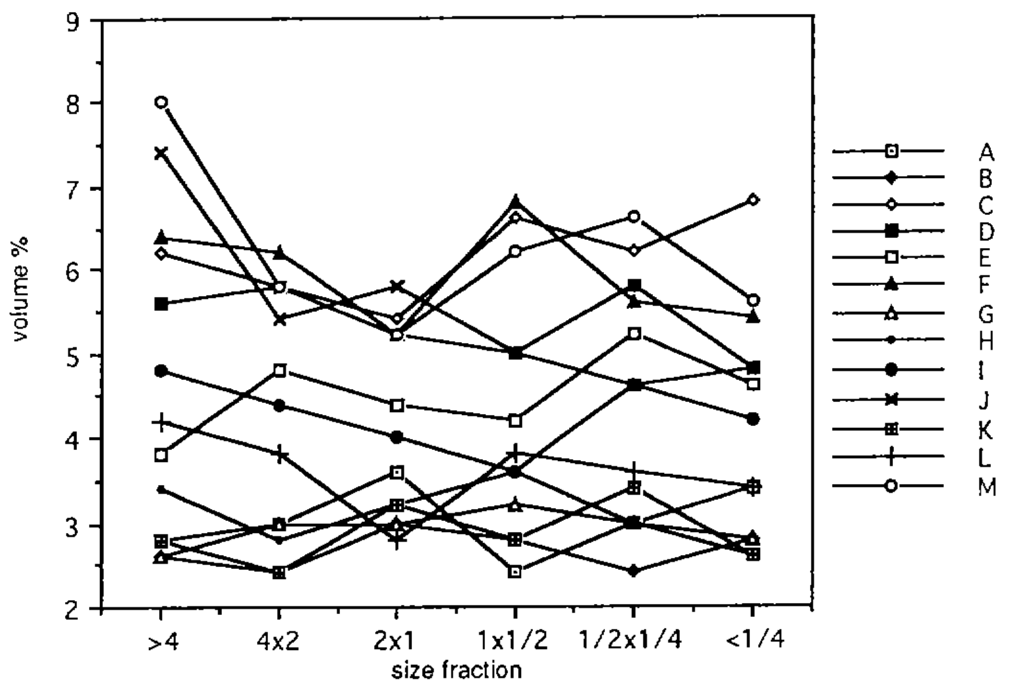


Inertinite content of size fractions, seams A to M, drill hole CRCH 1

Figure 4.27.a. Vitrinite and inertinite content variations of the size fractions, seams A to M, drill hole CRCH 1, Vasse Shelf, Perth Basin.

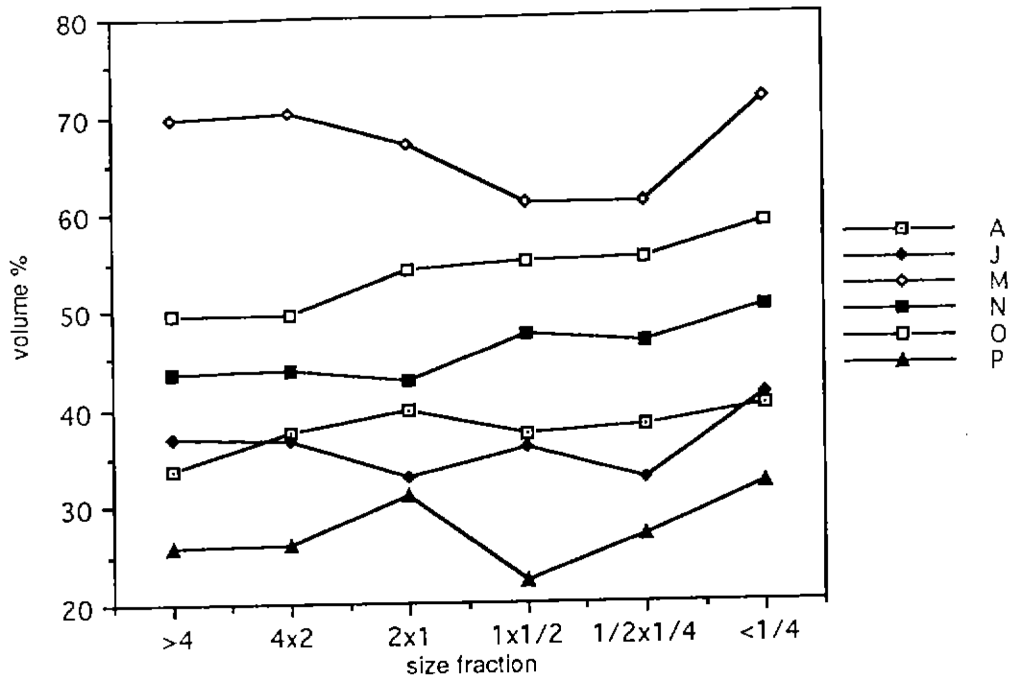


Exinite content of size fractions, seams A to M, drill hole CRCH 1

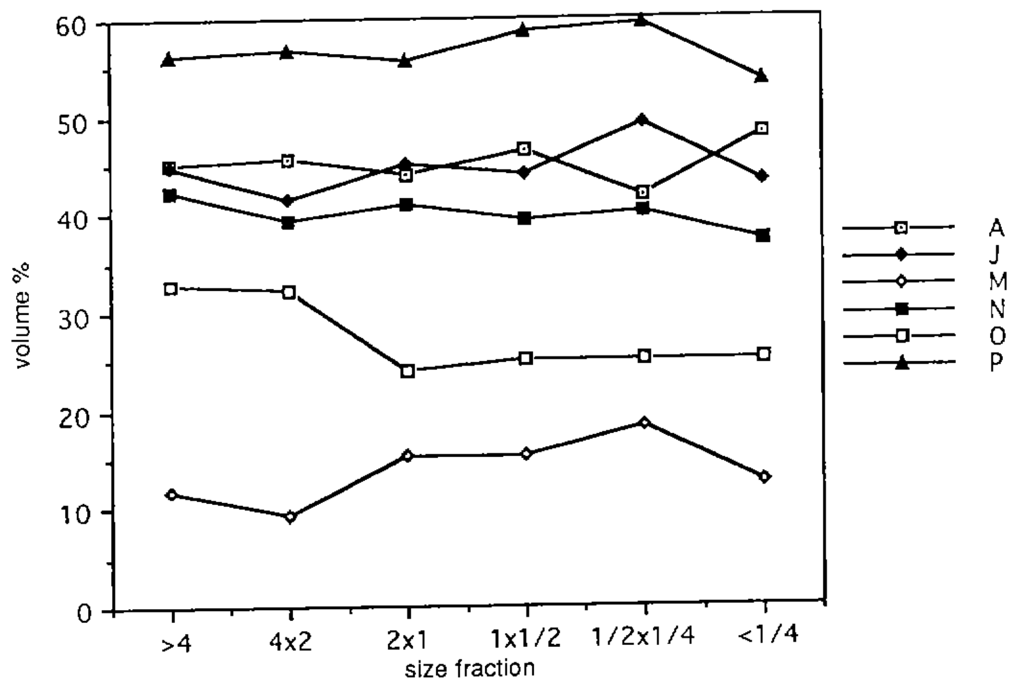


Mineral matter content of size fractions, seams A to M, drill hole CRCH 1

Figure 4.27.b. Exinite and mineral matter content variations of the size fractions, seams A to M, drill hole CRCH 1, Vasse Shelf, Perth Basin.

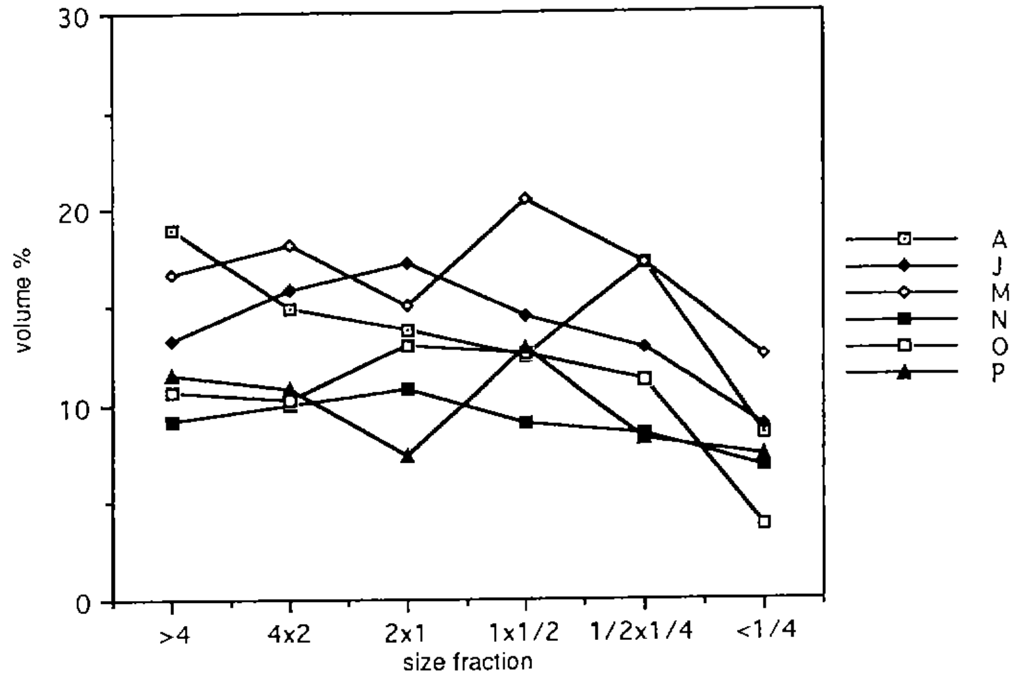


Vitrinite content of size fractions, seams A, J, M, N, O and P, drill hole CRCH 2

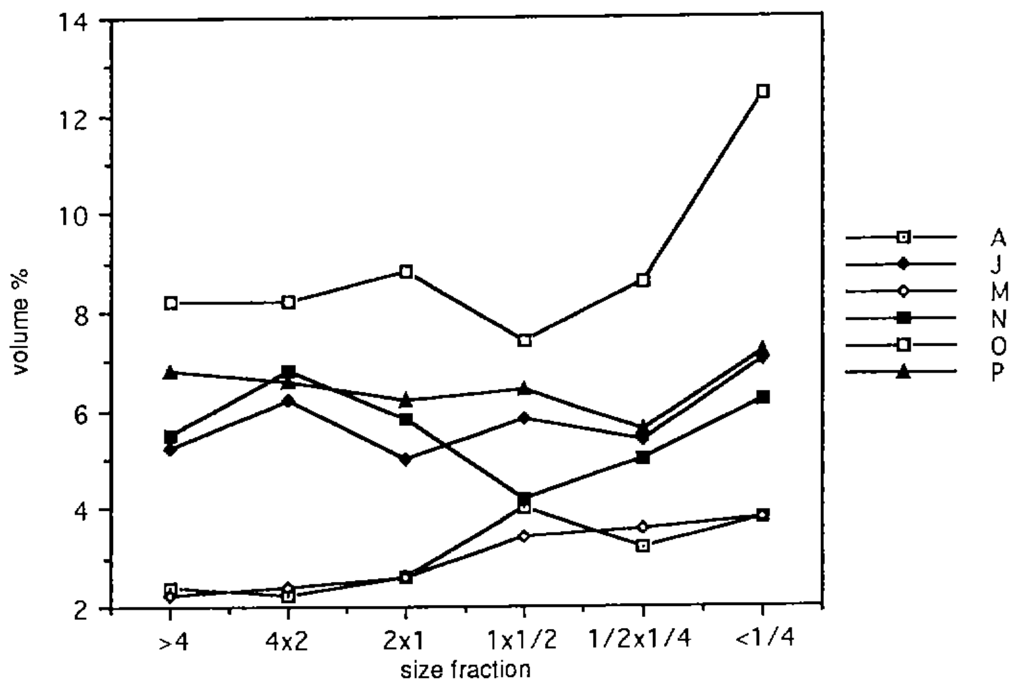


Inertinite content of size fractions, seams A, J, M, N, O and P, drill hole CRCH 2

Figure 4.28.a. Vitrinite and inertinite content variations of the size fractions, seams A, J, M, N, O and P, drill hole CRCH 2, Vasse Shelf, Perth Basin.



Exinite content of size fractions, seams A, J, M, N, O and P, drill hole CRCH 2



Mineral matter content of size fractions, seams A, J, M, N, O and P, drill hole CRCH 2

Figure 4.28.b. Exinite and mineral matter content variations of the size fractions, seams A, J, M, N, O and P, drill hole CRCH 2, Vasse Shelf, Perth Basin.

The vitrinite and inertinite contents of different size fractions of the seams A to P in drill holes RBCH 5, RBCH 6, RB 3, CRCH 1 and CRCH 2 are shown in Figures 4.24.a, 4.25.a, 4.26.a, 4.27.a and 4.28.a. In the majority of the seams, the vitrinite content shows a slight increase followed by a decrease with declining size fractions, and the reverse is true for the inertinite content in the size fractions. The exinite and mineral matter contents of the size fractions are given in Figures 4.24.b, 4.25.b, 4.26.b, 4.27.b and 4.28.b, which follow trends similar to those of vitrinite and inertinite, with the exceptions for the exinite content in the seams G, H and I of drill hole RB 3 (Figure 4.26.b), and the mineral matter content in the seams D, F, J, L and M of drill hole CRCH 1 (Figure 4.23.b); this is probably due to influx of the mineral matter during the deposition of the seams.

4.2.6. Microlithotype Analyses

The data on microlithotype analyses of the Vasse Shelf coal are presented using the following groupings :

. Monomaceral (vitrite, liptite and inertite), bimaceral (clarite, vitrinertite and durite) and trimaceral (duroclarite, vitrinertoliptite and clarodurite).

. The composition of carbominerites in the coal samples is calculated in terms of carbargilite, carbopyrite and carbosilicate.

The microlithotype compositions of the coal are given in Table 4.4 and Figures 4.29.a and 4.29.b which show that the typical microlithotype observed in the coal consists of inertite, vitrite, clarite, vitrinertite, durite, duroclarite and clarodurite. The liptite occurs in very low amount in the coal. The carbominerite is composed mainly of carbargillite and carbopyrite. In terms of microlithotype group, the coal is predominantly composed of monomaceral and bimaceral, followed by trimaceral and

DRILL HOLES	MICROLITHOTYPE GROUP (%)	SEAMS															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
RBCH 5	**Monomaceral**																
	Vitrite	41.0	57.8	42.8	33.0	15.6	13.8	46.6	25.8	31.2	33.4						
	Liptite	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2						
	Inertite	22.4	14.2	21.2	12.8	45.4	38.6	13.4	37.6	46.6	23.6						
	Bimaceral																
	Clarite	11.2	6.2	9.8	28.8	6.4	7.8	15.0	7.8	8.8	20.2						
	Vitrinertite	9.6	7.2	5.8	3.8	11.2	10.2	6.8	4.2	3.2	3.4						
	Durite	5.8	2.0	10.0	8.2	7.6	15.2	5.8	16.0	3.2	10.0						
	Trimaceral																
	Duroclarite	4.8	5.4	3.4	4.4	4.6	5.2	7.0	3.6	2.0	3.0						
	Vitrinertoliptite	0.0	0.4	1.0	0.8	0.6	0.6	0.6	1.2	0.8	1.4						
	Clarodurite	1.4	2.4	2.6	4.4	4.0	4.8	2.0	1.0	0.6	0.8						
	Carbominerites																
	Carbargilite	3.0	3.6	2.6	2.4	3.2	2.6	1.4	1.8	2.6	3.4						
	Carbopyrite	0.6	0.4	0.4	0.4	1.0	0.4	0.8	0.8	0.4	0.6						
	Carbosilicate	0.2	0.4	0.4	0.8	0.4	0.8	0.6	0.2	0.6	0.0						
RBCH 6	**Monomaceral**																
	Vitrite	36.0	45.6					21.2				22.2					
	Liptite	0.0	0.0					0.2				0.0					
	Inertite	26.8	16.2					24.2				42.4					
	Bimaceral																
	Clarite	11.4	10.2					12.0				13.2					
	Vitrinertite	2.2	6.4					9.2				4.0					
	Durite	10.6	3.4					8.8				8.2					
	Trimaceral																
	Duroclarite	6.4	10.0					11.6				3.4					
	Vitrinertoliptite	0.6	0.4					2.6				0.6					
	Clarodurite	2.8	3.6					6.0				1.8					
	Carbominerites																
	Carbargilite	1.8	3.6					3.2				2.6					
	Carbopyrite	1.0	0.4					0.8				1.2					
	Carbosilicate	0.4	0.2					0.2				0.4					

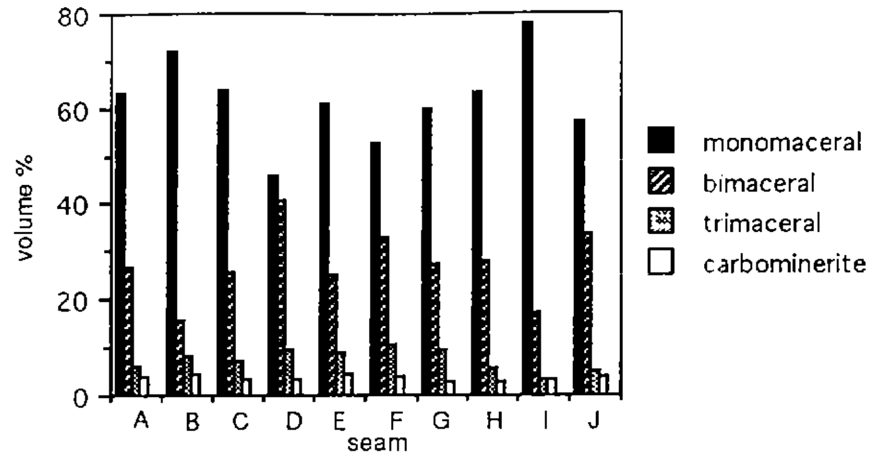
Table 4.4. Microlithotype composition (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.

DRILL HOLES	MICROLITHOTYPE GROUP (%)	SEAMS															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
RB 3	**Monomaceral**																
	Vitrite	23.2	22.2	33.6	35.4	23.4	13.2	19.0	14.2	14.2							
	Liptite	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.2	0.0							
	Inertite	24.4	26.2	27.2	18.8	41.0	32.2	49.0	43.4	44.8							
	Bimaceral																
	Clarite	18.6	4.2	7.0	15.4	6.6	18.8	4.4	1.0	5.6							
	Vitrinertite	13.4	16.2	13.2	5.6	9.8	7.2	7.6	6.4	6.8							
	Durite	3.2	3.2	3.0	4.2	9.4	13.0	8.2	20.0	15.6							
	Trimaceral																
	Duroclarite	9.0	16.8	10.0	7.4	3.2	6.4	4.4	5.2	4.2							
	Vitrinertoliptite	0.4	0.6	0.2	1.4	0.2	1.0	0.8	0.6	0.0							
	Clarodurite	5.2	7.8	4.2	5.2	3.6	4.4	3.6	5.0	7.8							
	Carbominerites																
	Carbargilite	2.2	2.0	0.8	5.2	1.2	2.2	1.4	3.0	0.6							
	Carbopyrite	0.2	0.2	0.2	0.2	0.8	1.0	1.0	0.6	0.2							
	Carbosilicate	0.2	0.6	0.6	0.6	0.8	0.6	0.6	0.4	0.2							
CRCH 1	**Monomaceral**																
	Vitrite	13.0	8.4	9.2	26.2	18.2	43.8	17.6	23.6	41.0	21.4	28.6	17.4	4.6			
	Liptite	0.2	0.0	0.4	0.8	0.2	2.2	0.0	0.0	0.0	0.8	0.0	0.0	0.0			
	Inertite	37.8	50.0	50.6	24.8	42.2	18.6	46.4	35.6	26.8	44.6	21.0	33.8	47.4			
	Bimaceral																
	Clarite	2.4	0.2	2.8	4.6	2.8	11.0	1.6	1.6	5.2	7.2	6.2	2.8	0.4			
	Vitrinertite	26.2	27.8	14.0	21.4	15.0	6.8	16.2	22.2	14.0	7.6	27.0	13.4	8.8			
	Durite	7.6	4.8	9.2	4.4	9.4	3.6	8.2	3.8	1.8	10.2	0.8	14.2	25.2			
	Trimaceral																
	Duroclarite	5.8	1.8	3.0	9.0	2.6	4.4	3.8	5.4	4.0	1.2	7.4	6.0	3.0			
	Vitrinertoliptite	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.4	0.0	0.0	0.4	0.8	0.4			
	Clarodurite	4.2	3.2	3.6	1.8	2.6	1.4	2.4	2.2	1.2	0.8	4.4	7.6	4.0			
	Carbominerites																
	Carbargilite	1.6	3.0	5.4	6.2	6.0	6.2	2.4	3.4	3.8	4.0	2.2	1.4	4.0			
	Carbopyrite	0.8	0.8	1.0	0.8	0.6	1.0	0.4	0.8	1.0	1.4	1.4	2.2	1.4			
	Carbosilicate	0.4	0.0	0.8	0.0	0.4	0.2	1.0	1.0	1.2	0.8	0.6	0.4	0.8			

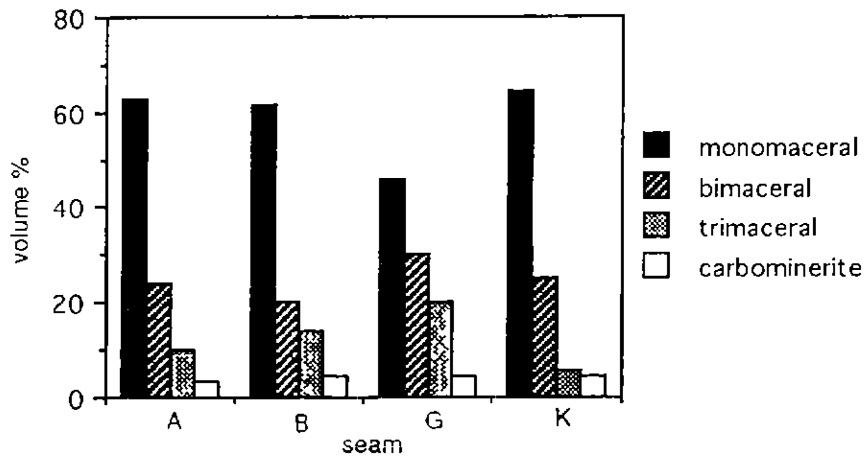
Table 4.4. Microlithotype composition (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.

DRILL HOLES	MICROLITHOTYPE GROUP (%)	SEAMS															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
CRCH 2	**Monomaceral**																
	Vitrite	19.0									16.8			53.2	24.8	32.6	14.0
	Liptite	0.0									0.2			0.8	0.6	0.2	0.0
	Inertite	23.6									18.8			4.4	23.0	17.8	37.2
	Bimaceral																
	Clarite	18.8									15.8			31.6	14.4	30.8	3.2
	Vitrinertite	8.4									2.0			2.8	3.4	3.0	7.2
	Durite	12.8									36.4			1.8	12.2	3.4	17.6
	Trimaceral																
	Duroclarite	11.0									2.0			1.8	12.8	6.8	7.2
	Vitrinertoliptite	1.0									2.0			0.6	1.6	0.2	1.6
	Clarodurite	3.2									1.2			0.4	4.0	1.2	7.6
	Carbominerites																
	Carbargilite	1.2									3.6			0.8	2.6	2.4	3.2
	Carbopyrite	0.6									0.4			1.2	0.2	1.2	0.8
	Carbosilicate	0.4									0.8			0.6	0.4	0.4	0.4

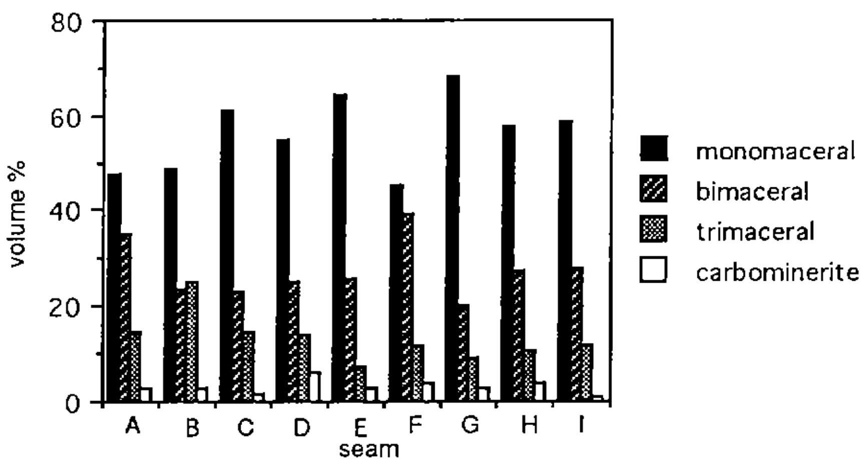
Table 4.4. Microlithotype composition (%) of the coal seams, Vasse Shelf, Perth Basin, Western Australia.



Microlithotype distribution, RBCH 5

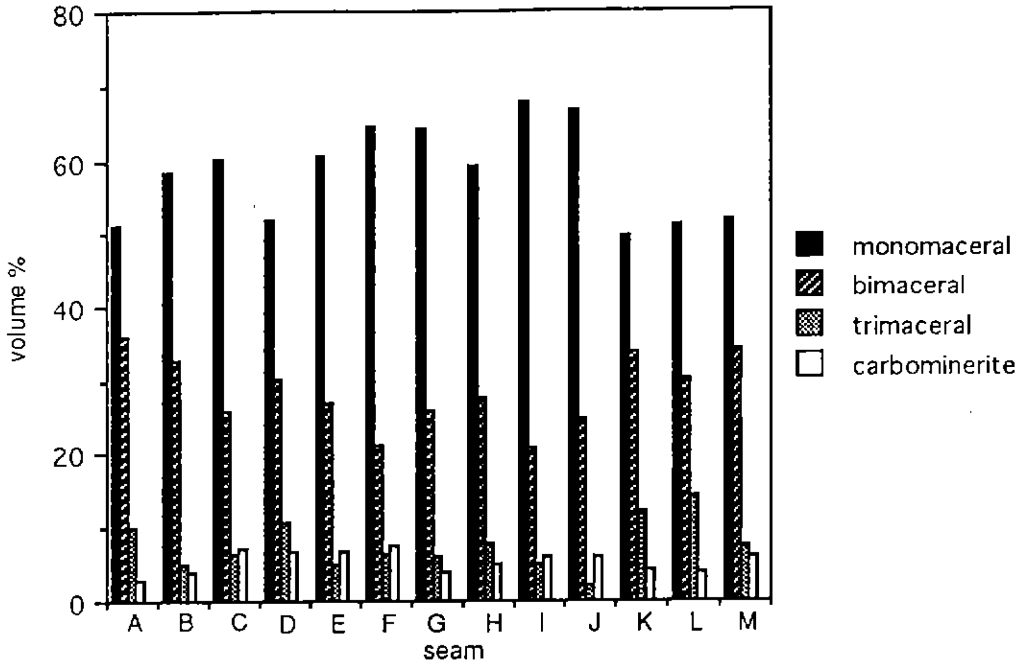


Microlithotype distribution, RBCH 6

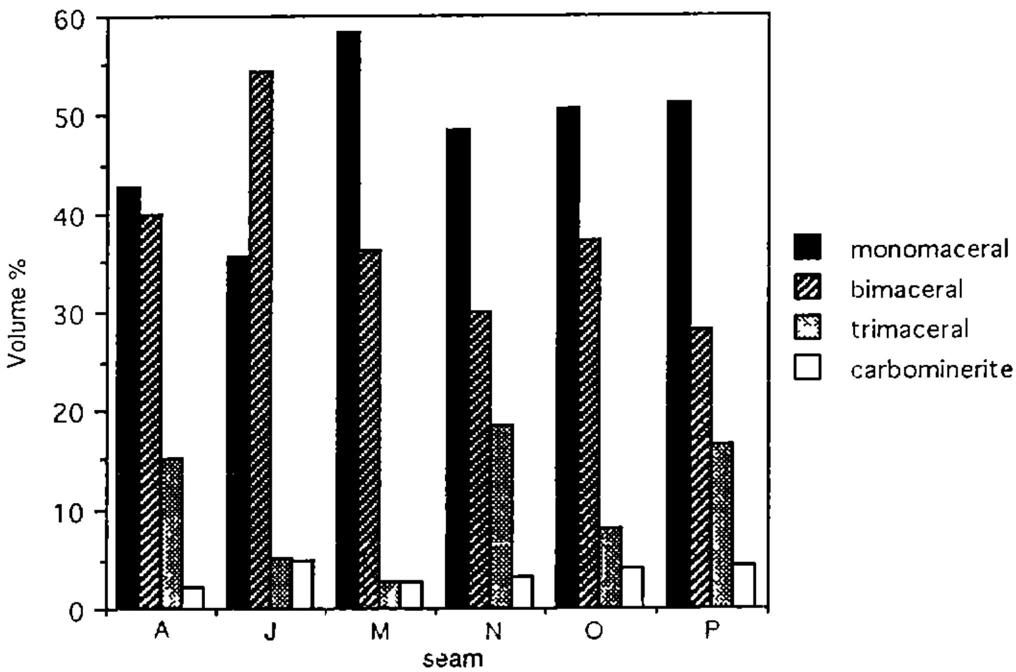


Microlithotype distribution, RB 3

Figure 4.29.a. Microlithotype distribution of the Vasse Shelf coal, drill holes RBCH 5, RBCH 6 and RB 3.



Microlithotype distribution, CRCH 1



Microlithotype distribution, CRCH 2

Figure 4.29.b. Microlithotype distribution of the Vasse Shelf coal, drill holes CRCH 1 and CRCH 2.

minor carbominerite. The data on microlithotype composition of the coal are also given in a ternary diagram in Figure 4.30 on carbominerite free-basis. The figure shows the abundance of the monomaceral microlithotype. The dominant monomaceral suggests the coal was formed under either drier or wetter conditions during its deposition, depending on the domination of the inertite or vitrite contents, respectively.

The inertite and vitrite are dominant monomaceral microlithotypes occurring in the seams A to P, and their contents vary between 4.4% in the seam M of CRCH 2 and 50.6% in the seam C of CRCH 1 and 4.6% in the seam M of CRCH 1 and 57.8% in the seam B of RBCH 5, respectively, as shown in Table 4.4. The liptite content is very low in all seams, and the content 0.8%is recorded (Figure 4.31) in the seam J of CRCH 1 and the seam M of CRCH 2. The dominance of inertite suggests the coal was formed under drier condition with high degree of oxidation during its deposition.

The major bimaceral microlithotypes occurring in the coal is clarite, and its content ranges from 0.4% in the seam M of CRCH 1 and 31.6% in the seam M of CRCH 2. This is followed by vitrinertite ranging between 2.0% in the seam J of CRCH 2 and 27.8% in the seam B of CRCH 1, and durite with a range of 0.8% in the seam K of CRCH 1 and 36.4% in the seam J of CRCH 2. The data on bimaceral microlithotype is illustrated as a ternary diagram in Figure 4.32, which shows the predominance of vitrinertite over clarite and durite, this reflects the different rates of subsidence during the deposition of the coal.

The duroclarite and clarodurite are the major trimaceral microlithotypes in the coal, which occur within the range of 1.2% in the seam J of CRCH 1 and

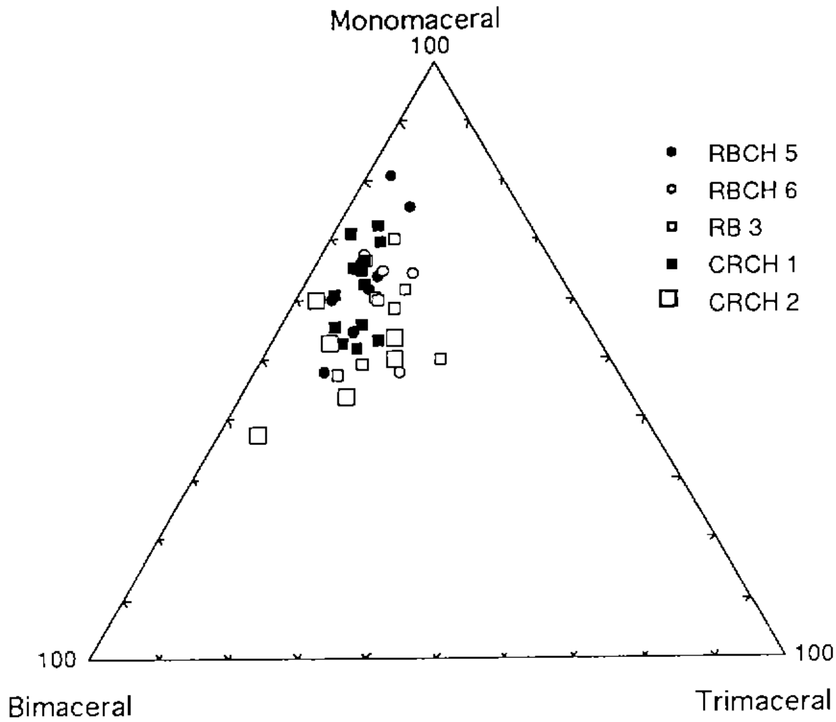


Figure 4.30. Microlithotype composition of the Vasse Shelf coal (carbominerite free).

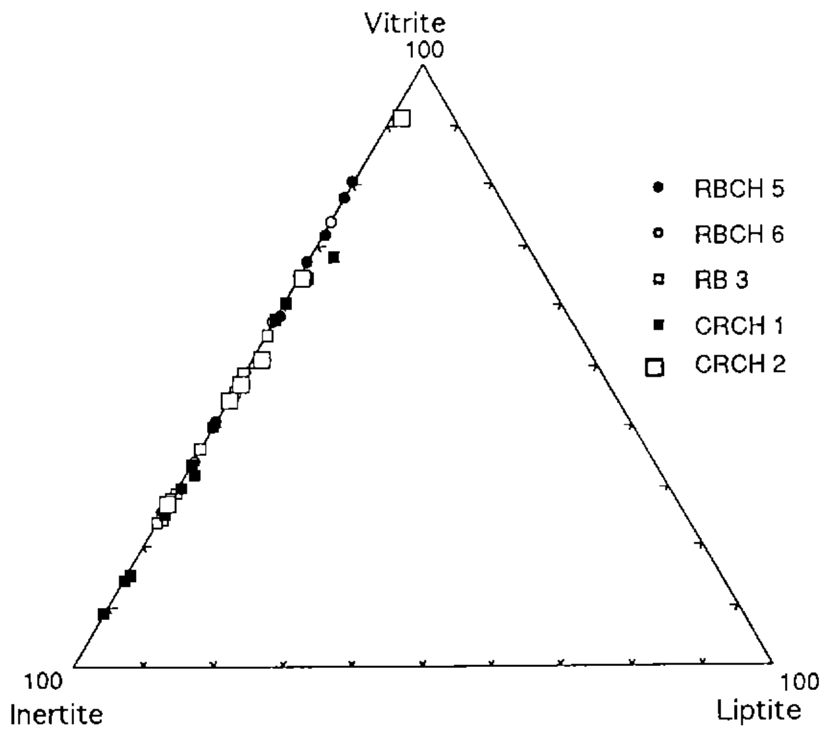


Figure 4.31. Composition of monomaceral group of the Vasse Shelf coal.

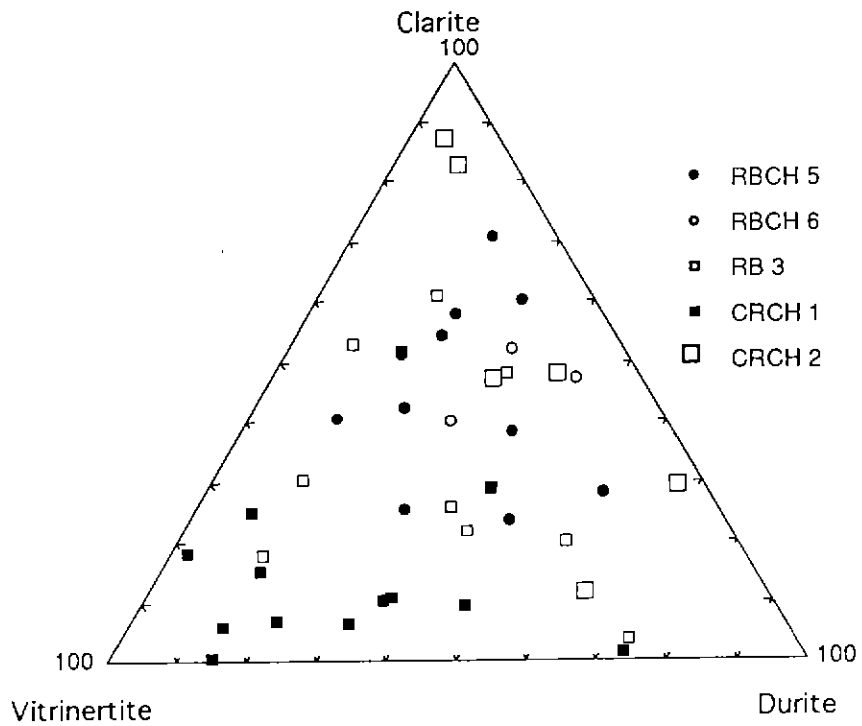


Figure 4.32. Composition of bimaceral group of the Vasse Shelf coal.

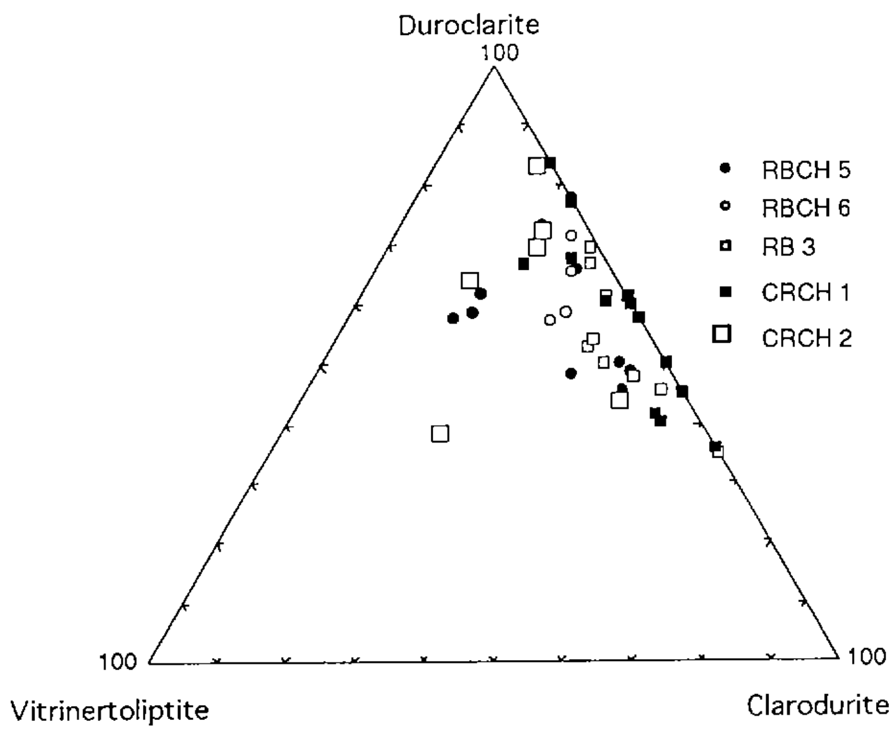


Figure 4.33. Composition of trimaceral group of the Vasse Shelf coal.

12.8% in the seam N of CRCH 2, and 0.4% in the seam M of CRCH 2 and 7.6% in the seam L of CRCH 1 and the seam P of CRCH 2, respectively. The subordinate microlithotype is vitrinertoliptite occurring within the range of 0.0% in all seams of CRCH 1 and 2.6% in the seam G of RBCH 6. Figure 4.33 depicts the trimaceral composition of the coal, and it shows the domination of duroclarite over clarodurite and vitrinertoliptite. This suggests the coal was formed under wetter conditions of deposition.

The carbominerites predominantly comprise carbargilite and carbopyrite and minor carbosilicate. Range of carbargilite content is between 0.6% in the seam I of RB 3 and 6.2% in the seams D and F of CRCH 1, whereas carbopyrite shows a value of 0.2% in most of the seams of RB 3 and 2.2% in the seam L of CRCH 1. The carbosilicate displays a range of 0.0% to 0.8% in all seams of drill holes. Figure 4.34 illustrates carbominerite composition of the coal, and it shows the predominance of carbargilite and carbopyrite over carbosilicate.

Overall the coal is characterized by monomaceral microlithotypes, followed by bimaceral, trimaceral and carbominerites. The predominance of monomaceral microlithotypes was due to the type of flora and the depositional environment of the coal.

In Figure 4.35, microlithotype and carbominerite compositions are illustrated for the individual seams in the drill holes. Vertically, the abundance of monomaceral group generally varies downward through the drill holes, and in RBCH 5, it shows a slight increase downward from the seams F to I, and from D to J of CRCH 1. The distribution of bimaceral and trimaceral groups also displays a similar variation. In all drill holes, carbominerite content has an almost similar amount with small variations

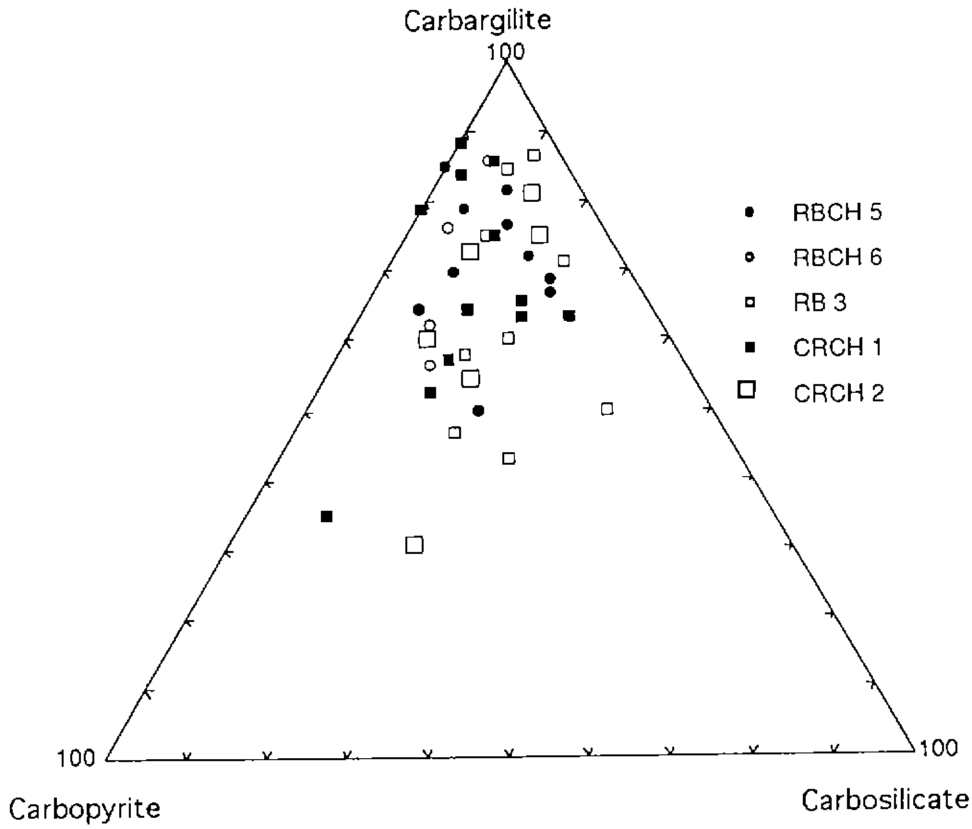


Figure 4.34. Composition of carbominerites of the Vasse Shelf coal.

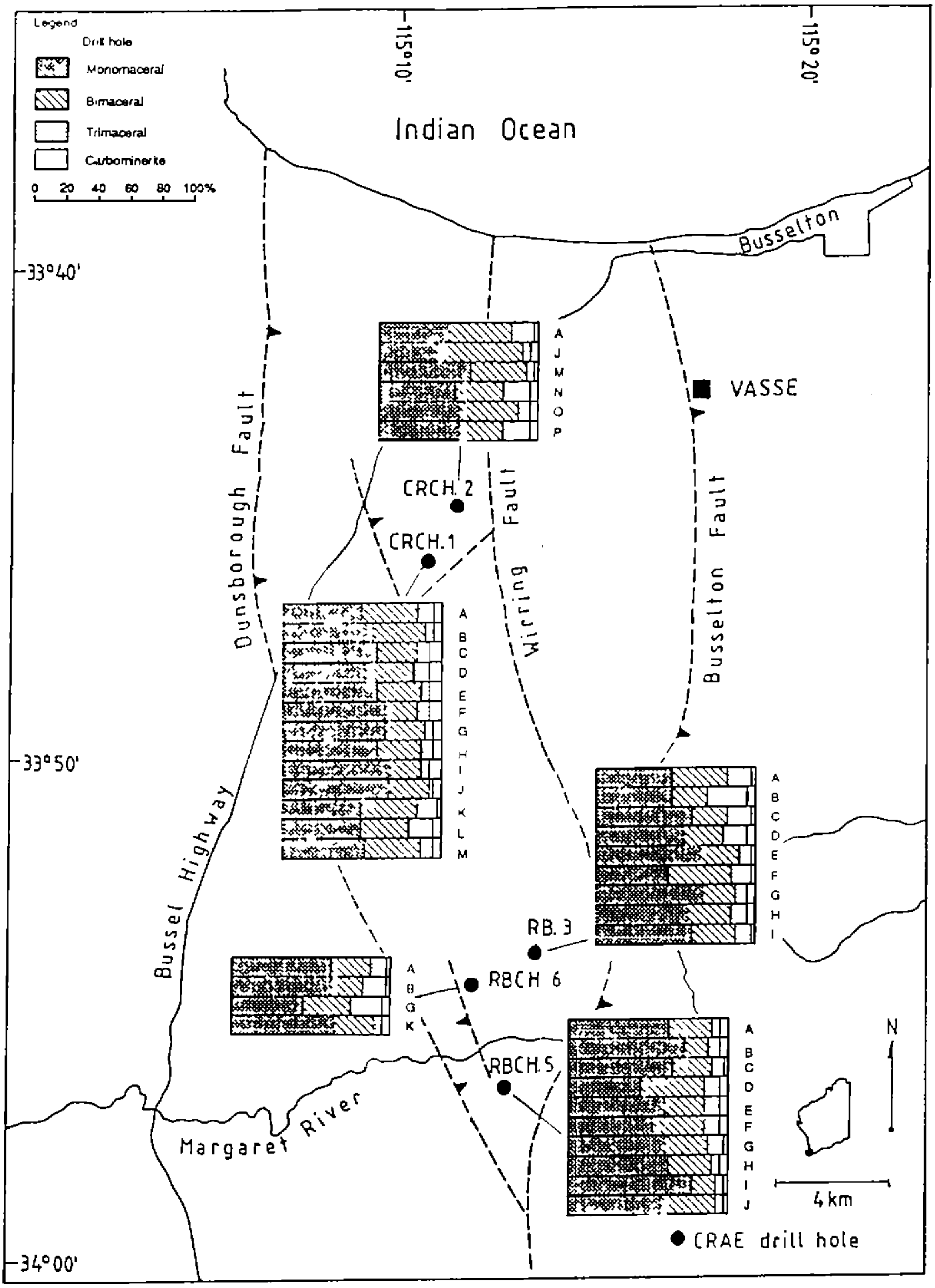


Figure 4.35. Variations of microlithotypes of the Vasse Shelf coal, Perth Basin, Western Australia.

throughout the seams. However, the seams C and I of RB 3 show the least carbominerite values.

4.2.7. Relationship of Lithotypes, Macerals and Microlithotypes

Diessel (1992) stated that the actual proportions of macerals and minerals contained in the various lithotypes follow set patterns which are specific for individual coal seams. The coal seams are not affected by marked lateral facies and/or range changes which would alter lithotype properties. Table 4.5 shows an example of the compositional relationship among lithotypes, macerals and microlithotypes of the coal from the Vasse Shelf.

In the present study, the seams A to P of the Vasse Shelf coal are generally dominated by the dull and dull banded lithotypes. These lithotypes consist mainly of the inertinite group, followed by vitrinite, minor exinite and mineral matter. The inertinite content is correlated with the inertite content of the microlithotype composition. However, the exinite and liptite contents do not follow the same pattern as above, and the mineral mater and carbominerite contents remain fairly constant. On the other hand, the coal containing a high amount of the bright and bright banded lithotypes (seam G of RBCH 5, seam D of RB 3, seams F, I and K of CRCH 1 and seam O of CRCH 2) consist mainly of the vitrinite, followed by inertinite and low exinite and mineral matter. The vitrinite content is correlated with the vitrite content. Like the dull and dull banded coal lithotypes, the mineral matter and carbominerite compositions remain fairly constant, and the exinite and liptite contents do not display the same trend as above.

From the above statement, a distinction can be made between two kinds of dull and bright lithotypes in terms of their maceral and microlithotype

DRILL HOLES	SEAMS	LITHOTYPES (%)						MACERALS+MM (%)				MICROLITHOTYPES (%)			
		D	DB	BD	BB	B	SHALE	V	I	E	MM	VITR	INERT	LIPT	CARB
RBCH 5	A	48.1	_	9.3	25.9	16.7	_	40.8	48.0	5.4	5.8	41.0	22.4	_	3.8
	B	70.5	_	16.7	_	12.8	_	41.9	43.5	9.1	5.5	57.8	14.2	_	4.4
	C	55.0	10.0	10.0	12.5	12.5	_	42.6	44.9	7.8	4.7	42.8	21.2	_	3.4
	D	25.4	40.7	_	20.3	13.6	_	44.6	35.1	17.3	3.0	33.0	12.8	0.2	3.6
	E	38.8	35.3	25.9	_	_	_	41.1	49.1	5.6	4.2	15.6	45.4	_	4.6
	F	48.1	26.0	_	16.4	9.6	_	37.9	49.5	8.5	4.1	13.8	38.6	_	3.8
	G	17.9	_	28.6	53.6	_	_	48.4	40.6	8.6	2.4	46.6	13.4	_	2.8
	H	37.1	11.4	28.6	22.9	_	_	37.0	45.8	11.6	5.6	25.8	37.6	_	2.8
	I	62.2	_	_	37.8	_	_	45.4	46.2	5.4	3.0	31.2	46.6	_	3.6
	J	_	29.8	48.9	14.9	6.4	_	44.2	39.9	11.0	4.9	33.4	23.6	0.2	4.0
RBCH 6	A	85.1	4.5	_	_	10.5	_	41.8	44.1	10.3	3.8	36.0	26.8	_	3.2
	B	23.5	61.8	8.8	_	5.9	_	40.8	44.0	10.8	4.4	45.6	16.2	_	4.2
	G	22.7	45.5	31.8	_	_	_	43.6	44.4	8.2	3.8	21.2	24.2	0.2	4.2
	K	82.1	_	17.9	_	_	_	37.6	50.4	7.6	4.4	22.2	42.4	_	4.2
RB 3	A	16.7	38.9	16.7	_	27.8	_	39.2	50.6	7.8	2.4	23.2	24.4	_	2.6
	B	68.8	12.5	12.5	_	6.3	_	40.2	50.4	6.0	3.4	22.2	26.2	_	2.8
	C	23.3	41.7	11.7	20.0	3.3	_	33.1	56.5	7.9	2.5	33.6	27.2	_	1.6
	D	12.5	43.8	_	37.5	6.3	_	44.6	40.4	9.2	5.8	35.4	18.8	0.6	6.0
	E	54.0	5.0	39.0	_	2.0	_	36.2	50.9	8.8	4.1	23.4	41.0	_	2.8
	F	57.9	36.8	_	_	5.3	_	36.2	47.8	11.4	4.6	13.2	32.2	_	3.8
	G	63.3	6.1	2.0	5.1	6.1	17.4	34.3	51.1	9.9	4.6	19.0	49.0	_	3.0
	H	84.4	_	9.4	3.1	3.1	_	33.0	53.4	9.8	3.8	14.2	43.4	0.2	4.0
	I	82.1	4.6	7.2	2.1	4.1	_	33.9	53.8	9.7	2.7	14.2	44.8	_	1.0

Table 4.5. Relationship of lithotypes, macerals and microlithotypes of the coal, Vasse Shelf, Perth Basin, Western Australia.

DRILL HOLES	SEAMS	LITHOTYPES (%)						MACERALS+MM (%)				MICROLITHOTYPES (%)			
		D	DB	BD	BB	B	SHALE	V	I	E	MM	VITR	INERT	LIPT	CARB
CRCH 1	A	–	98.3	–	1.7	–	–	40.8	49.6	6.6	3.0	13.0	37.8	0.2	2.8
	B	96.3	–	–	3.7	–	–	39.6	49.2	8.8	2.4	8.4	50.0	–	3.8
	C	95.1	4.9	–	–	–	–	31.6	54.4	7.6	6.4	9.2	50.6	0.4	6.4
	D	22.0	56.1	–	22.0	–	–	37.0	47.0	10.4	5.6	26.2	24.8	0.8	7.0
	E	43.8	40.6	–	15.6	–	–	34.0	55.6	5.8	4.6	18.2	42.2	0.2	7.0
	F	12.2	53.3	–	21.1	13.3	–	48.2	36.5	10.4	4.9	43.8	18.6	2.2	7.4
	G	63.6	21.6	4.5	2.3	8.0	–	36.5	54.4	5.6	3.5	17.6	46.4	–	3.8
	H	58.0	37.0	–	4.0	1.0	–	42.6	48.3	6.6	2.5	23.6	35.6	–	5.2
	I	37.5	7.8	6.3	28.1	20.3	–	52.7	35.9	7.5	3.9	41.0	26.8	–	6.0
	J	81.3	5.0	13.8	–	–	–	36.3	50.6	8.8	4.3	21.4	44.6	0.8	6.2
	K	–	55.6	–	–	44.5	–	51.8	37.8	8.2	2.2	28.6	21.0	–	4.2
	L	54.7	32.6	–	6.3	6.3	–	41.7	49.9	5.3	3.1	17.4	33.8	–	4.0
	M	–	–	21.7	78.3	–	–	19.6	63.0	12.0	5.4	4.6	47.4	–	6.2
CRCH 2	A	–	42.3	23.1	19.2	15.4	–	42.2	43.2	13.0	1.6	19.0	23.6	–	2.2
	J	100.0	–	–	–	–	–	32.6	47.8	14.6	5.0	16.8	18.8	0.2	4.8
	M	40.9	22.7	27.3	–	9.1	–	64.2	14.8	18.0	3.0	53.2	4.4	0.8	2.6
	N	66.7	–	–	–	–	33.3	42.2	45.2	8.2	4.4	24.8	23.0	0.6	3.2
	O	28.0	24.0	28.0	20.0	–	–	44.4	38.4	9.0	8.2	32.6	17.8	0.2	4.0
	P	37.8	62.2	–	–	–	–	30.9	55.2	9.1	4.8	14.0	37.2	–	4.4

Table 4.5. Relationship of lithotypes, macerals and microlithotypes of the coal, Vasse Shelf, Perth Basin, Western Australia.

compositions. One in which the dullness is due to a concentration of inertinite and inertite, and another is bright type because of vitrinite and vitrite contents. Therefore, the microlithotype composition of the coal follows the same pattern as the maceral content of the certain lithotypes.

4.2.8. Rank and Classification of Coal

The rank of coal in the study was determined by measuring the maximum reflectance of vitrinite. The reflectance may be defined as the percentage of an incident light beam's intensity which is reflected from a polished surface of coal, and it is related to the aromaticity of organic compounds in coal, and is related to its rank. The reflectance is dependent on level of coalification, and thus it is widely used as a rank parameter, and it increases as the rank of coal increases. Reflectance may be measured on any of the macerals, although vitrinite is always selected in rank studies. Vitrinite is preferred due to the following:

- presence in almost all coals,
- can be easily polished and identified under a microscope,
- characterized by a fairly even increase in reflectivity during coalification and its reflectance shows good correlation with other rank parameters at most levels.

The maximum and random reflectances of vitrinite are measured for technological purposes. In the present study, the random reflectance was measured, and the maximum reflectance calculated by the formula described in chapter 3.

The vitrinite reflectance data on the coal are presented in Table 4.6. The n in the table represents number of measurements, s represents standard

DRILL HOLES	SEAMS	ROrnd	n	s	RANGE	ROmax	n	s	RANGE
RBCH 5	A	0.56	100	0.02	0.53-0.62	0.58	30	0.02	0.54-0.63
	B	0.57	100	0.02	0.51-0.62	0.59	30	0.03	0.54-0.64
	C	0.57	100	0.03	0.52-0.62	0.59	30	0.02	0.54-0.64
	D	0.58	100	0.02	0.52-0.63	0.60	30	0.02	0.55-0.64
	E	0.59	100	0.03	0.53-0.63	0.61	30	0.03	0.56-0.65
	F	0.61	100	0.02	0.59-0.65	0.63	30	0.02	0.58-0.66
	G	0.61	100	0.02	0.57-0.63	0.62	30	0.02	0.56-0.66
	H	0.60	100	0.02	0.57-0.64	0.62	30	0.02	0.58-0.66
	I	0.60	100	0.02	0.56-0.63	0.62	30	0.02	0.58-0.66
	J	0.60	100	0.03	0.54-0.65	0.62	30	0.02	0.58-0.65
RBCH 6	A	0.56	100	0.02	0.53-0.62	0.58	30	0.02	0.54-0.63
	B	0.57	100	0.02	0.51-0.62	0.59	30	0.02	0.55-0.63
	G	0.60	100	0.02	0.57-0.64	0.62	30	0.02	0.58-0.66
	K	0.60	100	0.03	0.54-0.65	0.62	30	0.02	0.57-0.66
RB 3	A	0.56	100	0.03	0.53-0.62	0.58	30	0.03	0.54-0.63
	B	0.57	100	0.02	0.51-0.62	0.59	30	0.03	0.54-0.64
	C	0.57	100	0.03	0.51-0.62	0.59	30	0.02	0.54-0.63
	D	0.57	100	0.02	0.51-0.62	0.59	30	0.02	0.54-0.63
	E	0.58	100	0.02	0.52-0.63	0.60	30	0.02	0.55-0.64
	F	0.59	100	0.02	0.53-0.63	0.61	30	0.02	0.56-0.66
	G	0.60	100	0.02	0.57-0.64	0.62	30	0.03	0.56-0.66
	H	0.61	100	0.02	0.57-0.63	0.63	30	0.03	0.58-0.66
	I	0.60	100	0.03	0.56-0.63	0.62	30	0.03	0.58-0.65
CRCH 1	A	0.56	100	0.02	0.52-0.62	0.58	30	0.02	0.54-0.63
	B	0.57	100	0.02	0.51-0.62	0.59	30	0.03	0.54-0.65
	C	0.57	100	0.03	0.52-0.62	0.59	30	0.02	0.54-0.65
	D	0.58	100	0.03	0.52-0.64	0.60	30	0.02	0.54-0.64
	E	0.59	100	0.03	0.51-0.64	0.61	30	0.03	0.54-0.65
	F	0.61	100	0.02	0.59-0.65	0.63	30	0.03	0.56-0.67
	G	0.60	100	0.02	0.57-0.64	0.62	30	0.02	0.55-0.67
	H	0.60	100	0.02	0.56-0.64	0.62	30	0.03	0.56-0.67
	I	0.59	100	0.02	0.58-0.63	0.61	30	0.02	0.56-0.66
	J	0.59	100	0.02	0.55-0.63	0.61	30	0.02	0.55-0.67
	K	0.60	100	0.03	0.52-0.65	0.62	30	0.02	0.56-0.65
	L	0.61	100	0.02	0.56-0.64	0.63	30	0.02	0.58-0.67
	M	0.61	100	0.02	0.56-0.63	0.63	30	0.03	0.57-0.67
CRCH 2	A	0.56	100	0.02	0.52-0.62	0.59	30	0.02	0.55-0.64
	J	0.59	100	0.02	0.56-0.63	0.61	30	0.02	0.56-0.66
	M	0.60	100	0.02	0.57-0.64	0.62	30	0.02	0.56-0.66
	N	0.60	100	0.02	0.56-0.64	0.62	30	0.02	0.56-0.67
	O	0.60	100	0.02	0.56-0.64	0.62	30	0.02	0.57-0.67
	P	0.61	100	0.02	0.56-0.64	0.63	30	0.03	0.59-0.67

Table 4.6. Reflectance of vitrinite, Vasse Shelf, Perth Basin, Western Australia.

deviation, and the maximum reflectance is calculated from the mean random value as per the formula.

The measurement of vitrinite reflectance on the coal was carried out on 42 samples of the seams A to P from drill holes RBCH 5, RBCH 6, RB 3, CRCH 1 and CRCH 2. The range of vitrinite reflectance of the coal varies from 0.54% to 0.67%, whereas the mean maximum reflectance is between 0.58% to 0.63%, as presented in Table 4.6. The maximum reflectance of vitrinite values for the coal are plotted against the Australian and the North American (ASTM) classifications of coal in Figures 4.36.a and 4.36.b. The reflectance values between 0.58% to 0.63% indicate a coalification stage at sub-bituminous to high volatile bituminous levels, according to the Australian rank values, which approximately correspond to the sub-bituminous A rank of the ASTM classification.

Bennet and Taylor (1970) and Sappal (1986) have classified the Eastern Australian and Western Australian coals respectively on the basis of vitrinite content and maximum reflectance of vitrinite. The coal samples of the Vasse Shelf area are also classified using the reflectance and vitrinite content as depicted in Table 4.7 and Figure 4.37, in which the maximum reflectance (RO max %) of vitrinite is plotted against the vitrinite content of the individual samples from seams A to P for all the drill holes. The points entry in the square 'boxes' is shown by three digits, e.g. '053' in the box indicates that the reflectance of vitrinite is between 0.50 % and 0.60 %, and the value of vitrinite content is between 30% and 39%. The Vasse Shelf coals range from 053 to 054 and between 061 and 066, and this indicates that the vitrinite reflectance of the coal is between 0.50% to 0.60% and 0.60% to 0.70%, and the vitrinite content varies from 30.0% to 50.0% and 10.0% to 70.0%, respectively.

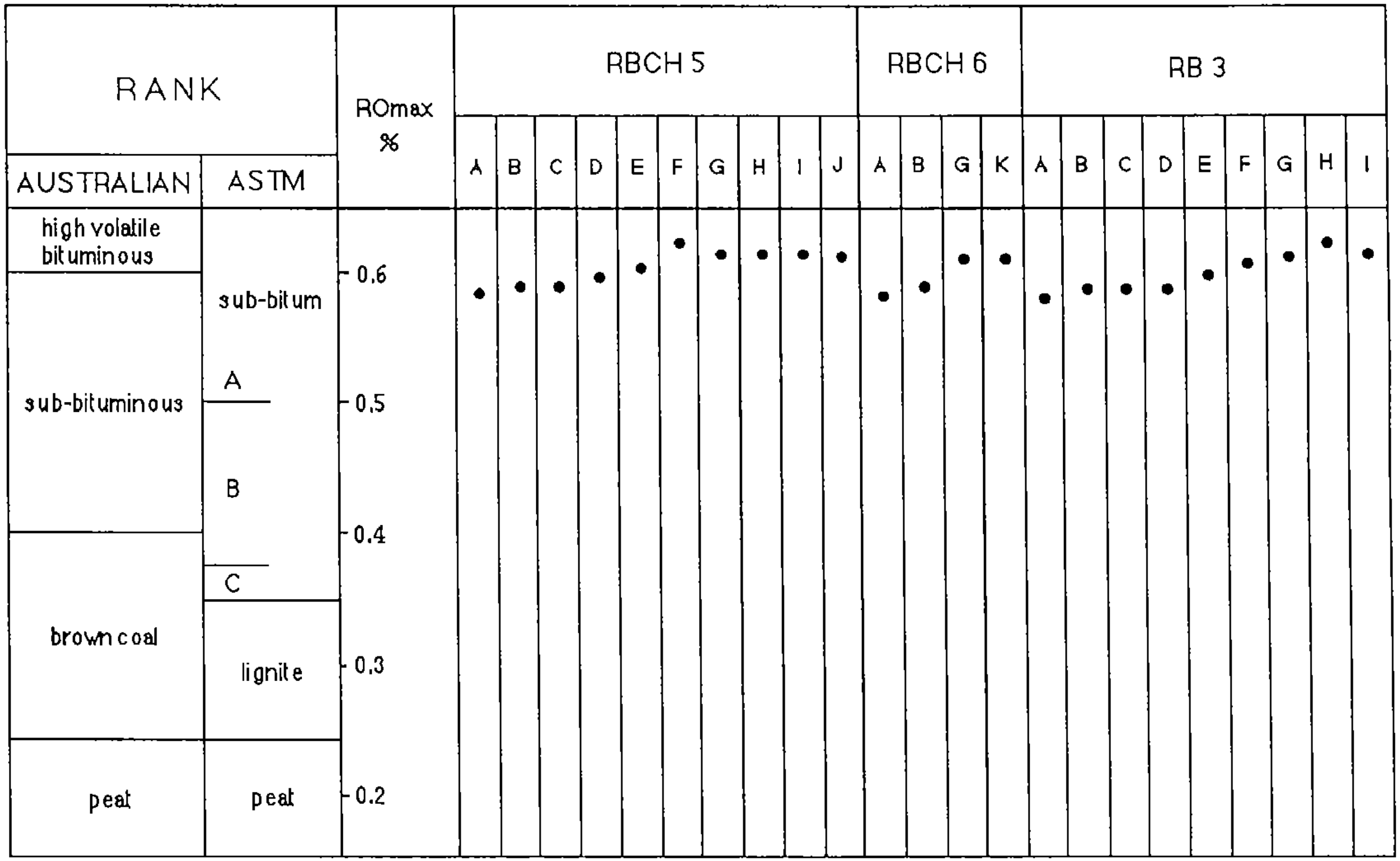


Figure 4.36.a. Reflectance of vitrinite of the Yasse Shelf coal, drill holes RBCH 5, RBCH 6 and RB 3.

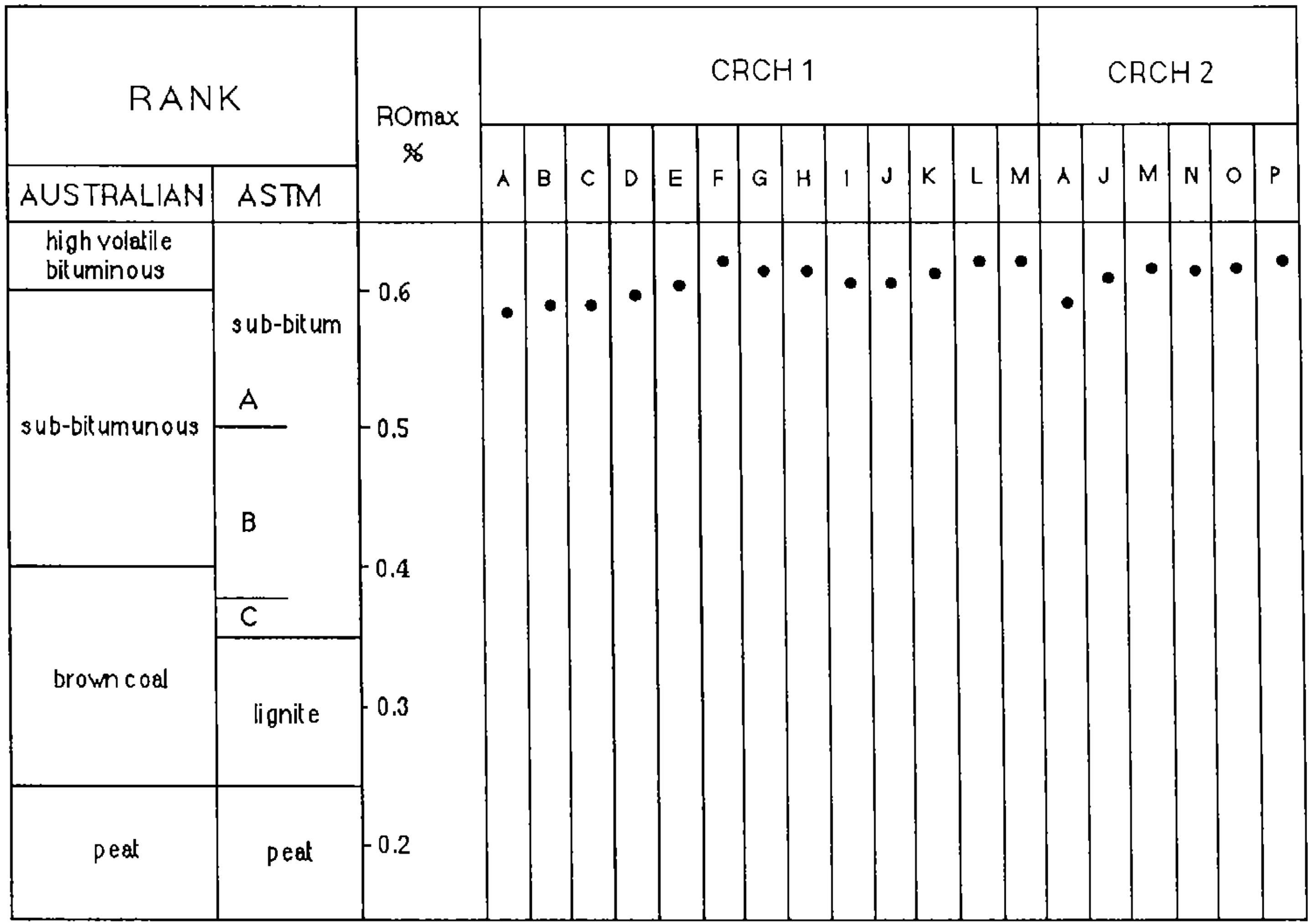


Figure 4.36.b. Reflectance of vitrinite of the Vasse Shelf coal, drill holes CRCH 1 and CRCH 2.

DRILL HOLES	SEAMS	VITRINITE CONTENT (%)	RO max (%)
RBCH 5	A	40.8	0.58
	B	41.9	0.59
	C	42.6	0.59
	D	44.6	0.60
	E	41.1	0.61
	F	37.9	0.63
	G	48.4	0.62
	H	37.0	0.62
	I	45.4	0.62
	J	44.2	0.62
RBCH 6	A	41.8	0.58
	B	40.8	0.59
	G	43.6	0.62
	K	37.6	0.62
RB 3	A	39.2	0.58
	B	40.2	0.59
	C	33.1	0.59
	D	44.6	0.59
	E	36.2	0.60
	F	36.2	0.61
	G	34.3	0.62
	H	33.0	0.63
	I	33.9	0.62
CRCH 1	A	40.8	0.58
	B	39.6	0.59
	C	31.6	0.59
	D	37.0	0.60
	E	34.0	0.61
	F	48.2	0.63
	G	36.5	0.62
	H	42.6	0.62
	I	52.7	0.61
	J	36.3	0.61
	K	51.8	0.62
	L	41.7	0.63
	M	19.6	0.63
CRCH 2	A	42.2	0.59
	J	32.6	0.61
	M	64.2	0.62
	N	42.2	0.62
	O	44.4	0.62
	P	30.9	0.63

Table 4.7. Vitrinite content and reflectance of vitrinite of the Vasse Shelf coal.

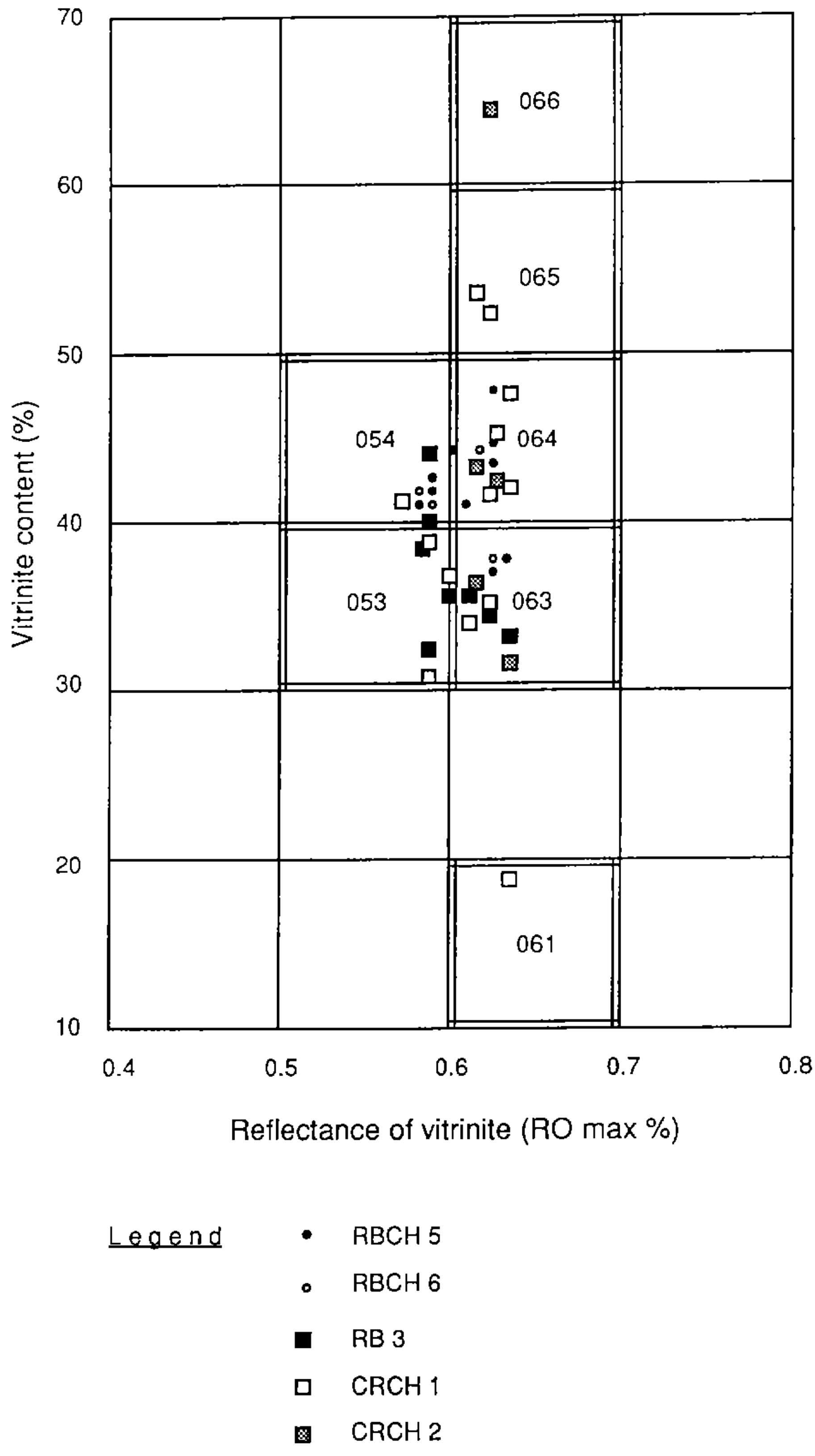


Figure 4.37. Classification of the Vasse Shelf coal.

4.2.9. Petrological Characteristics

On the basis of the above petrographic descriptions and the data, the Vasse Shelf coal has the following characters:

. The coal is predominantly composed of dull and dull banded lithotypes, whereas bright banded, banded and bright lithotypes and carbonaceous shale are present as low constituents. This suggests the peat was formed under transition of wet conditions to relatively drier conditions with fluctuating water table.

. The coal is inertinite-rich with inertodetrinite as the dominant maceral, which suggests that the coal has undergone high degree of decomposition during its deposition.

. The vitrinite group in the coal is dominated by desmocollinite showing a thoroughly decomposed attritus, and this suggests the coal has undergone a high degree of diagenesis.

. The exinite content is low, and it is dominated by sporinite, cutinite and liptodetrinite. The low exinite content in the coal reflects the type of flora which has formed the coal.

. The coal is characterized by very low to medium semifusinite ratio, and medium to high vitrinite content, which suggests the coal was deposited in an anaerobic wet environment with some degree of oxidation during its deposition.

. In terms of microlithotype group, the predominance of monomaceral over the other microlithotypes in the coal suggests that the coal was formed under either wetter or drier conditions, depending on the inertite or vitrite contents, respectively.

. On the basis of maximum reflectance of vitrinite, the coal is classified as sub-bituminous to high volatile bituminous of Australian rank or sub-bituminous A of the ASTM classification.

4.3. The Collie Coal

The coal samples from the fourteen coal seams from the five drill holes named: BUC 212, BUC 213, BUC 214, BUC 215 and BUC 217, from the Early Permian Ewington Coal Measures of the Premier Sub-basin, Collie Basin have been petrographically analysed (Figure 3.3, page 29). The coal samples in this thesis are also referred under the name "Collie coal". The coal seams analysed are E 9, E 10, E 15, E 20, E 22, E 25, E 30, E 35, E 40, E 50, E 60, E 70, E 80 and E 90 (Figure 4.38). The particulate coal samples were obtained from the Griffin Coal Mining Company Ltd., and the maceral and microlithotype analyses were undertaken on these samples. The lithotype analysis could not be undertaken due to the unavailability of the cores. Thicknesses of the individual seams range from 0.29 m to 3.97 m.

4.3.1. Maceral and Mineral Matter Analyses

The detailed petrographic study of the coal was completed in this project, and the maceral groups and macerals identified in the coal are described supported by photomicrographs. The maceral and mineral matter analyses of the coal were performed on fourteen seams named E 9 to E 90, given in Table 4.8 and Figures 4.39.a and 4.39.b. The coal is dominated by

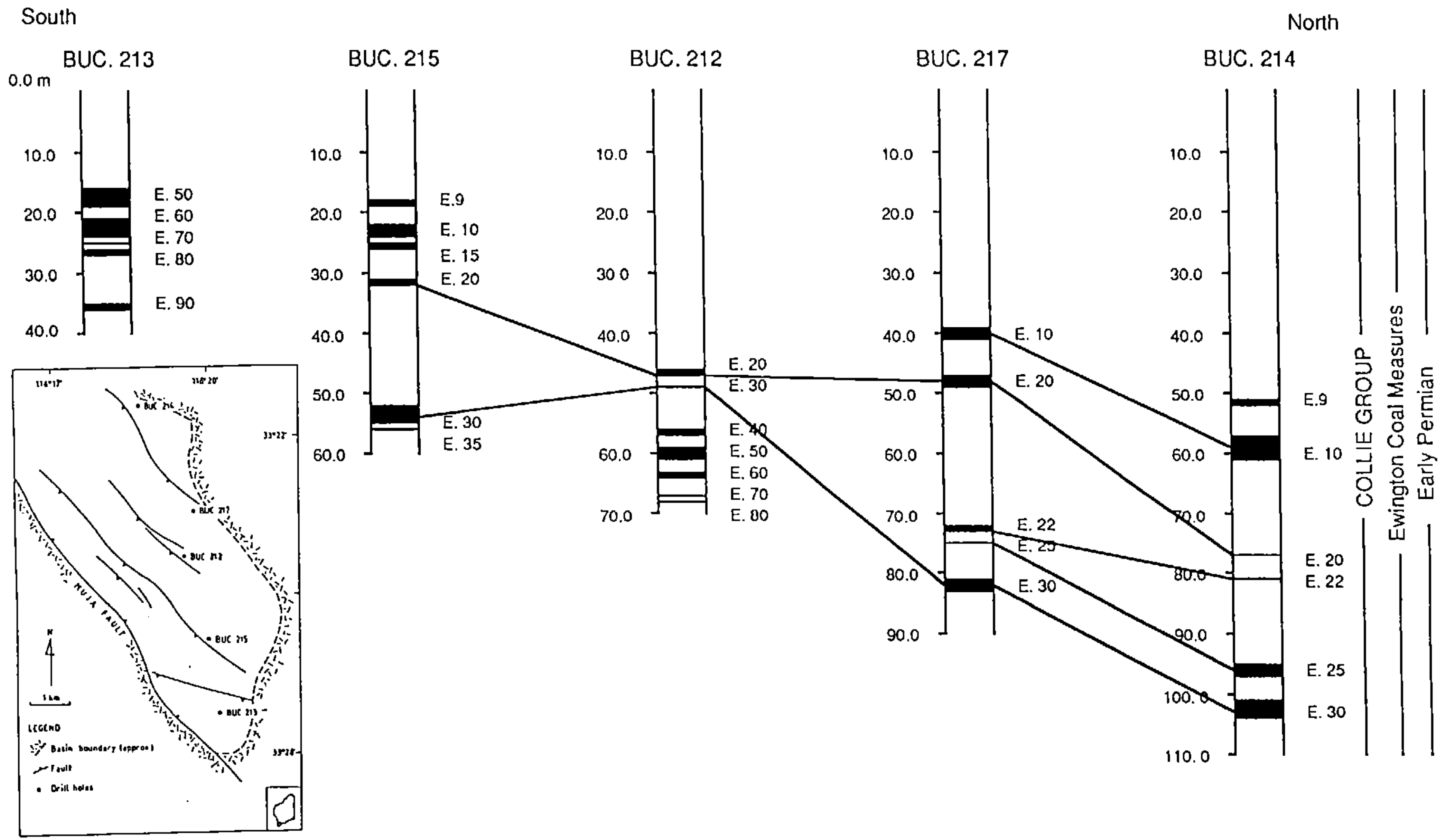


Figure 4.38. Stratigraphic succession of the Early Permian coal seams, Ewington Coal Measures, Premier Sub-basin, Collie Basin, Western Australia (after Griffin Coal Mining Company Ltd., 1991).

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS													
		E9	E10	E15	E20	E22	E25	E30	E35	E40	E50	E60	E70	E80	E90
BUC 213	Telinite										0.4	1.2	2 8	1.2	1.8
	Telocollinite										15.8	12.2	7.6	20.2	18.0
	Corpocollinite										2.4	1.0	1 4	0.4	1.4
	Desmocollinite										19.0	26.8	30.2	25.0	18.4
	Vitrodetrinite										0.8	0.8	1.0	0.6	1.2
	Vitrinite Group										**38.4**	**42.0**	**43.0**	**47.4**	**40.8**
	Fusinite										14.6	6.6	6.0	18.0	7.4
	Semifusinite										0.6	0.6	1.2	1.4	1.4
	Sclerotinite										1.8	0.2	1.0	0.6	0.6
	Micrinite										2.0	1.6	1.2	3.0	2.4
	Macrinite										0 8	2 0	0.6	0.6	0.4
	Inertodetrinite										30.6	35 2	31.2	20.2	32.4
	Inertinite Group										**50.4**	**46.2**	**41.2**	**43.8**	**44.6**
	Sporinite										3.4	5.8	5.8	1.4	6 0
	Cutinite										0.6	0.8	3.0	1.0	1.8
	Resinite										0.2	0.4	_	0 4	0.6
	Alginite										_	_	0 2	_	0.4
	Liptodetrinite										1.4	1.0	1.6	1.8	0.6
	Exinite Group										**5.6**	**8.0**	**10.6**	**4.6**	**9.4**
	Clay										3.0	2.0	3 2	1 2	2.8
	Pyrite										1.8	1.2	1.8	2.6	1.8
	Quartz										0.8	0.6	0.2	0.4	0.6
	Mineral Matter										**5.6**	**3.8**	**5.2**	**4.2**	**5.2**

Table 4.8. Maceral and mineral matter contents (%) of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS													
		E9	E10	E15	E20	E22	E25	E30	E35	E40	E50	E60	E70	E80	E90
BUC 215	Telinite	1.2	2.0	2.8	_			0.8	_						
	Telocollinite	15.4	20.2	7.6	19.0			10.2	1.0						
	Corpocollinite	0.6	0.6	_	0.4			0.4	0.6						
	Desmocollinite	19.4	16.2	14.0	22.6			23.2	8.2						
	Vitrodetrinite	1.4	1.4	3.4	0.4			1.4	5.4						
	Vitrinite Group	**38.0**	**40.4**	**27.8**	**42.4**			**36.0**	**15.2**						
	Fusinite	1.8	20.2	11.4	14.6			17.4	0.6						
	Semifusinite	_	2.8	1.8	0.4			0.6	_						
	Sclerotinite	_	1.0	0.6	_			1.8	_						
	Micrinite	3.8	4.6	3.0	1.6			3.2	2.8						
	Macrinite	0.2	0.2	0.2	0.6			1.4	1.8						
	Inertodetrinite	38.2	17.0	42.2	30.2			27.8	56.2						
	Inertinite Group	**44.0**	**45.8**	**59.2**	**47.4**			**52.2**	**61.4**						
	Sporinite	1.0	5.8	1.2	1.8			2.8	1.4						
	Cutinite	1.6	0.6	3.0	0.8			1.8	0.4						
	Resinite	_	_	_	_			_	_						
	Alginite	11.0	_	_	_			_	9.2						
	Liptodetrinite	0.2	1.2	2.2	3.0			2.2	3.4						
	Exinite Group	**13.8**	**7.6**	**6.4**	**5.6**			**6.8**	**14.4**						
	Clay	1.4	2.8	4.2	1.8			3.0	7.4						
	Pyrite	1.8	3.0	1.6	2.4			2.0	1.6						
	Quartz	1.0	0.4	0.8	0.4			_	_						
	Mineral Matter	**4.2**	**6.2**	**6.6**	**4.6**			**5.0**	**9.0**						

Table 4.8. Maceral and mineral matter contents (%) of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS													
		E9	E10	E15	E20	E22	E25	E30	E35	E40	E50	E60	E70	E80	E90
BUC 212	Telinite				0.4			1.4		1.2	1.0	1.8		1.2	
	Telocollinite				17.0			15 6		20.8	10.0	19.4		22.6	
	Corpocollinite				0.8			_		0.6	0.4	1.2		0.8	
	Desmocollinite				19.8			23.8		20.8	31.0	20.6		12.2	
	Vitrodetrinite				0.2			1.0		0.4	0.6	1.0		3.4	
	Vitrinite Group				**38.2**			**41.8**		**43.8**	**43.0**	**44.0**		**40.2**	
	Fusinite				9.0			16 6		11.0	11.8	13.6		1.8	
	Semifusinite				2.0			1.8		0.8	1.0	1.2		0.6	
	Sclerotinite				1.6			0.6		0.4	_	0.6		_	
	Micrinite				3.2			1.4		0.8	2.0	0.8		1 6	
	Macrinite				0.6			0.6		1.2	0.4	1.2		0.2	
	Inertodetrinite				31.2			24.0		30.6	26.8	25.2		42.8	
	Inertinite Group				**47.6**			**45.0**		**44.8**	**42.0**	**42.6**		**47.0**	
	Sporinite				5 0			6 2		4.6	3.8	6.2		3.2	
	Cutinite				2.6			1.0		0.2	1.2	1.4		1.4	
	Resinite				0.6			0.4		1.0	0.4	_		0.2	
	Alginite				_			_		_	4.4	0.2		0 8	
	Liptodetrinite				1.2			2 0		1.4	0.2	0.8		0.6	
	Exinite Group				**9.4**			**9.6**		**7.2**	**10.2**	**8.6**		**6.2**	
	Clay				1.2			1.0		2.4	1.8	2.6		4.2	
	Pyrite				2.8			2 6		1.4	2.0	1 8		2.2	
	Quartz				0.8			_		0 4	1.0	0.4		0.2	
	Mineral Matter				**4.8**			**3.6**		**4.2**	**4.8**	**4.8**		**6.6**	

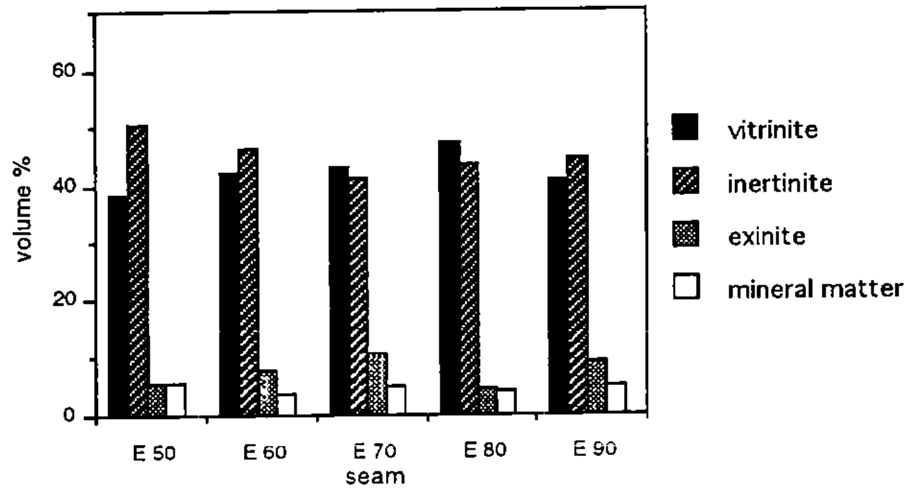
Table 4.8. Maceral and mineral matter contents (%) of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS													
		E9	E10	E15	E20	E22	E25	E30	E35	E40	E50	E60	E70	E80	E90
BUC 217	Telinite		3.2			0.4	0.2	2.0							
	Telocollinite		17.4			7.2	6.4	12.8							
	Corpocollinite		1.0			1.0	0.2	1.8							
	Desmocollinite		10.6			17.0	12.4	19.0							
	Vitrodetrinite		0.6			1.6	1.2	0.4							
	Vitrinite Group		**32.8**			**27.2**	**20.4**	**36.0**							
	Fusinite		15.2			11.0	18.2	17.6							
	Semifusinite		1.0			0.8	1.6	0.4							
	Sclerotinite		0.2			1.0	1.2	1.2							
	Micrinite		3.0			2.4	3.6	1.4							
	Macrinite		0.8			0.6	0.2	0.2							
	Inertodetrinite		36.6			42.2	44.2	29.2							
	Inertinite Group		**56.8**			**58.0**	**69.0**	**50.0**							
	Sporinite		4.0			1.2	0.4	4.2							
	Cutinite		1.4			0.8	2.0	2.4							
	Resinite		–			–	–	–							
	Alginite		–			3.8	–	–							
	Liptodetrinite		0.8			2.2	4.4	3.2							
	Exinite Group		**6.2**			**8.0**	**6.8**	**9.8**							
	Clay		2.0			5.2	1.0	1.6							
	Pyrite		1.6			1.4	2.4	2.0							
	Quartz		0.6			0.2	0.4	0.6							
	Mineral Matter		**4.2**			**6.8**	**3.8**	**4.2**							

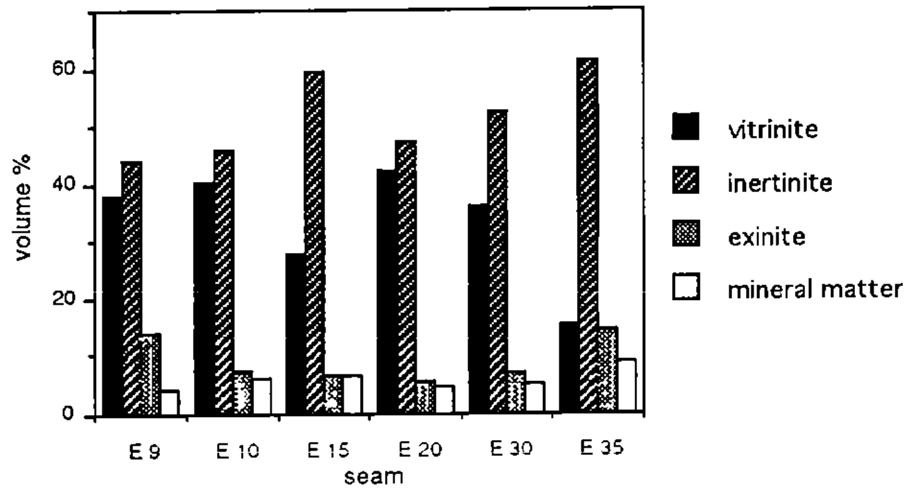
Table 4.8. Maceral and mineral matter contents (%) of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

DRILL HOLES	MACERALS/ MINERAL MATTER %	SEAMS													
		E9	E10	E15	E20	E22	E25	E30	E35	E40	E50	E60	E70	E80	E90
BUC 214	Telinite	1.4	2.8		0 6	–	0.9	0.8							
	Telocollinite	16.0	20.4		11.6	15.2	14.9	17.0							
	Corpocollinite	0.6	1.0		–	1.0	0.5	0.2							
	Desmocollinite	16.7	13.0		13.0	14.6	17.3	19.6							
	Vitrodetrinite	2.3	1.2		1.0	2.2	2.1	1.0							
	Vitrinite Group	**37.0**	**38.4**		**26.2**	**33.0**	**35.7**	**38.6**							
	Fusinite	11 3	18 2		22.4	20.8	18.0	16.4							
	Semifusinite	1.4	0.6		0.8	1.0	1.1	1.2							
	Sclerotinite	0.4	1.0		0.2	1.4	0.4	1.4							
	Micrinite	2.8	5.4		1.8	3 0	2.4	3.2							
	Macrinite	0.4	0.4		0.8	0.6	0.6	–							
	Inertodetrinite	32.7	24.4		35.2	27.0	29.9	24.6							
	Inertinite Group	**49.0**	**50.0**		**61.2**	**53.8**	**52.4**	**46.8**							
	Sporinite	4.2	2.0		1.2	2.6	1.4	6.4							
	Cutinite	1.8	3.2		4.2	2.6	0.7	0.6							
	Resinite	0.1	0.2		–	–	–	–							
	Alginite	1.6	–		–	–	1 0	0.2							
	Liptodetrinite	1.1	2.0		1.8	4.4	2.4	2.0							
	Exinite Group	**8.8**	**7.4**		**7.2**	**9.6**	**5.5**	**9.2**							
	Clay	2.7	1.4		2.2	0.8	3.9	2.0							
	Pyrite	1.9	2 0		2.6	2 2	2.0	2.8							
	Quartz	0.6	0.8		0.6	0.6	0.5	0.6							
	Mineral Matter	**5.2**	**4.2**		**5.4**	**3.6**	**6.4**	**5.4**							

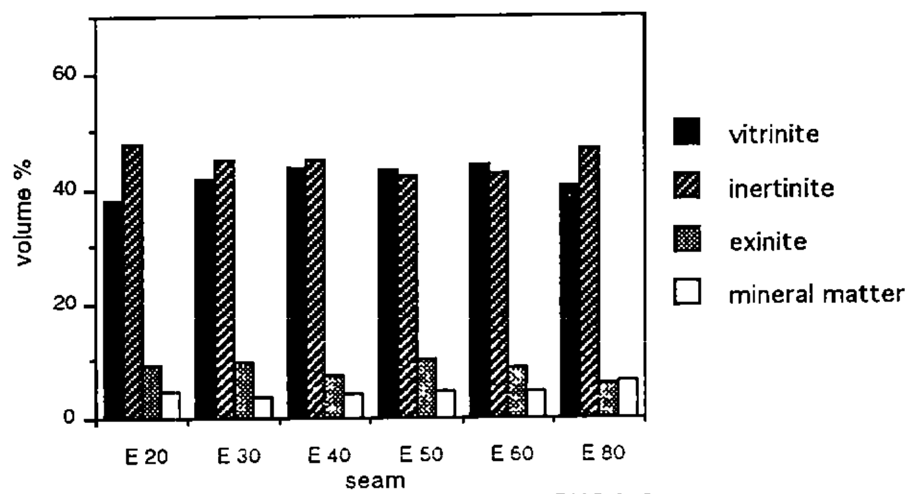
Table 4.8. Maceral and mineral matter contents (%) of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.



Maceral and mineral matter distribution, BUC 213

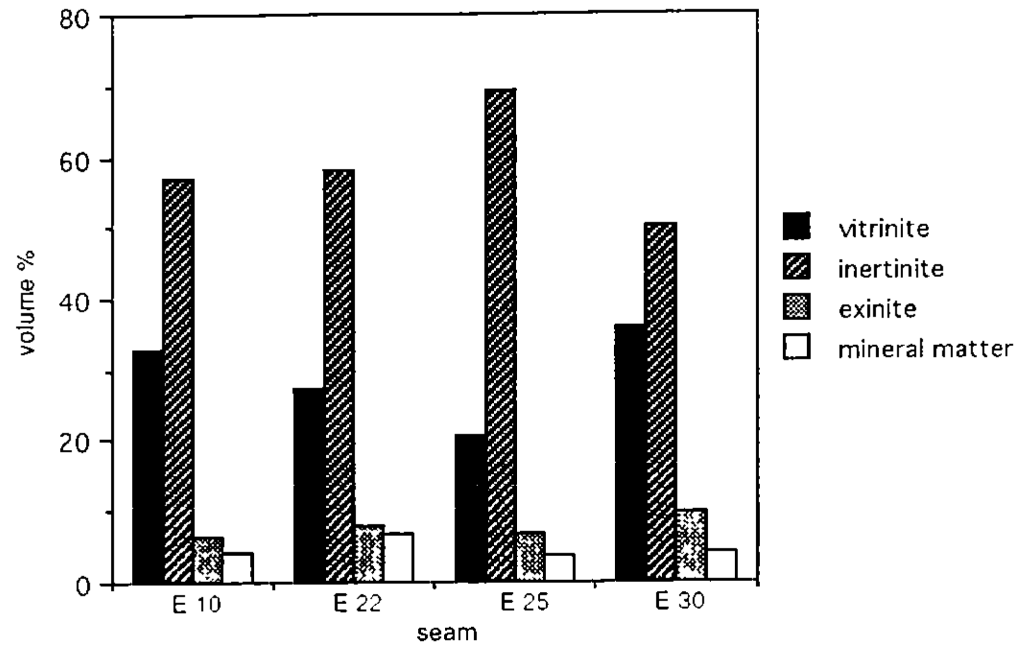


Maceral and mineral matter distribution, BUC 215

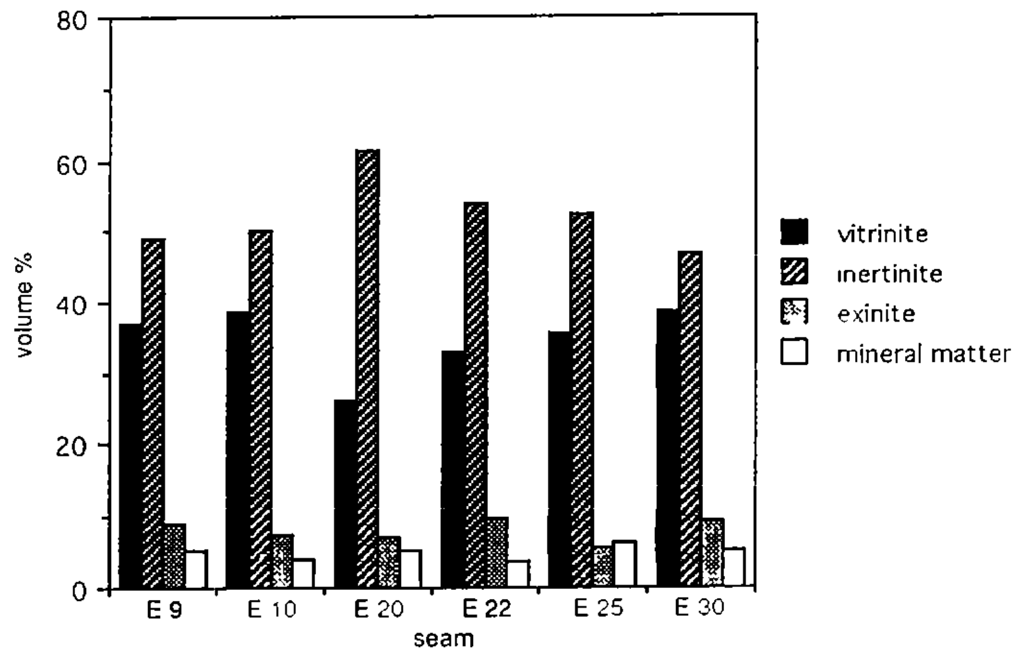


Maceral and mineral matter distribution, BUC 212

Figure 4.39.a. Maceral and mineral matter distribution of the Collie coal, drill holes BUC 213, BUC 215 and BUC 212.



Maceral and mineral matter distribution, BUC 217



Maceral and mineral matter distribution, BUC 214

Figure 4.39.b. Maceral and mineral matter distribution of the Collie coal, drill holes BUC 217 and BUC 214.

inertinite (41.2% in seam E 70 of BUC 213 to 69.0% in seam E 25 of BUC 217), followed by vitrinite (15.2% in seam E 35 of BUC 215 to 47.4% in seam E 80 of BUC 213), low exinite (4.6% in seam E 80 of BUC 213 to 14.4% in seam E 35 of BUC 215) and mineral matter (3.6% in seam E 30 of BUC 212 to 9.0% in seam E 35 of BUC 215). The maceral composition of individual seams on a mineral matter free basis is also given in Figure 4.40, which shows the predominance of inertinite over vitrinite and exinite.

The inertinite is present as the dominant maceral group, ranging from 41.2% in the seam E 70 of BUC 213 and 69.0% in the seam E 25 of BUC 217. This maceral group consists mainly of inertodetrinite, low fusinite and semifusinite and very low micrinite, sclerotinite and macrinite. The highest inertodetrinite content is recorded in the seam E 35 of BUC 215 which contains 56.2%. However, its lowest content (17.0%) is found in the seam E 10 of BUC 215. The fusinite and semifusinite contents are relatively low, with amounts of 0.6% in the seam E 35 of BUC 215 and 22.4% in the seam E 20 of BUC 214, and 0.4% in the seam E 20 of BUC 215 and the seam E 30 of BUC 217, respectively. The fusinite content is consistently higher than the semifusinite content. The micrinite has a low range of 0.8% in the seams E 40 and E 60 of BUC 212 and 5.4% in the seam E 10 of BUC 214. The sclerotinite and macrinite are very low constituents in the coal, containing 0.0% in the seams E 9, E 20 and E 35 of BUC 215 and 1.8% in the seam E 50 of BUC 213, and 0.0% in the seam E 30 of BUC 214 and 2.0% in the seam E 60 of BUC 213, respectively. Figure 4.41 depicts inertinite composition of the coal, and it shows the dominance of the other inertinite over fusinite and semifusinite.

Figures 4.42.a, 4.42.b and 4.42.d show cellular structure of fusinite associated with pyrite, sclerotinite and telocollinite. The inertodetrinite, the

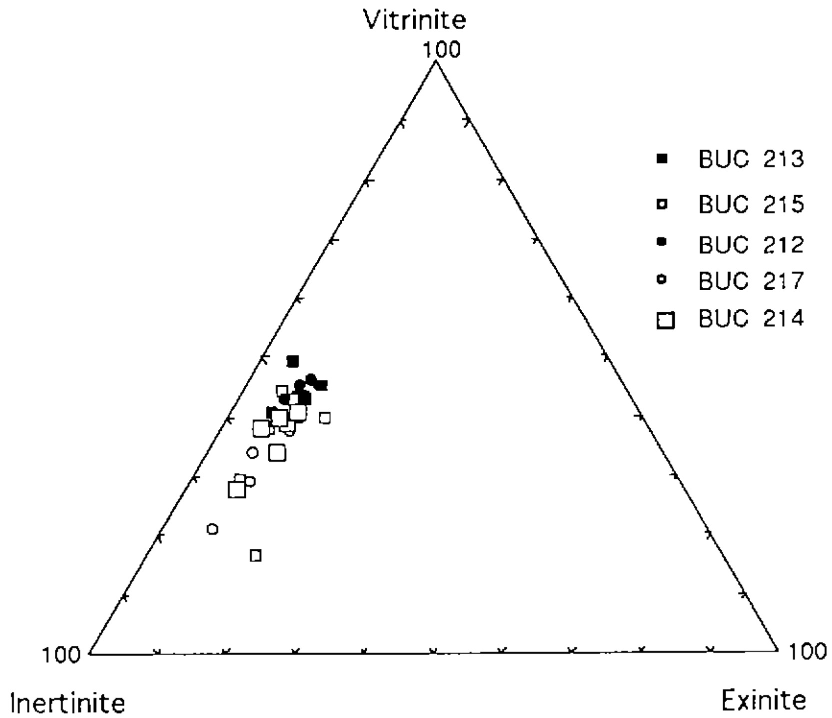


Figure 4.40. Maceral composition of the Collie coal (mineral matter free).

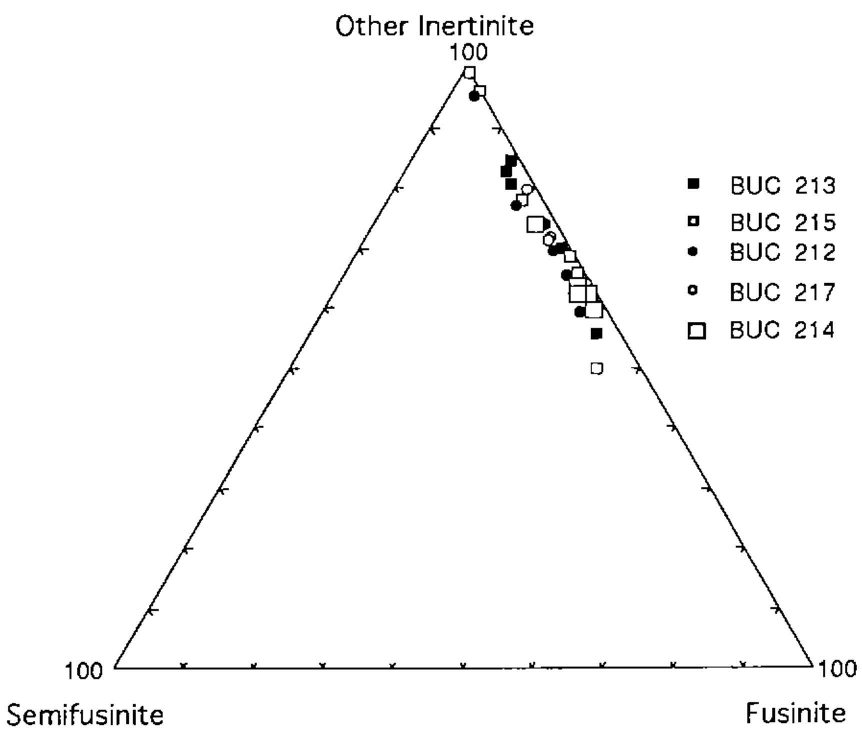
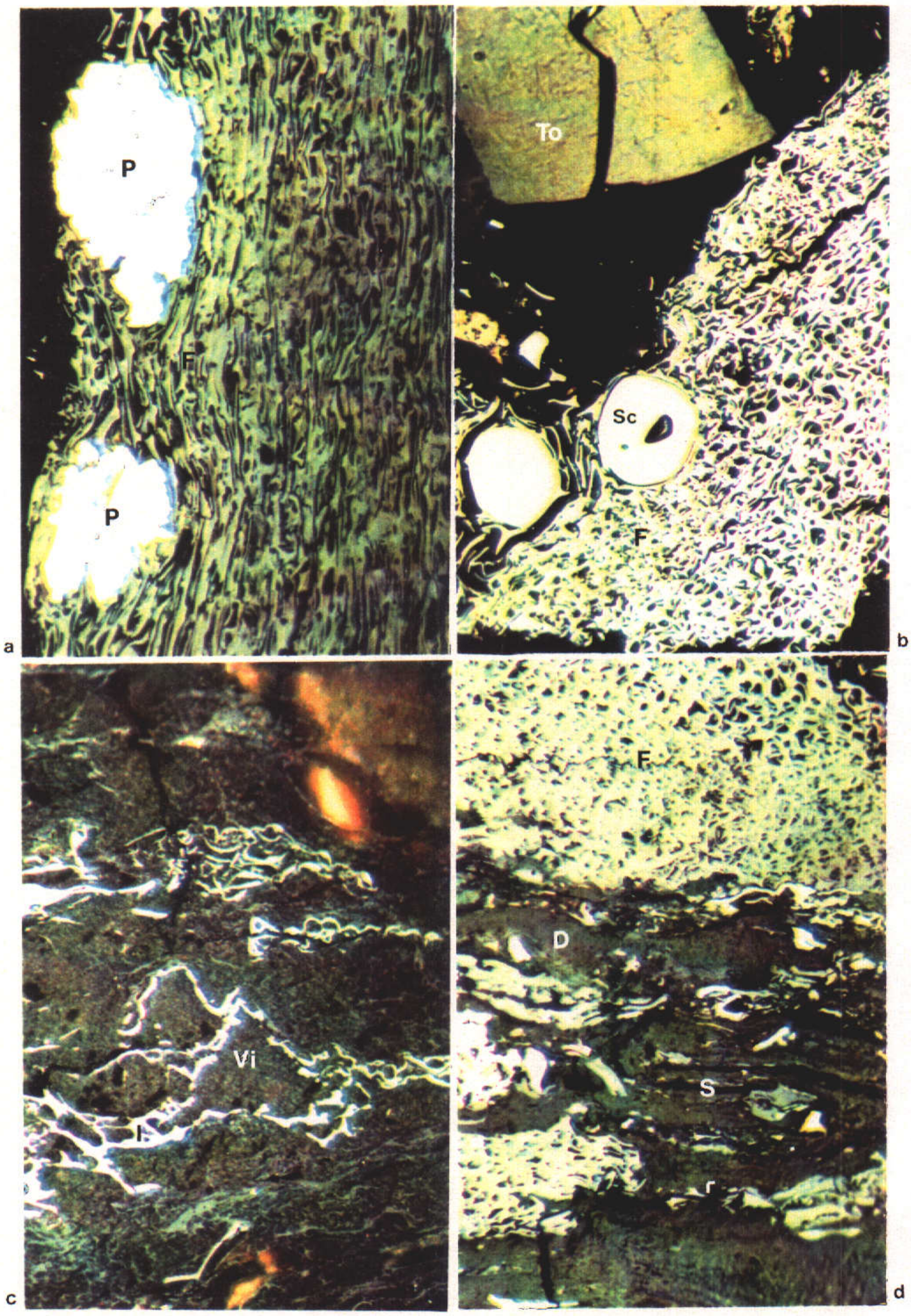


Figure 4.41. Composition of inertinite group of the Collie coal.



Macerals of the inertinite group, Collie coal (reflected light, oil immersion, x320).

Figure 4.42.a. Pyrite (P) associated with fusinite (F). E 25 seam, BUC 214.

Figure 4.42.b. Fusinite (F) associated with sclerotinite (Sc) and telocollinite (To). E 50 seam, BUC 213.

Figure 4.42.c. Inertodetrinite (I) associated with vitrodetrinite (Vi). E 15 seam, BUC 215.

Figure 4.42.d. Fusinite (F) associated with desmocollinite (D) and sporinite (S). E 10 seam, BUC 217.

dominant inertinite in the coal, is shown in Figures 4.42.c and 4.42.d. Figure 4.42.b shows the sclerotinite (oval shaped) associated with fusinite and telocollinite.

The maceral group vitrinite identified in the coal consists mainly of desmocollinite and telocollinite, with minor vitrodetrinite, telinite and corpocollinite, as shown in Table 4.8. The desmocollinite content varies between 8.2% in the seam E 35 of BUC 215 and 31.0% in the seam E 50 of BUC 212, and telocollinite content is between 1.0% in the seam E 35 of BUC 215 and 22.6% in the seam E 80 of BUC 212. The vitrodetrinite, telinite and corpocollinite occur in very low amounts and constitute 0.2% in the seam E 20 of BUC 212 and 5.4% in the seam E 35 of BUC 215, 0.2% in the seam E 25 of BUC 217 and 3.2% in the seam E 10 of BUC 217 and 0.0% in the seam E 15 of BUC 215 and 2.4% in the seam E 50 of BUC 213, respectively. Figure 4.43 illustrates vitrinite composition of the coal, which shows the domination of desmocollinite and telocollinite over the other vitrinite.

Figures 4.44.a and 4.44.b show telinite with cellular structure filled with clay, and associated with desmocollinite. The desmocollinite shows a thoroughly decomposed and gelified attritus of a variety of source materials, which is shown in Figure 4.44.c associated with sporinite and inertodetrinite. The corpocollinite includes round or ovoid bodies which are homogenous, massive and similar to the surrounding vitrinite in reflectance, occurs either as cell fillings or as isolated particles in a groundmass of desmocollinite as shown in Figure 4.44.d. The corpocollinite in this figure is associated with desmocollinite and sporinite.

The exinite group recognized in the coal consists mainly of sporinite,

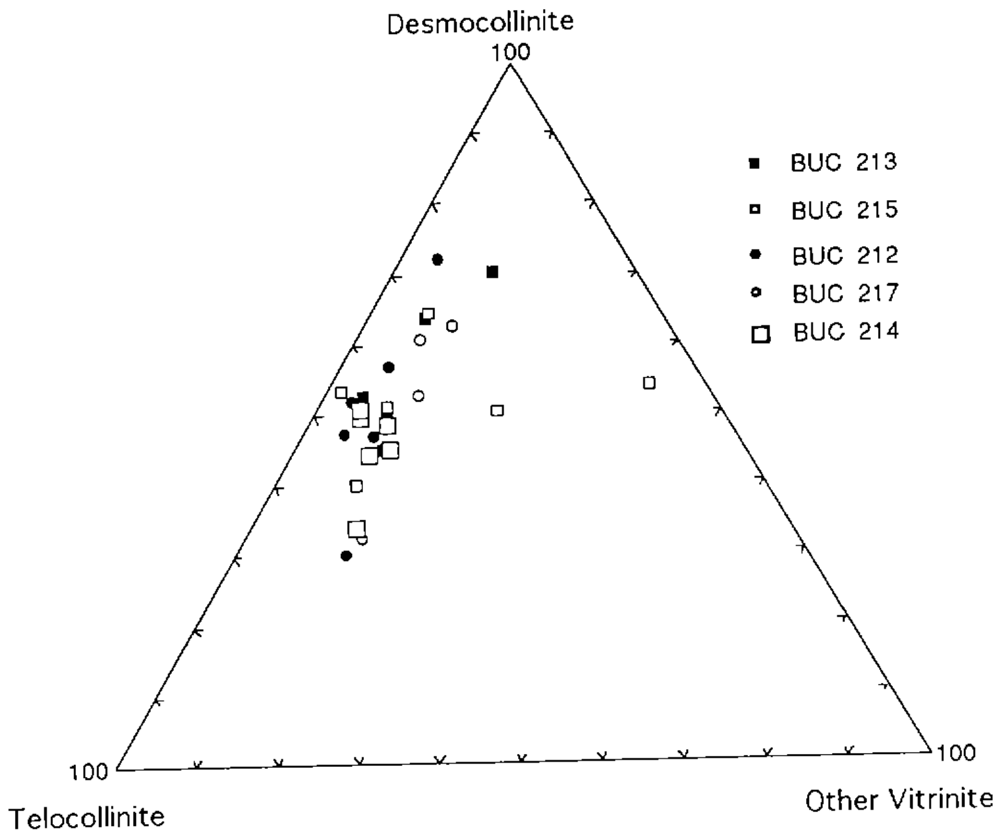
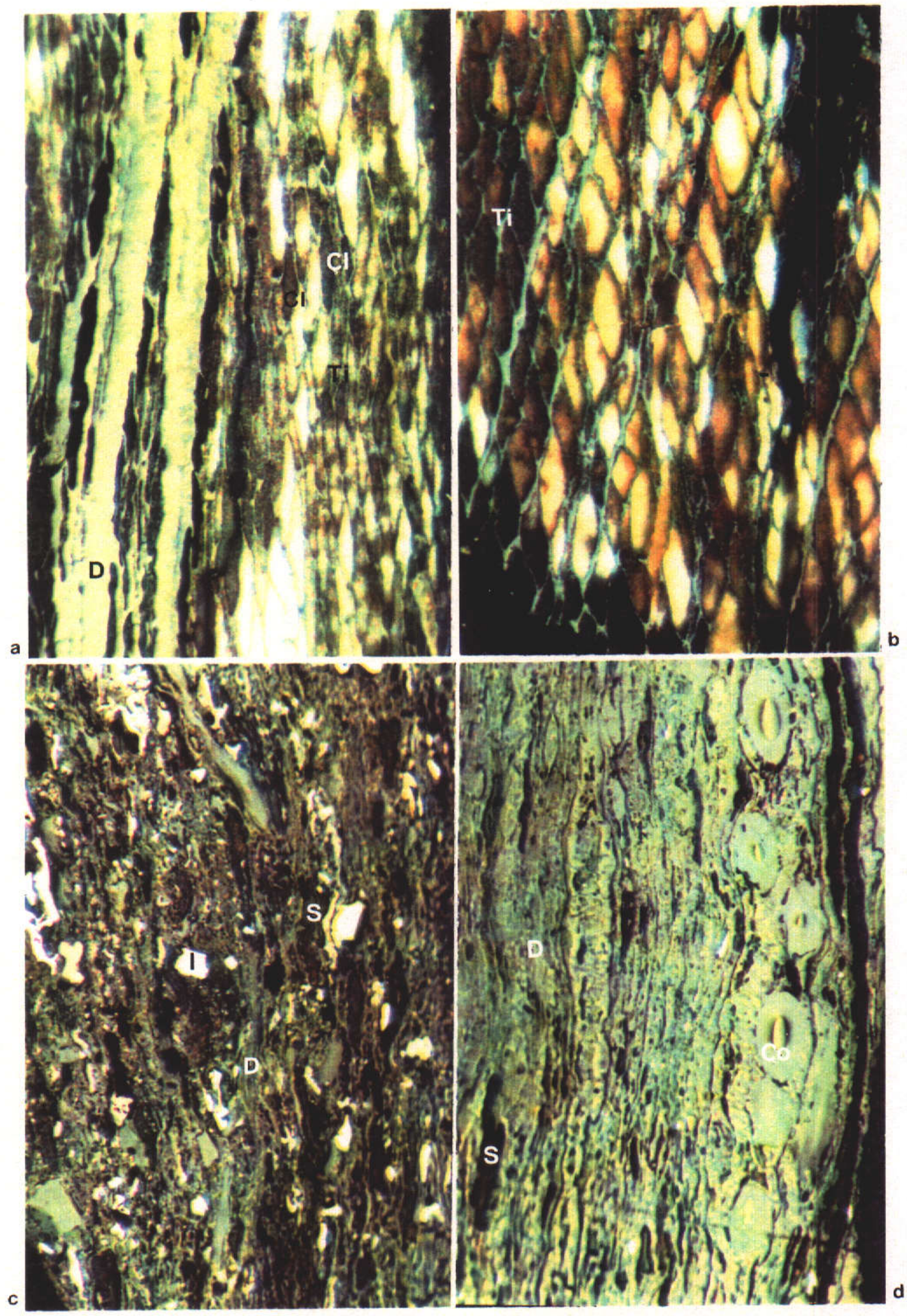


Figure 4.43. Composition of vitrinite group of the Collie coal.



Macerals of the vitrinite group, Collie coal (reflected light, oil immersion, x320).

Figure 4.44.a. Telinite (Ti) associated with desmocollinite (D) and clay (Cl). E 70 seam, BUC 213.
Figure 4.44.b. Telinite (Ti) showing cellular structure. E 10 seam, BUC 215.
Figure 4.44.c. Desmocollinite (D) associated with sporinite (S) and inertodetrinite (I). E 30 seam, BUC 212.
Figure 4.44.d. Corpocollinite (Co) associated with desmocollinite (D) and sporinite (S). E 50 seam, BUC 213.

cutinite and liptodetrinite, with low alginite and resinite, as presented in Table 4.8. The sporinite, the dominant maceral of this group, has a range from 0.4% in the seam E 25 of BUC 217 and 6.4% in the seam E 30 of BUC 214. The cutinite varies from 0.2% in the seam E 40 of BUC 212 and 4.2% in the seam E 20 of BUC 214, and liptodetrinite is between 0.2% in the seam E 9 of BUC 215 and the seam E 50 of BUC 212 and 4.4% in the seam E 30 of BUC 217 and the seam E 22 of BUC 214. The alginite and resinite contents range between 0.0% in most of the seams in all drill holes and 11.0% in the seam E 9 of BUC 215, and 0.0% in most of the seams and 1.0% in the seam E 40 of BUC 212, respectively. The exinite composition of the coal is presented in Figure 4.45, which shows the predominance of sporinite and other exinite over cutinite.

The sporinite appears dark grey in incident light, and under fluorescence microscopy, the fluorescence colour for sporinite is brownish yellow to yellow, as shown in Figures 4.46.a and 4.46.b associated with resinite, liptodetrinite and inertodetrinite. The alginite comprises remnants of algae which flourish in lakes, lagoons and marine environments, and it appears dark in reflected light, and displays yellow fluorescence in ultraviolet light, as shown in Figures 4.46.c and 4.46.d associated with inertodetrinite. The cutinite is derived from cuticle which is a waxy outer protective layer of leaves, shoots, needles, stalks and thin stems. In incident light, it appears as dark wavy lines, and under fluorescence microscopy, it displays yellow fluorescence colour, as shown in Figures 4.47.a to d in matrix of vitrinite and inertinite. The resinite appears dark in reflected light and displays yellow fluorescence when examined in ultraviolet light as shown in Figures 4.46.a and 4.46.b. The liptodetrinite includes all shapes and forms of exinitic maceral, and it appears dark in reflected light (Figure 4.46.a) and displays brownish yellow colour in ultraviolet light (Figure 4.46.b).

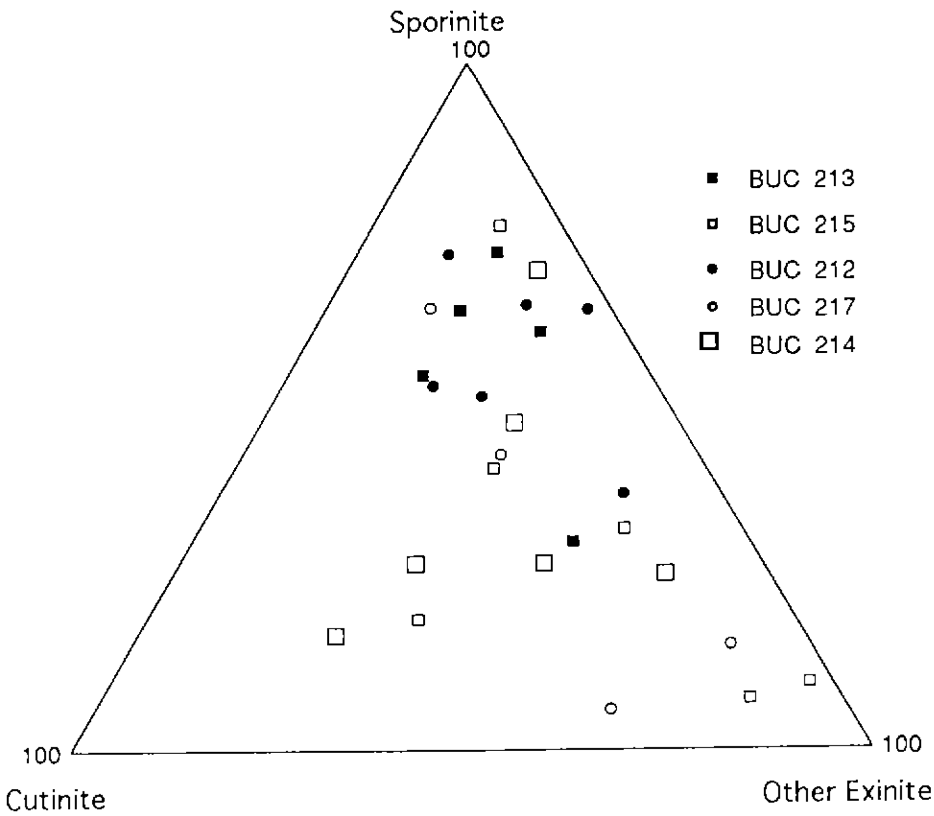
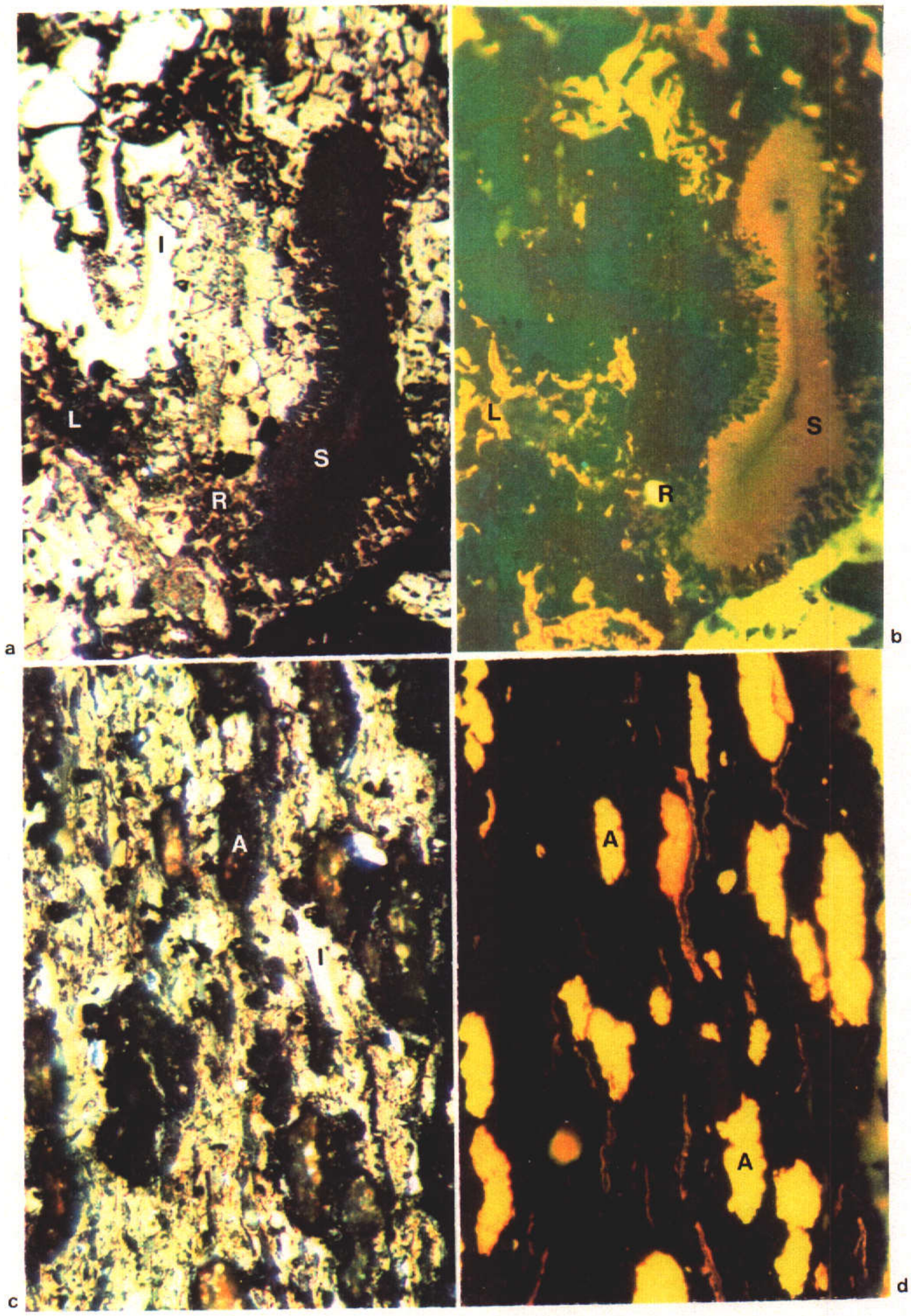


Figure 4.45. Composition of exinite group of the Collie coal.



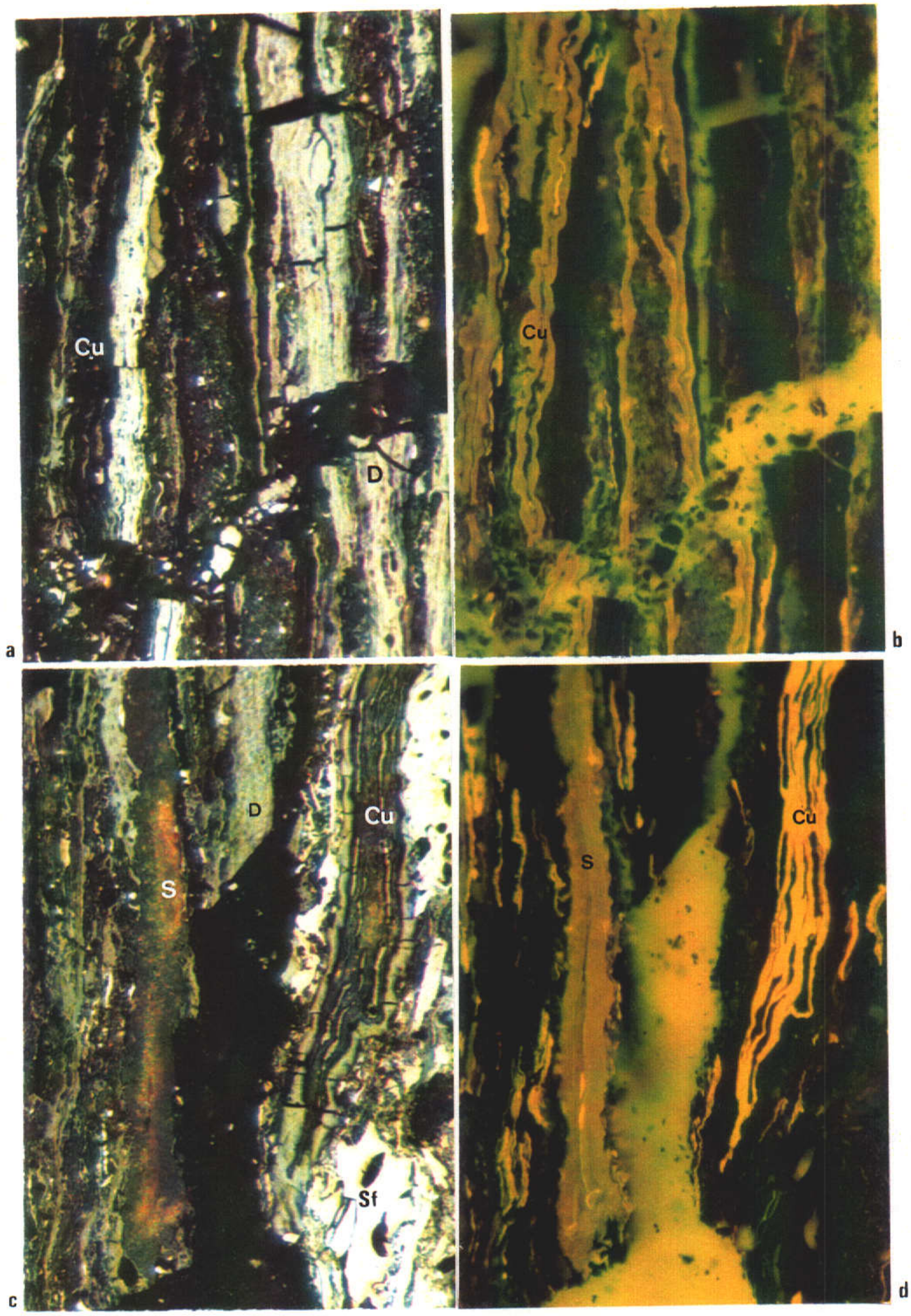
Macerals of the exinite group, Collie coal (reflected light, oil immersion, x320).

Figure 4.46.a. Sporinite (S) associated with resinite (R), liptodetrinite (L) and inertodetrinite (I). E 60 seam, BUC 213.

Figure 4.46.b. Same section after blue-light excitation, sporinite (S), resinite (R) and liptodetrinite (L) display yellowish-brownish, whitish-yellowish and greenish-yellowish fluorescence colours, respectively. E 60 seam, BUC 213.

Figure 4.46.c. Alginite (A) associated with inertodetrinite (I). E 9 seam, BUC 214.

Figure 4.46.d. Same section after blue-light excitation, alginite (A) displays yellow fluorescence colour. E 9 seam, BUC 214.



Macerals of the exinite group, Collie coal (reflected light, oil immersion, x320).

Figure 4.47.a. Cutinite (Cu) associated with desmocollinite (D). E 30 seam, BUC 212.

Figure 4.47.b. Same section after blue-light excitation, cutinite (Cu) displays yellowish-brownish fluorescence colour. E 30 seam, BUC 212.

Figure 4.47.c. Sporinite (S) associated with cutinite (Cu), desmocollinite (D) and semifusinite (Sf). E 70 seam, BUC 213.

Figure 4.47.d. Same section after blue-light excitation, sporinite (S) and cutinite (Cu) display yellowish-brownish and yellow fluorescence colours, respectively. E 70 seam, BUC 213.

On the basis of 'semifusinite ratio' and 'vitrinite content' values, the coal is characterized by the very low to low semifusinite ratio with low to medium vitrinite content (Figure 4.48), which is somewhat similar to the Vasse Shelf coal.

The vertical and lateral variations of maceral and mineral matter contents in all the seams of the drill holes BUC 213, BUC 215, BUC 212, BUC 217 and BUC 214 are shown in Figure 4.49. The vertical variation in vitrinite content in all drill holes is variable; however, its content increases in abundance downward in BUC 213 (except within the seam E 90) and BUC 214 (except within the seams E 9 and E 10). On the other hand, the inertinite content displays a reverse trend to the vitrinite content. The exinite content in all seams is relatively low, and it does not show a specific trend. The mineral matter content in BUC 212 increases in abundance downward, except within the seam E 20, and this indicates that the wetter conditions prevailed downward which produced mineral matter. The variations in proportion of vitrinite and inertinite vertically reflect frequent fluctuations in water table which caused the degree of oxidation in the peat, a result of different rates of subsidence of swamp and peat growth.

The lateral variation of maceral distribution in the coal is observed within the seams in the drill holes, from south to north. The vitrinite distribution decreases towards north, and this decrease is compensated by an increase of inertinite content. This reflects the decrease of water table causing a high degree of oxidation during the coal deposition towards the north (BUC 217 and BUC 214). The exinite and mineral matter contents show variable trends from north to south, and this is due to floral change and variations in the ground water table during the coal deposition.

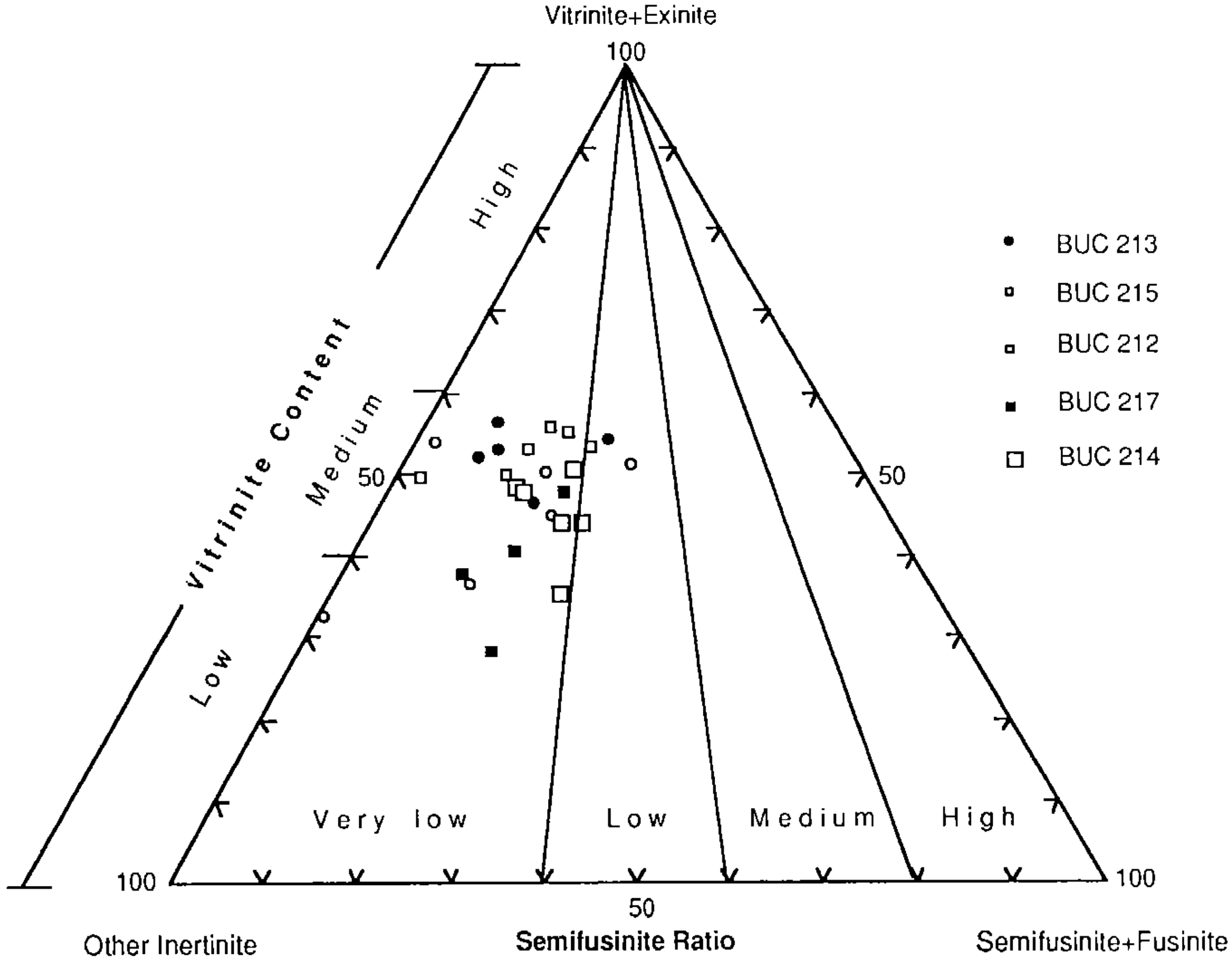


Figure 4.48. Maceral composition of the Collie coal, showing 'vitrinite content' and 'semifusinite ratio'.

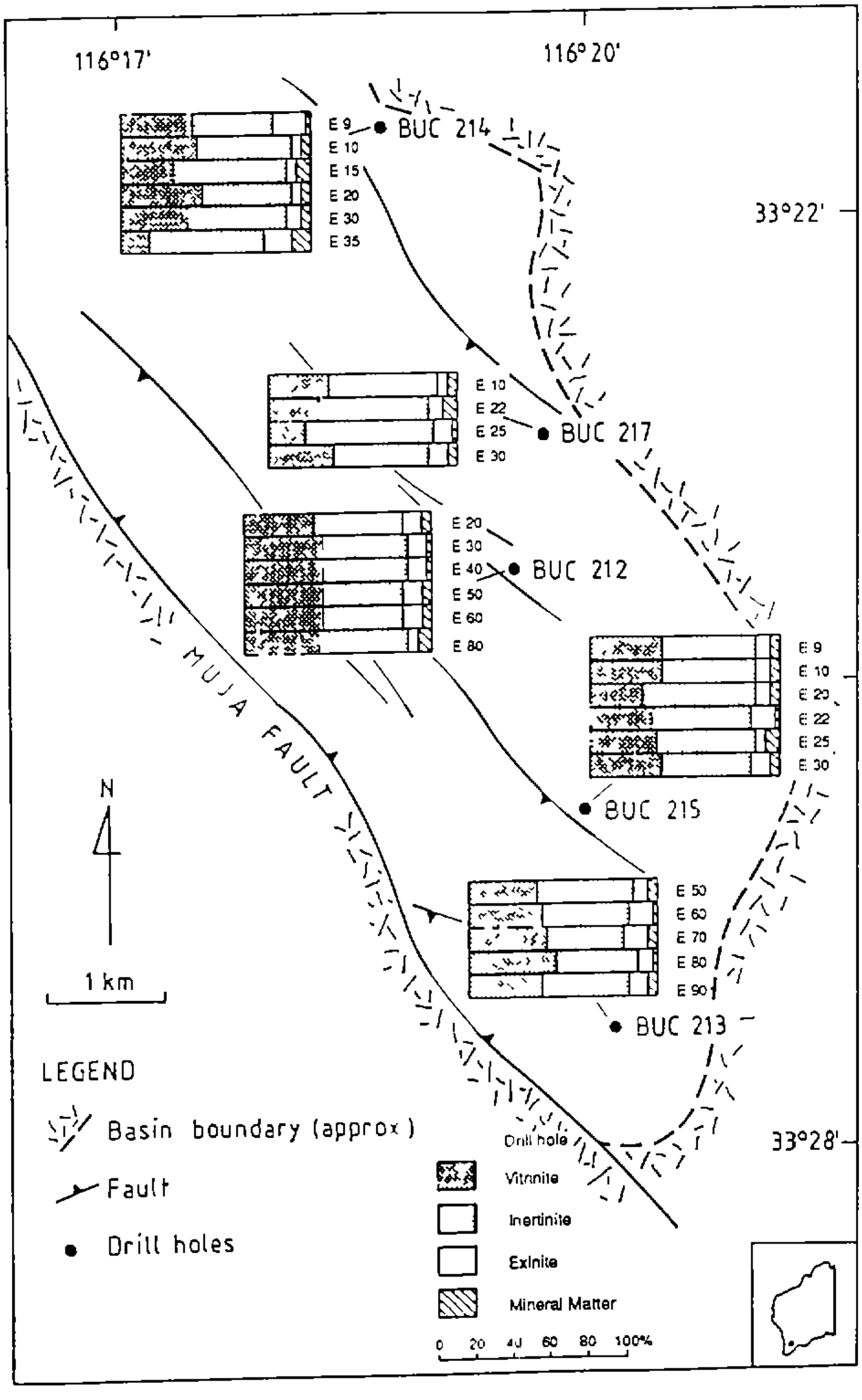


Figure 4.49. Variations of maceral and mineral matter of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

4.3.2. Microlithotype Analyses

The microlithotype analyses on the coal are presented in Table 4.9 and Figures 4.50.a and 4.50.b. The typical microlithotypes of the coal are inertite, durite, vitrite, vitrinertite, clarite, duroclarite and clarodurite. The liptite and vitrinertoliptite are present in low amounts in the coal. The carbargilite and carbopyrite are the dominant carbominerites of the coal (Table 4.9). In terms of microlithotype group, the coal is mainly dominated by monomaceral and bimaceral, followed by trimaceral and minor carbominerite. The data on microlithotype composition of the coal are also depicted in a ternary diagram on carbominerite free basis (Figure 4.51), and it shows the predominance of monomaceral over bimaceral and trimaceral, which is similar to the Vasse Shelf coal.

The dominant monomaceral microlithotype occurring in the coal is inertite, and its content varies from 6.4% in the seam E 70 of BUC 213 and 49.4% in the seam E 25 of BUC 217. This is followed by vitrite ranging between 2.4% in the seam E 22 of BUC 217 and 25.0% in the seam E 50 of BUC 212. The liptite content is present in low values, with a range of 0.0% in the most of all seams and 1.6% in the seams E 9 and E 35 of BUC 215. Figure 4.52 depicts the monomaceral composition of the coal on a ternary diagram, which shows the domination of inertite over vitrite and liptite. This means that the coal was formed under drier condition with high degree of oxidation during its deposition.

The durite and vitrinertite are the dominant bimaceral microlithotypes occurring in the seams E 9 to E 90, and their contents vary between 5.6% in the seam E 80 of BUC 213 and 36.2% in the seam E 9 of BUC 215, and 2.0% in the seam E 22 of BUC 217 and 27.6% in the seam E 80 of BUC

DRILL HOLES	MICROLITHOTYPE GROUP (%)	SEAMS													
		E 9	E10	E15	E20	E22	E25	E30	E35	E40	E50	E60	E70	E80	E90
BUC 213	**Monomaceral**														
	Vitrite										10.4	12.0	7.6	10.8	16.2
	Liptite										0.6	0.2	1.0	–	–
	Inertite										25.8	27.6	6.4	21.2	23.6
	Bimaceral														
	Clarite										6.0	2.4	11.6	1.0	3.2
	Vitrinertite										11.4	14.4	9.2	27.6	9.4
	Durite										23.4	17.8	9.8	5.6	18.0
	Trimaceral														
	Duroclarite										7.8	9.6	29.2	16.2	12.4
	Vitrinertoliptite										–	1.2	2.8	1.2	1.2
	Clarodurite										8.6	10.8	15.4	12.8	9.2
	Carbominerites														
	Carbargilite										4.0	2.8	4.8	2.4	5.4
	Carbopyrite										2.0	0.8	2.0	0.8	1.0
	Carbosilicate										–	0.4	0.2	0.4	0.4
BUC 215	**Monomaceral**														
	Vitrite	4.0	17.6	9.8	10.8			8.6	1.0						
	Liptite	1.6	–	–	–			–	1.6						
	Inertite	28.8	44.2	44.6	31.0			31.6	44.8						
	Bimaceral														
	Clarite	0.4	3.4	0.2	0.6			3.2	2.0						
	Vitrinertite	13.4	12.0	7.4	14.0			15.6	2.2						
	Durite	36.2	9.8	25.4	16.8			7.0	27.8						
	Trimaceral														
	Duroclarite	4.2	5.6	2.6	12.0			16.0	3.0						
	Vitrinertoliptite	1.0	0.4	0.4	1.0			1.2	0.4						
	Clarodurite	6.2	3.4	2.0	9.8			11.4	8.0						
	Carbominerites														
	Carbargilite	2.2	2.0	5.4	3.4			3.4	8.0						
	Carbopyrite	1.6	1.6	2.0	0.4			1.2	1.2						
	Carbosilicate	0.4	–	0.2	0.2			0.8	–						

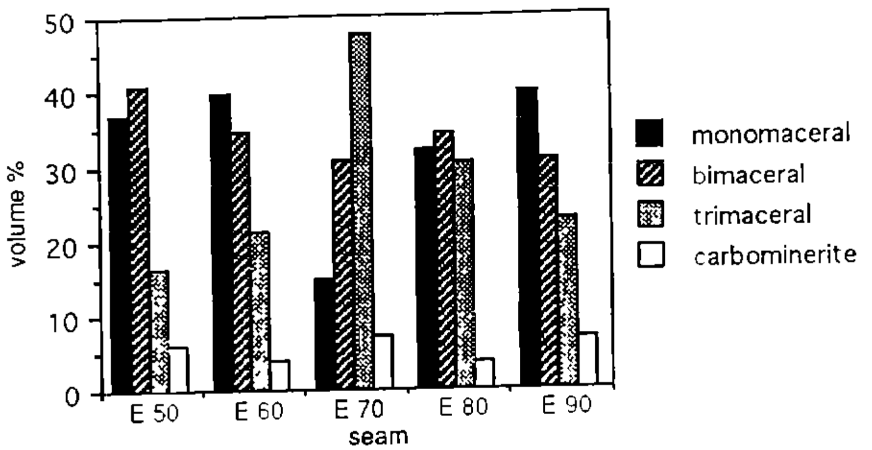
Table 4.9. Microlithotype composition (%) of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

DRILL HOLES	MICROLITHOTYPE GROUP (%)	SEAMS													
		E9	E10	E15	E20	E22	E25	E30	E35	E40	E50	E60	E70	E80	E90
BUC 212	**Monomaceral**														
	Vitrite				10.0			12.4		16.4	25.0	16.0		9.2	
	Liptite				–			0.4		0.2	–	–		0.4	
	Inertite				23.4			18.0		18.4	18.0	15.4		16.2	
	Bimaceral														
	Clarite				4.2			1.2		1.4	7.0	4.6		5.2	
	Vitrinertite				21.0			8.2		17.0	14.4	12.8		10.6	
	Durite				14.0			18.6		8.4	6.8	10.2		25.2	
	Trimaceral														
	Duroclarite				13.0			15.4		18.4	12.8	23.8		7.6	
	Vitrinertoliptite				0.6			1.8		1.2	0.8	1.0		1.0	
	Clarodurite				10.8			19.2		14.4	10.8	11.6		16.0	
	Carbominerites														
	Carbargilite				1.8			2.8		2.2	2.8	3.6		7.0	
	Carbopyrite				1.0			1.4		1.6	1.4	0.8		1.6	
	Carbosilicate				0.2			0.6		0.4	0.2	0.2		–	
BUC 217	**Monomaceral**														
	Vitrite		11.4			2.4	4.6	8.0							
	Liptite		0.2			0.8	0.6	0.2							
	Inertite		39.4			43.2	49.4	38.8							
	Bimaceral														
	Clarite		5.6			1.4	0.2	2.0							
	Vitrinertite		13.8			2.0	3.0	11.6							
	Durite		15.2			31.0	33.6	15.2							
	Trimaceral														
	Duroclarite		5.6			4.2	2.2	9.6							
	Vitrinertoliptite		0.8			1.2	1.4	1.8							
	Clarodurite		4.6			4.0	0.6	9.2							
	Carbominerites														
	Carbargilite		2.2			7.6	1.6	2.6							
	Carbopyrite		1.0			1.6	1.8	0.4							
	Carbosilicate		0.2			0.6	1.0	0.6							

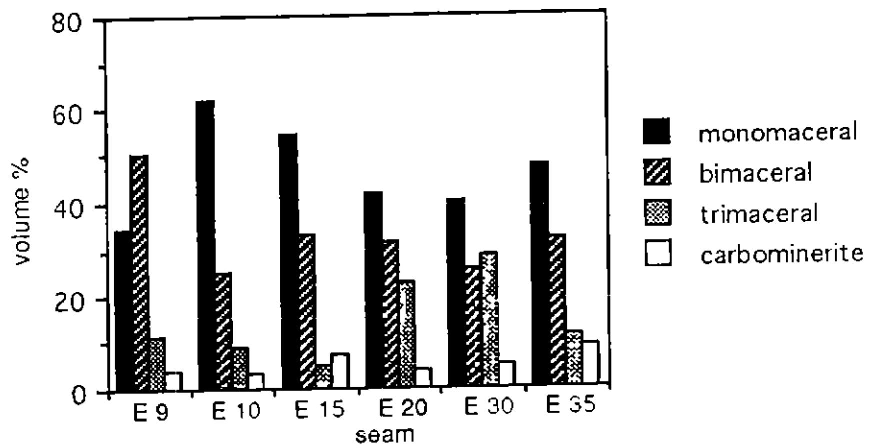
Table 4.9. Microlithotype composition (%) of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

DRILL HOLES	MICROLITHOTYPE GROUP (%)	SEAMS													
		E9	E10	E15	E20	E22	E25	E30	E35	E40	E50	E60	E70	E80	E90
BUC 214	**Monomaceral**														
	Vitrite	14.2	14.4		6.0	9.2	10.1	12.4							
	Liptite	0.2	–		–	–	0.1	–							
	Inertite	36.3	28.6		34.2	27.6	45.5	35.6							
	Bimaceral														
	Clarite	11.0	3.0		0.4	1.4	2.3	1.4							
	Vitrinertite	8.2	11.8		11.2	9.4	8.6	20.6							
	Durite	11.1	23.4		30.8	28.8	10.3	9.6							
	Trimaceral														
	Duroclarite	6.7	5.6		3.2	8.8	7.7	4.8							
	Vitrinertoliptite	0.7	0.4		0.6	1.2	0.5	0.6							
	Clarodurite	6.8	9.4		8.8	9.2	8.7	11.0							
	Carbominerites														
	Carbargilite	3.0	2.2		1.6	3.0	4.4	2.0							
	Carbopyrite	1.4	0.6		2.8	1.4	1.5	1.6							
	Carbosilicate	0.4	0.6		0.4	–	0.3	0.4							

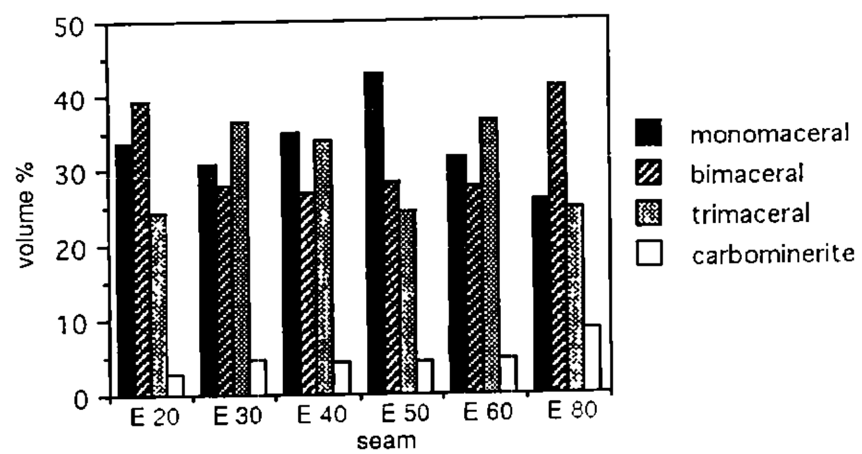
Table 4.9. Microlithotype composition (%) of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.



Microlithotype distribution, BUC 213

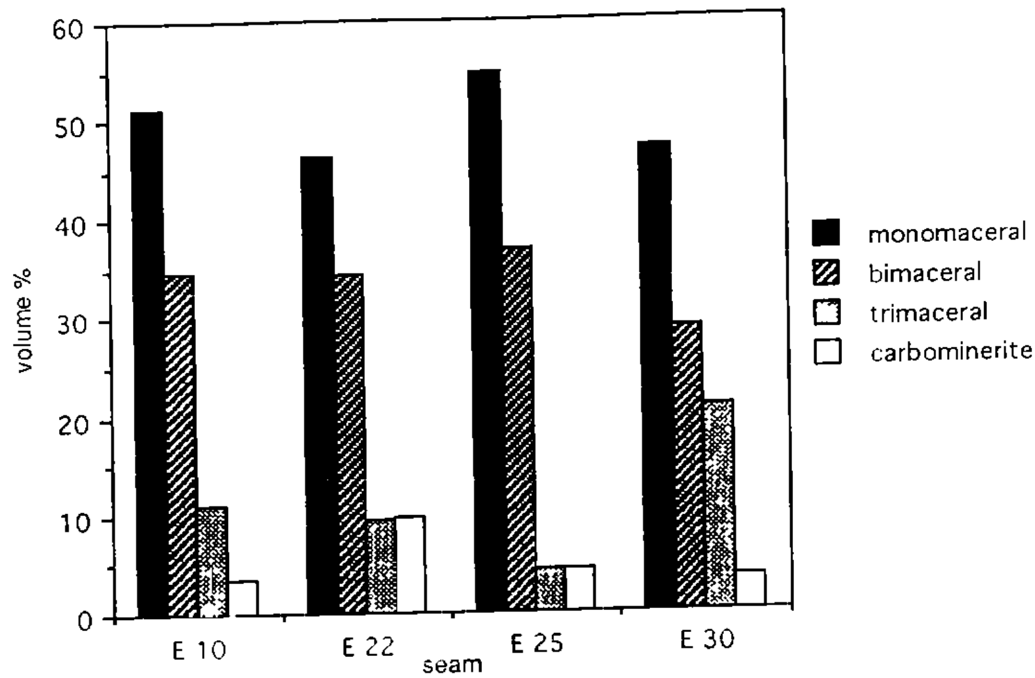


Microlithotype distribution, BUC 215

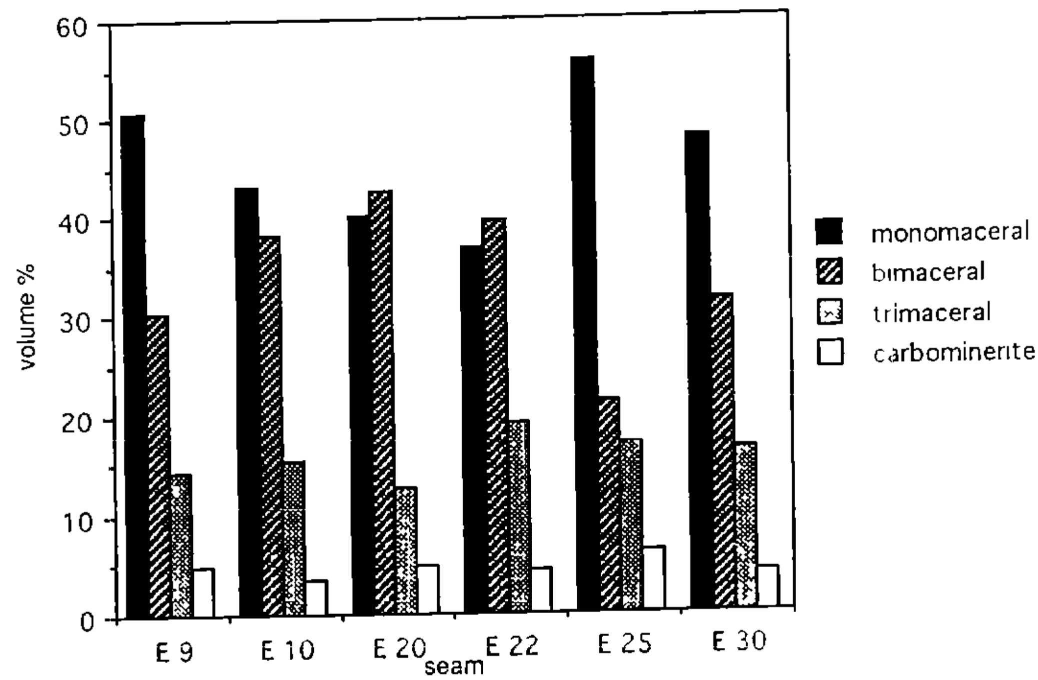


Microlithotype distribution, BUC 212

Figure 4.50.a. Microlithotype distribution of the Collie coal, drill holes BUC 213, BUC 215 and BUC 212.



Microlithotype distribution, BUC 217



Microlithotype distribution, BUC 214

Figure 4.50.b. Microlithotype distribution of the Collie coal, drill holes BUC 217 and BUC 214.

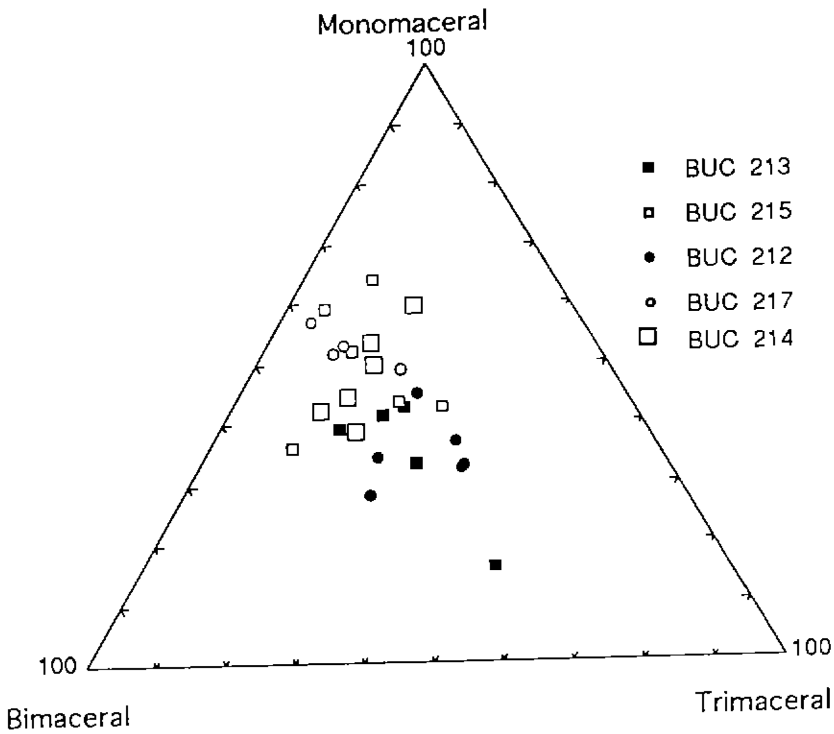


Figure 4.51. Microlithotype composition of the Collie coal (carbominerite free).

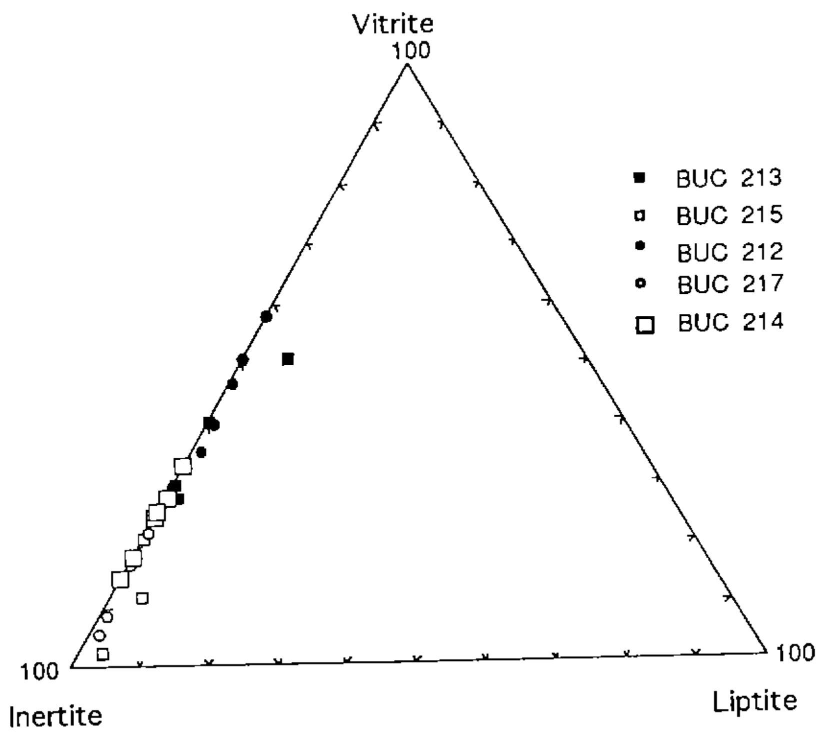


Figure 4.52. Composition of monomaceral group of the Collie coal.

213, respectively. The clarite content is 0.2% in the seam E 15 of BUC 215 and 11.6% in the seam E 70 of BUC 213. The bimaceral composition is depicted in a ternary diagram (Figure 4.53), and it shows the predominance of durite and vitrinertite over clarite. This reflects that the coal was formed under low water cover with a floral change during its deposition.

The clarodurite and duroclarite are the major trimaceral microlithotypes in the coal, which occur within the range of 0.6% in the seam E 25 of BUC 217 and 19.2% in the seam E 30 of BUC 212, and 2.2% in the seam E 25 of BUC 217 and 29.2% in the seam E 70 of BUC 213, respectively. The vitrinertoliptite is present in low amounts, with a range of 0.0% to 2.8% in the seam E 50 of BUC 213. The data on trimaceral composition of the coal is depicted in a ternary diagram as shown in Figure 4.54. Predominantly, the coal is constituted by clarodurite, followed by duroclarite and low vitrinertoliptite. This suggests the coal was formed under drier condition with low water table during its deposition.

The carbominerites predominantly consist of carbargilite, carbopyrite and minor carbosilicate. The range of carbargilite content is between 1.6% in the seam E 20 of BUC 214 and 8.0% in the seam E35 of BUC 215, whereas carbopyrite shows a value of 0.4% in the seam E 30 of BUC 217 and 2.8% in the seam E 20 of BUC 214. The carbosilicate displays a range of 0.0% in almost all seams and 1.0% in E 25 of BUC 217. The carbominerite composition of the coal dominated by carbargilite, is shown in Figure 4.55.

Overall the coal is characterized by monomaceral microlithotypes, followed by bimaceral, trimaceral and carbominerites. The dominance of monomaceral microlithotypes in the coal is due to the type of flora and the depositional environment of the coal.

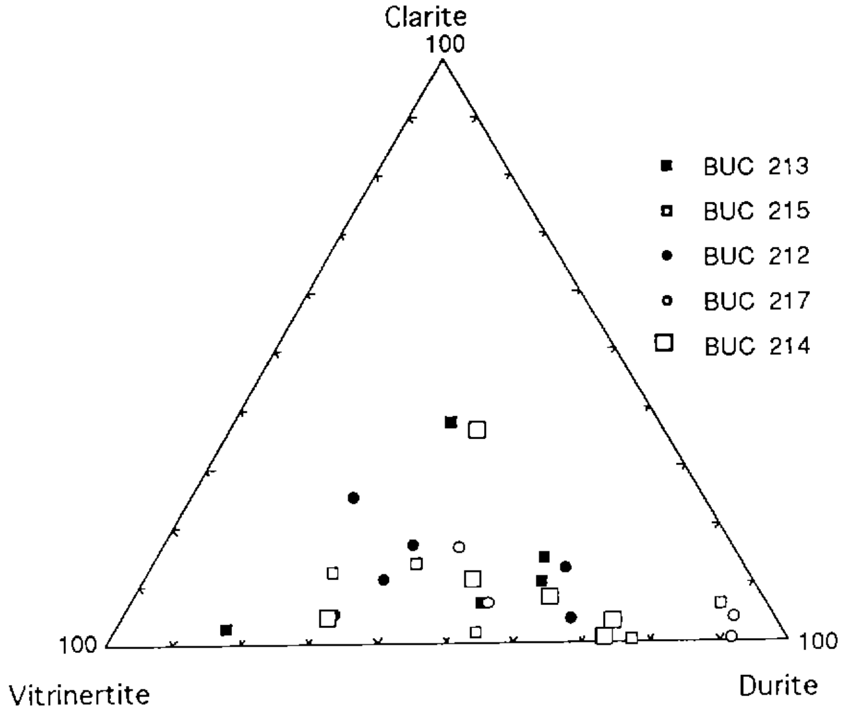


Figure 4.53. Composition of bimaceral group of the Collie coal.

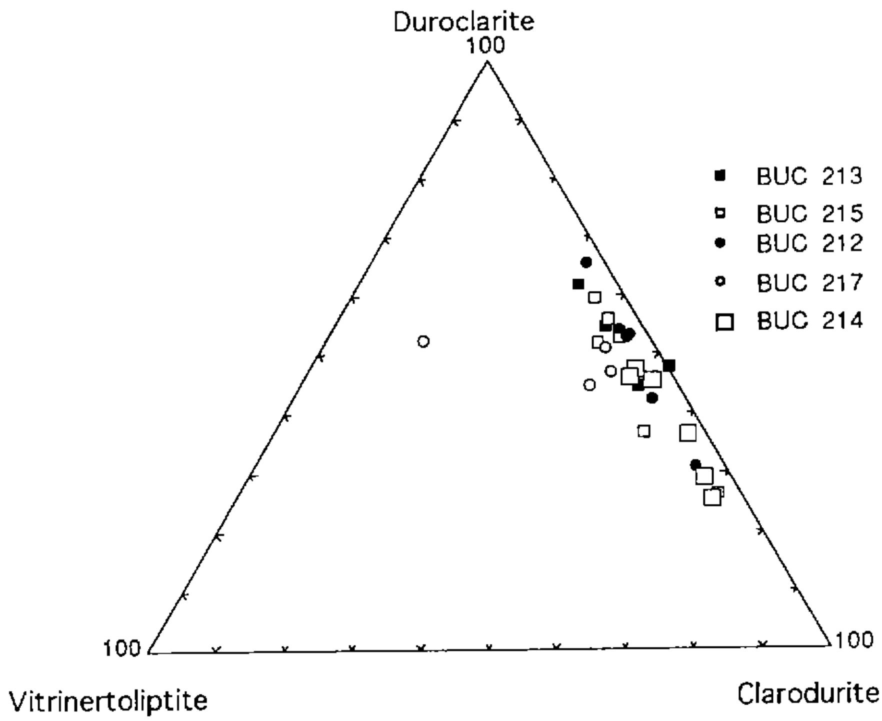


Figure 4.54. Composition of trimaceral group of the Collie coal.

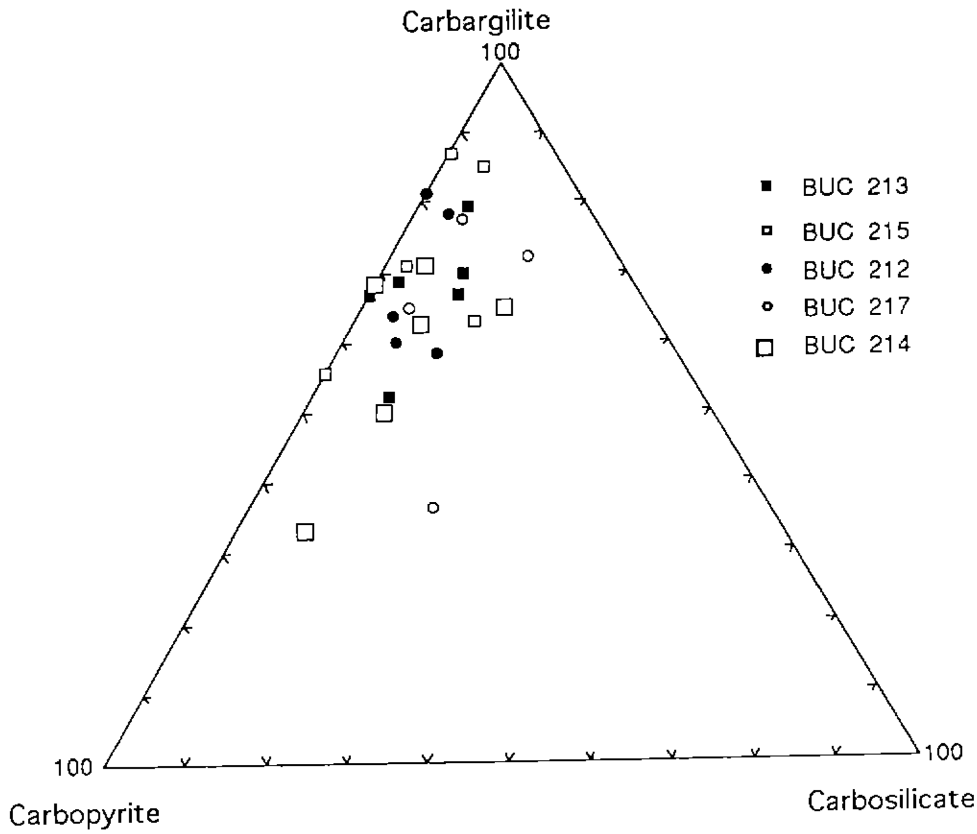


Figure 4.55. Composition of carbominerites of the Collie coal.

In Figure 4.56, microlithotype and carbominerite variations are illustrated for individual seams in the drill holes. Vertically, the abundance of monomaceral group (dominated by the inertite) varies downward through the drill holes, however, in BUC 214 and BUC 215, it shows a decrease downward from the seams E 9 to E 22, and from E 10 to E 30, respectively.

4.3.3. Relationship of Macerals and Microlithotypes

In general, the inertinite group predominates the seams E 9 to E 90 of the coal, and this is followed by vitrinite and low exinite and mineral matter, as shown in Table 4.10. The inertinite content is in correspondence with the inertite content, except within the seam E 80 of BUC 213. However, the exinite and mineral matter contents do not show a similar trend, and the mineral matter and carbominerite contents remain fairly constant. Thus, the microlithotype composition follows the similar trend as the maceral content of the coal.

4.3.4. Rank and Classification of Coal

The rank of the coal is determined by measuring the maximum reflectance of vitrinite on 27 samples of the seams E 9 to E 90 from drill holes BUC 212, BUC 213, BUC 214, BUC 215 and BUC 217, and the results are given in Table 4.11. The range of the reflectance of vitrinite varies between 0.39% to 0.50%, with the mean maximum reflectance values of 0.45% to 0.48% (Table 4.11). These values are plotted against the Australian and the ASTM classifications of coal in Figure 4.57, which correspond to the sub-bituminous rank according to the Australian Classification, and sub-bituminous B of the ASTM standard.

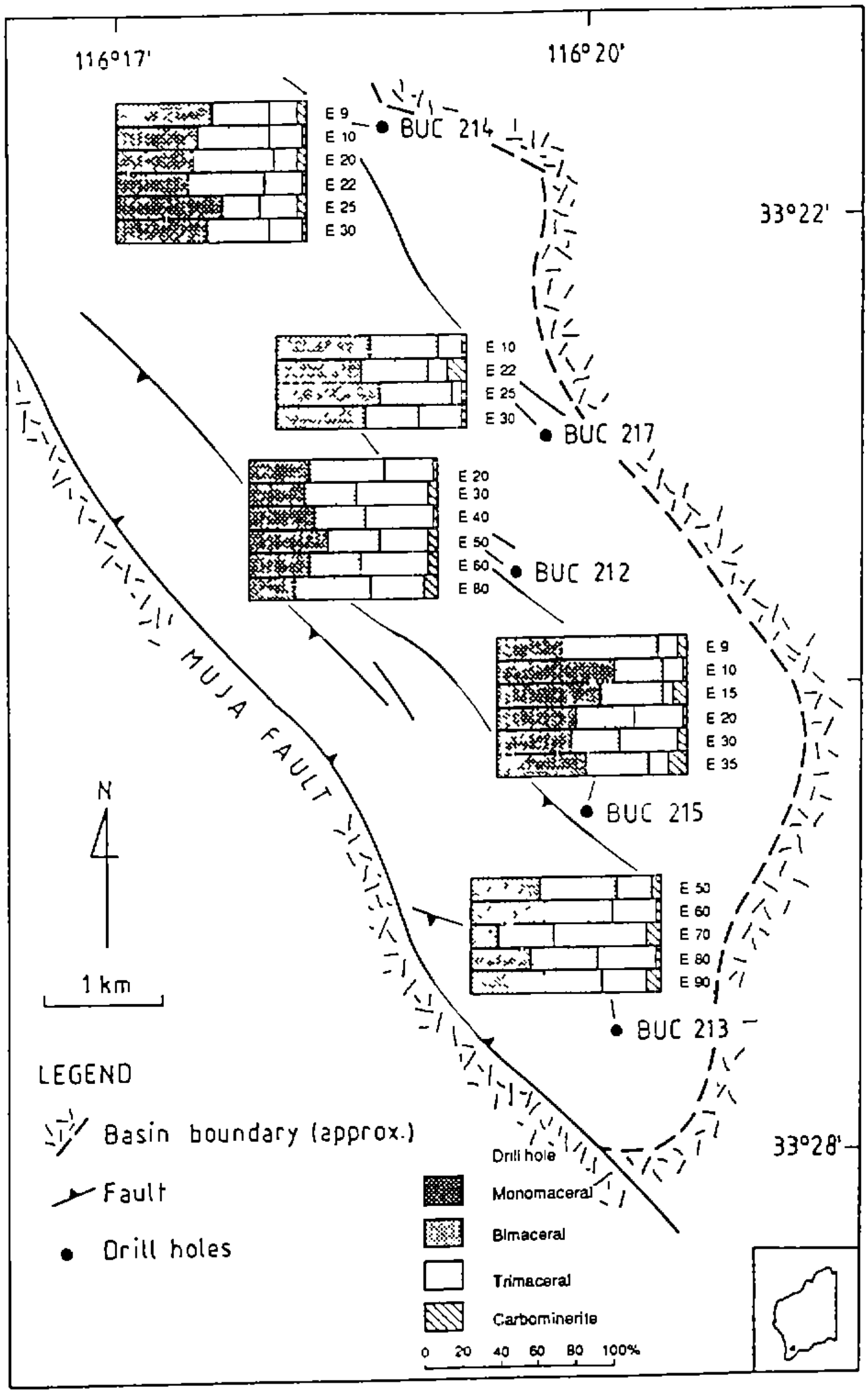


Figure 4.56. Variations of microlithotypes of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

DRILL HOLES	SEAMS	MACERALS+MM (%)				MICROLITHOTYPES (%)			
		Vitrinite	Inertinite	Exinite	MM	Vitrite	Inertite	Liptite	Carb
BUC 213	E 50	38.4	50.4	5.6	5.6	10.4	25.8	0.6	6.0
	E 60	42.0	46.2	8.0	3.8	12.0	27.6	0.2	4.0
	E 70	43.0	41.2	10.6	5.2	7.6	6.4	1.0	7.0
	E 80	47.4	43.8	4.6	4.2	10.8	21.2	0.0	3.6
	E 90	40.8	44.6	9.4	5.2	16.2	23.6	0.0	6.8
BUC 212	E 9	38.0	44.0	13.8	4.2	4.0	28.8	1.6	4.2
	E 10	40.4	45.8	7.6	6.2	17.6	44.2	0.0	3.6
	E 15	27.8	59.2	6.4	6.6	9.8	44.6	0.0	7.6
	E 20	42.4	47.7	5.6	4.6	10.8	31.0	0.0	4.0
	E 30	36.0	52.2	6.8	5.0	8.6	31.6	0.0	5.4
	E 35	15.2	61.4	14.4	9.0	1.0	44.8	1.6	9.2
BUC 212	E 20	38.2	47.6	9.4	4.8	10.0	23.4	0.0	3.0
	E 30	41.8	45.0	9.6	3.6	12.4	18.0	0.4	4.8
	E 40	43.8	44.8	7.2	4.2	16.4	18.4	0.2	4.2
	E 50	43.0	42.0	10.2	4.8	25.0	18.0	0.0	4.4
	E 60	44.0	42.6	8.6	4.8	16.0	15.4	0.0	4.6
	E 80	40.2	47.0	6.2	6.6	9.2	16.2	0.4	8.6
BUC 217	E 10	32.8	56.8	6.2	4.2	11.4	39.4	0.2	3.4
	E 22	27.2	58.0	8.0	6.8	2.4	43.2	0.8	9.8
	E 25	20.4	69.0	6.8	3.8	4.6	49.4	0.6	4.4
	E 30	36.0	50.0	9.8	4.2	8.0	38.8	0.2	3.6
BUC 214	E 9	37.0	49.0	8.8	5.2	14.2	36.3	0.2	4.8
	E 10	38.4	50.0	7.4	4.2	14.4	28.6	0.0	3.4
	E 20	26.2	61.2	7.2	5.4	6.0	34.2	0.0	4.8
	E 22	33.0	53.8	9.6	3.6	9.2	27.6	0.0	4.4
	E 25	35.7	52.4	5.5	6.4	10.1	45.5	0.1	6.2
	E 30	38.6	46.8	9.2	5.4	12.4	35.6	0.0	4.0

MM : Mineral Matter   Carb : Carbominerite

Table 4.10. Relationship of macerals and microlithotypes of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

DRILL HOLES	SEAMS	ROrnd	n	s	RANGE	ROmax	n	s	RANGE
BUC 213	E 50	0.46	100	0.02	0.40-0.49	0.48	30	0.02	0.41-0.50
	E 60	0.45	100	0.03	0.40-0.50	0.47	30	0.02	0.42-0.50
	E 70	0.45	100	0.02	0.40-0.50	0.47	30	0.02	0.41-0.50
	E 80	0.45	100	0.02	0.41-0.50	0.47	30	0.02	0.41-0.50
	E 90	0.46	100	0.02	0.41-0.50	0.48	30	0.02	0.43-0.50
BUC 215	E 9	0.44	100	0.03	0.40-0.49	0.46	30	0.02	0.40-0.48
	E 10	0.43	100	0.03	0.40-0.49	0.45	30	0.02	0.42-0.48
	E 15	0.44	100	0.02	0.40-0.49	0.46	30	0.02	0.41-0.49
	E 20	0.44	100	0.02	0.40-0.49	0.46	30	0.02	0.41-0.49
	E 30	0.44	100	0.02	0.40-0.49	0.45	30	0.02	0.40-0.49
	E 35	–	–	–	–	–	–	–	–
BUC 212	E 20	0.44	100	0.02	0.40-0.49	0.46	30	0.02	0.41-0.49
	E 30	0.44	100	0.03	0.40-0.49	0.46	30	0.02	0.41-0.48
	E 40	0.45	100	0.03	0.40-0.50	0.47	30	0.02	0.40-0.50
	E 50	0.46	100	0.02	0.40-0.50	0.47	30	0.02	0.41-0.48
	E 60	0.45	100	0.02	0.40-0.50	0.47	30	0.03	0.40-0.50
	E 80	0.45	100	0.02	0.41-0.50	0.47	30	0.02	0.42-0.50
BUC 217	E 10	0.43	100	0.02	0.39-0.49	0.45	30	0.02	0.40-0.49
	E 22	0.44	100	0.03	0.40-0.49	0.46	30	0.02	0.40-0.49
	E 25	0.44	100	0.02	0.40-0.49	0.46	30	0.02	0.40-0.49
	E 30	0.44	100	0.02	0.40-0.50	0.46	30	0.02	0.39-0.49
BUC 214	E 9	0.44	100	0.02	0.40-0.49	0.46	30	0.02	0.41-0.49
	E 10	0.43	100	0.02	0.39-0.49	0.45	30	0.02	0.40-0.49
	E 20	0.44	100	0.03	0.40-0.49	0.46	30	0.02	0.41-0.49
	E 22	0.44	100	0.02	0.40-0.49	0.46	30	0.02	0.40-0.48
	E 25	0.44	100	0.02	0.40-0.50	0.46	30	0.02	0.41-0.49
	E 30	0.44	100	0.02	0.40-0.50	0.47	30	0.02	0.41-0.50

Table 4.11. Reflectance of vitrinite of the Collie coal, Premier Sub-basin, Collie Basin, Western Australia.

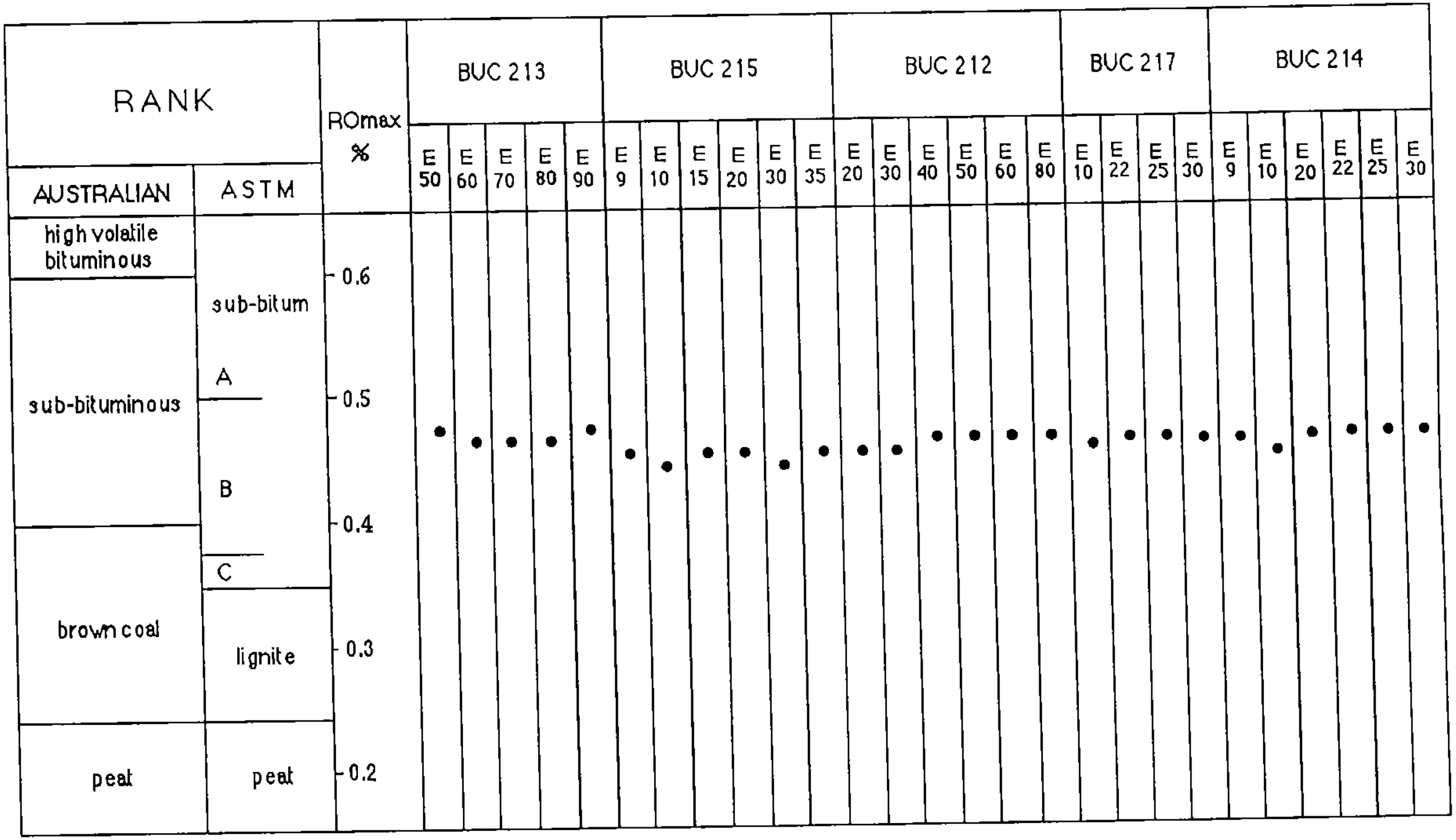


Figure 4.57. Reflectance of vitrinite of the Collie coal, drill holes BUC 213, BUC 215, BUC 212, BUC 217 and BUC 214.

The coal like Vasse Shelf coal is classified according to vitrinite content and reflectance of vitrinite, as given in Table 4.12 and Figure 4.58. The class of the coal determined in the square boxes ranges between 042 to 044 indicating the vitrinite reflectance is between 0.40% to 0.50% and the vitrinite content is from 20.0% to 50.0%.

4.3.5. Petrological Characteristics

The coal on the basis of petrographic data has the following characters:

. The coal is categorized as an inertinite-rich coal, with the predominance of the inertodetrinite maceral. This suggests that the coal has undergone a high degree of decomposition during its deposition.

. The predominance of desmocollinite in the vitrinite group indicates its dominance over well preserved cell structure in the vitrinite, and this reflects the coal has undergone high degree of diagenesis.

. The exinite content is relatively low, and it is predominated by sporinite, cutinite and liptodetrinite.

. Very low to low semifusinite ratio and low to medium vitrinite content of the coal suggest that the coal was formed in an aerobic dry to wet environment with some degree of oxidation.

. The predominance of inertite and durite over vitrite and clarite contents in the coal suggests the deposition under drier conditions with fluctuations in the water table.

DRILL HOLES	SEAMS	VITRINITE CONTENT (%)	RO max (%)
BUC 213	E 50	38.4	0.48
	E 60	42.0	0.47
	E 70	43.0	0.47
	E 80	47.4	0.47
	E 90	40.8	0.48
BUC 215	E 9	38.0	0.46
	E 10	40.4	0.45
	E 15	27.8	0.46
	E 20	42.4	0.46
	E 30	36.0	0.45
	E 35	15.2	–
BUC 212	E 20	38.2	0.46
	E 30	41.8	0.46
	E 40	43.8	0.47
	E 50	43.0	0.47
	E 60	44.0	0.47
	E 80	40.2	0.47
BUC 217	E 10	32.8	0.45
	E 22	27.2	0.46
	E 25	20.4	0.46
	E 30	36.0	0.46
BUC 214	E 9	37.0	0.46
	E 10	38.4	0.45
	E 20	26.2	0.46
	E 22	33.0	0.46
	E 25	35.7	0.46
	E 30	38.6	0.47

Table 4.12. Vitrinite content and reflectance of vitrinite of the Collie coal.

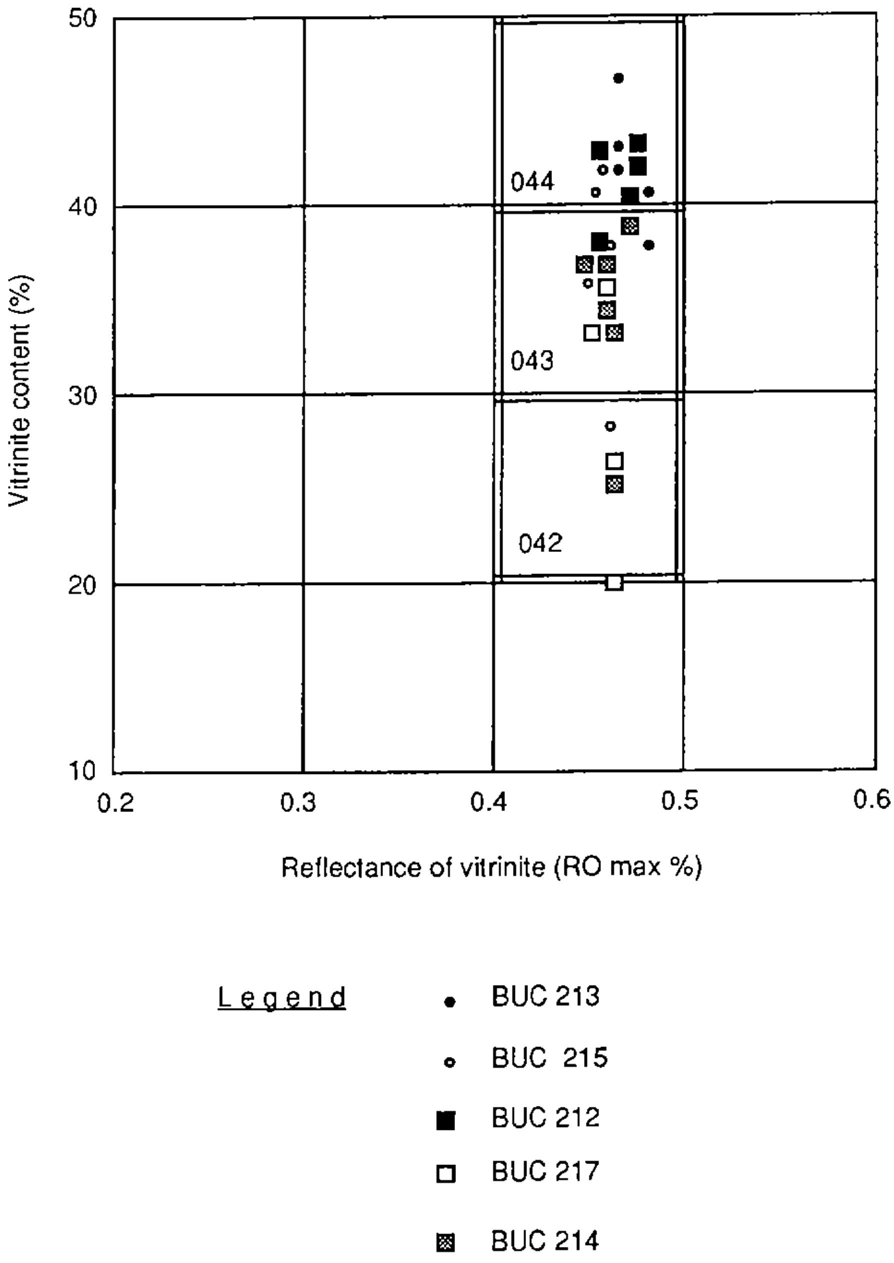


Figure 4.58. Classification of the Collie coal.

. The rank of the coal is sub-bituminous according to the Australian Classification.

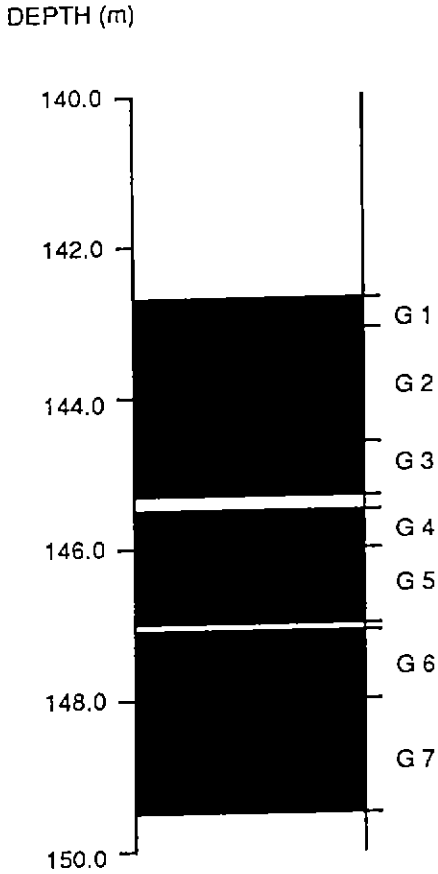
4.4. The Irwin River Coal

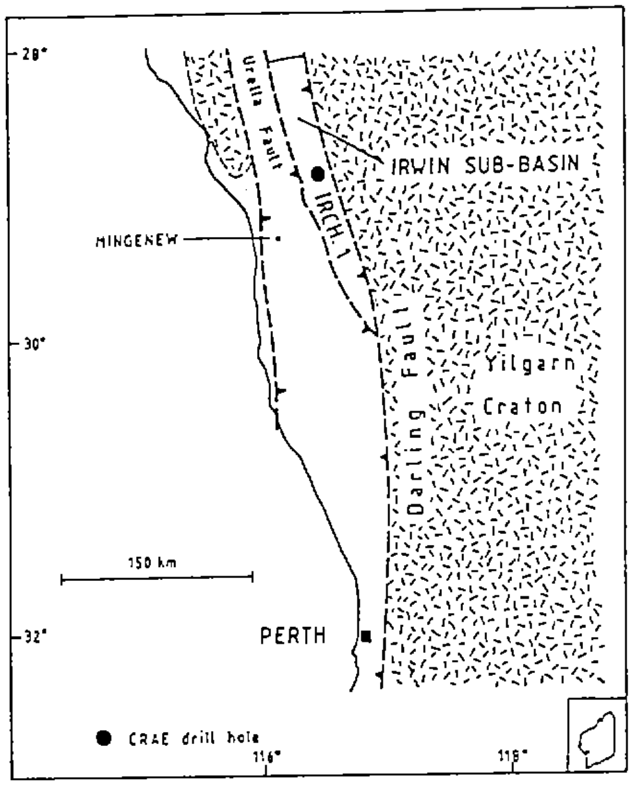
The particulate samples of coal from the seam G, with sub-seams G 1 to G 7 of the Early Permian Irwin River Coal Measures were obtained for analyses from the IRCH 1 drill hole drilled in the Irwin Sub-basin by CRAE (Figure 4.59). The seam is 6.74 m thick, and due to the particulate nature of the samples, the analyses were restricted to macerals and microlithotypes.

4.4.1. Maceral and MIneral Matter Analyses

The maceral and mineral matter composition of the coal is shown in Table 4.13 and Figure 4.60. The maceral composition of the sub-seams G 1 to G 7 is dominated by vitrinite (45.4%-55.2%), followed by inertinite (35.2%-44.4%), with minor exinite (4.8%-8.6%) and mineral matter (2.8%-8.2%). The maceral composition on a mineral matter free basis is depicted in Figure 4.61, and it shows the predominance of vitrinite over inertinite and exinite. This suggests that the coal deposition was under wetter conditions with fluctuations in the water table.

The vitrinite is present as the most dominant maceral group in the coal, and it is mainly predominated by the maceral desmocollinite, very low telocollinite, vitrodetrinite, corpocollinite and telinite. The desmocollinite content ranges between 38.0% in G 7 and 51.8% in G 4. The telocollinite, vitrodetrinite, corpocollinite and telinite occur in very low amounts and constitute 0.6% in G 1 and 6.0% in G 2, 0.2% in G 2 and 3.0% in G 3, 0.4% in G 4 and 1.8% in G 3 and G 7 and 0.2% in G 3, respectively. The





Location of IRCH 1 drill hole.

Figure 4.59. Irwin River coal, seam G (sub-seams G 1 to G 7), drill hole IRCH 1.

MACERALS/ MINERAL MATTER %	SUB - SEAMS						
	G 1	G 2	G 3	G 4	G 5	G 6	G 7
Telinite	–	–	0.2	–	–	–	–
Telocollinite	0.6	6.0	–	–	1.2	2.0	3.4
Corpocollinite	–	1.4	1.8	0.4	1.0	1.0	1.8
Desmocollinite	46.4	40.0	40.4	51.8	45.6	49.6	38.0
Vitrodetrinite	1.2	0.2	3.0	1.2	0.6	2.6	2.2
Vitrinite group	**48.2**	**47.6**	**45.4**	**53.4**	**48.4**	**55.2**	**45.4**
Fusinite	0.8	10.4	11.2	1.8	3.4	2.4	6.0
Semifusinite	3.0	3.4	2.8	2.2	5.8	3.0	4.2
Sclerotinite	–	0.4	–	–	–	–	0.2
Micrinite	–	0.2	0.8	0.8	1.0	0.6	3.4
Macrinite	–	0.2	–	–	0.2	0.4	0.6
Inertodetrinite	34.2	27.2	26.2	31.0	27.4	28.8	30.0
Inertinite group	**38.0**	**41.8**	**41.0**	**35.8**	**37.8**	**35.2**	**44.4**
Sporinite	1.6	0.6	3.8	2.0	2.2	2.0	3.2
Cutinite	1.4	2.2	2.6	1.2	1.6	1.0	1.8
Resinite	0.6	0.6	0.8	0.4	0.2	0.8	1.0
Alginite	–	–	–	0.4	–	–	0.2
Liptodetrinite	2.4	2.6	1.4	1.6	1.6	1.0	1.2
Exinite group	**6.0**	**6.0**	**8.6**	**5.6**	**5.6**	**4.8**	**7.4**
Clay	1.8	2.4	1.4	1.4	1.8	2.0	1.4
Pyrite	5.8	1.4	3.2	3.0	5.6	2.2	0.8
Quartz	0.2	0.8	0.4	0.8	0.8	0.6	0.6
Mineral matter	**7.8**	**4.6**	**5.0**	**5.2**	**8.2**	**4.8**	**2.8**

Table 4.13. Maceral and mineral matter contents (%) of the Irwin River coal, seam G (sub-seams G 1 to G 7).

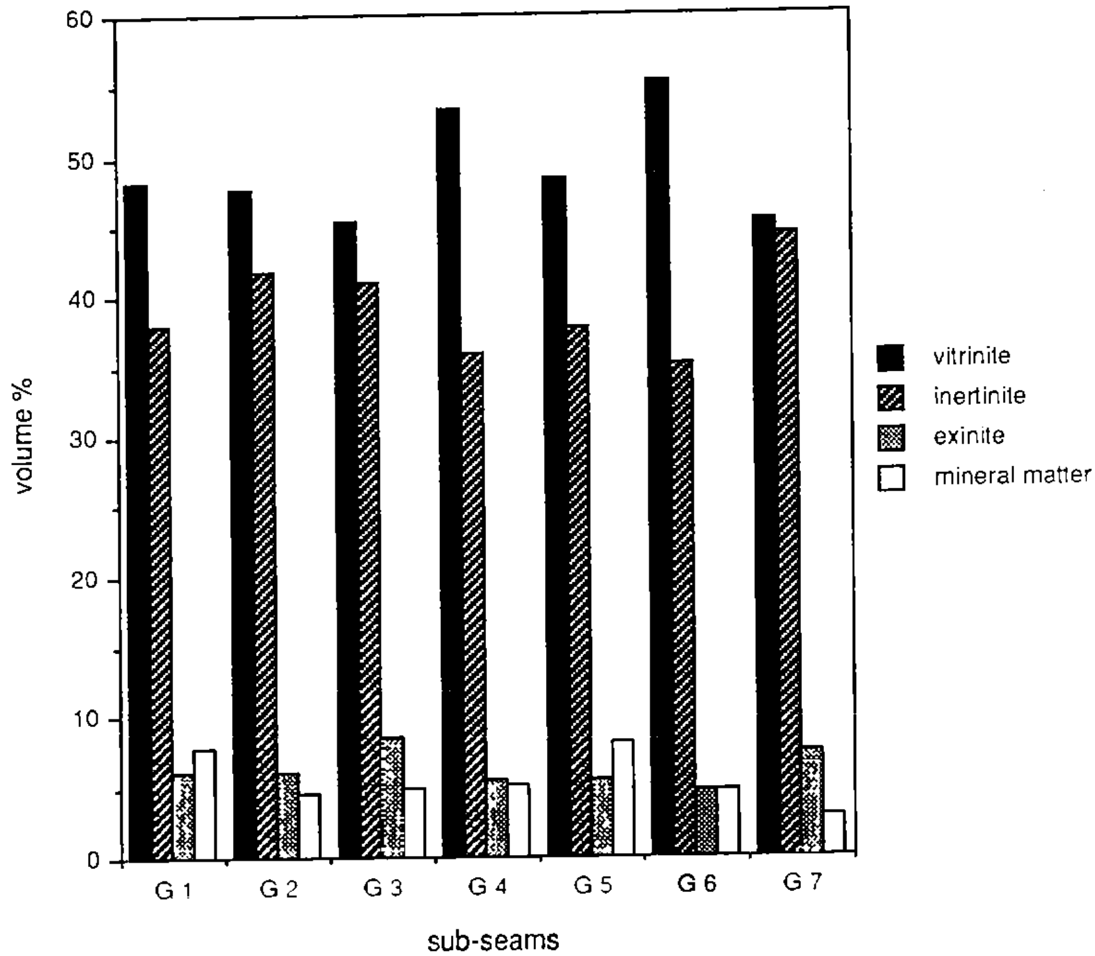


Figure 4.60. Maceral and mineral matter distribution of the Irwin River coal, seam G (sub-seams G 1 to G 7).

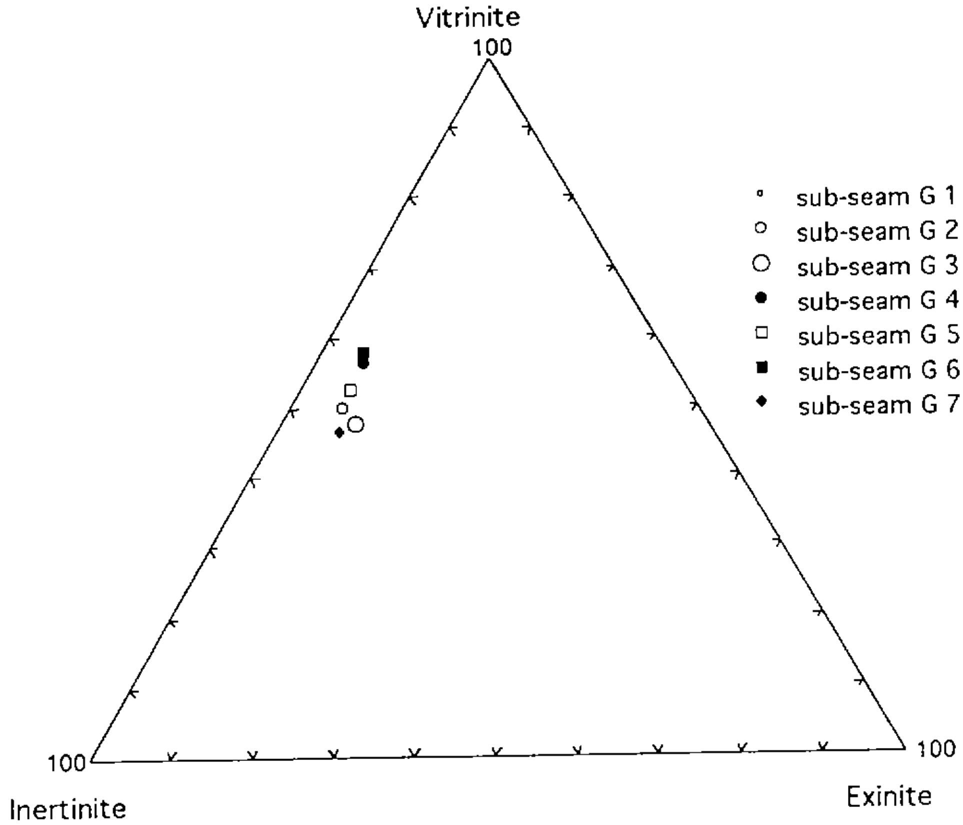
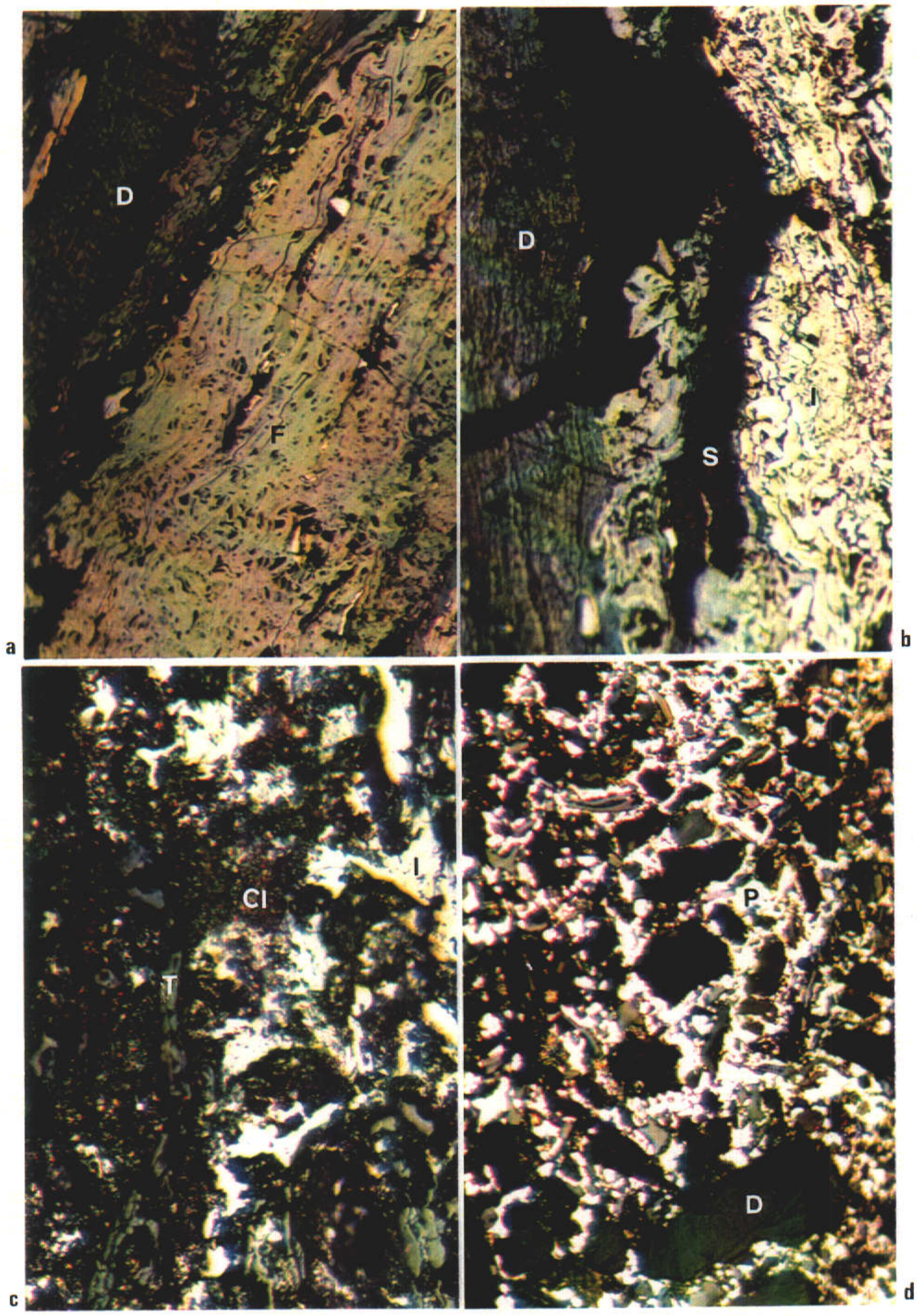


Figure 4.61. Maceral composition of the Irwin River coal (mineral matter free).

desmocollinite shows a thoroughly decomposed and gelified attritus of a variety of source materials, as given in Figures 4.62.a to 4.62.d, associated with fusinite, sporinite, inertodetrinite, clay and pyrite. Figure 4.63 depicts vitrinite composition of the coal, and it shows the domination of desmocollinite over telocollinite and the other vitrinite.

The macerals of the inertinite group identified in the coal in order of abundance are inertodetrinite, fusinite and semifusinite. The inertodetrinite content varies between 26.2% in G 3 and 34.2% in G 1, fusinite content is between 0.8% in G 1 to 11.2% in G 3 and semifusinite content is from 2.2% to 5.8% in G 5. The micrinite, macrinite and sclerotinite occur in very low amounts. The micrinite has a range of 0.0% in G 1 and 3.4% in G 7, macrinite is between 0.0% in G 1, G 3 and G 4 and sclerotinite is from 0.0% in the most of sub-seams to 0.4% in 0.2%. Figure 4.62.a shows cellular structure of fusinite in association with desmocollinite, and Figures 4.62.b and 4.62.c show the inertodetrinite consisting of fragmental cell walls. The inertinite composition of the coal is dominated by the other inertinite, as given in Figure 4.64, and this indicates a high degree of decomposition of the peat.

The exinite group of macerals recognized in the coal consists mainly of sporinite, cutinite and liptodetrinite and low resinite and alginite. The sporinite content has a range from 0.6% in G 2 to 3.8% in G 3, cutinite content varies between 1.0% in G 6 to 2.6% in G 3 and liptodetrinite is between 1.0% in G 6 and 2.6% in G 2. The resinite and alginite contents range between 0.2% in G 5 and 1.0% in G 7, and 0.0% in the most of sub-seams to 0.4% in G 4, respectively. Figures 4.65.a to 4.65.d show the cutinite as dark wavy lines in incident light and with yellow colour under



Maceral groups of the Irwin River coal (reflected light, oil immersion, x320, G seam, IRCH 1).

Figure 4.62.a. Desmocollinite (D) associated with fusinite (F).

Figure 4.62.b. Desmocollinite (D) associated with sporinite (S) and inertodetrinite (I).

Figure 4.62.c. Telocollinite (T) associated with inertodetrinite (I) and clay (Cl).

Figure 4.62.d. Desmocollinite (D) associated with pyrite (P).

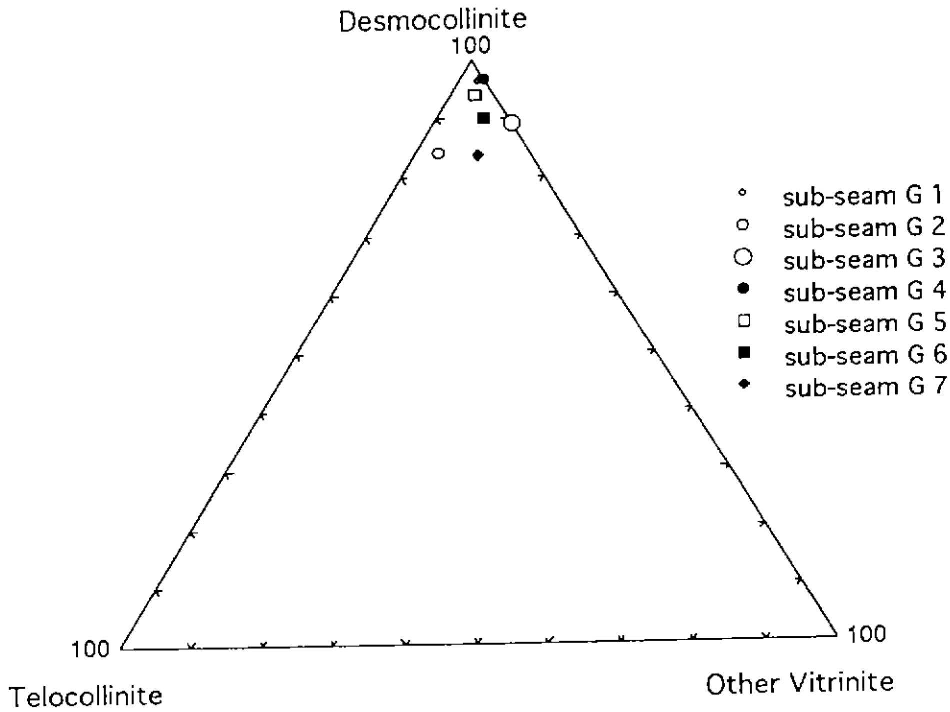


Figure 4.63. Composition of vitrinite group of the Irwin River coal

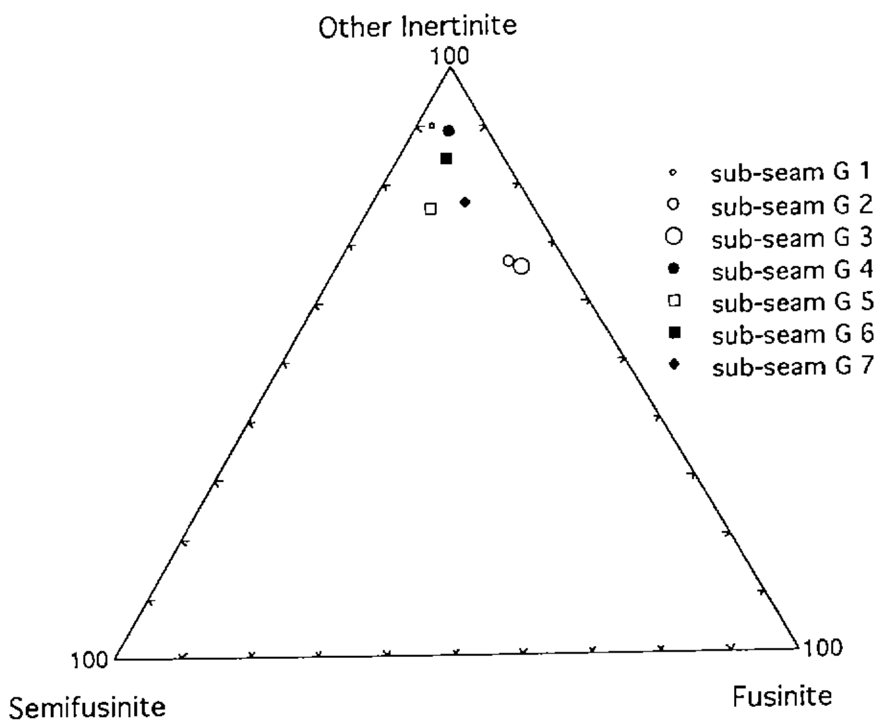
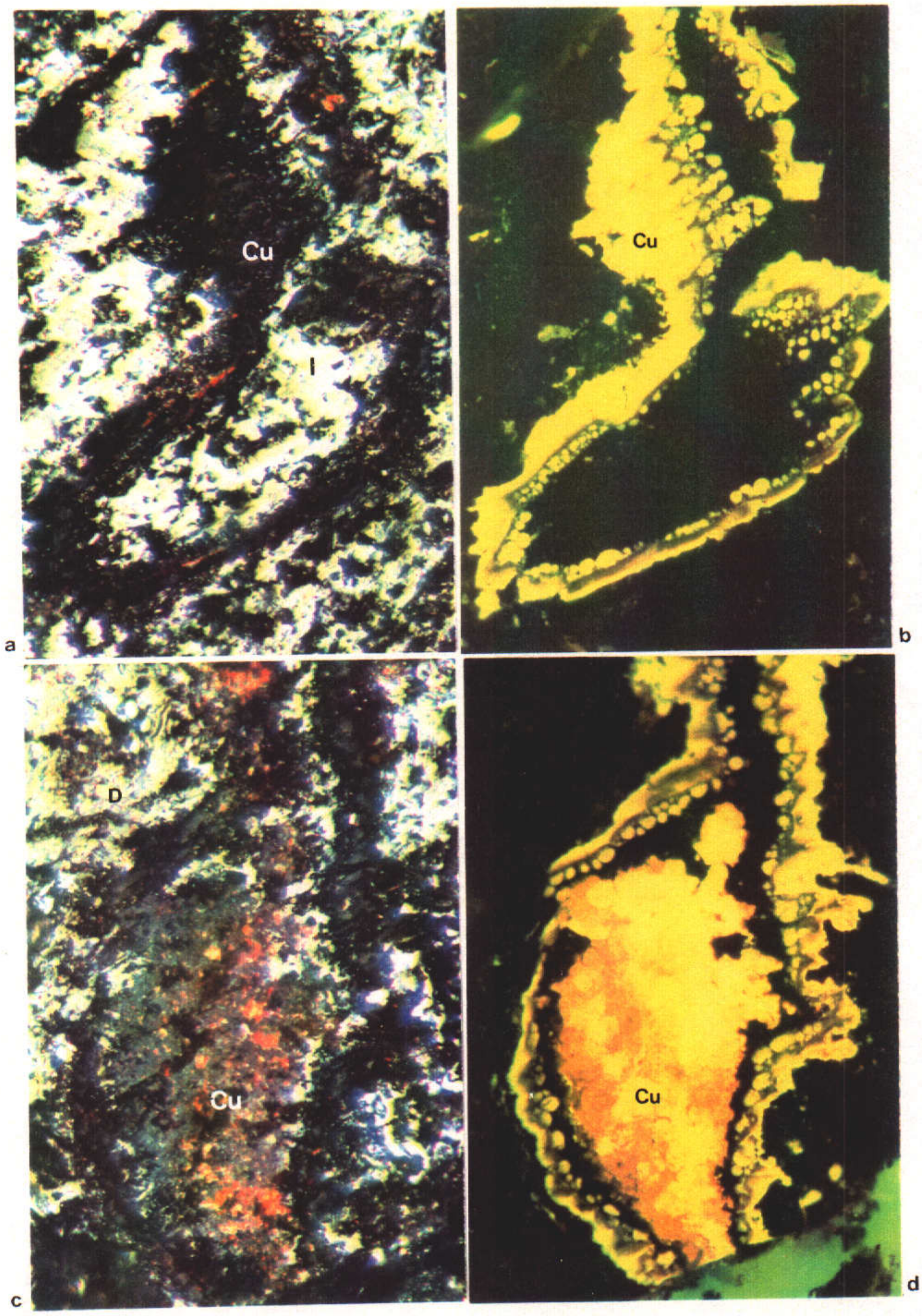


Figure 4.64. Composition of inertinite group of the Irwin River coal.



Macerals of the exinite group, Irwin River coal (reflected light, oil immersion, x320).

Figure 4.65.a. Cutinite (Cu) associated with inertodetrinite (I). G 2 sub-seam, IRCH 1.

Figure 4.65.b. Same section after blue- light excitation, cutinite (Cu) displays brownish-yellowish fluorescence colour. G 2 sub-seam, IRCH 1.

Figure 4.65.c. Cutinite (Cu) associated with desmocollinite (D). G 3 sub-seam, IRCH 1.

Figure 4.65.d. Same section after blue-light excitation, cutinite (Cu) displays brownish-yellowish fluorescence colour. G 3 sub-seam, IRCH 1.

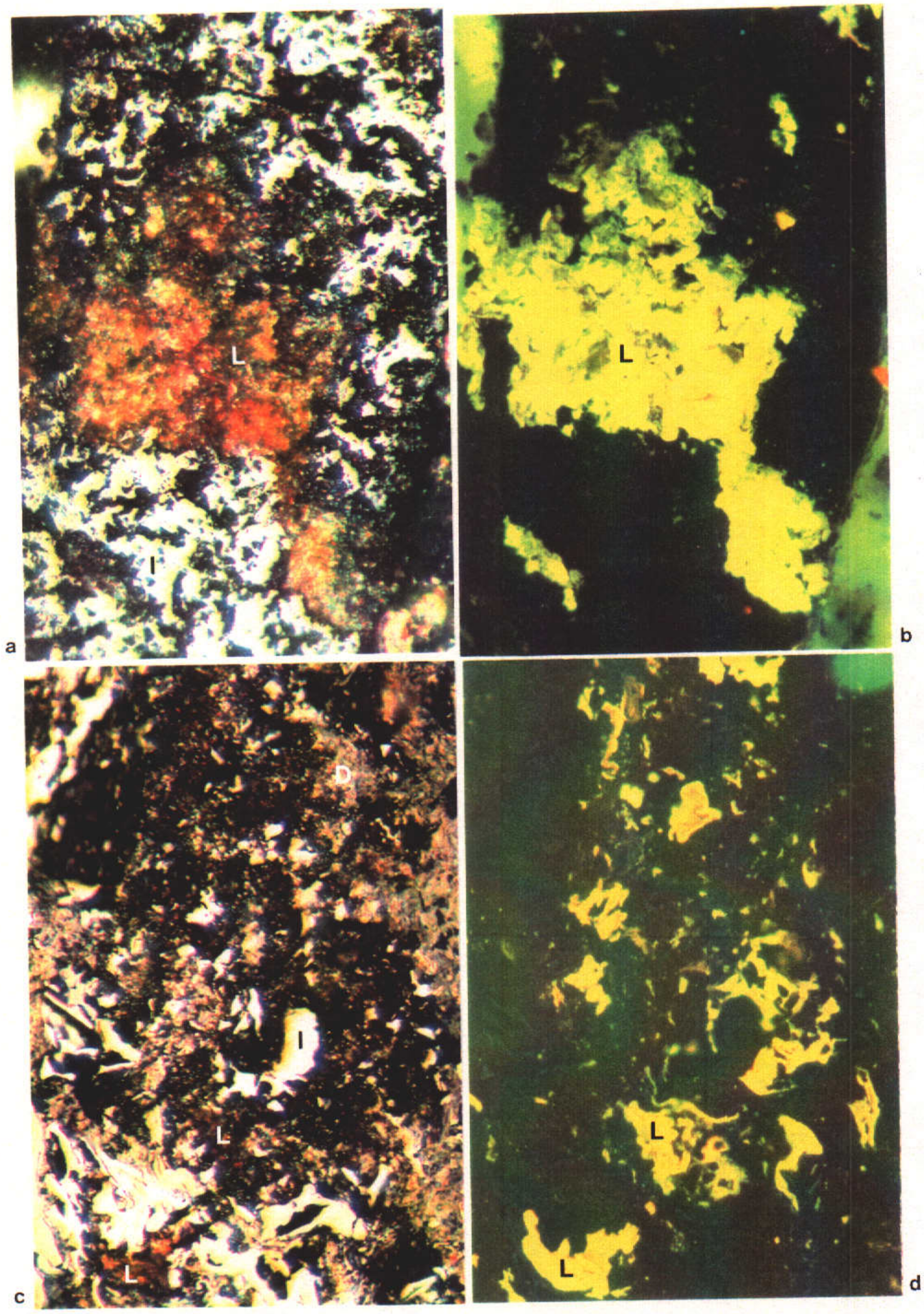
fluorescence microscopy, associated with inertodetrinite and desmocollinite. The liptodetrinite including all shapes and forms of exinitic maceral, and appears dark in reflected light and yellow colour in fluorescence mode, as shown in Figures 4.66.a to 4.66.d associated with inertodetrinite and desmocollinite. Figure 4.67 depicts exinite composition, and it shows the predominance of the other exinite over sporinite and cutinite. This indicates that the coal has undergone a high degree of decomposition during its deposition.

The coal is characterized by very low semifusinite ratio and medium to high vitrinite content, as shown in Figure 4.68. This indicates that the coal was formed in an anaerobic wet environment with some degree of oxidation during its deposition.

The vertical variation of maceral and mineral matter contents in all sub-seams is given in Figure 4.69. Vertically, the vitrinite content in the coal is variable in the individual sub-seams, with the maximum concentration in the sub-seams G 4 and G 6. Similar trend is shown by the contents of inertinite, exinite and mineral matter. The variations in proportion of macerals and mineral matter reflect fluctuations in water cover in the swamp during the deposition of peat.

4.4.2. Microlithotype Analyses

The microlithotypes in the coal consist mainly of vitrite and inertite, followed by vitrinertite, durite and clarite, and low duroclarite and clarodurite, as shown in Table 4.14. The distribution of microlithotypes in the coal is given in Figure 4.70. The liptite and vitrinertoliptite are present in small amounts in the coal. The carbargilite and carbopyrite are the dominant carbominerite



Macerals of the exinite group, Irwin River coal (reflected light, oil immersion, x320).

Figure 4.66.a. Liptodetrinite (L) associated with inertodetrinite (I). G 1 sub-seam, IRCH 1.

Figure 4.66.b. Same section after blue-light excitation, liptodetrinite (L) displays greenish-yellowish fluorescence colour. G 1 sub-seam, IRCH 1.

Figure 4.66.c. Liptodetrinite (L) associated with inertodetrinite (I) and desmocollinite (D). G 2 sub-seam, IRCH 1.

Figure 4.66.d. Same section after blue-light excitation, liptodetrinite (L) displays greenish-yellowish fluorescence colour. G 2 sub-seam, IRCH 1.

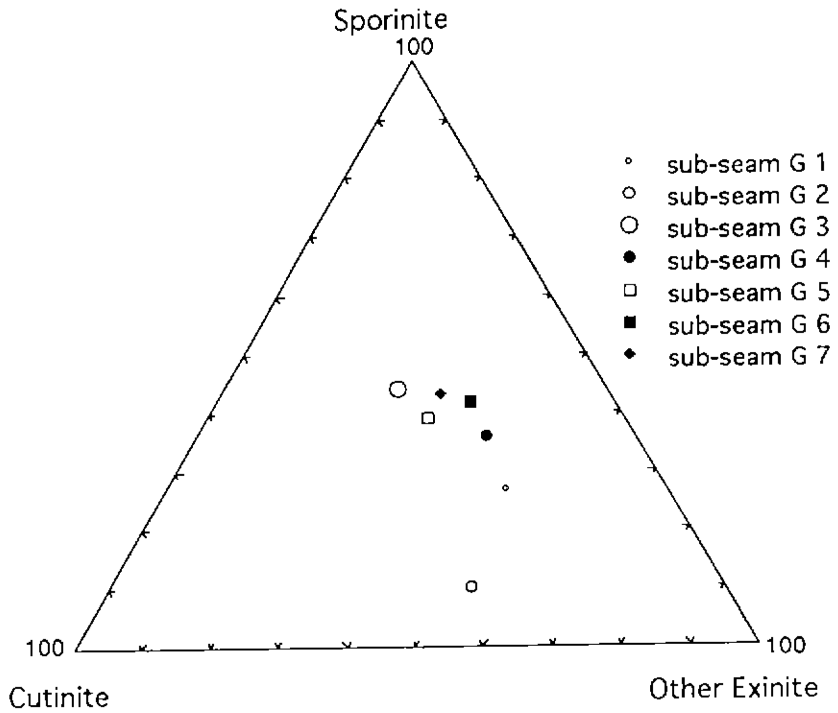


Figure 4.67. Composition of exinite group of the Irwin River coal.

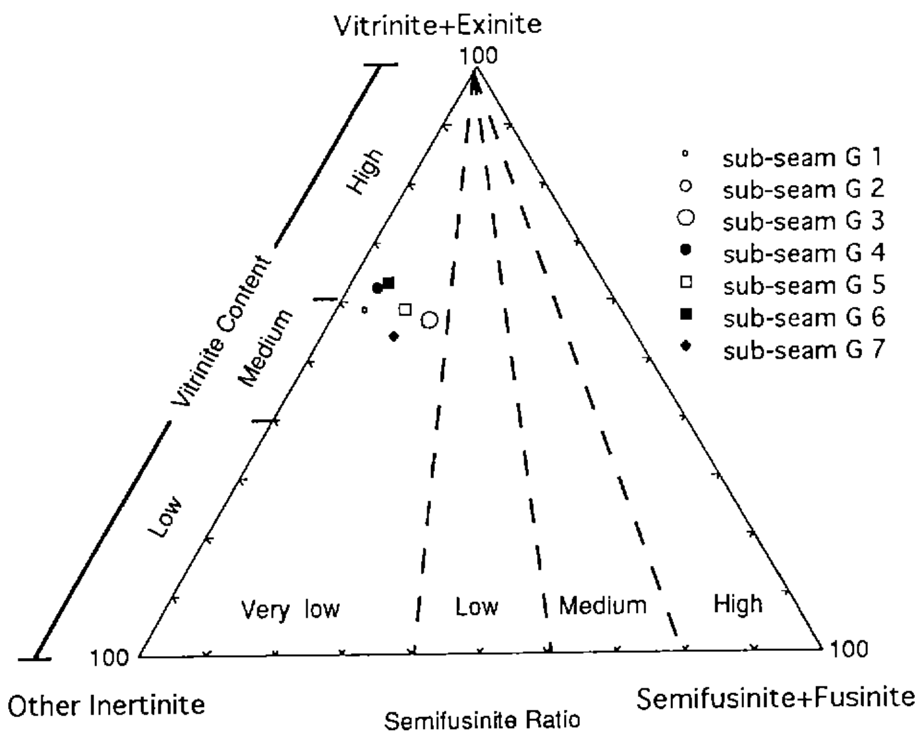


Figure 4.68. Maceral composition of the Irwin River coal, showing 'vitrinite content' and 'semifusinite ratio'.

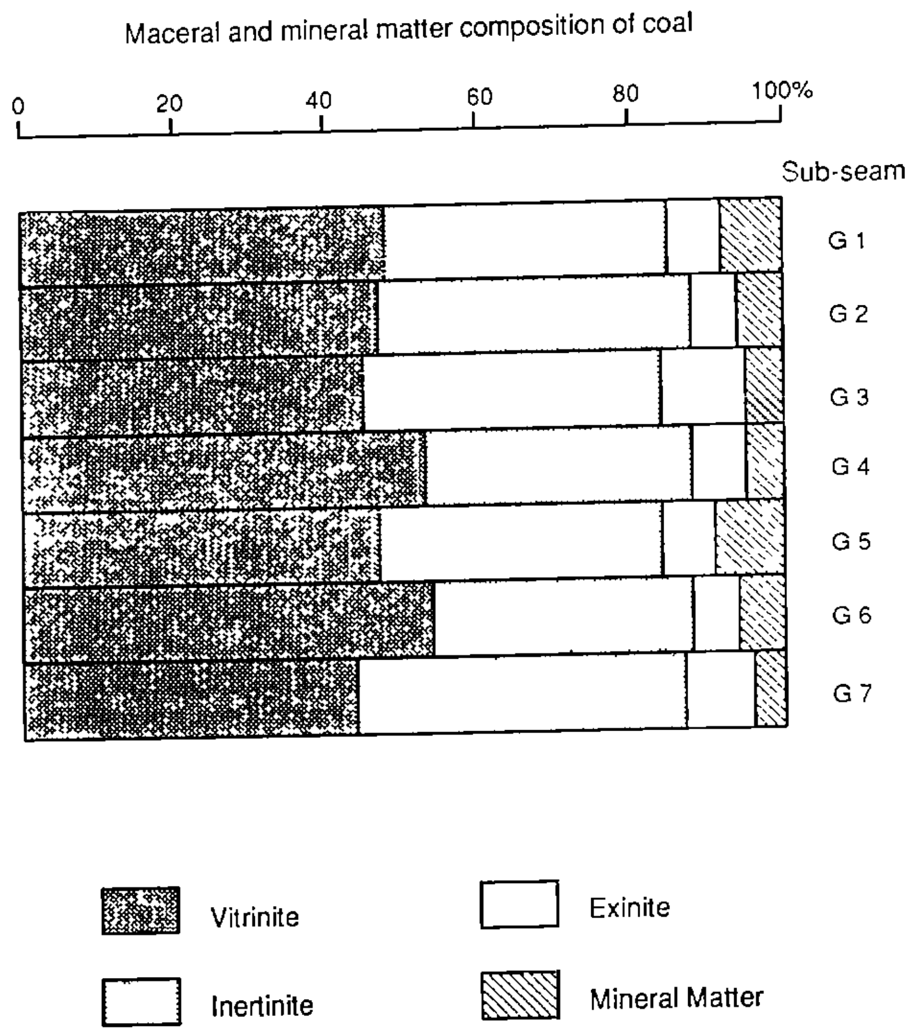


Figure 4.69. Maceral and mineral matter composition (%) of the Irwin River coal, seam G (sub-seams G 1 to G 7).

MICROLITHOTYPE GROUP (%)	SUB - SEAMS						
	G 1	G 2	G 3	G 4	G 5	G 6	G 7
Vitrite	23.8	28.6	29.0	36.4	25.2	34.4	35.0
Liptite	0.4	0.2	–	–	–	0.4	0.2
Inertite	36.6	27.6	25.4	17.2	20.6	24.0	15.6
Monomaceral	**60.8**	**56.4**	**54.4**	**53.6**	**45.8**	**58.8**	**50.8**
Clarite	6.2	4.0	7.4	9.8	5.6	3.8	6.8
Vitrinertite	6.6	18.2	11.6	8.6	13.6	13.0	21.6
Durite	6.8	5.8	7.0	6.6	9.2	7.2	2.4
Bimaceral	**19.6**	**28.0**	**26.0**	**25.0**	**28.4**	**24.0**	**30.8**
Duroclarite	5.2	5.6	11.0	10.4	9.6	5.4	6.8
Vitrinertoliptite	2.2	1.0	0.6	1.6	0.2	0.8	0.6
Clarodurite	3.0	4.4	4.6	4.4	8.2	2.6	5.8
Trimaceral	**10.4**	**11.0**	**16.2**	**16.4**	**18.0**	**8.8**	**13.2**
Carbargilite	5.8	3.2	0.8	3.6	2.6	4.2	2.6
Carbopyrite	3.2	1.0	2.0	1.0	5.2	3.8	2.2
Carbosilicate	0.2	0.4	0.6	0.4	–	0.4	0.4
Carbominerites	**9.2**	**4.6**	**3.4**	**5.0**	**7.8**	**8.4**	**5.2**

Table 4.14. Microlithotype composition (%) of the Irwin River coal, seam G (sub-seams G 1 to G 7).

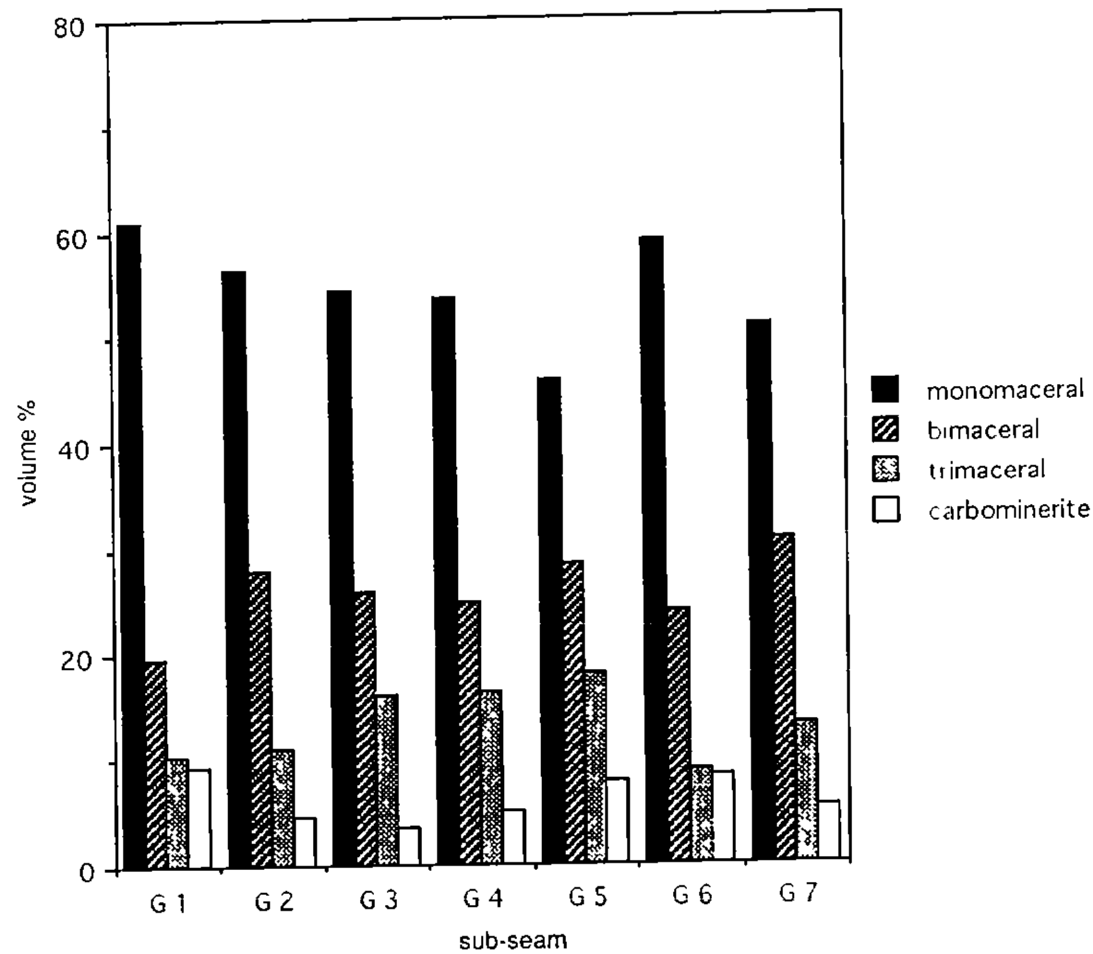


Figure 4.70. Microlithotype distribution of the Irwin River coal, seam G (sub-seams G 1 to G 7).

of the coal (Table 4.14). In terms of microlithotype group, the coal is mainly dominated by monomaceral and bimaceral, followed by trimaceral and low carbominerite. The microlithotype composition of the coal is depicted in a ternary diagram on a carbominerite free basis (Figure 4.71), and it shows the domination of monomaceral over bimaceral and trimaceral.

The vitrite and inertite are the predominant monomaceral microlithotypes of the coal in the sub-seams. Their contents vary from 23.8% in G 1 to 36.4% in G 4, and 15.6% in G 7 to 36.6% in G 1, respectively. The liptite content is present in low amounts, with a range of 0.0% in G 3, G 4 and G 5 to 0.4% in G 1 and G 6. Figure 4.72 depicts the monomaceral composition of the coal, and it shows the predominance of vitrite and inertite over liptite. This indicates that the deposition of the coal was under wetter conditions with low degree of oxidation.

The vitrinertite is the dominant bimaceral microlithotype of the coal, and its content is 6.6% in G 1 and 21.6% in G 7. The durite content is between 2.4% in G 7 to 9.2% in G 5, whereas the clarite content is from 3.8% in G 6 to 9.8% in G 4. The bimaceral composition in Figure 4.73 shows the dominance of vitrinertite over durite and clarite. This reflects that the coal was formed under varying conditions during its deposition.

The duroclarite and clarodurite are the major trimaceral microlithotypes in the coal, and their contents range from 5.2% in G 1 to 11.0% in G 3, and 2.6% in G 6 to 8.2% in G 5, respectively. The vitrinertoliptite content is low, 0.2% in G 5 and 2.2% in G 1. The data on trimaceral composition of the coal is depicted in a ternary diagram (Figure 4.74), and it shows the predominance of duroclarite and clarodurite over vitrinertoliptite. This suggests the coal was formed under wet conditions which lead to floral

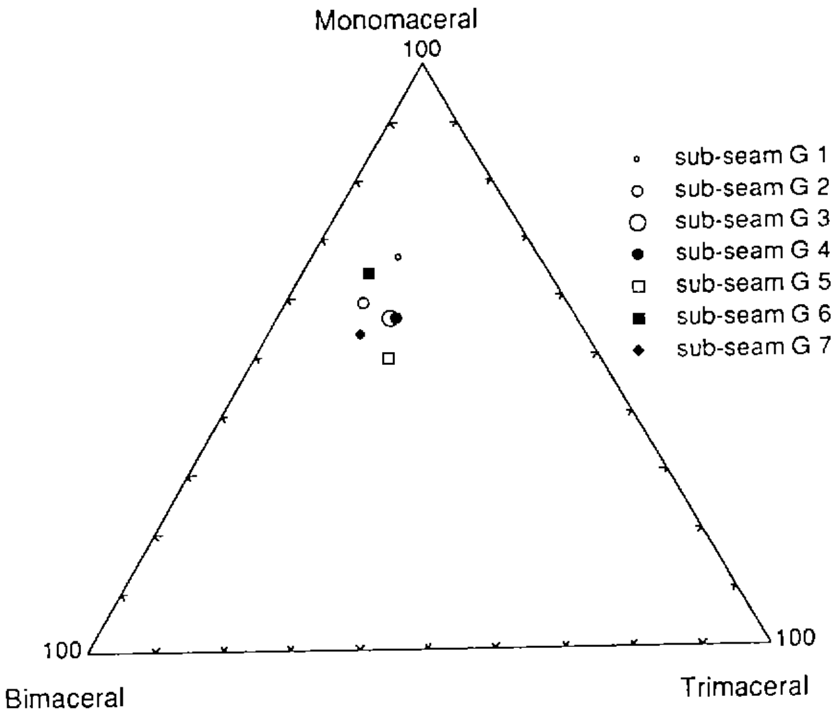


Figure 4.71. Microlithotype composition of the Irwin River coal (carbominerite free).

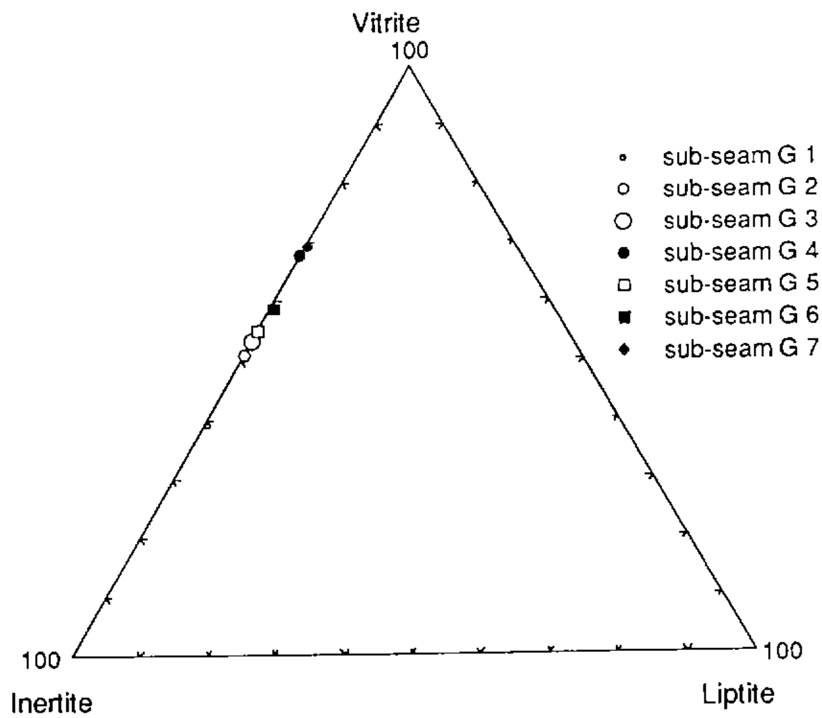


Figure 4.72. Composition of monomaceral group of the Irwin River coal.

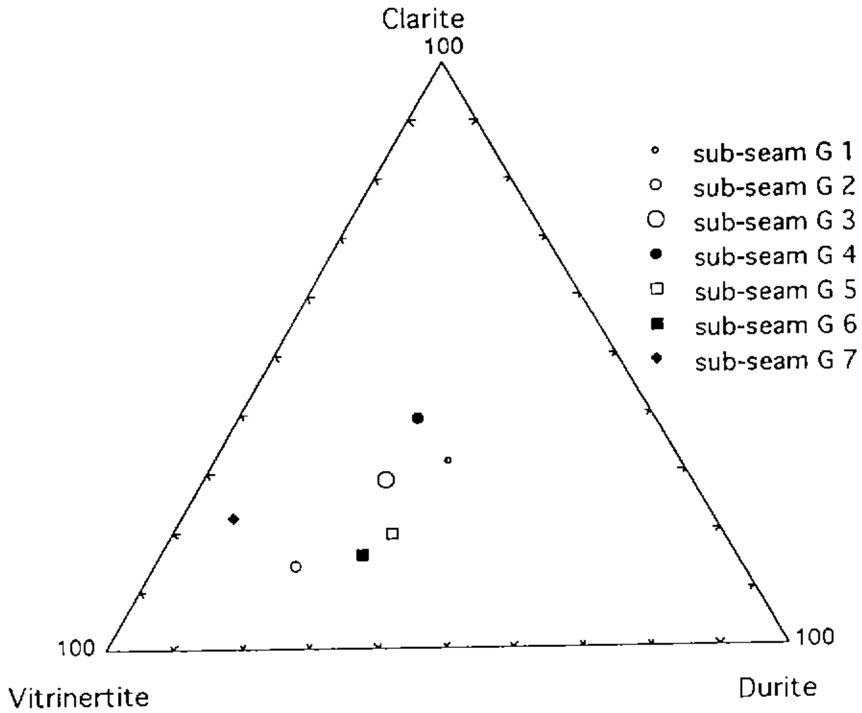


Figure 4.73. Composition of bimaceral group of the Irwin River coal.

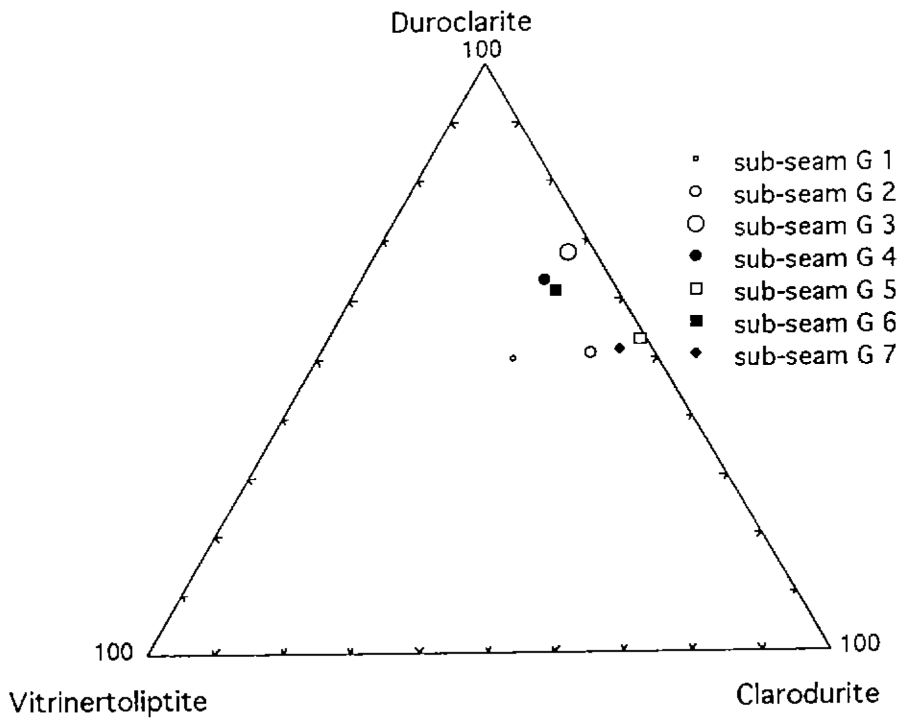


Figure 4.74. Composition of trimaceral group of the Irwin River coal.

changes during its deposition.

The carbargilite and carbopyrite are the dominant carbominerites in the coal (Figure 4.75), with a range between 0.8% in G 3 to 5.8% in G 1, and 1.0% in G 2 and G 4 to 5.2% in G 5. The carbosilicate is present in a low amount, ranging from 0.0% in G 5 and 0.6% in G 3.

Overall the coal is predominantly composed of vitrite, inertite and vitrinertite, followed by durite, clarite, duroclarite and clarodurite and low vitrinertoliptite, liptite and carbominerite. The dominance of vitrite and inertite is due to the type of flora and the depositional environment of the coal.

The microlithotype and carbominerite variations are illustrated in Figure 4.76. The abundance of monomacerals decrease downward with the exception of the sub-seams G 6 and G 7, the trimacerals follow a similar trend. The bimaceral group and carbominerite do not show a remarkable trend, and their contents display various amounts in the sub-seams. This suggests that a decreasing water table and a high degree of oxidation down the sequence occurred during the deposition of the coal.

4.4.3. Relationship of Macerals and Microlithotypes

The relationship of macerals and microlithotypes in the coal is presented in Table 4.15. The predominance of vitrinite over inertinite groups in the sub-seams G 1 to G 7 of the coal, is followed by vitrite over inertite contents in terms of microlithotype composition, with the exception of the sub-seam G 1. However, the exinite and mineral matter contents do not show a similar trend. The microlithotype composition of the coal follows the same pattern

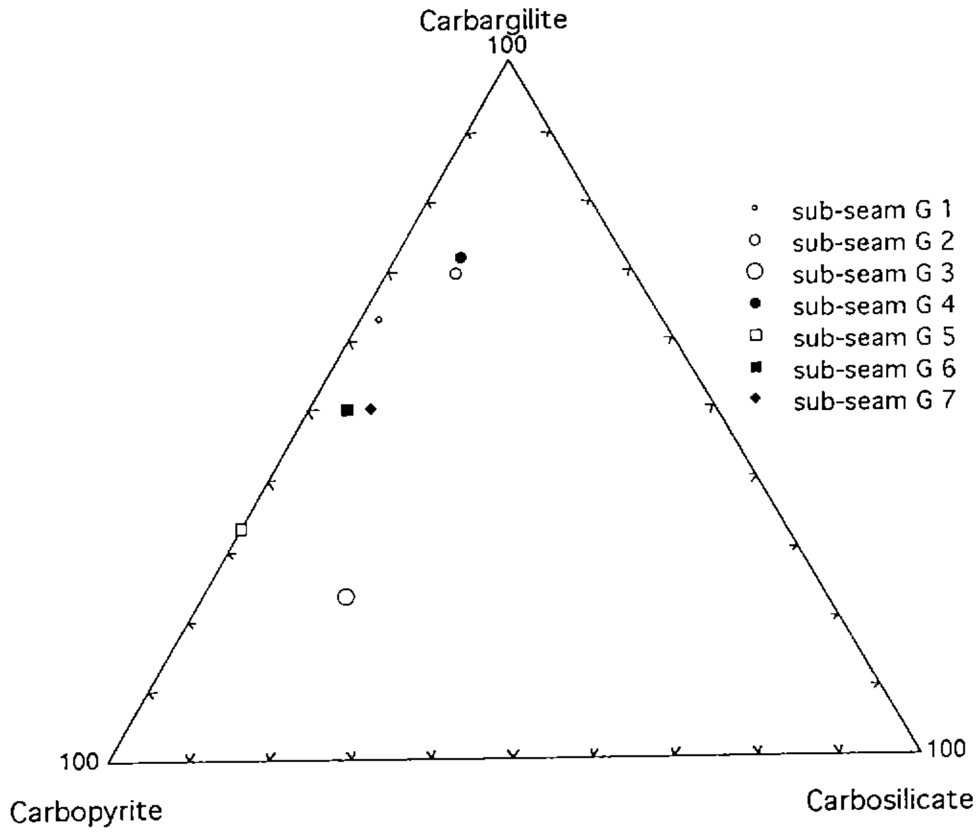


Figure 4.75. Composition of carbominerites of the Irwin River coal.

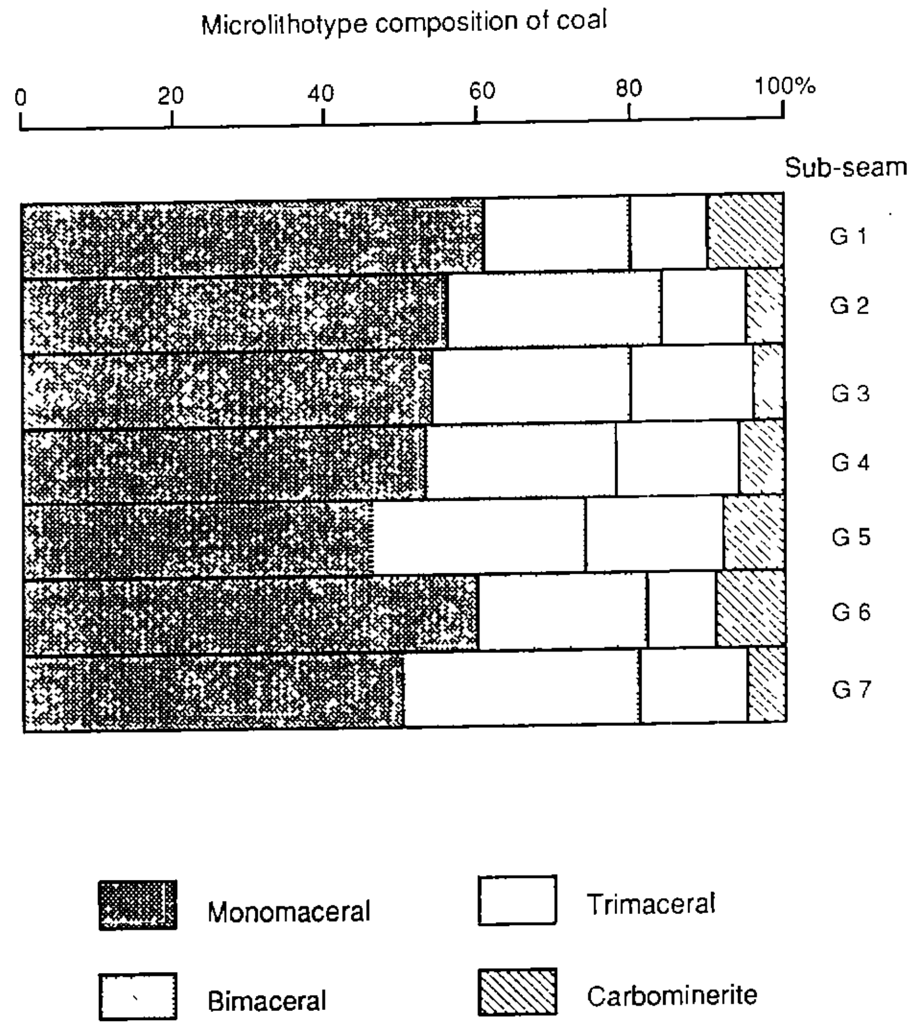


Figure 4.76. Variation of microlithotypes of the Irwin River coal, seam G (sub-seams G 1 to G 7).

SUB-SEAMS	MACERALS+MINERALS (%)				MICROLITHOTYPES (%)			
	VITRINITE	INERTINITE	EXINITE	MM	VITRITE	INERTITE	LIPTITE	CARBOMINERITE
G 1	48.2	38.0	6.0	7.8	23.8	36.6	0.4	9.2
G 2	47.6	41.8	6.0	4.6	28.6	27.6	0.2	4.6
G 3	45.4	41.0	8.6	5.0	29.0	25.4	–	3.4
G 4	53.4	35.8	5.6	5.2	36.4	17.2	–	5.0
G 5	48.4	37.8	5.6	8.2	25.2	20.6	–	7.8
G 6	55.2	35.2	4.8	4.8	34.4	24.0	0.4	8.4
G 7	45.4	44.4	7.4	2.8	35.0	15.6	0.2	5.2

MM : Mineral Matter

Table 4.15. Relationship of macerals and microlithotypes of the Irwin River coal, seam G (sub-seams G 1 to G 7).

as the maceral content, similar to the Vasse Shelf and Collie coals.

4.4.4. Rank and Classification of Coal

The maximum reflectance of vitrinite in the coal is between 0.42% to 0.59%, as shown in Table 4.16. The reflectance value in the sub-seam G 4 is anomalously high, due to a high exinite (H_2) suppression, as observed by Cook and Kantsler (1979). The rank of the coal is sub-bituminous according to the Australian Classification, and sub-bituminous A to B as per the ASTM standard (Figure 4.77).

The coal is also classified according to vitrinite content and maximum reflectance of vitrinite (Table 4.17 and Figure 4.78). The class of the coal as determined in the square boxes ranges from 044 to 045 and 055, and this indicates that the reflectance is between 0.4% to 0.5% and 0.5% to 0.6% and the vitrinite content is between 40.0% to 60.0% and 50.0% to 60.0%.

4.4.5. Petrological Characteristics

The Irwin River coal has the following characters based on the above petrographic data:

. The coal is rich in vitrinite in comparison to the Vasse Shelf and Collie coals.

. The inertodetrinite is the predominant maceral of the inertinite group, which reflects that the coal has undergone a high degree of decomposition during its deposition.

SUB-SEAMS	RO rnd	n	s	RANGE	RO max	n	s	RANGE
G 1	0.40	100	0.02	0.36-0.44	0.42	30	0.02	0.36-0.46
G 2	0.46	100	0.02	0.42-0.50	0.48	30	0.02	0.46-0.50
G 3	0.45	100	0.02	0.40-0.49	0.47	30	0.02	0.41-0.50
G 4	0.57	100	0.03	0.53-0.61	0.59	30	0.02	0.57-0.61
G 5	0.44	100	0.02	0.40-0.49	0.46	30	0.02	0.43-0.50
G 6	0.44	100	0.02	0.40-0.49	0.46	30	0.02	0.44-0.51
G 7	0.43	100	0.02	0.40-0.48	0.45	30	0.02	0.41-0.52

Table 4.16. Vitrinite reflectance of the Irwin River coal, seam G (sub-seams G 1 to G 7).

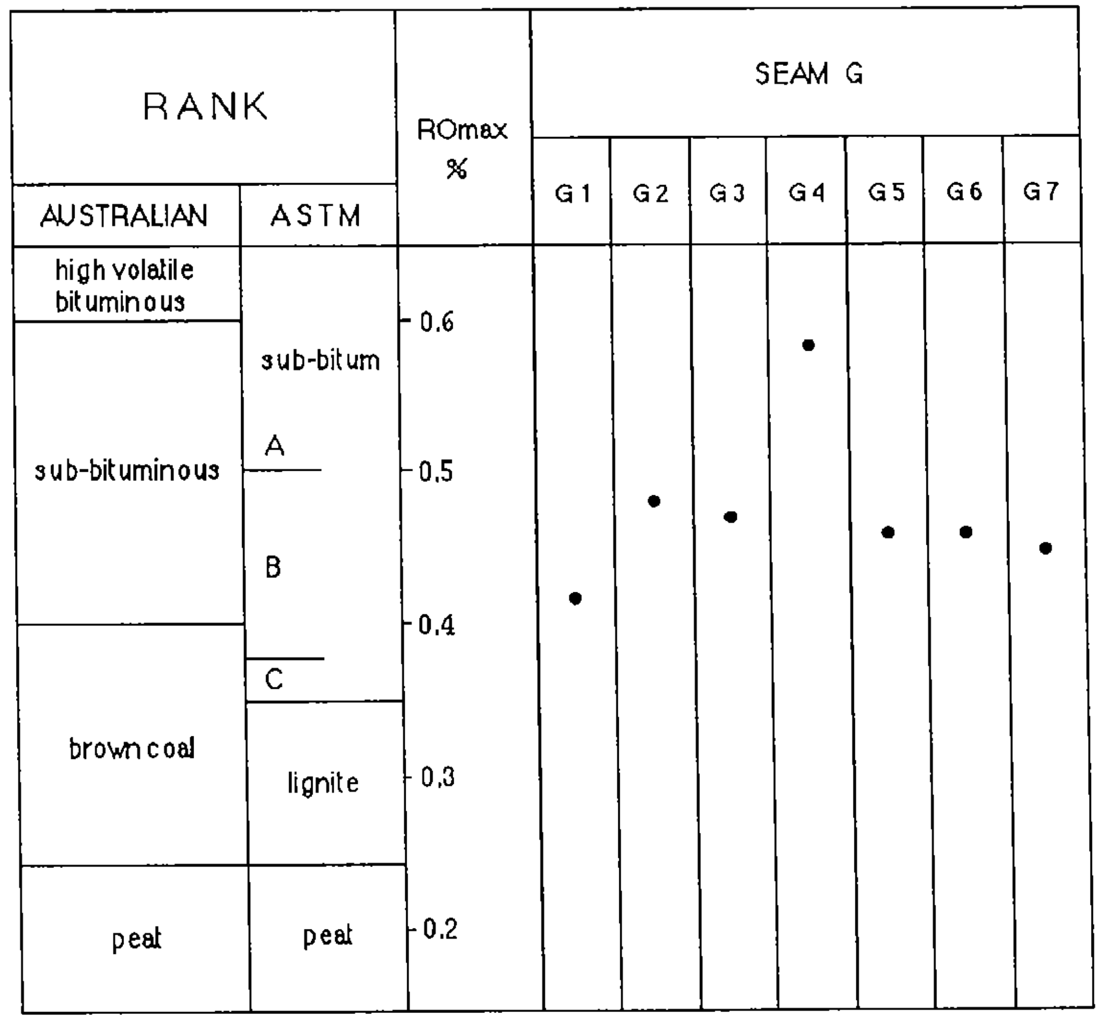
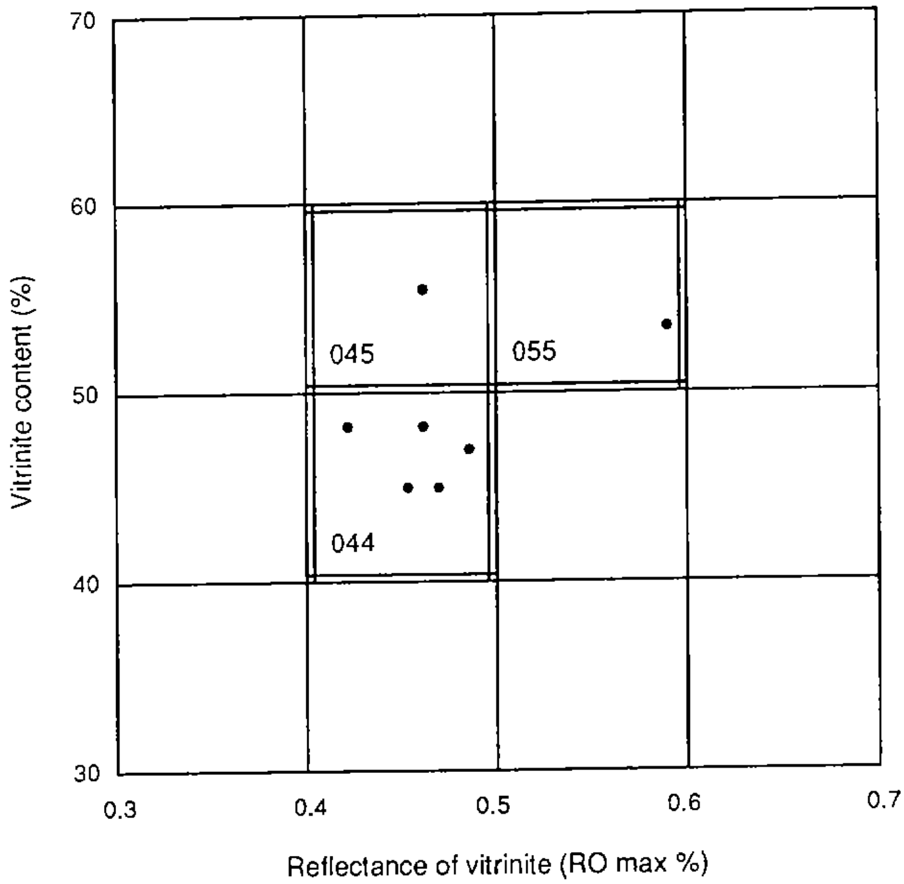


Figure 4.77. Reflectance of vitrinite of the Irwin River coal, seam G (sub-seams G 1 to G 7).

SUB-SEAMS	VITRINITE CONTENT (%)	RO max %
G 1	48.2	0.42
G 2	47.6	0.48
G 3	45.4	0.47
G 4	53.4	0.59
G 5	48.4	0.46
G 6	55.2	0.46
G 7	45.4	0.45

Table 4.17. Vitrinite content and reflectance of vitrinite of the Irwin River coal, seam G (sub-seams G 1 to G 7).



<u>Legend</u> • sub-seams G 1 to G 7

Figure 4.78. Classification of the Irwin River coal, seam G (sub-seams G 1 to G 7).

. The exinite content is low, less than 10.0% in all the sub-seams, and it is dominated by sporinite, cutinite and liptodetrinite. The low exinite content in the coal reflects the type of flora which has formed the coal.

. The coal has very low semifusinite ratio and medium to high vitrinite content, which suggest the coal was deposited in an anaerobic wet environment with some degree of oxidation.

. The predominance of vitrite and clarite over inertite and durite contents in the microlithotype composition suggests the coal was formed in wetter conditions and in high water covers with low degree of oxidation.

. The coal is classified as sub-bituminous according to the Australian standard or sub-bituminous B to A of the ASTM standard.

CHAPTER 5. MINERAL MATTER

5.1. Introduction

Coal invariably contains smaller or larger amounts of inorganic components, which occur in the form of mineral matter. The components form the bulk of ash left after burning of coal. Francis (1961) distinguished two groups of inorganic components depending on their origin. The first group is of inherent which is present in coal forming plants, and the common components are compounds of Ca, Mg, Fe, Al, Na, K, Mn, Ti, S, Si, Cl and P, but some of these (Na, K, Mg and Cl) are removed by water during the biochemical stage of coalification. The proportion of inorganic component contained in plants is often less than 2%. Thus, their contribution to the total mineral matter content of coal is relatively small. The second group of inorganic components consists of all mineral matter which was either washed into the coal swamp as detrital fragments or which was precipitated in the swamp from solutions. This mineral matter is referred to as adventitious. According to Diessel (1992), mineral matter in coal occurs in the form of mineral inclusions which constitute the bulk of non-combustible portion of coal which are left as ash after burning of coal. Minerals usually occur in association with the coal matrix either as infillings of cleats, cell lumens or as partial metasomatic replacement of organic matter, as outlined by Balme and Brooks (1953), Cook (1962) and Beeston (1981). However, other minerals are concentrated in concretions, lenses or dirt bands. The Standards Association of Australia (1982) defined the term mineral matter as "the minerals and other inorganic material in, and associated with coal". The mineral matter can be categorized as follows :

. Discrete, crystalline mineral particles in the coal or associated strata (e.g. intraseam non-coal bands).

.Inorganic elements or compounds, usually excluding nitrogen and sulphur, incorporated in the organic molecules of the coal.

. Dissolved inorganic compounds in the coal's pore water or surface water.

In the geological sense, only the discrete, crystalline inorganic compounds can be categorized as true minerals (adventitious). However, such minerals can also be formed by crystallization of any dissolved constituents as the coal dries out with exposure or storage, Ward (1986). The minerals in coal affect mining, preparation and utilization. Therefore, an understanding of the nature and distribution of minerals in coal can assist in solving problems in mining and utilization.

Several techniques are used to investigate mineral matter in coal based on traditional chemical and petrographic methods, and the minerals found in coal have been described from a petrographic point of view by ICCP (1963), Marshall and Tompkins (1964), Mackowsky (1968), Stach *et al.* (1982) and Ward (1986)

The adventitious minerals associated with the coal have been identified by microscopic and SEM techniques, and their distribution in the coal seams established.

5.2. Mineral Matter in the Vasse Shelf Coal

For the present study, the relative proportions of different minerals associated with the macerals in the coal were determined microscopically by the point count technique on polished sections. The data on minerals for coal are given in Table 5.1 and depicted in Figure 5.1 in terms of clays, pyrite and quartz, and it shows the predominance of clays and pyrite over

DRILL HOLES	SEAMS	MINERAL MATTER	CLAY	PYRITE	QUARTZ
RBCH 5	A	5.8	3.1	2.1	0.6
	B	5.5	2.7	2.0	0.8
	C	4.7	3.7	0.6	0.4
	D	3.0	2.0	0.5	0.5
	E	4.2	2.7	0.8	0.7
	F	4.1	2.7	1.0	0.4
	G	2.4	0.8	1.2	0.4
	H	5.6	4.0	1.6	0.0
	I	3.0	1.4	1.0	0.6
	J	4.9	3.0	1.3	0.6
RBCH 6	A	3.8	2.2	1.4	0.2
	B	4.4	3.0	0.6	0.8
	G	3.8	2.8	0.6	0.4
	K	4.4	1.0	2.8	0.6
RB 3	A	2.4	1.0	0.8	0.6
	B	3.4	1.8	1.0	0.6
	C	2.5	1.2	0.9	0.4
	D	5.8	2.8	2.2	0.8
	E	4.1	1.7	1.5	0.9
	F	4.6	1.8	1.6	1.2
	G	4.6	1.5	2.2	0.9
	H	3.8	1.4	1.8	0.6
	I	2.7	1.2	1.0	0.5
CRCH 1	A	3.0	0.4	2.0	0.6
	B	2.4	0.6	1.4	0.4
	C	6.4	3.4	2.2	0.8
	D	5.6	2.2	2.6	0.8
	E	4.6	2.0	1.8	0.8
	F	4.9	3.1	1.2	0.6
	G	3.5	1.3	1.9	0.3
	H	2.5	1.1	1.1	0.3
	I	3.9	1.3	2.0	0.6
	J	4.3	1.6	2.2	0.5
	K	2.2	0.4	1.4	0.4
	L	3.1	0.5	2.2	0.4
	M	5.4	1.4	3.4	0.6
CRCH 2	A	1.6	0.2	0.6	0.8
	J	5.0	3.8	1.0	0.2
	M	3.0	1.6	1.0	0.4
	N	4.4	3.4	0.8	0.2
	O	8.2	5.0	2.4	0.8
	P	4.8	2.2	2.3	0.3

Table 5.1. Distribution of mineral matter (%) in the Vasse Shelf coal, Western Australia.

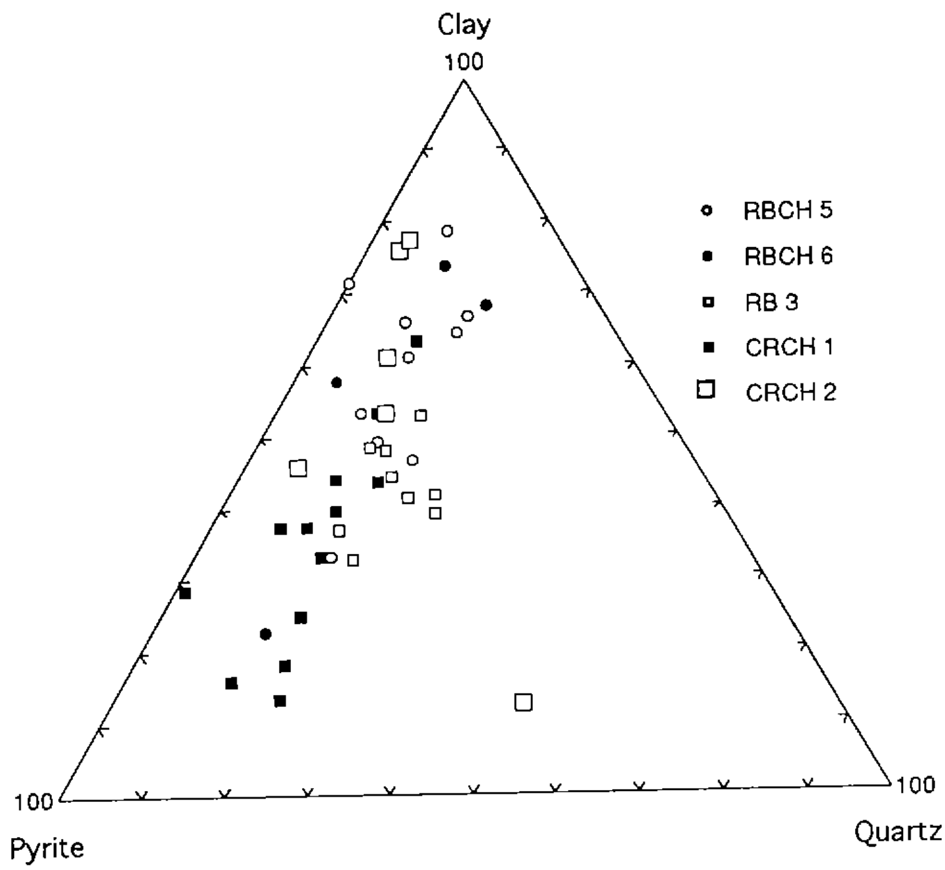


Figure 5.1. Composition of mineral matter of the Vasse Shelf coal.

quartz. The quantitative assessment of the major minerals in the Vasse Shelf coal was carried out under the microscope for the clay minerals, pyrite and quartz. The examination shows that many of the minerals in the coal occur as extremely fine associations with macerals and are very difficult to recognize under the microscope, and so SEM examination is used to supplement microscopic examination in particular with reference to clay minerals and quartz.

5.2.1. Clay Minerals

The clay minerals in the coal are described as a group under the microscope, because the individual clay minerals require X-ray diffraction, thermal analysis or electron microscopy for accurate identification. The clay minerals are the most important group of minerals in the Vasse Shelf coal. They occur mostly either as infillings in plant cells of fusinite and semifusinite or as finely dispersed inclusions in vitrinite. The clay mineral content in the coal ranges between 0.2% to 5.0% (Table 5.1). These are probably products of chemical and biochemical processes in coal swamp. The composition and distribution of the mineral matter in the coal are given in Figure 5.1, in which the clay minerals constitute the dominant component followed by pyrite and quartz. The variation in the contents of clay minerals and pyrite in the seams is more in a comparison to the contents of quartz.

The SEM observation consists of backscatter electron (BS) and secondary electron (SE) modes. Each mode of observation in the SEM provides different information, and it is usual to have BS and SE images displayed simultaneously. The SE mode essentially relates to surface topography, and the BS mode responds to average atomic number of density, and this is related to mineral matter composition. Under the SEM examination, the clay minerals identified in the coal are montmorillonite, kaolinite and illite. Figures 5.2.a and 5.2.b show fusinite with infilling montmorillonite under SE and BS modes displayed simultaneously. Figures 5.3.a and 5.3.b show kaolinite in association with vitrinite, and Figures 5.4.a and 5.4.b show illite under SE and BS modes displayed simultaneously, in association with vitrinite.

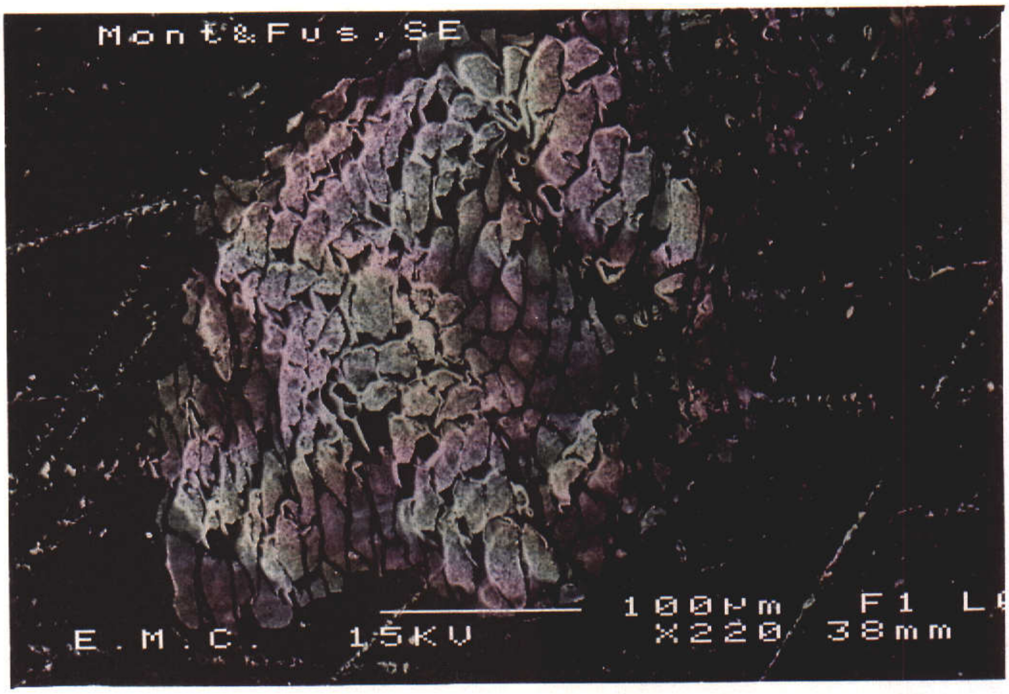
5.2.2. Pyrite

The most commonly occurring sulphide or iron bearing mineral in coal is pyrite. The pyrite occurs in cracks and fissures of the coal, and also infillings in cell cavities of fusinite and semifusinite (Figures 4.8.c and 4.12.b, pages 84 and 90, respectively).

The distribution of pyrite in coal is of particular interest, because an excessive sulphur content requires desulphurization of the flue gases in power stations in order to avoid pollution by emission due to sulphur dioxide. Because of fluvial and braided river environment of deposition of the coal, fortunately the pyrite content in coal is very low, varying between 0.5% to 3.4%, as shown in Table 5.1.

5.2.3. Quartz

Most of the quartz identified in the coal is clastic quartz. The quartz formed from solution and of finely crystalline structure may be present in the coal, however, it has not been identified under the microscope. Most of the quartz identified is usually associated with the inertinite and vitrinite. It is interpreted that the clastic quartz fraction in coal is washed or windblown into the swamp as part of the sedimentation. The quartz content in the



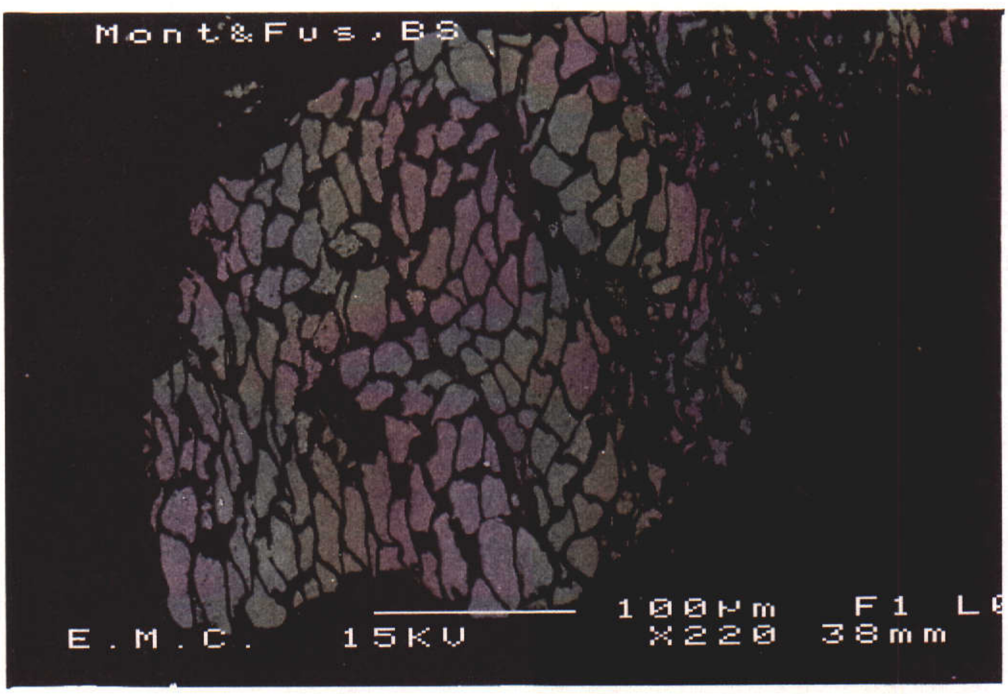
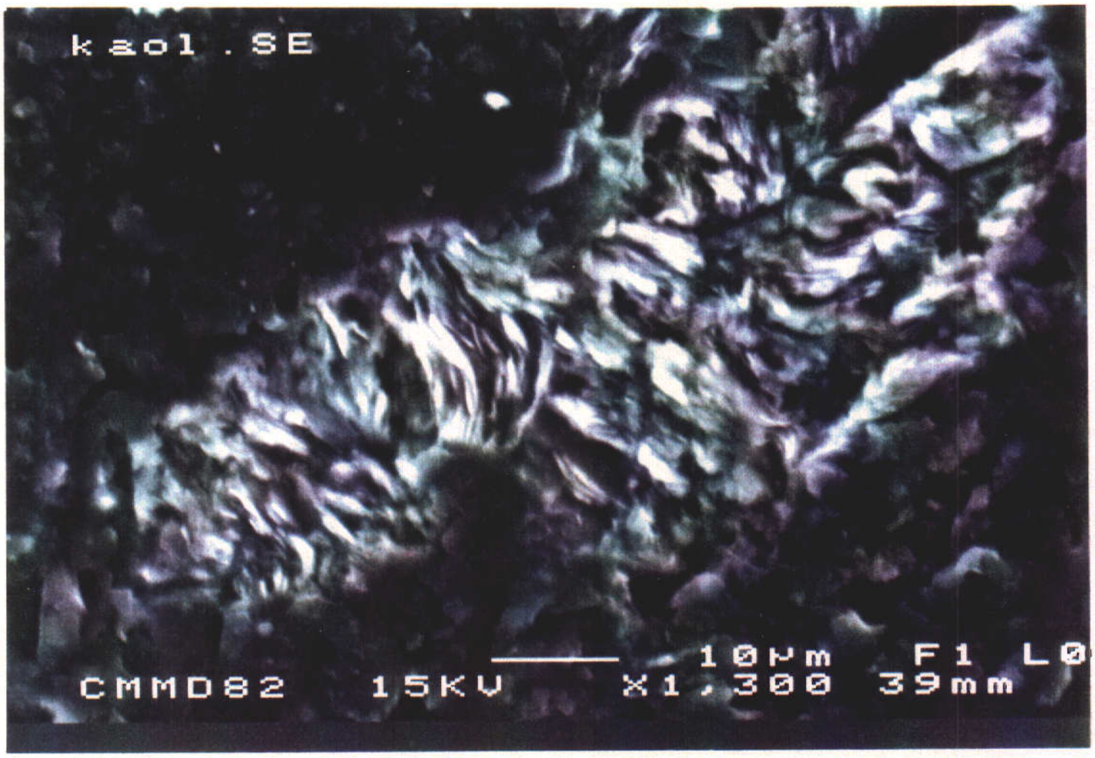


Figure 5.2.a. Fusinite with infilling montmorillonite, in SEM, SE mode. A seam, CRCH 1.

Figure 5.2.b. Similar to the top figure, in SEM, BS mode. A seam, CRCH 1.



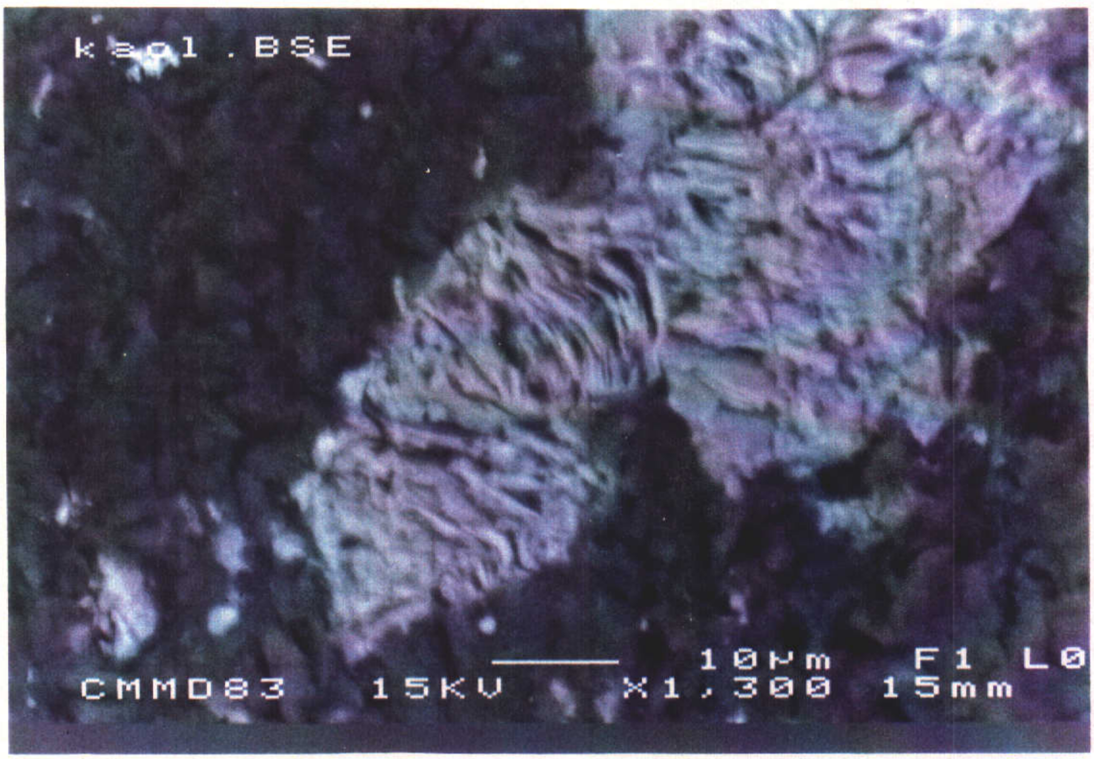
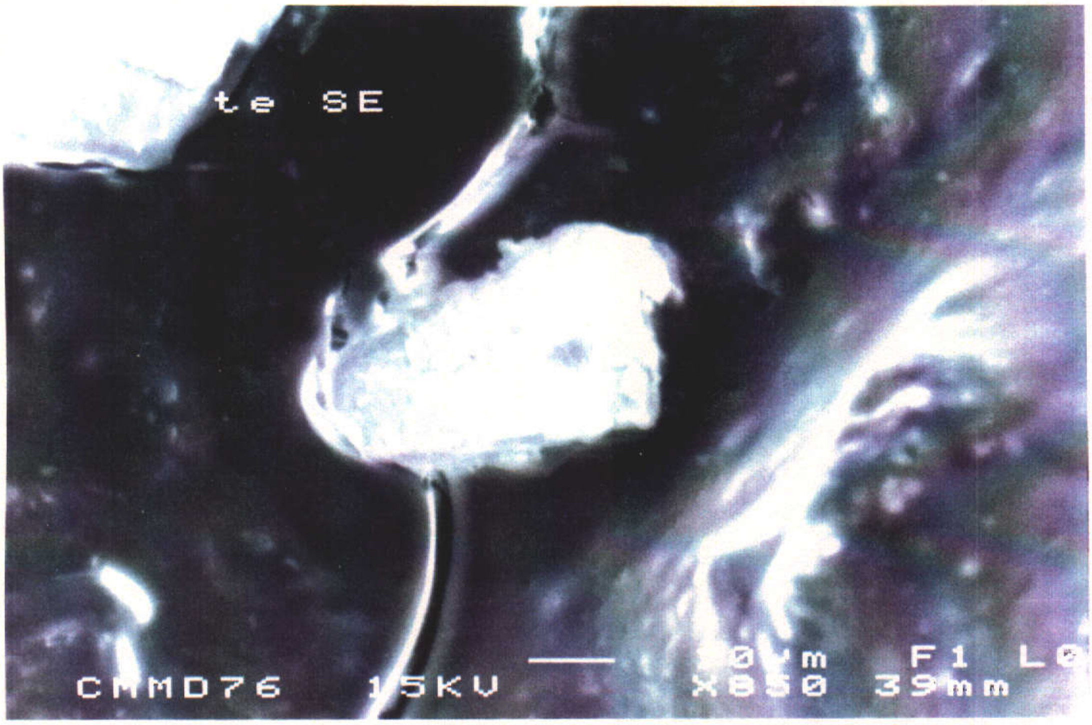


Figure 5.3.a. Kaolinite in SEM, SE mode. C seam, RB 3.

Figure 5.3.b. Similar to the top figure, in SEM, BS mode. C seam, RB 3.



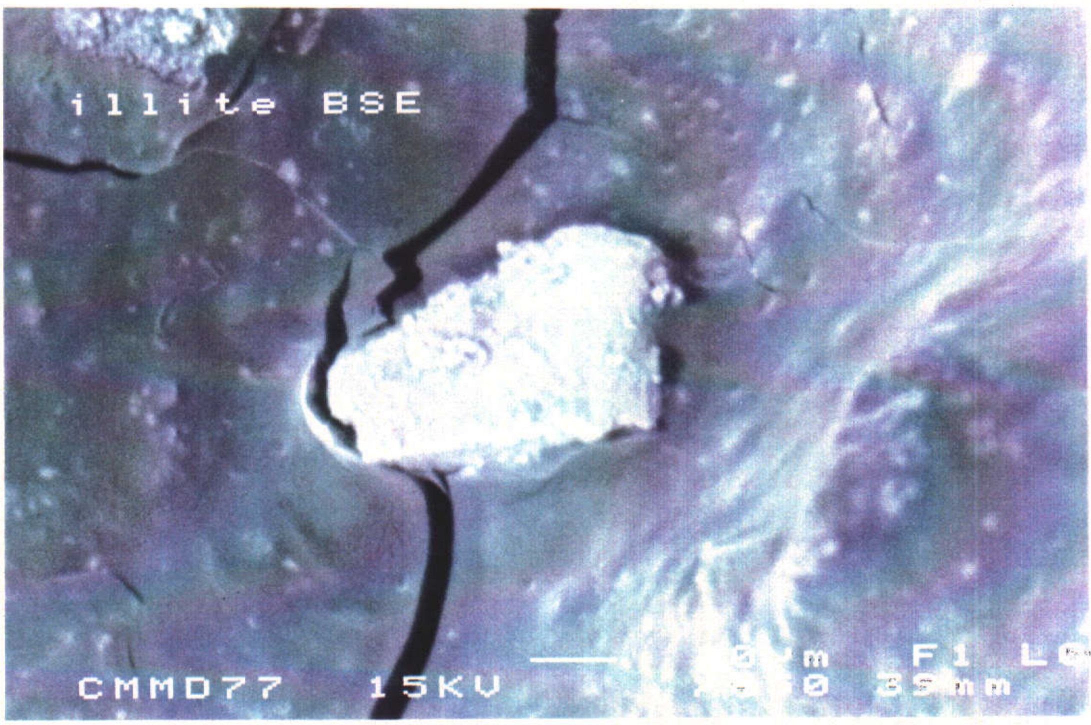


Figure 5.4.a. Illite in SEM, SE mode. B seam, CRCH 1.

Figure 5.4.b. Similar to the top figure, in SEM, BS mode. B seam, CRCH 1.

Vasse Shelf coal varies from 0.0% to 1.2% (Table 5.1). Figures 5.5.a and 5.5.b show quartz under SE and BS modes in association with the vitrinite in the coal.

The mineral matter in the Vasse Shelf coal has the following characteristics on the basis of the above description.

. The mineral matter in the coal is mainly composed of clay minerals and pyrite, with low amount of quartz.

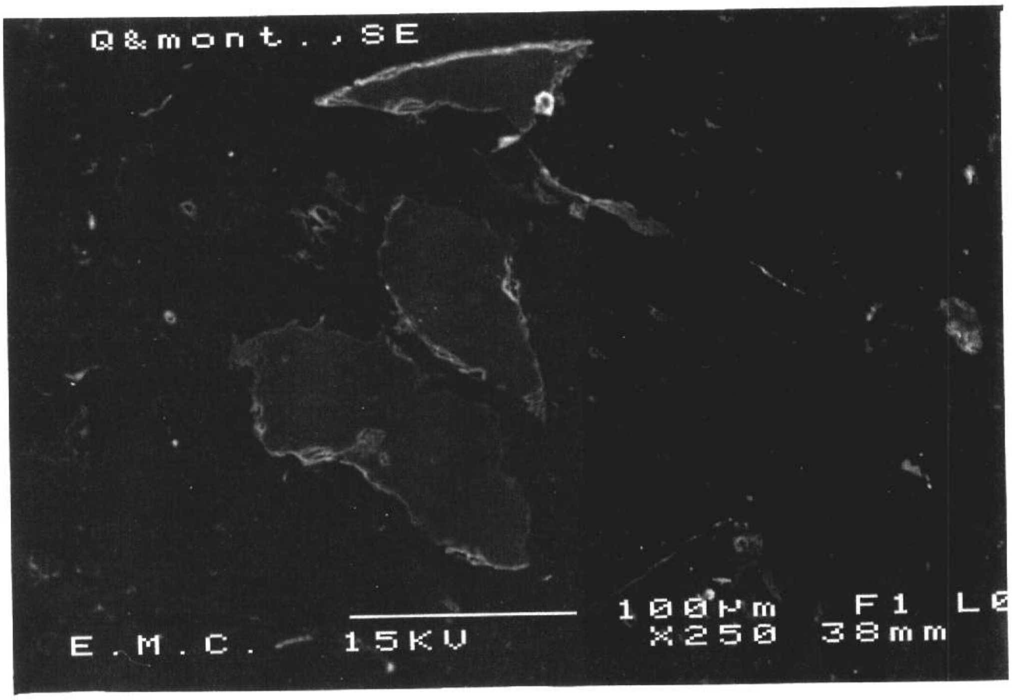
. The mineral matter is commonly associated with vitrinite and inertinite groups of macerals (Figures 4.8.b and 4.8.c, page 84).

5.3. Mineral Matter in the Collie Coal

The mineral matter analyses of the coal from the seams E 9 to E 90 of drill holes BUC 213, BUC 215, BUC 212, BUC 217 and BUC 214 were undertaken to determine its type and distribution, and the data are presented in Table 5.2 and Figure 5.6. The type and distribution of mineral matter in the coal has similarities with the Vasse Shelf coal.

5.3.1. Clay Minerals

The clay minerals are the most dominant minerals in the coal. They occur mostly either as infillings in plant cells of fusinite and semifusinite or as finely dispersed inclusions in vitrinite, as presented in Figure 4.44.a (page 166). They are probably products of chemical and biochemical processes in the swamp. The clay content has a range of 0.8% in the seam E 22 of BUC 214 and 7.4% in the seam E 35 of BUC 215, as shown in Table 5.2.



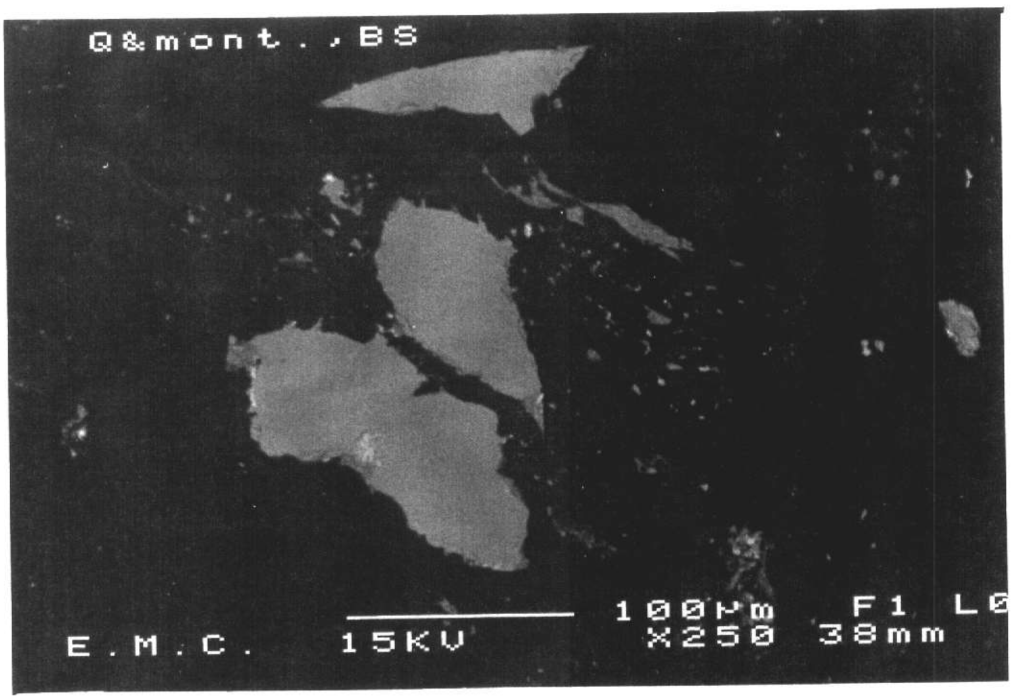


Figure 5.5.a. Quartz (foreground) and vitrinite (background) in SEM, SE mode. B seam, CRCH 1.

Figure 5.5.b. Similar to the top figure, in SEM, BS mode. B seam, CRCH 1.

DRILL HOLES	SEAMS	MINERAL MATTER	CLAY	PYRITE	QUARTZ
BUC 213	E 50	5.6	3.0	1.8	0.8
	E 60	3.8	2.0	1.2	0.6
	E 70	5.2	3.2	1.8	0.2
	E 80	4.2	1.2	2.6	0.4
	E 90	5.2	2.8	1.8	0.6
BUC 215	E 9	4.2	1.4	1.8	1.0
	E 10	6.2	2.8	3.0	0.4
	E 15	6.6	4.2	1.6	0.8
	E 20	4.6	1.8	2.4	0.4
	E 30	5.0	3.0	2.0	0.0
	E 35	9.0	7.4	1.6	0.0
BUC 212	E 20	4.8	1.2	2.8	0.8
	E 30	3.6	1.0	2.6	0.0
	E 40	4.2	2.4	1.4	0.4
	E 50	4.8	1.8	2.0	1.0
	E 60	4.8	2.6	1 8	0.4
	E 80	6.6	4.2	2.2	0.2
BUC 217	E 10	4.2	2.0	1.6	0.6
	E 22	6.8	5.2	1.4	0.2
	E 25	3.8	1.0	2.4	0.4
	E 30	4.2	1.6	2.0	0.6
BUC 214	E 9	5.2	2.7	1.9	0.6
	E 10	4.2	1.4	2.0	0.8
	E 20	5.4	2.2	2.6	0.6
	E 22	3.6	0.8	2.2	0.6
	E 25	6.4	3.9	2.0	0.5
	E 30	5.4	2.0	2.8	0.6

Table 5.2. Distribution of mineral matter (%) in the Collie coal, Western Australia.

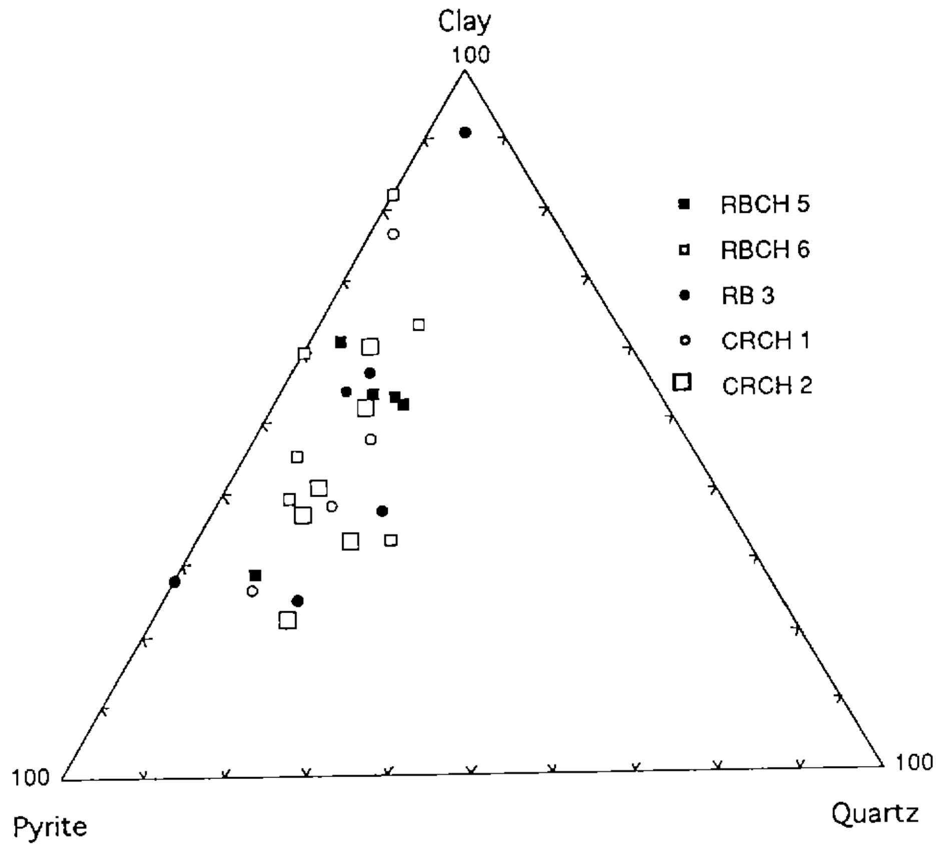


Figure 5.6. Composition of mineral matter of the Collie coal.

5.3.2. Pyrite

The pyrite in the coal occurs in cracks and fissures and also infillings in cell cavities of fusinite and semifusinite, as presented in Figure 4.42.a (page 161). The pyrite content in the coal varies between 1.2% to 3.0% in the seam E 60 of BUC 213 and the seam E 10 of BUC 215, respectively.

5.3.3. Quartz

Most of the quartz identified in the coal is clastic quartz. The quartz formed from solution and of finely crystalline structure may be present in the coal, but could not be identified under the microscope. The quartz is usually associated with inertinite and vitrinite. It is interpreted that the clastic quartz fraction in the coal was washed or windblown into the swamp as part of the sedimentation pattern. The quartz content is absent in the seams E 30 and E 35 of BUC 215, while the highest one of 1.0% is present in the seam E 9 of BUC 215 and the seam E 50 of BUC 212.

On the basis of the above petrological examination, the characteristics of the mineral matter are:

- Clay minerals followed by pyrite are the dominant minerals in the coal.

- The mineral matter is mainly associated with the vitrinite and inertinite group of macerals (Figures 4.42.a and 4.44.a, pages 161 and 164, respectively)

5.4. Mineral Matter in the Irwin River Coal

The examination of mineral matter in the coal from the sub-seams G 1 to G 7 of the drill hole IRCH 1 was also completed to determine its distribution. The data on mineral matter analyses of the coal are presented in Table 5.3 and depicted in Figure 5.7.

The mineral matter identified in the Irwin River coal is predominantly composed of pyrite (0.8%-5.8%) followed by clay (1.4%-2.4%) and low amounts of quartz (0.2%-0.8%) as presented in Table 5.3 and Figure 5.7.

5.4.1. Pyrite

The predominant mineral matter in the coal is pyrite, as depicted in Figure 5.7. The pyrite content in the coal varies from 0.8% in the sub-seam G 7 and 5.8% in the sub-seam G 1. Its association with desmocollinite is common, as shown in Figure 4.62.d, page 196.

5.4.2. Clay Minerals

The clay content in the coal has a range of 1.4% in the sub-seams G 3, G 4 and G 7 to 2.4% in the sub-seam G 2. Figure 4.62.c (page 198) shows the clay minerals associated with desmocollinite and inertodetrinite in the coal.

5.4.3. Quartz

The quartz content ranges between 0.2% in the sub-seam G 1 and 0.8% in the sub-seams G 2, G 4 and G 5. Most of the quartz identified in the coal is clastic quartz which is usually associated with inertinite and vitrinite group

DRILL HOLE	SUB-SEAMS	MINERAL MATTER	CLAY	PYRITE	QUARTZ
IRCH 1	G 1	7.8	1.8	5.8	0.2
	G 2	4.6	2.4	1.4	0.8
	G 3	5.0	1.4	3.2	0.4
	G 4	5.2	1.4	3.0	0.8
	G 5	8.2	1.8	5.6	0.8
	G 6	4.8	2.0	2.2	0.6
	G 7	2.8	1.4	0.8	0.6

Table 5.3. Distribution of mineral matter (%) in the Irwin River coal, seam G (sub-seams G 1 to G 7), Western Australia.

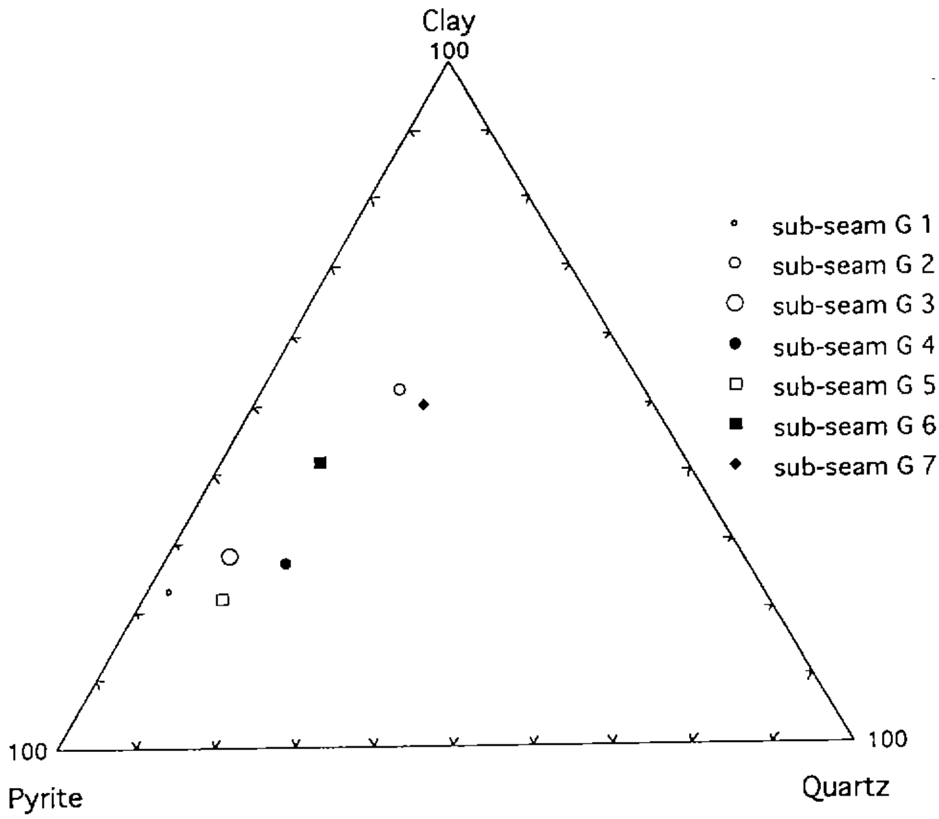


Figure 5.7. Composition of mineral matter of the Irwin River coal.

of macerals.

The characteristics of mineral matter in the Irwin River coal on the basis of petrological examination are:

- The predominant mineral matter content in the coal is pyrite, followed by clay, unlike the Vasse Shelf and the Collie coals, which contain clay as the dominant mineral in the coal.

- The mineral matter is commonly associated with vitrinite and inertinite group of macerals (Figures 4.62.c and 4.62.d, page 196).

CHAPTER 6. COMPARATIVE PETROLOGY OF COAL

6.1. Introduction

The petrology of Vasse Shelf, Collie and the Irwin River coals is compared with one another. The comparisons of these coals are also made with the published petrological data of the Early Permian coals from the Gondwanaland basins of eastern Australia, India, South Africa and Brazil.

6.2. Vasse Shelf, Collie and Irwin River Coals

The maceral and microlithotype analyses of the coals are compared in this section. Table 6.1 and Figure 6.1 show maceral compositions of the coals. The table and the figure show that the vitrinite content of the Irwin River coal is highest (49.1%) and that of the Collie coal is lowest (37.3%). The vitrinite group in these coals is dominated by the macerals like desmocollinite, telocollinite and vitrodetrinite. The inertinite content is highest in the Collie coal (49.1%), followed by the Vasse Shelf (46.4%) and the Irwin River (39.2%) coals. The inertodetrinite, fusinite and semifusinite are the most common macerals of the inertinite group present in the coals from Vasse Shelf and Irwin River, whereas the Collie coal is predominantly composed of inertodetrinite, followed by fusinite and micrinite. The exinite content is low in the Irwin River coal (6.3%) as compared with Vasse Shelf (9.0%) and Collie (8.3%) coals, and macerals of the exinite group present in the coals are sporinite, cutinite and liptodetrinite. The mineral matter consists of clay, pyrite and quartz which is present in all the coals, and the lowest content is in the Vasse Shelf coal (4.4%). Therefore, the maceral composition of the Vasse Shelf and the Collie coals is somewhat similar to one another.

MACERAL GROUP		VASSE SHELF	COLLIE	IRWIN RIVER
Vitrinite	Mean Content	40.2	37.3	49.1
	Range	19.6-64.2	15.2-47.4	45.4-55.2
	Common Macerals	Des, To, Vo	Des, To, Vo	Des, Vo, To
Inertinite	Mean Content	46.4	49.1	39.2
	Range	14.8-63.0	41.2-69.0	35.2-44.4
	Common Macerals	Id, F, Sf	Id, F, Mi	Id, F, Sf
Exinite	Mean Content	9.0	8.3	6.3
	Range	5.3-18.0	4.6-14.4	4.8-8.6
	Common Macerals	Sp, Cut, Lip	Sp, Cut, Lip	Sp, Lip, Cut
Mineral Matter	Mean Content	4.4	5.3	5.4
	Range	1.6-8.2	3.6-9.0	2.8-8.2
	Common Minerals	Cl, Py, Q	Cl, Py, Q	Py, Cl, Q
Semifus. Ratio Vit. Content		very low-medium low-high	very low-low low-medium	very low medium-high
Vitrinite Reflectance	ROmax	0.58-0.63	0.45-0.48	0.42-0.59
Rank	Australian Classification	Sub-bituminous-High vol. bituminous	Sub-bituminous	Sub-bituminous
	ASTM	Sub-bit A-High vol. bit	Sub-bituminous B	Sub-bituminous B-A

Vitrinite
Des - Desmocollinite
To - Telocollinite
Vo - Vitrodetrinite

Inertinite
F - Fusinite
Sf - Semifusinite
Mi - Micrinite
Id - Inertodetrinite

Exinite
Sp - Sporinite
Cut - Cutinite
Lip - Liptodetrinite

Mineral Matter
Cl - Clay
Py - Pyrite
Q - Quartz

Table 6.1. Maceral composition, mineral matter content, vitrinite reflectance and rank of the Vasse Shelf, Collie and the Irwin River coals.

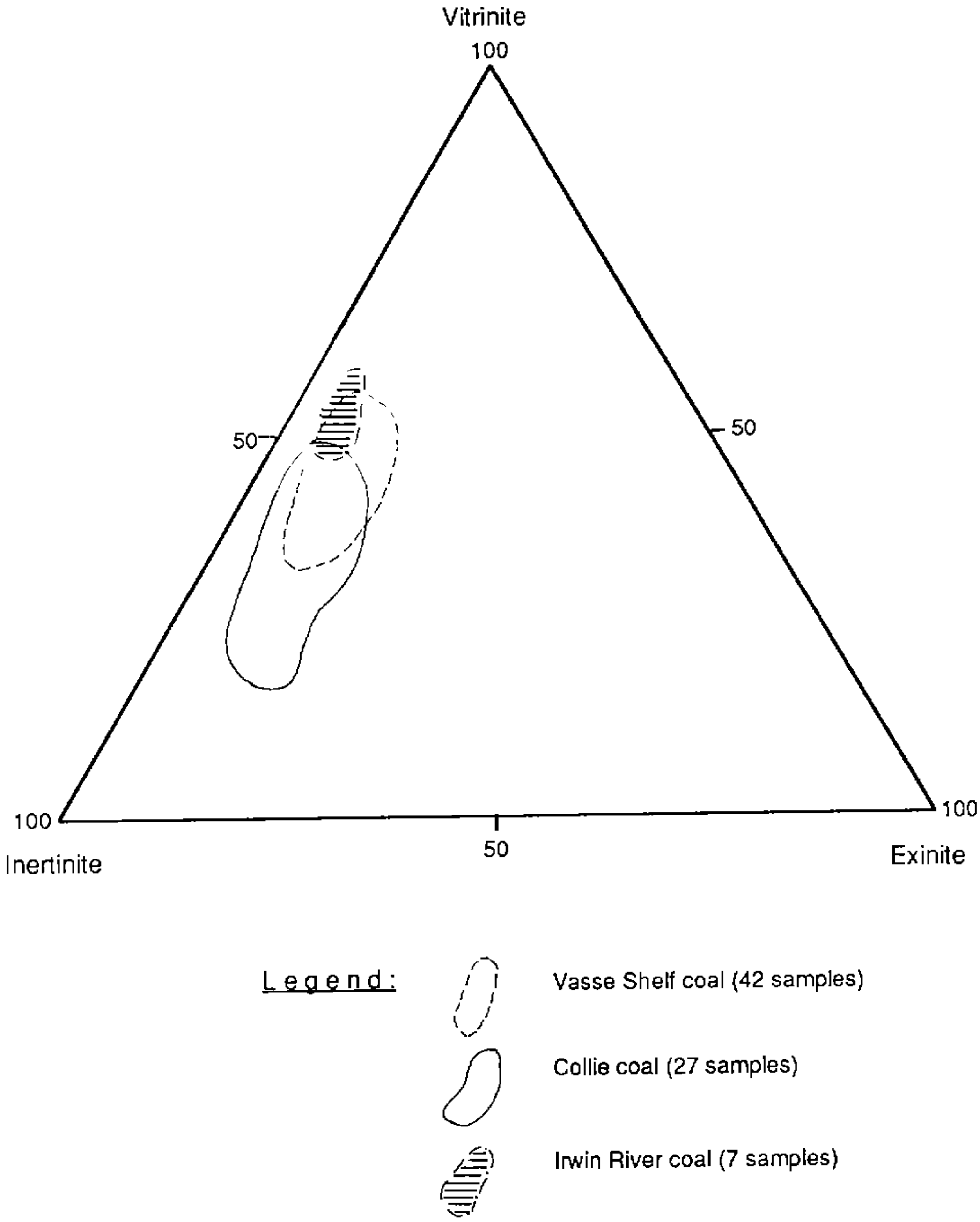


Figure 6.1. Maceral composition of the Vasse Shelf, Collie and the Irwin River coals (mineral matter free).

The semifusinite ratio is very low in the Irwin River coal, very low to low in the Collie coal and very low to medium in the Vasse Shelf coal, and vitrinite content is higher in the Vasse Shelf and the Irwin River coals as compared with the Collie coal (Figure 6.2). This suggests that the Vasse Shelf and Irwin River coals were formed in an anaerobic and wet environment, whereas somewhat drier conditions which prevailed during the deposition of Collie coal.

The vitrinite reflectance (RO max) values of the Vasse Shelf coal are high as compared with the Collie and Irwin River coals (Figure 6.3). The Vasse Shelf coal is sub-bituminous to high volatile bituminous according to the Australian rank values and sub-bituminous A of the ASTM classification. The Collie and Irwin River coals are sub-bituminous based on the Australian classification, and sub-bituminous B and sub-bituminous B to A of the ASTM values, respectively. The vitrinite reflectance is high for the Vasse Shelf coal possibly due to the average depth of burial which is much greater than that of the Collie and Irwin River coals, as described by Kristensen and Wilson (1986). On the basis of the maceral composition and the vitrinite reflectance, the Vasse Shelf coal is of higher rank and better quality than the other two coals.

The microlithotypes of the Vasse Shelf, Collie and the Irwin River coals are given in Table 6.2 and Figure 6.4. The Vasse Shelf coal contains more monomaceralic microlithotypes (56.2%) than the coals from Irwin River (54.4%) and Collie (42.7%), and the microlithotypes present in the coals are inertite and vitrite. The bimaceralic content is highest in the Collie coal (31.5%) and lowest in the Irwin River coal (26.0%). The Vasse Shelf coal is dominated by clarite and vitrinertite, Collie coal by durite and vitrinertite and the Irwin River coal by vitrinertite and durite. The trimaceralic content is high

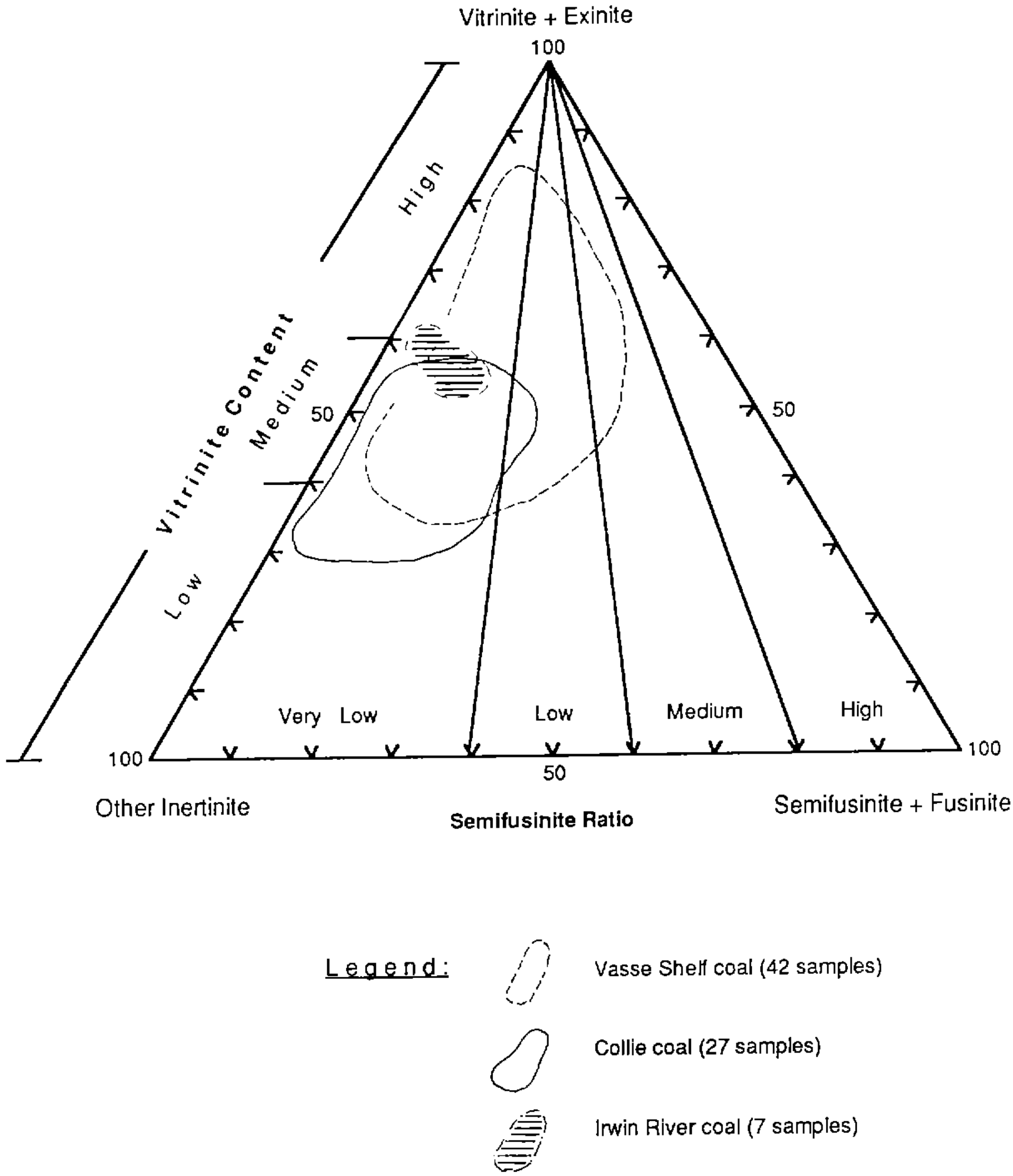


Figure 6.2. 'Semifusinite ratio' and 'vitrinite content' of the Vasse Shelf, Collie and the Irwin River coals.

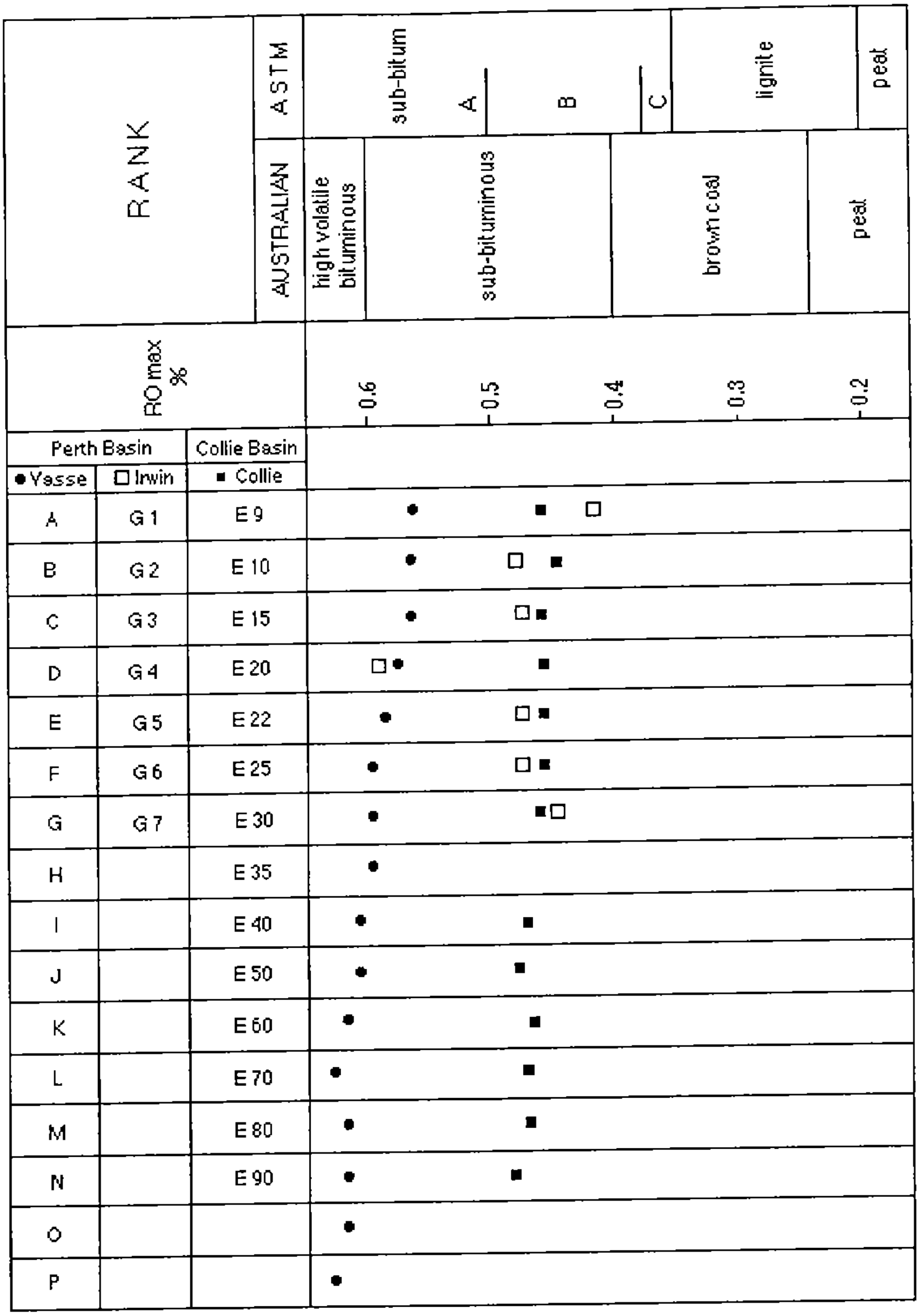


Figure 6.3. Reflectance of vitrinite and rank of the Vasse Shelf, Collie and the Irwin River coals.

MICROLITHOTYPES		VASSE SHELF	COLLIE	IRWIN RIVER
Monomaceral	Mean Content	56.2	42.7	54.4
	Range	48.4-68.2	15.0-58.0	45.8-60.8
	Common Microlithotypes	Int, Vit	Int, Vit	Vit, Int
Bimaceral	Mean Content	29.4	31.5	26.0
	Range	21.4-37.6	20.2-37.7	19.6-30.8
	Common Microlithotypes	Clar, Vtr	Dur, Vtr	Vtr, Dur
Trimaceral	Mean Content	10.3	20.4	12.4
	Range	4.1-18.4	5.0-47.4	8.8-16.4
	Common Microlithotypes	Duro, Claro	Duro, Claro	Dur, Claro
Carbominerites	Mean Content	4.1	5.4	6.2
	Range	2.9-5.5	3.0-9.2	3.4-9.2
	Common Carbominerites	Cgl, Cpy	Cgl, Cpy	Cgl, Cpy

Monomaceral
Int - Inertite
Vit - Vitrite

Bimaceral
Clar - Clarite
Vtr - Vitrinertite
Dur - Durite

Trimaceral
Duro - Duroclarite
Claro - Clarodurite

Carbominerites :
Cgl - Carbargillite
Cpy - Carbopyrite

Table 6.2. Microlithotypes of the Vasse Shelf, Collie and the Irwin River coals.

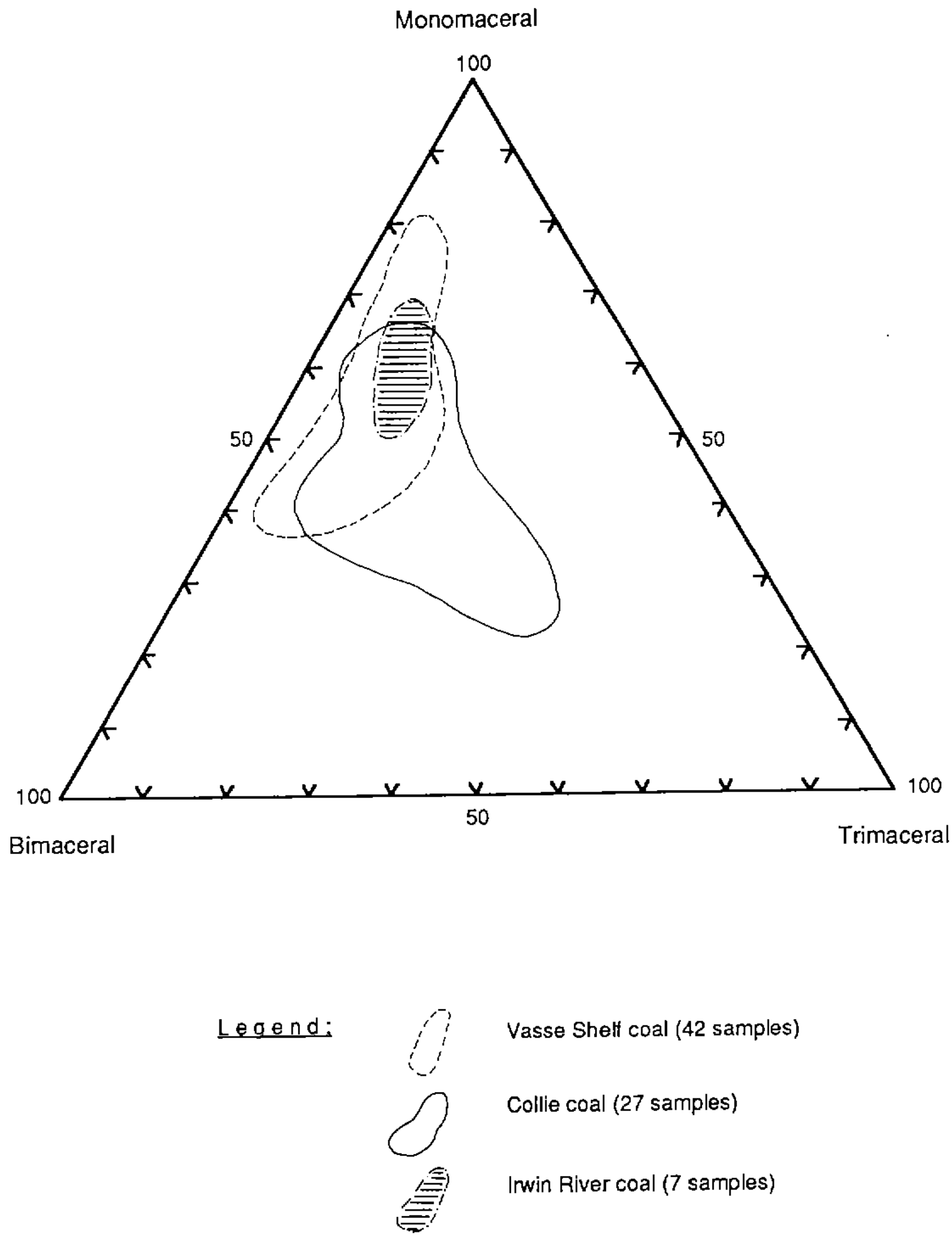


Figure 6.4. Microlithotypes of the Vasse Shelf, Collie and the Irwin River coals.

in the Collie coal (20.4%) as compared with the Irwin (12.4%) and Vasse Shelf (10.3%) coals, and duroclarite and clarodurite are present as bimaceralic microlithotypes. The carbargilite and carbopyrite are highest in the Irwin River coal (6.2%) and lowest in the Vasse Shelf coal (4.1%). Overall, there is a similarity of the microlithotype compositions of Vasse Shelf and the Irwin River coals, as shown in Figure 6.4, which supports the similarity of the flora which formed the peat during Early Permian in the Perth Basin.

From the above comparisons based on macerals and microlithotypes, it is summarized that the Vasse Shelf coal is rich in inertinite, vitrinite, and low in exinite and mineral matter, and rich in inertite and vitrite, respectively. The inertodetrinite, fusinite and semifusinite are the main inertinite macerals present, semifusinite ratio is very low to medium and vitrinite content is medium to high. This suggests that the coal was formed under relatively drier conditions with higher degree of oxidation during its deposition. The coal rank is sub-bituminous to high volatile bituminous and sub-bituminous A according to the Australian Classification and ASTM, respectively.

The Collie coal like the Vasse Shelf coal for macerals and microlithotypes is predominantly composed of inertinite, vitrinite, inertite and vitrite, and with low exinite and mineral matter. The inertinite group is dominated by the macerals inertodetrinite, fusinite and micrinite. The semifusinite ratio is very low to low and vitrinite content is low to medium. This indicates that the depositional environment of the Collie coal and the type of flora is somewhat similar to that which formed the Vasse Shelf coal. The coal rank is sub-bituminous and sub-bituminous B according to the Australian Classification and ASTM, respectively.

The Irwin River coal is mainly dominated by vitrinite and vitrite followed by inertinite and inertite with low exinite and mineral matter. The desmocollinite, vitrodetrinite and telocollinite are common macerals in the coal. The semifusinite ratio is very low and vitrinite content is medium to high. This suggests that the coal was formed from woody peat under consistently high water table condition and lower degree of oxidation during its deposition. The rank is sub-bituminous and sub-bituminous B to A based on the Australian Classification and ASTM, respectively.

6.3. Gondwana Coals

The name Gondwanaland was given by Suess (1885) to the landmass of South Africa, South America, Australia, India, Madagascar and Antarctica. The concept of Gondwanaland became popular with authors working on theories of continental drift, Wegener (1936) and King (1953, 1962). The authors advocated reassembly of the world's continents into two supercontinents that existed during the Late Palaeozoic, namely: a southern supercontinent called Gondwanaland that comprised Australia, South America, Africa, India and Antarctica, and a northern supercontinent called Laurasia that included the rest of the world's continental areas. The two supercontinents were separated by a sea known as Tethys.

Various workers have given different reconstruction of Gondwanaland such as: Du Toit (1937), Ahmad (1961), Crawford (1969), Smith and Hallam (1970), Tarling (1972) and Powell, Johnson and Veveers (1980). Figure 6.5 shows the reconstruction of Gondwanaland suggested by Du Toit (1937), Smith and Hallam (1970), Tarling (1972) and Powell, Johnson and Veevers (1980). All of them agree that Australia, Antarctica, India, Africa and South America were in close proximity before the break-up of Gondwanaland in

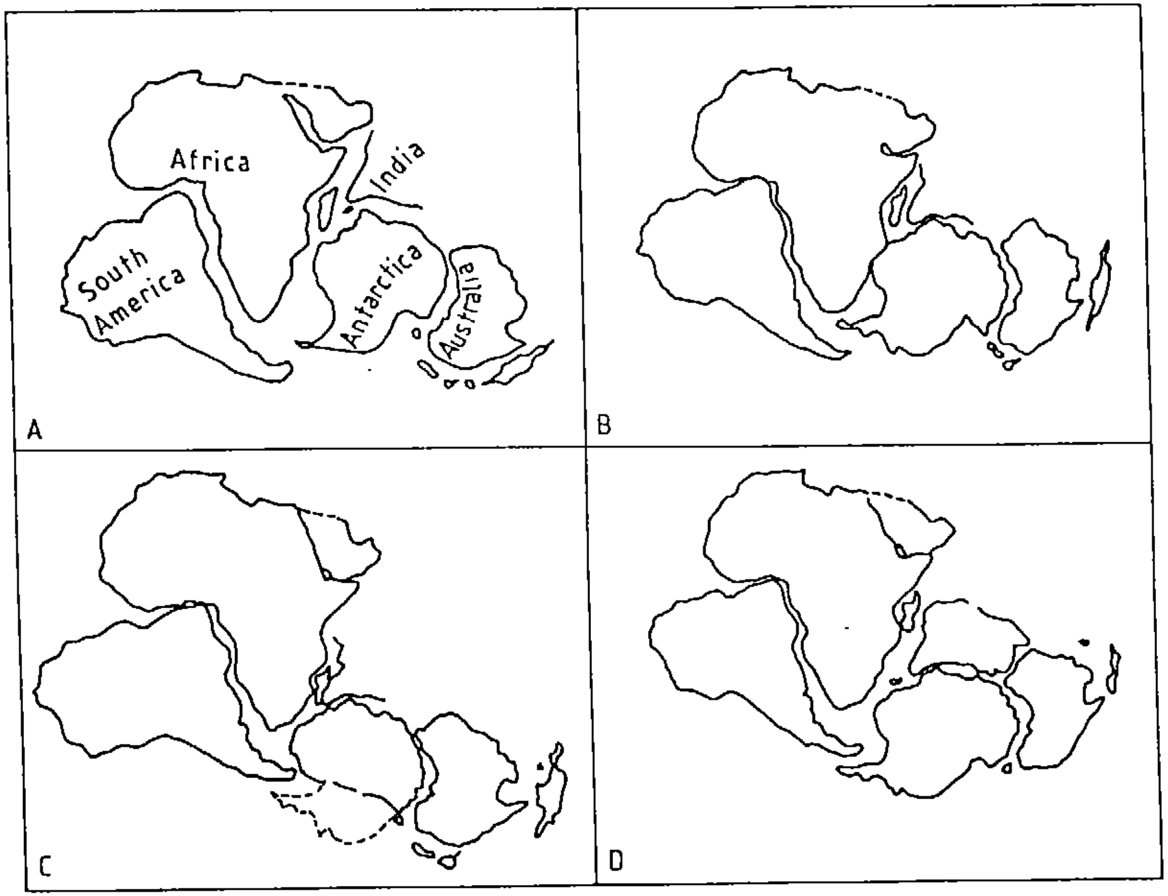


Figure 6.5. Reconstruction of Gondwanaland

A. Du Toit (1937

B. Smith and Hallam (1970)

C. Tarling (1972)

D. Powell, Johnson and Veevers (1980)

Early Cretaceous.

In the present study, petrological comparisons of Early Permian Western Australian coal (Vasse Shelf, Collie and Irwin River) are made with the selected Gondwana Early Permian coals from eastern Australia, India, South Africa and Brazil (Figure 6.6). Information on petrology of Antarctican coals is unavailable, although geology of coal from Antarctica has been described by Wright and Williams (1974), Splettstoesser (1985), Rose and McElroy (1987) and Tingey (1991). The data on petrology of eastern Australian coals are taken from the Bowen, Gunnedah and Sydney Basins, Harrington *et al.* (1989) and Hunt (1989), Indian coals from the Pench-Kanhan Valley, Son-Mahanadi Valley and Damodar Valley Basins, Mishra, Chandra and Verma (1990), South African coal from the Karoo Basin, Stavrakis and Smyth (1991) and Brazilian coal from Candiota coalfield, Correa da Silva (1993). Due to the availability of the published data on the Gondwana coals from different continents, the comparison with the Western Australian coals is based only on maceral analyses.

Table 6.3 and Figure 6.7 show comparisons of the composite maceral and mineral matter contents and rank of the Western Australian coals with the selected Gondwana coals. The vitrinite and inertinite contents of all the coals vary greatly, the highest vitrinite content is in the eastern Australian coals of the Sydney Basin (59.8%) and the Bowen Basin (58.5%), and the lowest is in the Collie coal (37.3%) from Western Australia. The Western Australian coals contain the highest inertinite content (49.1% in the Collie Basin, 46.4% in Vasse Shelf and 39.2% in the Irwin Sub-basin), and the Brazilian coal contains the lowest (19.0%) inertinite content amongst the Gondwana coals. The exinite content is relatively higher in the Indian coal, Son-Mahanadi Valley (14.0%) and Pench-Kanhan Valley (11.0%) Basins

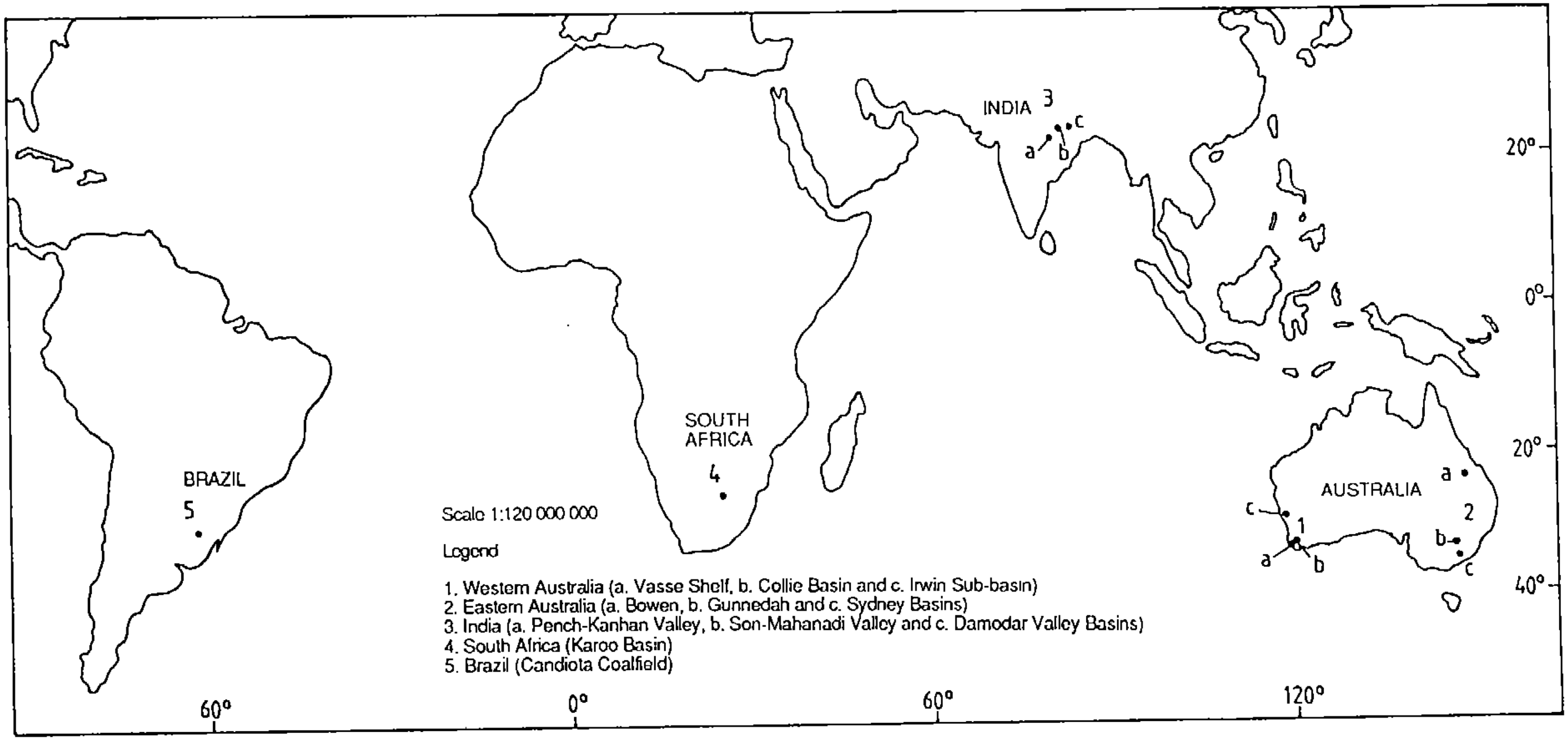


Figure 6.6. Locations of the Early Permian coals in the world (after Harrington *et al.*, 1989 and Hunt, 1989, Mishra, Chandra and Verma, 1990, Stavrakis and Smyth, 1991 and Correa da Silva, 1993).

MACERAL GROUP	WA			EA 1)			INDIA 2)			SA 3)	BRAZIL 4)
	VS	Collie	Irwin	Bowen	Gunnedah	Sydney	PKV	SMV	DV	Karoo	Candiota
Vitrinite	40.2	37.3	49.1	58.5	54.8	59.8	42.0	42.0	55.0	42.0	54.0
Inertinite	46.4	49.1	39.2	24.0	27.6	31.5	29.0	32.0	28.5	32.5	19.0
Exinite	9.0	8.3	6.3	5.0	5.0	5.0	11.0	14.0	7.0	10.5	9.0
Mineral Matter	4.4	5.3	5.4	12.5	12.6	3.7	18.0	12.0	9.5	15.0	18.0
RO max %	0.58-0.63	0.45-0.48	0.42-0.59	0.60-0.90	0.53-0.83	0.61-1.05	0.4-0.65	0.4-0.65	0.85-1.30	0.5-1.45	0.4-0.51
Rank Australia	sub-bit.- high vol. bit.	sub-bit.	sub-bit.	high vol. bit.	sub-bit.- high vol. bit.	high vol. bit.	sub-bit.- high vol. bit.	sub-bit.- high vol. bit.	high vol. bit.- med. vol. bit.	sub-bit.- med. vol. bit.	sub-bit.
Rank ASTM	sub-bit A- high vol bit	sub-bit. B	sub-bit. B-A	high vol. bit.	sub-bit. A- high vol. bit.	high vol. bit.	sub-bit. B- high vol. bit	sub-bit. B- high vol. bit.	high vol. bit.- med. vol. bit.	sub-bit A- med vol. bit.	sub-bit. B-A

WA : Western Australia
EA : Eastern Australia
SA : South Africa
VS : Vasse Shelf
PKV : Pench-Kanhan Valley
SMV : Son-Mahanadi Valley
DV : Damodar Valley

sub-bit. : sub-bituminous
high vol. bit. : high volatile bituminous
med. vol. bit. : medium volatile bituminous

1). Harrington et al (1989) and Hunt (1989)
2). Mishra, Chandra and Verma (1990)
3). Stavrakis and Smyth (1991)
4). Correa da Silva (1993)

Table 6.3. Maceral composition and rank of the Early Permian Gondwana coals of Western Australia, eastern Australia, India, South Africa and Brazil (after Harrington et al.,1989 and Hunt, 1989; Mishra, Chandra and Verma,1990; Stavrakis and Smyth, 1991 and Correa da Silva, 1993).

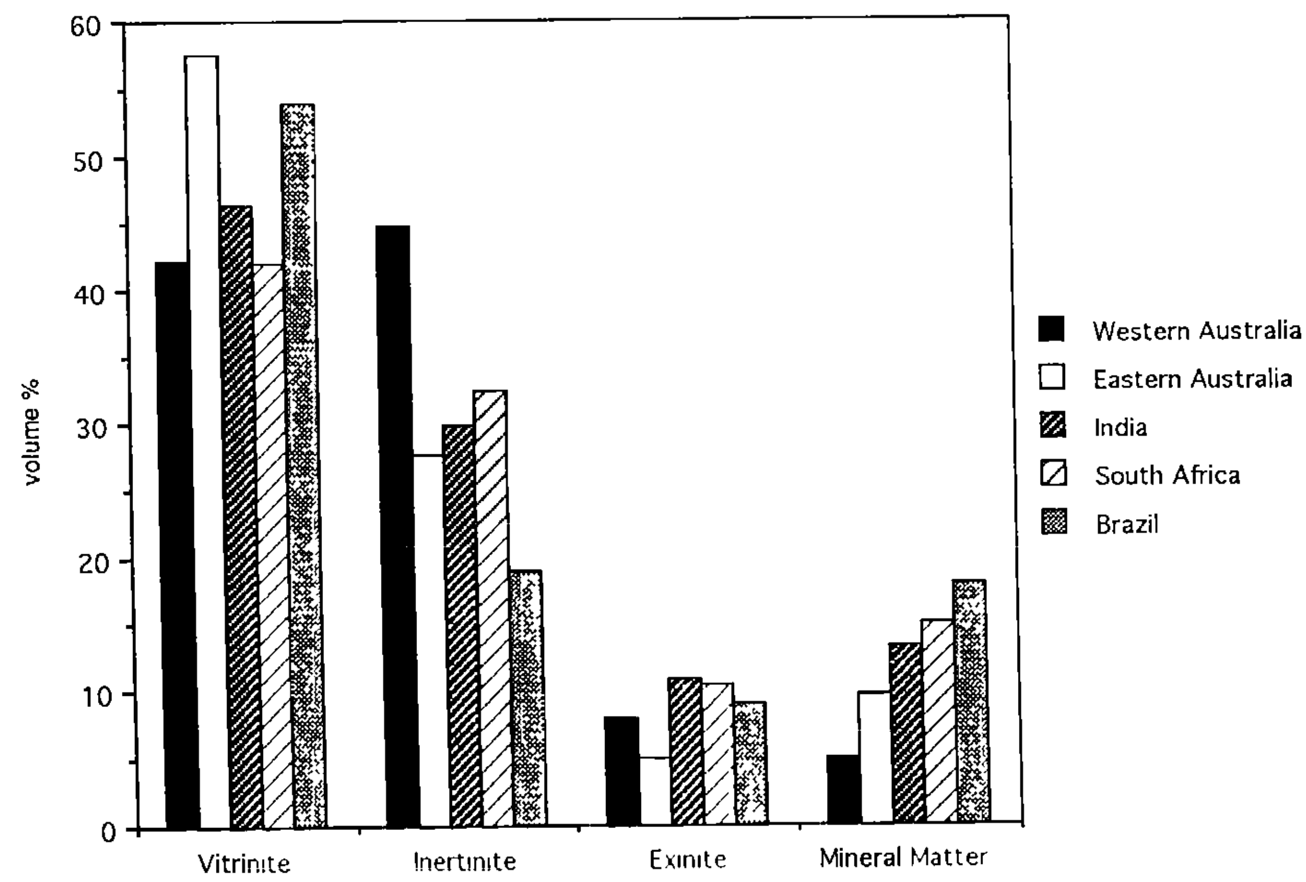


Figure 6.7. Maceral and mineral matter compositions of the Early Permian Gondwana coals of Western Australia, eastern Australia, India, South Africa and Brazil (after Harrington *et al.*, 1989 and Hunt, 1989; Mishra, Chandra and Verma, 1990; Stavrakis and Smyth, 1991 and Correa da Silva, 1993).

and is lowest (5.0%) in eastern Australian coals. The Brazilian and Indian coals (Pench-Kanhan Valley Basin) contain the highest amount of mineral matter content (18.0%) and the Sydney Basin in eastern Australia and Vasse Shelf in Western Australia contain the lowest content of 3.7% and 4.4%, respectively. The rank of the coals varies widely, the South African coal from the Karoo Basin has the highest rank as sub-bituminous to medium volatile bituminous (RO max% of 0.5 to 1.45), and the lowest rank is the Collie coal from Western Australian (RO max% of 0.45 to 0.48), and the Brazilian coal (RO max% of 0.4 to 0.51) is sub-bituminous, according to the Australian Classification.

In summary, the predominance of inertinite over vitrinite contents occurs in the Western Australian (Vasse Shelf and Collie Basin) coals, otherwise the Brazilian (Candiota coalfield), eastern Australian (all the three basins), Indian (all the basins) and Western Australian (Irwin Sub-basin) coals are dominated by vitrinite over inertinite. The exinite contents are highest in the Indian coal (Son-Mahanadi Valley and Pench-Kanhan Valley Basins) and lowest in eastern Australian coal (all the three basins). The higher exinite content in the Indian coal could be due to the character of the Gondwana flora. The mineral matter contents are highest in the Brazilian and Indian (Pench-Kanhan Valley Basin) coals and lowest in Western (Vasse Shelf) and eastern Australian (Sydney Basin) coals. The rank varies from sub-bituminous to medium volatile bituminous of the Australian values.

The above results suggest that the predominance of vitrinite and high mineral matter contents in the eastern Australian, Brazilian, South African and Indian coals shows periods of higher water table levels, low oxidation, rapid subsidence and wet environment during the depositional environment of the coals. On the other hand, the Western Australian coals

(Vasse Shelf and Collie Basin) show periods of lower water table levels, high oxidation, microbial degradation, slow subsidence and dry condition during their depositional environment. The coals of Western Australia and Brazil are low in rank, probably due to either shallow depths of burial or low heat flow, or both, as described by Middleton and Hunt (1989) and Correa da Silva (1993). The high rank coals in eastern Australia (Sydney Basin) are due to uplift of deeply buried Permian rocks and enhanced heat flow, Middleton and Hunt (1989).

CHAPTER 7. GEOCHEMISTRY

7.1. Introduction

Geochemistry of the selected coal seams from the Vasse Shelf and Premier Sub-basin (Collie Basin) is described on the basis of trace elements, proximate and ultimate analyses. The analyses for nineteen trace elements in the coal samples were undertaken by ANALABS, and the analyses on the Irwin River coal could not be completed due to insufficient samples. The data for proximate and ultimate analyses for the coal were obtained from CRAE (1986, 1993) and Le Blanc Smith (1993) for the Irwin River, Vasse Shelf and the Collie coals, respectively. The proximate analyses obtained for the coals do not correspond to the seams analysed petrographically. The data here are used to establish the rank of the coals. Similarly, the data for the ultimate analyses do not correspond to the seams used for petrographic analyses, and have been used in the Seyler chart to classify the coal.

7.2. Trace Elements

The term "trace element" is preferred to "uncommon or rare element", as outlined by Swaine (1990). The trace element unit used in the thesis is given as 'parts per million' (ppm) which is generally preferred by geochemists. The mode of occurrence of trace elements in coal indicates that the presence of every element is partly associated with organic matter and partly with inorganic matter. According to Finkelman (1981), trace elements in coal are associated with organic matter in low-ash coals (<5%), and Swaine (1990) added that "trace elements in coals with ash yields of more than 5% percent are likely to be predominantly mineral associated".

Trace elements in coal may be associated with either inorganic matter (present in mineral structures or adsorbed onto the surface of minerals) or with organic matter (present as chelated ions or ion-exchange positions), or both, Rimmer (1991). According to Mackowsky (1982), trace elements in coal originate either from the initial plant material or from mixtures of organic and inorganic constituents, for instance, uranium formed during the first stage of the coalification process. Trace elements can also be components of other minerals in the coal, for example, silver in galena, arsenic in pyrite or in clay minerals.

The presence of trace elements in coal has geological and environmental significance, particularly for the viewpoint of the depositional environment and seam correlation. Swaine (1971), Mackowsky (1982) and Diessel (1992) indicated that trace elements in coal may be helpful as an indicator of marine influence on coal deposition, especially the concentration of boron which can be used to interpret peat depositional environment.

In terms of environmental aspects, concentrations of trace elements cause potential environmental hazards affecting humans, animals and plants. Swaine (1990) indicated that coal containing some trace elements may be harmful to health under certain conditions, and essential elements show deficiency or toxicity depending on their concentrations. The relationship between coal utilization and environmental and health aspects was also examined by Gehrs *et al.* (1981) who concluded that "trace element emissions including radioactive elements, from coal combustion in power plants are generally considered an unimportant source of exposure to trace elements". Kohno, Takanashi and Fujiwara (1982) indicated that "it appears that atmospheric releases of trace elements are not likely to have significant and hazardous effects on soil and vegetation near power stations".

In order to interpret the correlation/relationship between two variables of coal data, a statistical method named "the simple-linear regression" is used as depicted in Figure 7.1 by Davis (1973), McPherson (1990) and Walpole and Myers (1978). The trend lines in the correlation show a condition in which change of values in one variable is related to change in the other. The correlation between the two variables is categorized as :

. *Positive correlation, increasing values of one variable are associated with increasing values of the other variable (Figure 7.1.a).*

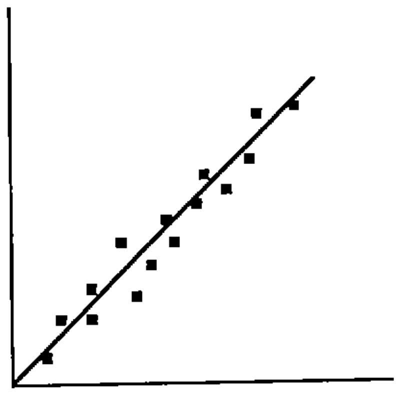
. *Negative correlation, increasing values in one variable are associated with decreasing values of the other variable (Figure 7.1.b).*

. *Weak positive/negative correlation, the correlation is weak since the points cluster less closely about the trend line (Figures 7.1.c and 7.1.d).*

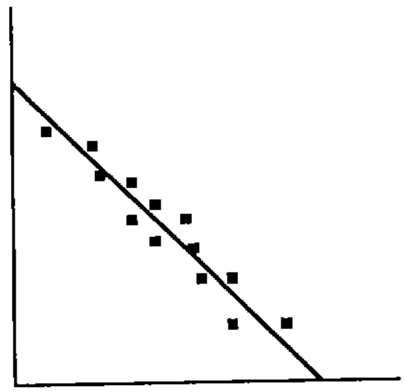
. *No apparent correlation, showing the trend line which runs parallel to one or other axis, and the implication is that an increase/decrease in the value of one variable gives no information to a corresponding increase/decrease in the other (Figure 7.1.e).*

According to Torrey (1978), the ash residue resulting from the combustion of coal is primarily derived from the inorganic mineral matter in the coal, and thus, the ash is predominantly associated with inorganic affinity. Therefore, on the basis of this viewpoint, the positive correlation represents predominant inorganic association, negative correlation indicates organic association, weak positive/negative correlation shows slightly predominant inorganic/organic association and no apparent correlation suggests both inorganic or organic association.

The studies on trace elements in coal have been made by authors: Goldschmidt (1935, 1937), Crossley (1947), Reynold (1948), Breger, Deul

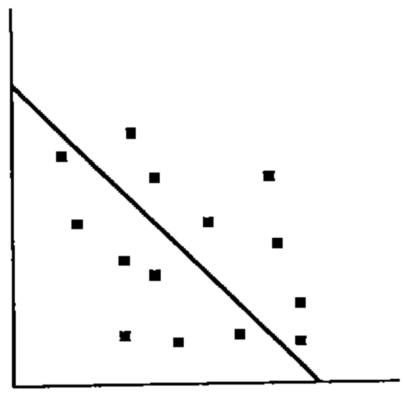


a. Positive correlation



b. Negative correlation

c. Weak positive correlation



d. Weak negative correlation

e. No apparent correlation

Figure 7.1. Scatter diagrams of two variables showing different correlations between variables.

and Meyrowitz (1955), Hawley (1955), Breger, Deul and Rubenstein (1955), Mason (1958), Zubovic (1961), Zubovic, Stadnichenko and Sheffey (1961), Brown and Swaine (1964), Manskaya and Drozdova (1968), Nicholls (1968), Somasekar (1971), Swaine (1975, 1986, 1990), Gluskoter *et al.* (1977), Cavallaro *et al.* (1978), Wagner *et al.* (1980), Ward (1980), Bouska (1981), Finkelman (1981, 1988), Singh, Singh and Chandra (1983), Palmer and Filby (1984), Bernstein (1985), McIntyre *et al.* (1985), Van der Flier and Fyfe (1985), Kojima and Furusawa (1986), Eskenazy (1987), Given and Miller (1987), Marczak and Lewinska-Ochwat (1987), Miller and Given (1987) and Steinmetz, Mohan and Zingaro (1988).

7.3. The Vasse Shelf Coal

The trace elements distribution, proximate and ultimate analyses of the selected coal seams from the drill holes RBCH 5, RBCH 6, RB 3, CRCH 1 and CRCH 2 are described here.

7.3.1. Trace Elements Distributions

The trace element analyses on thirteen coal samples collected from the three Vasse Shelf coal seams (A, B and G) were undertaken to establish distribution of the trace elements in the coal, their association with inorganic or organic matter and the trace element data are also used in the interpretation of the depositional environment of coal in chapter 8. The seams were chosen due to their continuity in the drill holes (Figure 4.1, page 68). The powdered coal samples crushed to -1/4 mm were ashed at 815° in an electric furnace with controlled air flow for oxidation. The trace elements determined by spectrometric analyses were undertaken in ANALABS, Perth, Western Australia. The trace elements analysed in the coal samples are B, Be, Co, Cr, Cu, Ga, Ge, Mn, Mo, Ni, Pb, Sb, Sn, Sr, Ti, U, V, Zn and Zr. These elements have been chosen in order to know their concentration and associations with the organic and inorganic affinities in the coal, and the trace elements such as B, Cr, Cu, Ga, Ge, Mn, Ni, Pb, V, Zn, Zr are useful as indicators of the depositional environment of the coal in chapter 8. The data on nineteen trace elements and ash contents of the selected coal are presented in Table 7.1 which shows that the concentrations of the individual trace elements and the ash vary considerably.

7.3.2. Trace Elements Associations

According to Goldschmidt (1937), many coal ashes contain high concentrations of trace elements as compared with their average contents in the earth's crust. Mason (1958) concluded that plants accumulate the elements during their growth, and the concentration is further enhanced by the accumulation of the elements from groundwater by absorption or chemical reaction during the process of coalification, and also from the mineral matter associated with coal deposited along with the plant materials. In the present study, the coals have low to very high contents of ash (3.2% to 20.4%). The seam A has a range of ash content between 3.6% in RB 3 to 20.2% in RBCH 5, the ash in seam B is between 6.9% in RB 3 and CRCH 1 and 20.4% in RBCH 5 and G is from 3.2% in RB 3 to 12.6% in RBCH 6, as shown in Table 7.1. This indicates considerable variation of mineral matter associated with the coal. The associations of trace elements with inorganic or organic matter in coal are illustrated in Figures 7.2.a and 7.2.b, and descriptions of individual trace elements and their variations in the coal are described and discussed below.

DRILL HOLES	SEAMS	ASH (%)	TRACE ELEMENTS (ppm)																	
			B	Be	Co	Cr	Cu	Ga	Ge	Mn	Mo	Ni	Pb	Sb	Sn	Sr	Ti	U	V	Zn	Zr
RBCH 5	A	20.2	69	42	180	253	93	54	390	500	10	213	50	2	7	290	1	9	166	150	185
	B	20.4	66	44	110	254	1210	58	350	845	10	214	50	7	5	213	1	9	153	78	287
	G	6.9	62	78	81	382	160	54	250	373	8	152	56	6	5	232	1	14	297	55	524
RBCH 6	A	15.2	51	48	123	204	136	67	300	376	9	208	75	6	10	185	1	13	12	332	338
	B	11.3	53	80	220	686	651	89	0	314	15	292	128	13	14	350	1	29	615	252	1230
	G	12.6	68	90	244	414	108	66	340	790	15	312	67	15	8	307	1	17	249	55	560
RB 3	A	3.6	45	54	139	354	148	54	150	508	14	359	86	8	6	113	1	23	343	154	322
	B	6.9	73	70	533	360	365	61	120	595	8	521	55	5	5	202	1	8	299	109	162
	G	3.2	45	56	189	511	251	51	110	493	8	548	52	8	8	184	1	20	368	109	181
CRCH 1	A	6.5	43	22	113	142	146	50	35	248	8	131	58	3	8	78	1	12	89	77	268
	B	6.9	49	18	104	132	88	48	55	226	8	129	69	2	8	80	1	12	165	106	442
	G	7.6	74	93	276	585	138	59	170	562	8	445	115	8	9	113	1	17	309	100	576
CRCH 2	A	5.2	141	275	513	840	209	111	500	1380	12	663	103	26	12	302	2	23	585	170	746

Table 7.1. Ash and trace element concentrations of the Vasse Shelf coal, Western Australia.

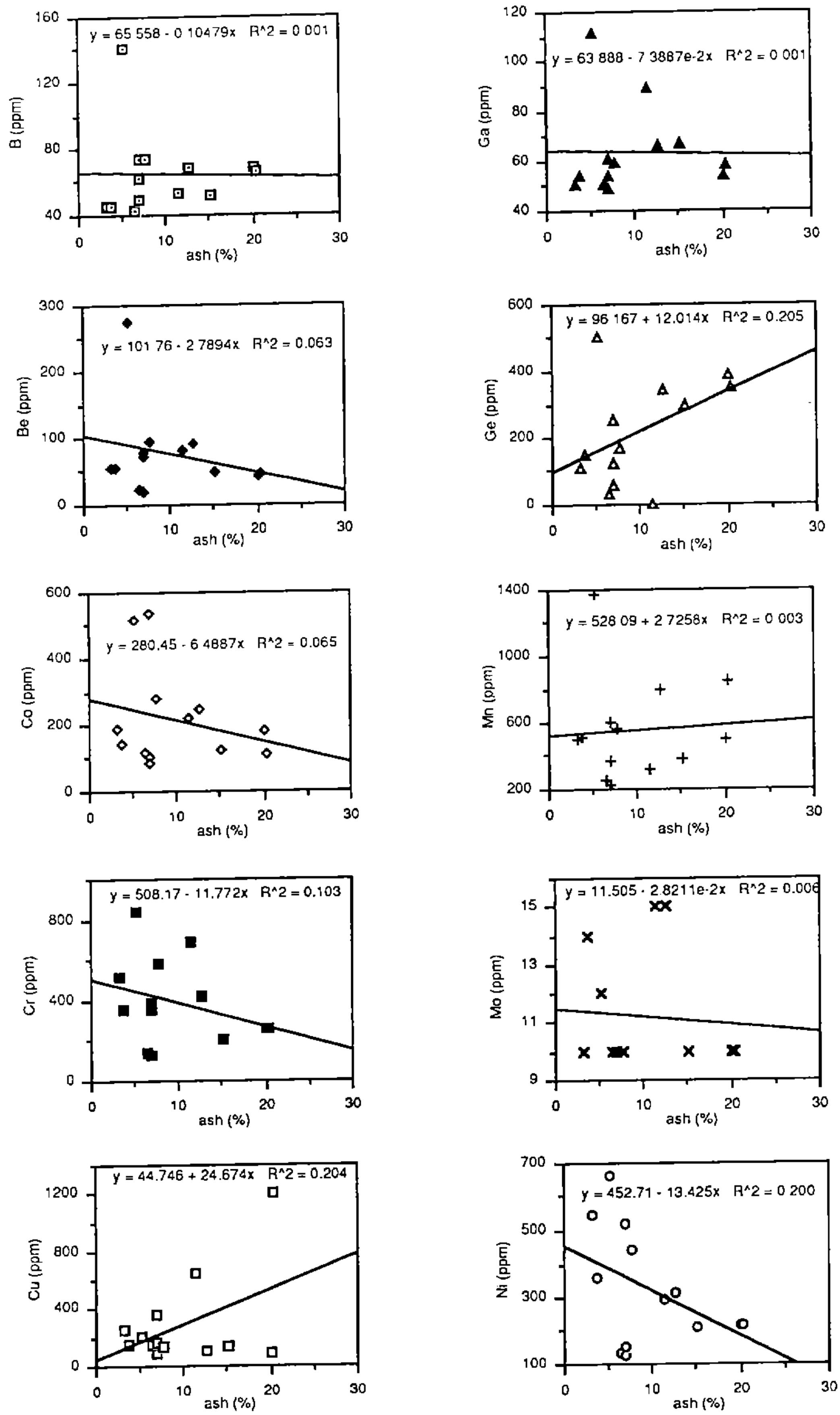


Figure 7.2.a. Relationship between ash (%) and trace element contents (ppm) of the Vasse Shelf coal.

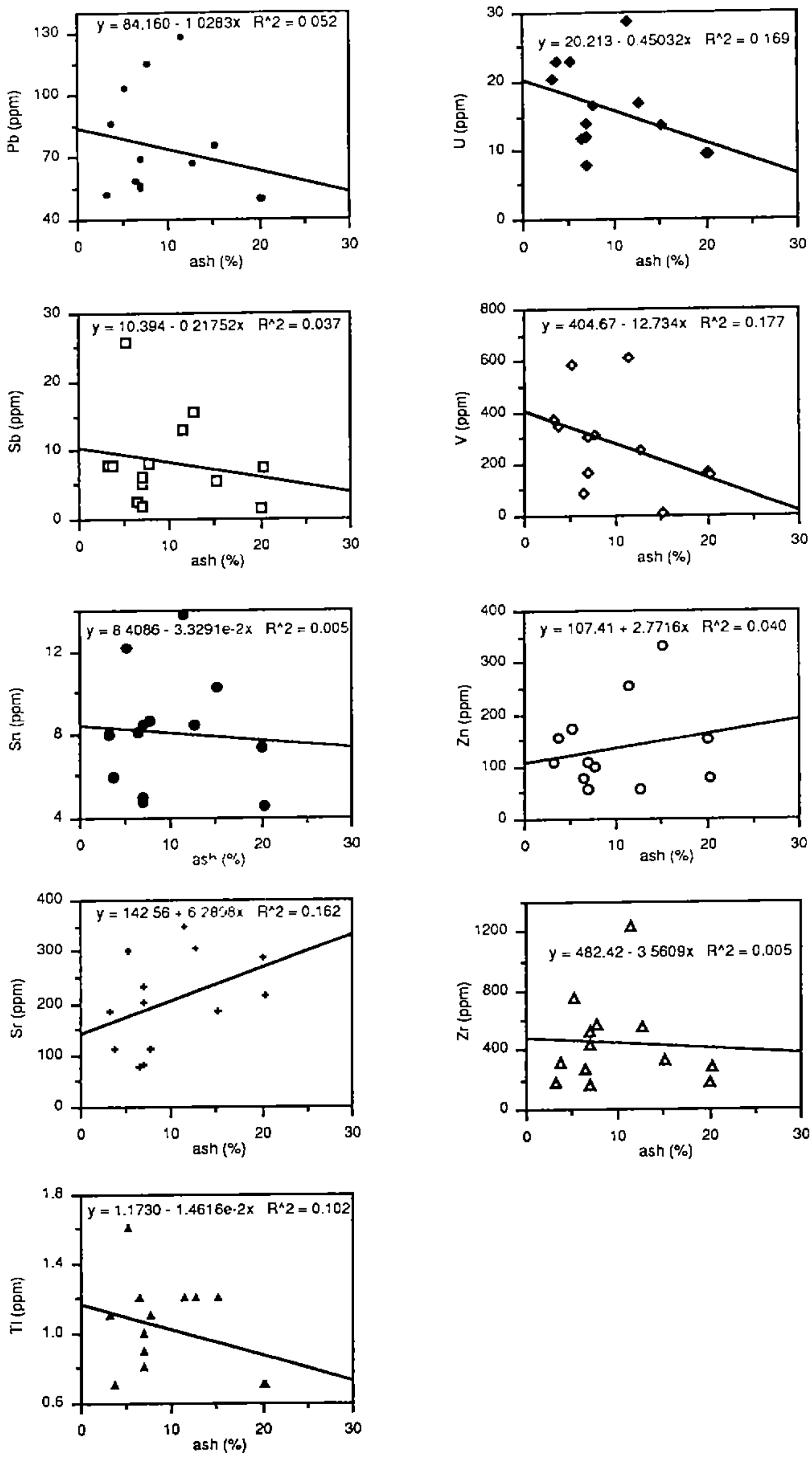


Figure 7.2.b. Relationship between ash (%) and trace element contents (ppm) of the Vasse Shelf coal.

Boron (B)

Bouska (1981) indicated that boron concentration in New Zealand coal is derived either from plants or is due to the effects of thermal springs and presence of inorganic compounds in coal. He established that the amount of boron bound to organic substances and absorbed boron in the coal decreases from bituminous to anthracite. Somasekar (1971) studied the distribution of boron in the main seam of the Kladno coal district in Czechoslovakia and found increased contents of 194-476 ppm in ash of bright banded coal, and the source of boron to be the original plant material. Ward (1980) suggested that boron tends to be associated with the organic fraction rather than the mineral matter of the coal. Swaine (1990) suggested that boron is predominantly organically bound in most coals. However, minor amounts of boron are often found in mineral matter, particularly clays.

The boron concentration in the coal varies from 43 ppm to 141 ppm, as presented in Table 7.1. No apparent organic or inorganic affinity is shown in the distribution of boron and ash contents as evident in Figure 7.2.a, suggesting its association with inorganic and organic affinities in the coal. The low concentration of boron in the coal suggests the absence of marine influence in the depositional environment of coal.

Beryllium (Be)

Goldschmidt (1935, 1937) reported the association of beryllium with humic soils in the European coals. Gluskoter *et al.* (1977) classified beryllium in the organic group, showing a maximum concentration of 4 ppm. Wagner *et al.* (1980) observed the association of beryllium with quartz present in coals. Ward (1980) suggested that beryllium occurs both in organic and inorganic combination in coals. Bouska (1981) reported that the concentration of beryllium in coal ash and also referred that the higher the ash content in coal, the lower is the content of beryllium. Singh, Singh and Chandra (1983) reported the presence of beryllium in quartz and clay minerals in Ghugus Permian coals from India. The concentration of beryllium 100 ppm or more do not pose health risks, Swaine (1990).

The beryllium content in the coal has a range of 18 ppm to 275 ppm, and its correlation with ash content in the coal is given in Figure 7.2.a, displaying a very weak negative correlation. This indicates that mostly beryllium is organically bound in the coal, with a small significant amount of inorganic association.

C o b a l t (Co)

Zubovic (1961) stated that association of cobalt in coals is mainly with the organic matter as cobalt occupies a higher position in the organic affinity series. Nicholls (1968) showed that cobalt is generally associated with the inorganic fractions of coal. Gluskoter *et al.* (1977) indicated that it is present in coals as organometallic compounds as well as associated with the sulphide minerals. Wagner *et al.* (1980) showed that cobalt is more concentrated in the clay minerals than the organic constituents of coal. Bouska (1981) stated that cobalt is generally thought to be inherent in inorganic matter, although part of it may concentrate in plants during their life and growth, and it is classed with the inorganic components of coal, because it may be absorbed in clay minerals or may derive from pyrite. Singh, Singh and Chandra (1983) indicated that cobalt is derived from organic constituents in Ghugus coals of India. Swaine (1990) suggested that cobalt may occur in coal associated with the mineral matter and with the organic matter. This element is not regarded as an element of concern in the normal environment, as outlined by Swaine (1990).

The cobalt content in the coal ranges between 81 ppm and 533 ppm. This element in the coal has more predominant organic association rather than inorganic association, which is illustrated by a weak negative correlation of the cobalt and ash contents in the coal (Figure 7.2.a).

Chromium (Cr)

Reynold (1948) reported abnormally high concentrations of chromium in coals associated with shaly bands. Gluskoter *et al.* (1977) and Wagner *et al.* (1980) found that high concentrations of chromium cannot be with organic matter alone in coal. Bouska (1981) indicated that the presence of chromium in coal and coal ash is almost usually associated with organic matter. Singh, Singh and Chandra (1983) indicated that chromium is associated with terrigenous ash containing silicate minerals.

The concentrations of chromium in the coal ranges between 132 ppm and 840 ppm. A weak negative correlation occurs between the chromium and ash contents, as illustrated in Figure 7.2.a. It is largely associated with organic matter, and to lesser extent in inorganic association in the coal.

Copper (Cu)

Crossley (1947) indicated that copper occurs intimately association with sulphides and pyrite in coal. Nicholls (1968) stated that copper is partly associated with the organic and partly with the inorganic fractions of coal and the organic fraction contains 1 ppm to 5 ppm of copper. If the concentration is higher, it is indicative of inorganic association and its concentration also increases with ash percentage. Gluskoter *et al.* (1977) suggested that although copper has an organic affinity, in most cases it is associated with sulphide minerals in coals. Cavallaro *et al.* (1978) observed the association of copper with inorganic matter in the coals. According to Wagner *et al.* (1980) it is mainly associated with clays, marcasite and pyrite, which form the inorganic constituents of coal. Bouska (1981) determined that copper often concentrates in plant bodies. He suggested, the greater part of it found in the coal ash will be a component of organic matter. Singh, Singh and Chandra (1983) indicated, it is associated with pyrite in Ghugus coals from India.

The concentration of copper varies from 88 ppm to 1210 ppm in the coal. It has a weak positive correlation with ash content in the coal, and this suggests the element is largely associated with inorganic matter rather than organic matter (Figure 7.2.a).

Gallium (Ga)

Bouska (1981) indicated that gallium belongs to the inorganic component of coal. Given and Miller (1987) suggested that gallium appears to be partly complexed with organic matter in lignites. Swaine (1990) reported that gallium occurs in coals associated with clays, sulphide minerals and to a lesser extent with organic matter, and he added that there are no deleterious effects from gallium in coal during coal mining and usage.

The gallium content in the coal has a range of 48 ppm to 111 ppm (Table 7.1). No apparent correlation occurs between the gallium concentration and ash content, as presented in Figure 7.2.a, suggesting it is associated with inorganic and organic affinities in the coal.

Germanium (Ge)

According to Manskaya and Drozdova (1968) germanium could form bonds with OH groups in humic acid during peat formation. Bernstein (1985) supported the organic bonding in coal and stated that "during coalification, highly condensed aromatic organogermanium compounds will form; these will have increased stability due to a greater number of germanium-carbon bonds". Swaine (1975) stated that pyrite is an unlikely source of germanium, but sphalerite is well known for enhanced contents of germanium. Finkelman (1981) also supported that germanium is organically bound in most coals, but some coals may have much of their germanium associated with sphalerite or clays.

The range of germanium content in the coal is between 0 ppm to 500 ppm. It has a weak positive correlation with ash content in the coal (Figure 7.2.a), and this means the germanium is predominantly present as an inorganic association. However, a less significant organic affinity may occur in the coal.

Manganese (Mn)

Bouska (1981) indicated that increased manganese content in coal is accounted by the presence of inorganic components, and it is present in coal in the form of carbonates, silicates or oxides. Swaine (1986) reported that there is evidence for manganese in carbonate minerals and an association with clays is also possible. Finkelman (1981) suggested that "in the absence of sufficient carbonates, manganese may be associated with clays". Also some manganese can occur with pyrite. Swaine (1990) reported that excessive manganese concentration in coal can cause environmental problems.

The manganese concentration ranges between 226 ppm to 1380 ppm in the coal (Table 7.1). A no apparent correlation exists between the manganese and ash contents, as depicted in Figure 7.2.a, and thus the manganese is probably associated with both inorganic and organic affinities.

Molybdenum (Mo)

Bouska (1981) has indicated that molybdenum could be accumulated by absorption on the organic matter in the initial phase of the coal-forming process and subsequently concentrated in the sulphides. Finkelman (1981) found an association of molybdenum with pyrite in coal. Swaine (1990) reported that the mode of occurrence of molybdenum in coals ranges from mostly inorganic to mostly organic, with varying proportions of each. Environmentally, an excessive concentration of molybdenum can harm animals, as described by Swaine (1990)

The distribution of molybdenum in the coal varies from 8 ppm to 15 ppm. No apparent correlation exists between the molybdenum and ash contents in the coal, and this indicates both organic and inorganic affinities are present in the coal.

Nickel (Ni)

Zubovic *et al.* (1961) expressed the opinion that nickel in coal has an association with organic compounds. Nicholls (1968) indicated that nickel shows variable relationships and he concluded that small amounts are associated with the organic fraction in coals (<1 ppm). If nickel is present in the larger concentration (> 3 ppm), it is associated with the inorganic constituents. Gluskoter *et al.* (1977) report that nickel is present in coals either as organometallic compound or absorbed cations. Finkelman (1981, 1988) concluded that the main modes of occurrence of nickel are associations of sulphides and clays and to a lesser degree organic association in coal. Nickel may be useful in nutrition and it may cause some health effects if present in excess, and it is classed as "a relatively non-toxic element", as described by Underwood (1977).

The nickel distribution in the coal varies between 129 ppm to 663 ppm. A weak negative correlation with the ash content in the coal is depicted in Figure 7.2.a, and this represents a slightly predominant organic association of nickel in the coal, and possibly some inorganic affinity is also present.

Lead (Pb)

Nicholls (1968), Gluskoter *et al.* (1977) and Wagner *et al.* (1980) indicated that the association of lead is mainly with mineral matter, particularly pyrite, sulphides and clays in coal. Bouska (1981) stated that part of the lead may be associated with pyrite or bound to galena in coal. Singh, Singh and Chandra (1983) also stated that the association of lead in coal is mainly with sulphide minerals. Finkelman (1981, 1988) indicated that lead may be associated with galena, pyrite and some barium minerals, where lead can replace barium. From the viewpoint of environmental and health implications, certain amounts of lead in coal can cause illness, as outlined by Swaine (1990).

This element has a range between 50 ppm to 128 ppm in the coal (Table 7.1). Figure 7.2.b shows a weak negative correlation between the lead and ash contents in the coal, suggesting that mostly the lead is organically bound in the coal, with a small significant amount of inorganic association.

Antimony (Sb)

According to Bouska (1981), antimony in coal is associated predominantly with the organic matter. Finkelman (1981) suggested that in some coals, antimony may be present as tiny grains in a sulphide mineral, closely associated with organic matter. Hence, it seems to have an organic association. Swaine (1990) indicated that "it is not clear how antimony occurs in coals, but it is likely that an organic association prevails in many coals, together with sulphide association, which may predominate in others".

The antimony concentration in the coal varies from 2 ppm to 26 ppm. Figure 7.2.b illustrates a very weak negative correlation between the antimony and ash contents in the coal, which leads to the assumption its association is slightly dominated by organic affinity with some inorganic affinity.

Tin (Sn)

Hawley (1955) indicated that the mode of occurrence of tin in most coals is probably in the mineral matter, although an organic association has been reported for some coals. According to Bouska (1981) tin content in coal is bound to organic matter. Finkelman (1981) reported that a number of tin-bearing minerals detected in most of the United States coals are associated mineral matter. Swaine (1990) indicated that it is clear that tin would be associated with mineral matter in most coals.

The range of tin content in the coal ranges from 5 ppm to 14 ppm (Table 7.1). No apparent correlation in Figure 7.2.b points to the inorganic and organic affinities.

Strontium (Sr)

According to Ward (1980) the rare strontium bearing mineral goyazite occurs in some Australian coals. The mode of occurrence of strontium in low-rank coals is organically bound, probably through carboxylic acid groups, Brown and Swaine (1964). Strontium content in coal is low and is usually attributed to inorganic constituents, as described by Bouska (1981). In relation to health and environment significance, there is no harmful effect present in strontium concentration in coal, as stated by Swaine (1990).

The range of strontium content in the coal is between 78 ppm to 350 ppm. A weak positive correlation exists between the strontium and ash contents in the coal as depicted in Figure 7.2.b, and therefore, the strontium is associated dominantly with inorganic fractions in the coal, with some amount of organic affinity.

Titanium (Ti)

Finkelman (1981) reported that several titanium minerals, notably rutile and anatase, are associated with clays in coal. According to McIntyre *et al.* (1985), Kojima and Furusawa (1986) and Miller and Given (1987), titanium content is organically bound. Steinmetz, Mohan and Zingaro (1988) found some titanium associated with quartz in coal. Swaine (1990) concluded that the mode of occurrence of titanium in most coals is partly organic, probably dominantly so in low-rank coals; and partly inorganic, particularly as rutile, anatase, other titanium-rich minerals associated with clays. No harmful effects are recognized caused by titanium content in coal.

The titanium concentration in the coal ranges from 1 ppm to 2 ppm (Table 7.1). Figure 7.2.b illustrates a weak negative correlation between the titanium concentration and ash content in the coal, which leads to the assumption its association is slightly dominated by organic affinity with some inorganic affinity.

Uranium (U)

Breger, Deul and Meyrowitz (1955) reported that uranium is carried out into the coal swamp in solution as carbonate complexes, which release uranyl ions to form uranyl-organic complexes. According to Breger, Deul and Rubenstein (1955), in many coals, especially low-uranium coals, uranium is predominantly organically bound. Manskaya and Drozdova (1968) suggested that "humic acids, depending on their degree of polymerization and pH of the solution, may either transport or deposit uranium" in coal. Finkelman (1981) studied some low-uranium coals and found uranium associated with zircons, phosphates and uraninite, and sometimes apatite, rutile and calcite. Van der Flier and Fyfe (1985) reported that an association between uranium and clays is found in two Canadian coals. Swaine (1990) stated that in some cases, uranium-containing minerals may be intimately associated with the organic matter, making identification difficult. He explained that the modes of occurrence of uranium in coal are diverse, but organic bonding seems general, together with associations with mineral matter.

The distribution of uranium in the coal has a range of 8 ppm to 29 ppm. Figure 7.2.b illustrates a weak negative correlation between the uranium and ash contents in the coal, which leads to the interpretation that the association of uranium is slightly dominated by organic affinity, with some inorganic affinity.

Vanadium (V)

Zubovic *et al.* (1961) showed that vanadium occupies a higher position in the organic matter and is present in coals as insoluble metal-organic complexes. Gluskoter *et al.* (1977) and Wagner *et al.* (1980) reported vanadium associated with inorganic matter (clays and quartz) in coals. According to Manskaya and Drozdova (1968) vanadium may be concentrated in coal in "the form of complexes with phenolic compounds", but Swaine (1990) stated that they did nor infer the presence of such complexes in any coals. Finkelman (1981) found vanadium in clays, especially illite. Palmer and Filby (1984) determined that vanadium in coal is concentrated in clays. Marczak and Lewinska-Ochwat (1987) concluded that 98 % of the total vanadium is present in mineral matter in Polish coals. Swaine (1990) concluded that there may be a small proportion of organically bound vanadium in some coals, together with inorganic vanadium in clays and other specific minerals. There are no nutritional or environmental problems from vanadium in coal during coal mining and usage.

The vanadium concentration in the coal ranges from 12 ppm to 615 ppm. The concentration shows a weak negative correlation with the ash content in the coal as illustrated in Figure 7.2.b, and thus, the vanadium is largely dominated by organic affinity, with a lesser amount of inorganic affinity in the coal.

Zinc (Zn)

According to Bouska (1981) zinc may be derived from plant bodies or adsorbed in a later stage, part of it may be associated with pyrite or bound directly to sphalerite. Swaine (1990) suggested that the mode of occurrence of zinc in coal is organically bound, especially in low-rank coals. Zinc is an important element biologically and environmentally in terms of its essentiality in nutrition, however, an excessive amount may be harmful, as reported by Swaine (1990).

The range of zinc content in the coal varies between 55 ppm to 332 ppm. The relationship between the zinc and ash contents in the coal shows almost no apparent correlation, and therefore, both organic and inorganic associations of zinc is presumably present in the coal.

Zirconium (Zr)

According to Ward (1980), on the basis of density separations, the zirconium in most Australian coals is predominantly associated with organic affinity. However, Swaine (1990) disagreed, because this statement would be nullified if very finely divided zircons were embedded in the organic coaly matter. Eskenazy (1987) reported that for Bulgarian coals, zirconium is mainly associated with mineral matter, except in some low-rank coals.

Given and Miller (1987) indicated that in USA lignites, zirconium is consistently associated with minerals. Due to its insolubility, zirconium is a rather harmless element in the coal and no harmful effect is present in coal containing zirconium.

The zirconium concentration in the coal has a range of 162 ppm to 1230 ppm. This element shows no apparent correlation with the ash content in the coal (Figure 7.2.b), and it is interpreted that the zirconium is associated with organic and inorganic matter.

From the above data on trace element concentration in the coal, the elements of Cu, Ge and Sr are predominantly present in inorganic affinity, Be, Co, Cr, Ni, Pb, Sb, Ti, U and V are associated with organic association, whereas B, Ga, Mn, Mo, Sn, Zn and Zr are present in both organic and inorganic associations.

7.3.3. Proximate Analysis

The proximate analysis includes the determination of moisture, volatile matter, ash, fixed carbon and specific energy of the coal, as described by the Australian Standard 1038, part 3 (1979). The moisture, volatile matter, ash and fixed carbon contents are expressed in percent, whereas calorific value is in MJ/kg. The moisture content in the coal is obtained after it has attained equilibrium with the laboratory atmosphere to which it has been exposed. The volatile matter occurs when the coal is heated in the absence of air under standard conditions, while the ash is the inorganic matter remaining after the coal has been burnt to constant mass under standard conditions. On the basis of the ash category in coal described by Graese *et al.* (1992), the ash contents are very high (15.0%-20.0%), high (10.0%-

15.0%), moderate (5.0%-10.0%) and low (<5.0%). The fixed carbon is obtained by subtracting the sum of the percentages of moisture, volatile matter and ash from one hundred. The specific energy is the number of heat units being liberated when unit mass of fuel is burnt in oxygen in a bomb under standard conditions, the Australian Standard 1038, part 16 (1975).

As mentioned earlier, the proximate analysis data of the Vasse Shelf coal obtained from CRAE (1993) for the drill holes RBCH 5, RBCH 6, RB 3, CRCH 1 and CRCH 2, do not correspond to the seams analysed petrographically. The proximate analysis of the coal on air dried basis (adb) and dry ash free (daf) presented in Table 7.2, includes ash content, moisture content, volatile matter, fixed carbon and specific energy.

The ash content in the coal has a range of 6.2% to 27.3% (adb), moisture content varies from 2.6% to 10.9% (adb) and the volatile matter content ranges between 25.2% to 43.9% (daf). On the basis of ash category described by Graese et *al.* (1992), it is dominated by a moderate to very high category (Table 7.2). The range of fixed carbon content in the coal is between 40.6% to 61.6% (adb), whereas specific energy of the coal has a range of 28.1 MJ/kg to 34.3 MJ/kg (daf).

7.3.4. Ultimate Analysis

The ultimate analysis of coal includes the determination of carbon, hydrogen, nitrogen and sulphur, as described by the Australian Standard 1038, part 6 (1971). Hunt (1984) described the total sulphur contents for Permian coal of Eastern Australia as: low (<0.55%, daf), medium (0.55-1.0%, daf) and high (>1.0%, daf).

DRILL HOLES	SEAMS	DEPTH (m)		ASH %	MOISTURE %	VOLATILE MATTER %	FIXED CARBON %	SPECIFIC ENERGY (MJ/kg)
		From	To	adb	adb	adb	adb	adb
RBCH 5	Osmington 1	487.19	487.29	10.7	5.9 (6.6)	22.3 (26.7)	61.1	27.5 (33.0)
	Osmington 2	487.29	487.60	11.6	6.2 (7.0)	27.9 (33.9)	54.3	27.3 (33.2)
	Osmington 3	487.60	487.80	13.1	6.5 (7.5)	24.7 (30.7)	55.7	26.9 (33.4)
	Osmington 4	487.80	488.02	14.4	6.8 (7.9)	22.1 (28.0)	56.7	26.4 (33.5)
	Osmington 5	488.02	488.42	11.1	7.3 (8.2)	26.5 (32.5)	55.1	27.1 (33.2)
RBCH 6	Osmington 1	473.93	474.00	9.3	6.9 (7.6)	27.1 (32.3)	56.7	27.9 (33.3)
	Osmington 2	474.00	474.16	6.2	8.6 (9.2)	29.4 (34.5)	55.8	28.7 (33.6)
	Osmington 3	474.16	474.69	11.6	8.2 (9.3)	22.1 (27.6)	58.1	26.8 (33.4)
	Osmington 4	474.69	474.86	16.2	6.3 (7.5)	21.0 (27.1)	56.5	25.3 (32.6)
RB 3	Osmington 1	230.80	231.10	7.6	8.3 (9.0)	28.0 (33.3)	56.1	27.7 (32.9)
	Osmington 2	231.10	231.65	10.6	9.3 (10.4)	22.8 (28.5)	57.3	25.9 (32.3)
	Osmington 3	231.65	232.62	21.1	8.2 (10.4)	19.8 (28.0)	50.9	22.2 (31.4)
	Osmington 4	232.62	233.38	10.8	9.1 (10.2)	23.5 (29.2)	56.9	26.2 (32.6)
	Osmington 5	233.38	234.12	12.6	10.9 (12.5)	22.9 (29.9)	53.6	24.8 (32.4)
CRCH 1	Harman 1	363.85	364.54	10.9	4.8 (5.4)	28.7 (34.0)	55.6	28.9 (34.3)
	Harman 2	364.54	365.12	15.2	4.6 (5.4)	24.6 (30.7)	55.6	27.1 (33.7)
	Osmington 1	366.32	367.18	10.2	4.6 (5.1)	23.6 (27.7)	61.6	29.0 (34.0)
	Osmington 2	367.18	367.50	27.3	3.3 (4.5)	17.5 (25.2)	51.9	22.9 (32.9)
	Osmington 3	367.50	368.38	10.9	4.4 (4.9)	25.0 (29.5)	59.7	28.8 (34.0)
CRCH 2	Harman 1	382.98	383.58	15.6	3.2 (3.8)	25.9 (31.9)	55.3	27.4 (33.8)
	Harman 2	383.58	384.14	23.2	3.6 (4.7)	18.6 (25.4)	54.6	24.2 (33.0)
	Osmington 1	384.19	384.81	24.0	3.4 (4.5)	20.5 (28.2)	52.1	23.6 (32.6)
	Osmington 2	384.81	384.92	25.0	2.6 (3.5)	31.8 (43.9)	40.6	20.3 (28.1)
	Osmington 3	384.92	385.11	9.2	3.5 (3.9)	28.1 (32.2)	59.2	29.1 (33.3)

Table 7.2. Proximate analysis of the Vasse Shelf coal (dry ash free values in brackets).

Similar to the proximate analysis data, the data for the ultimate analyses (adb and dry mineral matter free=dmmf) obtained from CRAE (1993) also do not correspond to the seams used for petrographic analyses. The data are available only for the CRCH 1 drill hole, as shown in Table 7.3.

The carbon concentration (adb) in the coal has a range of 58.8% to 71.9%, hydrogen content varies from 2.3% to 4.2% and the oxygen content ranges between 6.3% to 8.1%. The nitrogen content makes up 1.0% to 1.4% and sulphur content in the coal varies from 0.3% to 0.5% (adb). According to category proposed by Hunt (1984), the sulphur content in the coal is low due to the absence of marine sediments associated with or overlying the Sue Coal Measures.

7.3.5. Coal Rank and Classification

On the basis of moisture content, volatile matter and specific energy values, the rank of Vasse Shelf coal is depicted in Figures 7.3, 7.4 and 7.5, respectively. The rank determined on the basis of moisture content (3.5%-12.5%, daf) is categorized as sub-bituminous to high volatile bituminous according to the Australian rank values, which approximately correspond to high volatile bituminous rank of the ASTM classification. This classification is in agreement with the one based on reflectance of vitrinite of the coal described in Chapter 4 (pages 145 and 146). The rank based on volatile matter content (25.2%-43.9%, daf) indicates a coalification stage at sub-bituminous to medium volatile bituminous levels based on the Australian classification, or sub-bituminous A to medium volatile bituminous of the ASTM classification. This does not correspond to the rank based on reflectance of vitrinite of the coal described in Chapter 4, and therefore, this classification cannot be used as a precise rank parameter of the coal. The

DRILL HOLE	SEAMS	DEPTH (m)		CARBON % adb	HYDROGEN % adb	OXYGEN % adb	NITROGEN % adb	SULPHUR % adb
		From	To					
	Harman 1	363.85	364.54	70.7 (85.0)	4.2 (5.0)	7.5	1.4	0.5
	Harman 2	364.54	365.12	67.9 (86.3)	3.8 (4.8)	6.7	1.4	0.4
CRCH 1	Osmington 1	366.32	367.18	71.7 (85.2)	3.8 (4.5)	8.1	1.3	0.3
	Osmington 2	367.18	367.5	58.8 (88.2)	2.3 (3.4)	6.3	1	0.4
	Osmington 3	367.5	368.38	71.9 (86.0)	3.9 (4.7)	7.1	1.3	0.5

Table 7.3. Ultimate analysis of the Vasse Shelf coal (dry mineral matter free values in brackets).

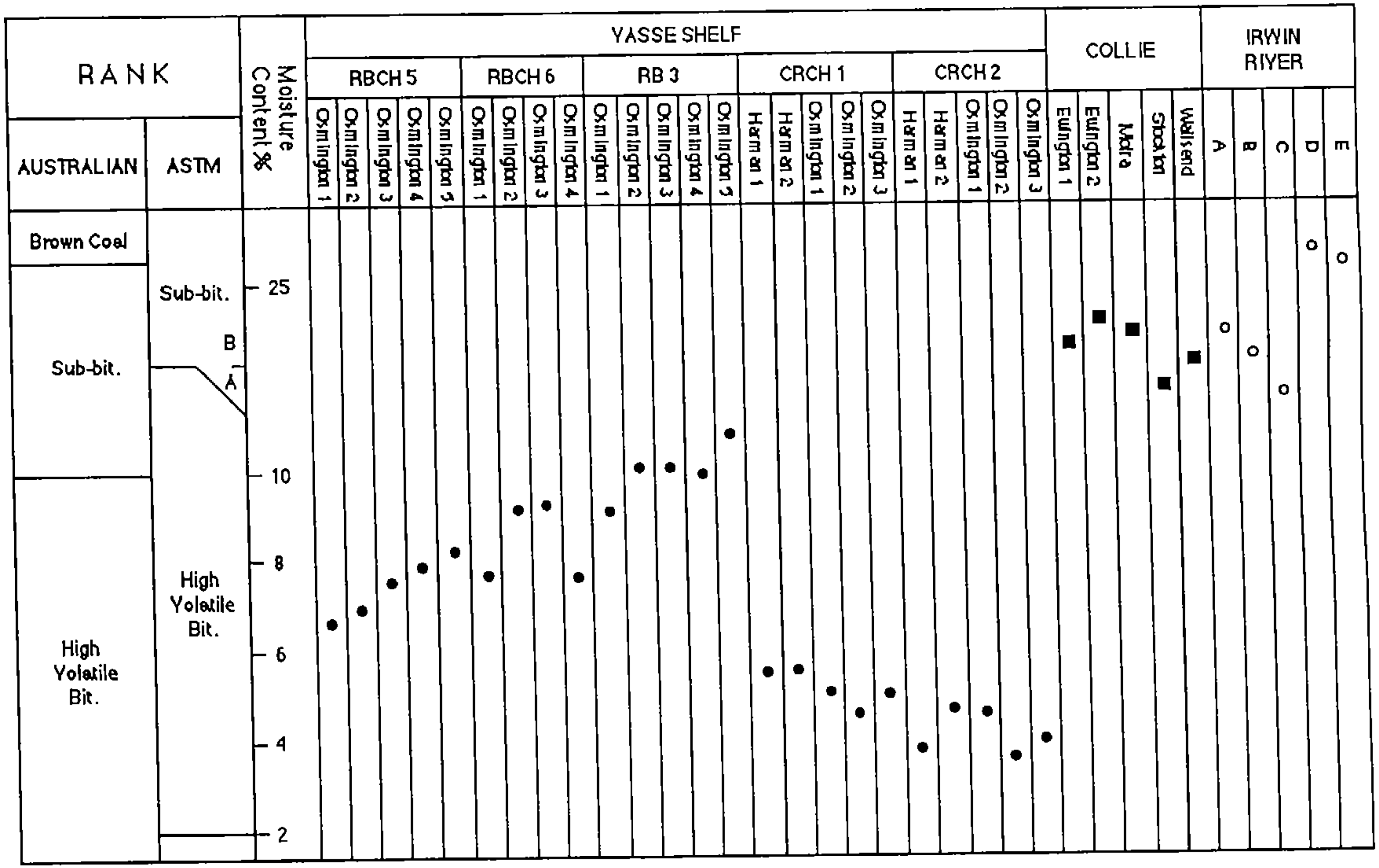


Figure 7.3. Rank and classification of the Yasse Shelf, Collie and the Irwin River coals on the basis of moisture content (% daf).

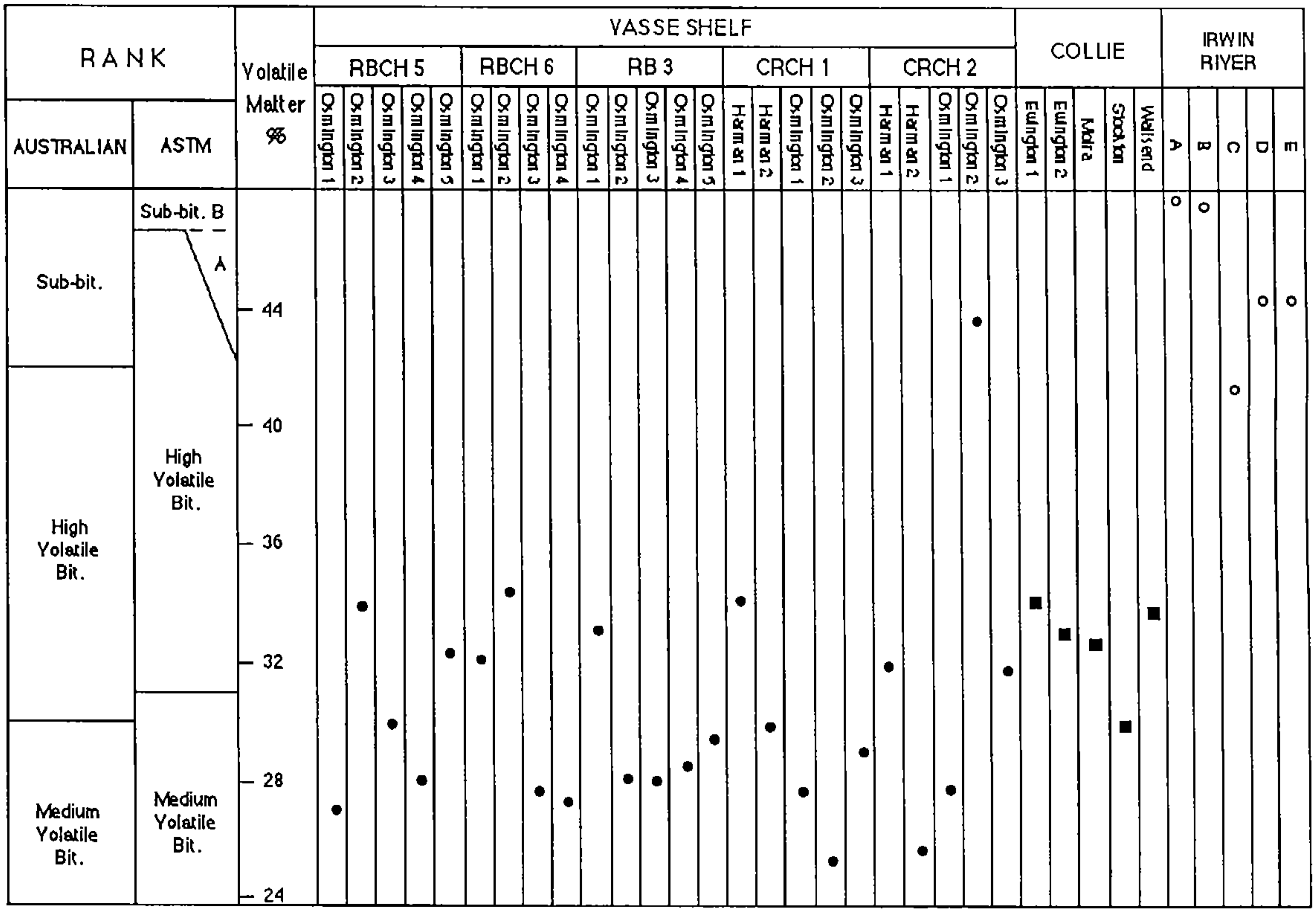


Figure 7.4. Rank and classification of the Vasse Shelf, Collie and the Irwin River coals on the basis of volatile matter (% daf).

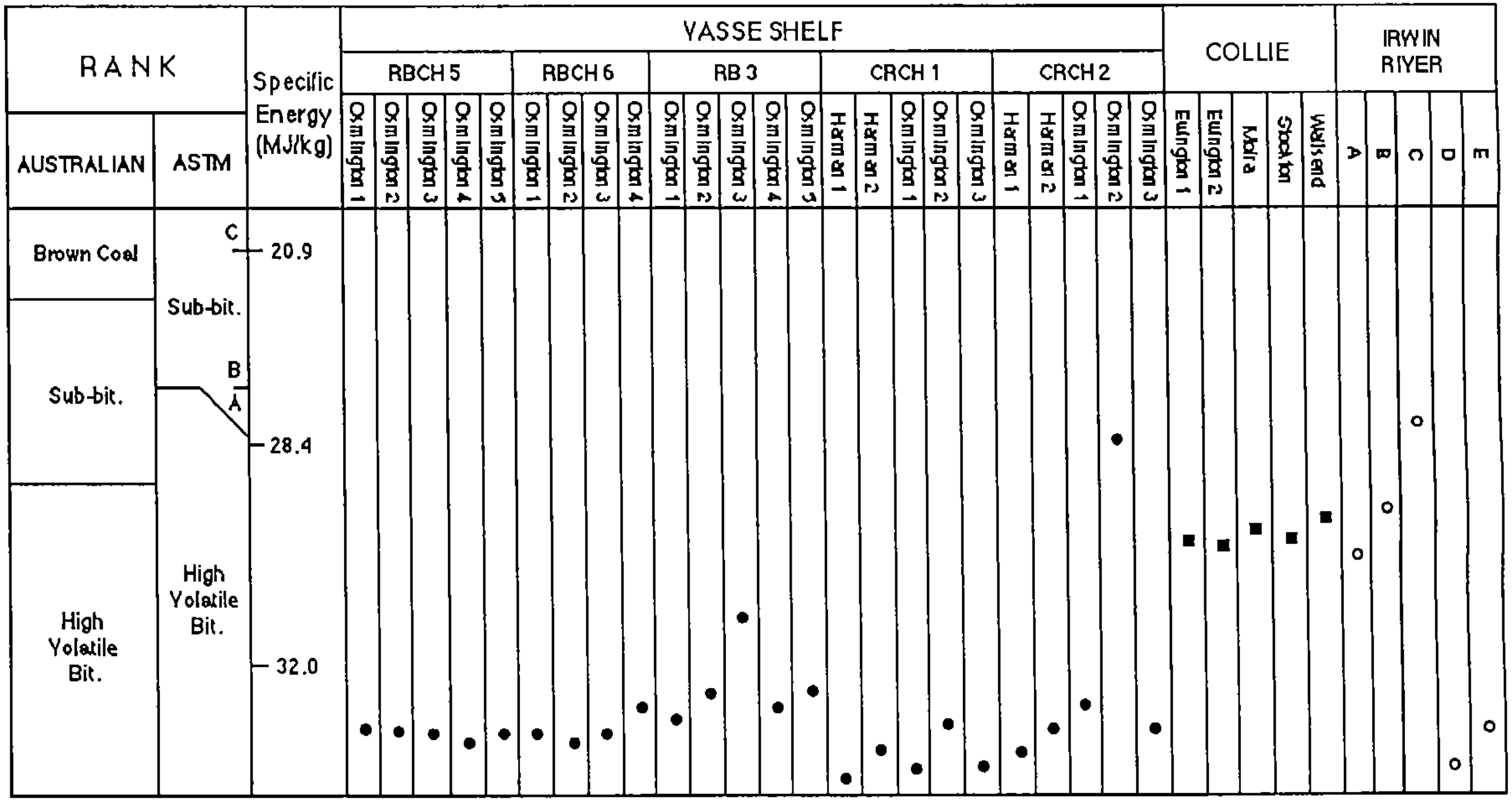


Figure 7.5. Rank and classification of the Vasse Shelf, Collie and the Irwin River coals on the basis of specific energy (MJ/kg daf).

difference is due to the relatively high inertinite content in the coal that leads to a decrease of the amount of volatile matter, as described by Kroeger and Pohl (1957). According to Stach *et al.* (1982) and Diessel (1992), specific energy is an important rank parameter of coal, because its values increase rapidly with increasing carbon content. On the basis of specific energy values (28.1-34.3 MJ/kg, daf), the rank is classified as sub-bituminous to high volatile bituminous and sub-bituminous A to high volatile bituminous, according to the Australian and ASTM classifications, respectively, which is in accordance with that of reflectance of vitrinite of the coal described in Chapter 4. Furthermore, the coal is plotted on the Seyler chart (Figure 7.6) on the basis of hydrogen and carbon contents (% dmmf), and it shows that the coal is classified as a sub-hydrous type.

Geochemical characteristics of the Vasse Shelf coal on the basis of trace elements distribution, proximate and ultimate analyses are:

. The elements of Cu, Ge and Sr occur predominantly in inorganic affinity and are part of the mineral matter in the coal. The Be, Co, Cr, Ni, Pb, Sb, Ti, U and V have organic association, which points to the fact that these elements are inherent in the flora which provided the vegetable matter for the formation of coal. The B, Ga, Mn, Mo, Sn, Zn and Zr are present in both organic and inorganic associations in the coal.

. The rank of the coal determined on the basis of moisture content and specific energy is categorized as sub-bituminous to high volatile bituminous, which is in accordance with that of reflectance of vitrinite of the coal. On the basis of hydrogen and carbon contents, the coal is classified as a sub-hydrous type.

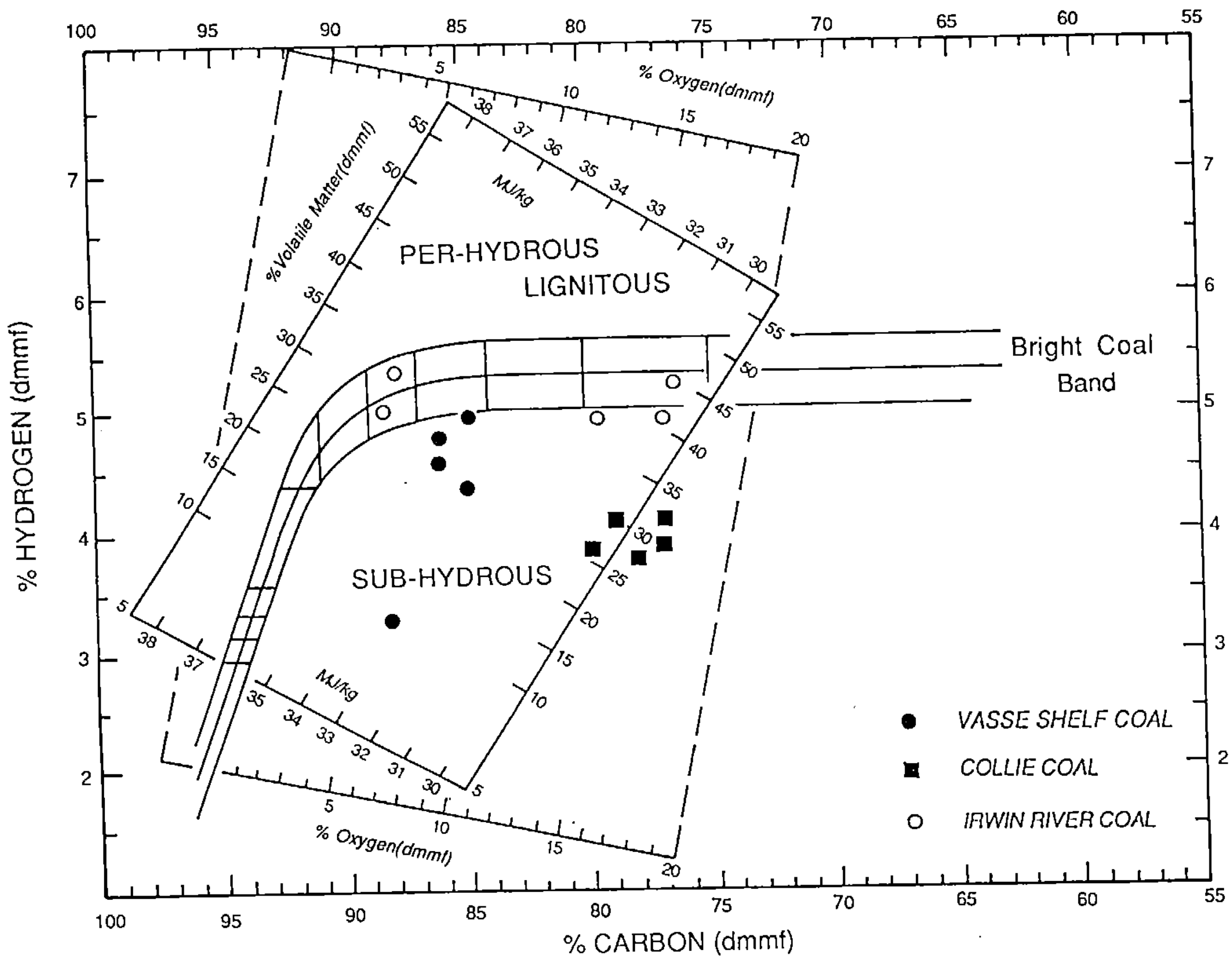


Figure 7.6. Seyler's chart showing classification of the Vasse Shelf, Collie and the Irwin River coals.

7.4. The Collie Coal

The distribution of trace elements, proximate and ultimate analyses of the selected coal seams from the drill holes BUC 213, BUC 215, BUC 212, BUC 217 and BUC 214 are discussed below. The data for proximate and ultimate analyses obtained from Le Blanc Smith (1993) do not correspond to the seams analysed petrographically. The data are used to establish the rank of the coal. The importance in environment health of individual trace elements and earlier work are already described in section 7.3.2.

7.4.1. Trace Elements Distributions

The trace elements analyses on sixteen coal samples collected from six Collie coal seams, namely E 10, E 20, E 30, E 50, E 60 and E 80 were undertaken to establish distribution of the trace elements and their association with inorganic or organic matter. The trace element data are also used in the interpretation of the depositional environment of coal in chapter 8. Table 7.4 shows ash percentages and the trace elements concentrations in the selected coal seams of Collie coal. Like the Vasse Shelf coal, the concentrations of trace elements in the coal also vary from 0 ppm to 5570 ppm, and the ash contents in the coal range between 8.1% to 16.2%.

7.4.2. Trace Elements Associations

The associations of trace elements with organic or inorganic matter in the coal are depicted in Figures 7.7.a and 7.7.b, and their variations in the coal are briefly discussed below. The descriptions of individual trace elements are presented in section 7.3.2.

DRILL HOLES	SEAMS	ASH (%)	TRACE ELEMENTS (ppm)																	
			B	Be	Co	Cr	Cu	Ga	Mn	Mo	Ni	Pb	Sb	Sn	Sr	Tl	U	V	Zn	Zr
BUC 213	E 50	9.1	10	5	21	125	38	47	93	10	71	149	0	6	13	1	8	136	107	141
	E 60	8.4	44	24	64	282	157	128	75	53	140	306	1	14	674	2	34	319	415	489
	E 80	16.2	71	37	664	1780	271	385	43	1020	1200	442	4	15	273	2	300	5570	598	1790
BUC 215	E 10	11.4	15	20	215	293	153	56	154	42	408	281	1	11	71	1	14	286	1000	231
	E 20	8.1	22	31	130	406	90	64	552	14	354	119	1	6	370	1	7	170	333	219
	E 30	13.2	41	41	352	506	148	77	437	20	479	69	2	8	305	1	10	391	595	205
BUC 212	E 20	8.9	35	45	101	226	117	65	53	26	233	93	1	14	1320	2	19	266	1090	438
	E 30	12.2	18	44	61	293	65	76	45	36	204	191	1	11	105	1	20	450	653	431
	E 50	8.8	48	47	228	275	147	86	79	77	535	233	1	10	384	1	16	220	2390	343
	E 60	9.3	10	103	1520	159	431	81	3750	218	717	184	1	13	354	2	17	390	475	362
	E 80	15.4	10	9	56	161	54	52	87	28	116	200	1	10	60	2	13	182	184	289
BUC 217	E 10	10.3	24	18	155	307	119	67	38	30	305	147	1	11	39	1	15	210	882	292
	E 30	11.8	31	46	162	358	160	101	1280	21	231	95	1	9	316	1	11	417	774	193
BUC 214	E 10	12.5	45	11	134	271	132	82	417	26	299	88	1	13	4600	2	17	177	524	307
	E 20	9.1	10	14	73	178	73	41	443	18	246	87	1	8	105	2	16	141	195	136
	E 30	12.0	39	21	133	253	119	63	1100	22	461	137	1	8	313	1	10	282	698	206

Table 7.4. Ash and trace element concentrations of the Collie coal, Western Australia.

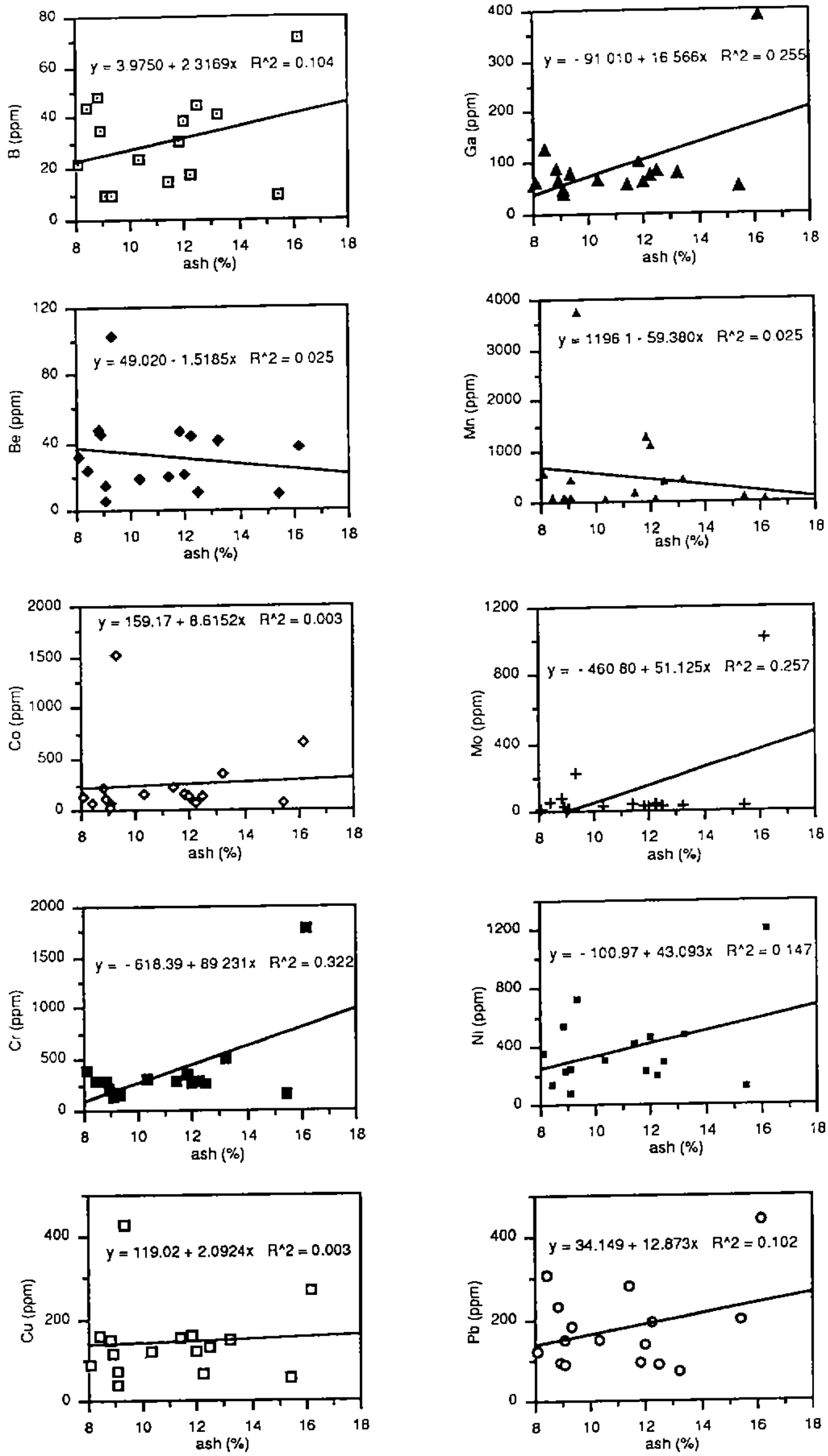


Figure 7.7.a. Relationship between ash (%) and trace element contents (ppm) of the Collie coal.

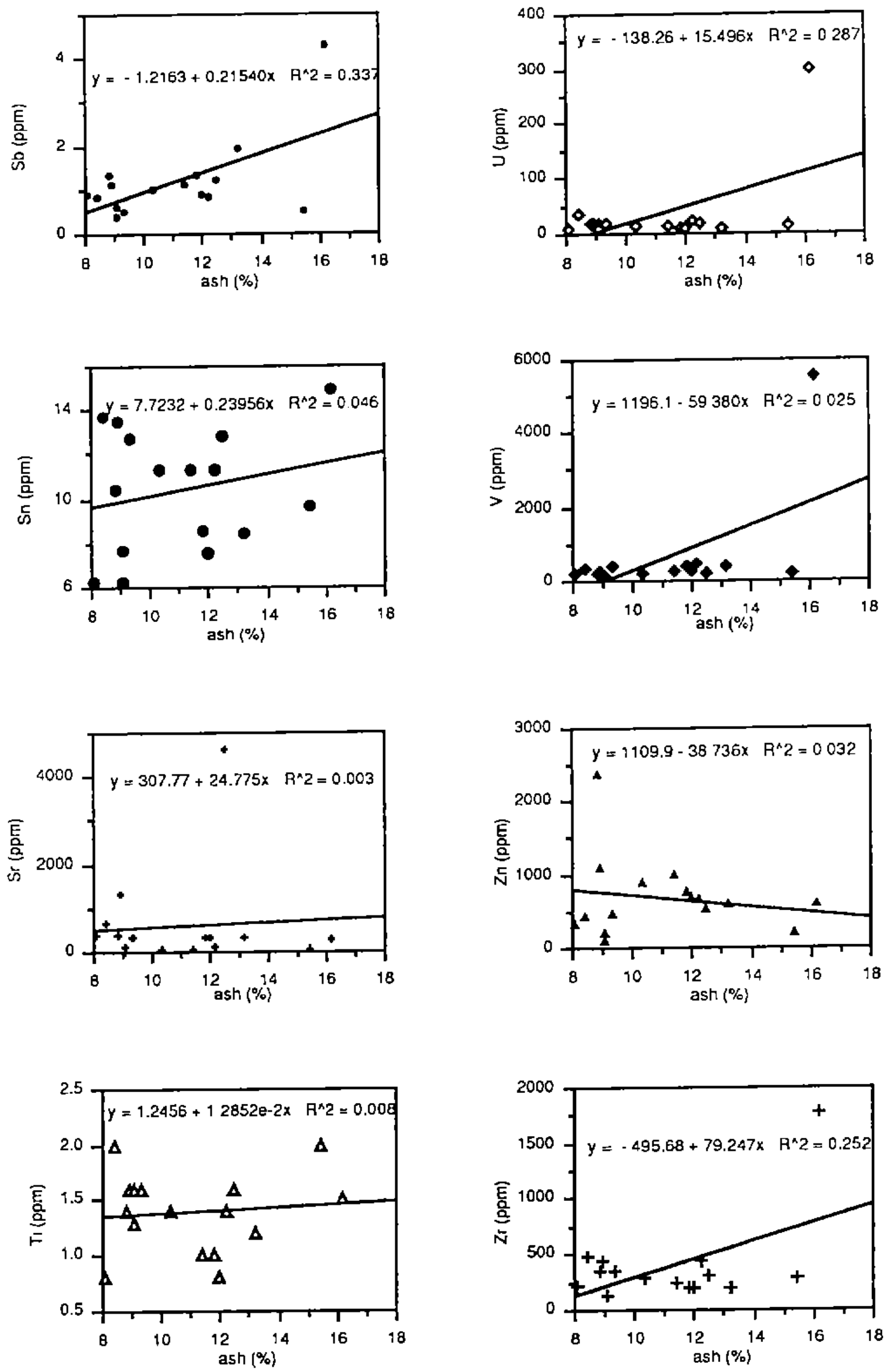


Figure 7.7.b. Relationship between ash (%) and trace element contents (ppm) of the Collie coal.

Boron (B)

The concentration of boron has a range between 10 ppm to 71 ppm in the coal (Table 7.4). Its correlation with ash content in the coal is illustrated in Figure 7.7.a, and it displays a weak positive correlation. This suggests that boron is mostly inorganically bound and to a lesser degree associated with the organic matter. The lower concentration of boron in the coal is indicative of the absence of marine influence during its deposition.

Beryllium (Be)

The beryllium content in the coal ranges from 5 ppm to 103 ppm. Figure 7.7.a depicts an almost no apparent correlation between the beryllium and ash contents in the coal, thus organic association of beryllium is presumably present mixed with inorganic association.

Cobalt (Co)

The range of cobalt content in the coal is between 21 ppm to 1520 ppm (Table 7.4). No apparent correlation occurs between cobalt and ash contents in the coal, as depicted in Figure 7.7.a. This indicates that cobalt has an inorganic and organic associations in the coal.

Chromium (Cr)

The chromium concentration in the coal has a range of 125 ppm to 1780 ppm. This element in the coal has a predominant inorganic association, which is presented by a weak positive correlation between chromium and the ash contents in the coal (Figure 7.7.a), however, less significant organic affinity is probably present in the coal.

Copper (Cu)

The range of copper concentration in the coal is between 38 ppm to 431 ppm (Table 7.4). It is significantly associated with inorganic and organic matter in the coal due to the lack of correlation between the ash content and the trace element (Figure 7.7.a).

Gallium (Ga)

The gallium concentration has a range of 41 ppm to 385 ppm in the coal (Table 7.4). It has a weak positive correlation between the gallium and ash contents (Figure 7.7.a), and this means that the gallium is predominantly present as an inorganic association, however, a less significant organic affinity may occur in the coal.

Manganese (Mn)

The manganese distribution in the coal varies from 38 ppm to 3750 ppm (Table 7.4). A weak negative correlation between the manganese and ash contents in the coal is illustrated in Figure 7.7.a, and it represents a predominant organic association of manganese in the coal, and probably some inorganic affinity also occurs.

Molybdenum (Mo)

The concentration of molybdenum in the coal has a range between 10 ppm to 1020 ppm. This element is predominantly associated with inorganic matter in the coal, which is represented by the weak positive correlation between the molybdenum and ash contents in the coal (Figure 7.7.a). However, a minor amount of molybdenum is probably organically bound in the coal.

Nickel (Ni)

The nickel content in the coal ranges between 71 ppm to 1200 ppm (Table 7.4). Figure 7.7.a depicts a weak positive correlation between the nickel and ash contents in the coal, and this means that the nickel is inorganically bound in the coal and to a lesser degree it has an organic association.

Lead (Pb)

The range of lead concentration in the coal is between 69 ppm to 442 ppm, as given in Table 7.4. It has predominantly an inorganic association in the coal, and to a lesser extent organic association due to a weak positive correlation between the lead and ash contents in the coal, as presented in Figure 7.7.a.

Antimony (Sb)

The antimony content has a range of 0 ppm to 4 ppm in the coal (Table 7.4). A weak positive correlation exists between the antimony and ash contents in the coal, as depicted in Figure 7.7.b, and therefore, the antimony is mostly associated with inorganic components in the coal, and possibly some organic affinity is also present.

Tin (Sn)

The distribution of tin in the coal varies between 6 ppm to 15 ppm, as shown in Table 7.4. An almost no apparent correlation occurs between the tin and ash contents (Figure 7.7.b), and this indicates the presence of inorganic and organic associations.

Strontium (Sr)

The contents range from 13 ppm to 4600 ppm in the coal. An almost no apparent correlation exists between the strontium and ash contents as depicted in Figure 7.7.b, and this suggests that strontium has inorganic and organic affinities in the coal.

Titanium (Ti)

The range of titanium content in the coal varies between 1 ppm to 2 ppm (Table 7.4). The relationship between the titanium and ash contents in the coal shows an almost no apparent correlation similar to strontium (Figure 7.7.b), which leads to the occurrence of inorganic and organic associations in the coal.

Uranium (U)

The uranium content in the coal has a range between 7 ppm to 300 ppm. The concentration shows a weak positive correlation between the uranium and ash contents in the coal (Figure 7.7.b), and thus, although the uranium is dominated by inorganic association, organic affinity to some degree is also present in the coal.

Vanadium (V)

The range of vanadium concentration in the coal is between 136 ppm to 5570 ppm (Table 7.4). The relationship between the vanadium and ash content in the coal is shown in Figure 7.7.b, and a weak positive correlation is present to indicate a dominant inorganic association in the coal.

Zinc (Zn)

The zinc content in the coal has a range between 107 ppm to 2390 ppm. This element displays a weak negative correlation with ash content in the coal (Figure 7.7.b), and this means that zinc has an organic affinity in the coal, with some inorganic association.

Zirconium (Zr)

The concentration of zirconium in the coal has a range of 136 ppm to 1790 ppm (Table 7.4). This element has a predominant inorganic association in the coal, mixed with probable organic affinity, according to the occurrence of a weak positive correlation between the zirconium and ash contents in the coal (Figure 7.7.b).

On the basis of the distribution of trace elements in the coal as described above, the elements of B, Cr, Ga, Mo, Ni, Pb, Sb, U, V and Zr occur predominantly in inorganic association, and are part of the mineral matter in the coal. The Mn and Zn in the coal have organic affinity, which points to the fact that these elements are inherent in the flora which provided the vegetable matter for the formation of coal. The Be, Co, Cu, Sn, Sr and Ti are present in both organic and inorganic associations.

7.4.3. Proximate Analysis

The proximate analysis of the Collie coal shown in Table 7.5 includes moisture content, ash content, volatile matter, fixed carbon and specific energy on as received values (ar), and the data are taken from Le Blanc Smith (1993). The moisture content is between 14.6% to 19.9%, ash content between 4.3% to 10.2%, volatile matter between 22.4% to 26.3%, fixed carbon between 49.0% to 52.9% and specific energy between 21.1 MJ/kg to 23.2 MJ/kg.

7.4.4. Ultimate Analysis

Table 7.6 gives ultimate analysis of the coal, and the elements analysed consist of carbon, hydrogen, oxygen, nitrogen and sulphur on dmmf and daf values. The ultimate analysis data like the proximate analysis data, are also obtained from Le Blanc Smith (1993). The carbon concentration (dmmf) has a range between 77.7% to 79.5%, hydrogen content makes up 3.9% to 4.2% (dmmf) and the oxygen content varies from 14.6% to 16.8% (daf) in the coal. The nitrogen content ranges between 1.2% to 1.5% (daf) and the sulphur content is between 0.2% to 1.0% (daf). The lower concentration of the sulphur in the coal, Hunt (1984), is indicative of the absence of marine influence during its deposition.

7.4.5. Coal Rank and Classification

The rank of coal based on moisture content, volatile matter and specific energy is depicted respectively in Figures 7.3, 7.4 and 7.5 (pages 279, 280 and 281, respectively). Based on the moisture content, the rank is classified as sub-bituminous of the Australian rank or sub-bituminous A to B to

SEAMS	ASH %	MOISTURE %	VOLATILE MATTER %	FIXED CARBON %	SPECIFIC ENERGY (MJ/kg)
	ar	ar	ar	ar	ar
Ewington 1	5.8	18.8 (20.0)	25.6 (34.0)	49.8	22.7 (30.1)
Ewington 2	10.2	19.9 (22.2)	22.9 (32.8)	49.0	21.1 (30.2)
Moira	6.5	19.7 (21.1)	24.0 (32.5)	49.8	22.1 (29.9)
Stockton	10.1	14.6 (16.2)	22.4 (29.7)	52.9	22.6 (30.1)
Wallsend	4.3	17.4 (18.2)	26.3 (33.6)	50.4	23.2 (29.6)

Table 7.5. Proximate analysis of the Collie coal (dry ash free values in brackets).

SEAMS	CARBON %	HYDROGEN %	OXYGEN %	NITROGEN %	SULPHUR %
	dmmf	dmmf	daf	daf	daf
Ewington 1	78.1	4.0	15.4	1.5	1.0
Ewington 2	78.0	3.9	15.9	1.4	0.8
Moira	77.8	4.0	16.8	1.2	0.2
Stockton	79.5	3.9	14.6	1.5	0.5
Wallsend	77.7	4.2	16.3	1.4	0.4

Table 7.6. Ultimate analysis of the Collie coal (dry ash free and dry mineral matter free values).

high volatile bituminous of the ASTM standard, which is in accordance with that of reflectance of vitrinite described in Chapter 4 (page 186). The rank determined on volatile matter content is categorized as high to medium volatile bituminous of both the Australian and ASTM ranks, and this does not correspond to the rank based on reflectance of vitrinite of the coal as described in Chapter 4. Similar to the Vasse Shelf coal, the difference is due to the relatively high inertinite content in the coal, which leads to a decrease of the amount of volatile matter, Kroeger and Pohl (1957). On the basis of specific energy, the coal is high volatile bituminous according to both the Australian and ASTM classifications. This classification based on this parameter cannot be used as a precise rank parameter of the coal, because it is not in agreement with the vitrinite reflectance basis described in Chapter 4. The difference is due to the high mineral matter which decreases the value of specific energy in the coal. The coal is classified as sub-hydrous, similar to the Vasse Shelf coal, on the basis of hydrogen and carbon contents (Figure 7.6, page 283).

The Collie coal on the basis of the above geochemical data has the following characters:

. The elements of B, Cr, Ga, Mo, Ni, Pb, Sb, U, V and Zr are present in inorganic association, whereas Mn and Zn occur in organic association in the coal. The Be, Co, Cu, Sn, Sr and Ti are present in both organic and inorganic associations.

. The rank of the coal on the basis of moisture content is categorized as sub-bituminous of the Australian classification or sub-bituminous A to B to high volatile bituminous of the ASTM standard, which is in agreement with that of vitrinite reflectance basis. On the basis of hydrogen and carbon contents (dmmf), the coal is classified as sub-hydrous, similar to the Vasse Shelf coal.

7.5. The Irwin River Coal

The proximate and ultimate analyses of the coal from the drill hole IRCH 1 are discussed below. The analyses data obtained from CRAE (1986) do not correspond to the seam analysed petrographically, and the data are used to establish the rank of the coal.

7.5.1. Proximate Analysis

The proximate analysis of the coal shown in Table 7.7 includes ash content, moisture content, volatile matter, fixed carbon and specific energy on air dried basis (adb). The ash content has a range between 11.2% to 30.6%, moisture content varies from 10.3% to 25.1% and the volatile matter ranges between 24.4% to 33.9%. The fixed carbon varies between 34.7% to 46.6% and the specific energy is between 16.4 MJ/kg to 21.7 MJ/kg.

7.5.2. Ultimate Analysis

Table 7.8 shows ultimate analysis of the coal, and the elements analysed comprise carbon, hydrogen, oxygen, nitrogen and sulphur (adb). The carbon concentration ranges from 42.7% to 55.5%, hydrogen content varies between 2.8% to 3.4% and the oxygen content is between 12.0% to 15.1%. The nitrogen content has a range of 1.1% to 1.4% and the sulphur content is between 0.5% to 2.8%. The higher concentration of the sulphur in the coal, Hunt (1984), is indicative of the presence of marine influence during its deposition.

SEAMS	ASH % adb	MOISTURE % adb	VOLATILE MATTER % adb	FIXED CARBON % adb	SPECIFIC ENERGY (MJ/kg) adb
A	14.4	18.1 (21.1)	33.9 (50.2)	39.0	20.8 (30.8)
B	15.5	15.7 (18.6)	32.8 (47.7)	38.9	20.3 (29.5)
C	30.6	10.3 (14.8)	24.4 (41.3)	34.7	16.4 (27.7)
D	11.2	25.1 (28.3)	28.2 (44.3)	46.6	21.7 (34.1)
E	12.7	23.2 (26.6)	28.4 (44.3)	45.8	21.5 (33.5)

Table 7.7. Proximate analysis of the Irwin River coal (dry ash free values in brackets).

SEAMS	CARBON % adb	HYDROGEN % adb	OXYGEN % adb	NITROGEN % adb	SULPHUR % adb
A	52.6 (79.6)	3.4 (5.1)	12.8	1.4	2.8
B	51.6 (76.8)	3.3 (4.9)	15.1	1.4	0.5
C	42.7 (76.3)	2.8 (5.4)	12.0	1.1	0.5
D	55.5 (88.7)	3.2 (5.1)	14.2	1.4	0.6
E	55.2 (87.9)	3.4 (5.4)	13.8	1.4	0.5

Table 7.8. Ultimate analysis of the Irwin River coal (dry mineral matter free values in brackets).

7.5.3. Coal Rank and Classification

On the basis of moisture content, volatile matter and specific energy, the rank of the coal is depicted respectively in Figures 7.3, 7.4 and 7.5 (pages 279, 280 and 281, respectively). The rank determined on moisture content is classified as sub-bituminous of the Australian classification or sub-bituminous A to B of the ASTM standard, which is in agreement with that of reflectance of vitrinite described in Chapter 4 (page 214). Based on the volatile matter content, the rank is classified as sub-bituminous to high volatile bituminous of the Australian classification or sub-bituminous B to high volatile bituminous of the ASTM standard, and this does not correspond to the rank based on reflectance of vitrinite of the coal as described in Chapter 4. Similar to the Vasse Shelf and Collie coals, the difference is due to the relatively high inertinite content in the coal, which leads to a decrease of the amount of volatile matter, Kroeger and Pohl (1957). On the basis of specific energy, the coal is sub-bituminous to high volatile bituminous according to the Australian classification or sub-bituminous A to high volatile bituminous of the ASTM standard. This classification based on this parameter cannot be used as a precise rank parameter of the coal, because it is not in accordance with the vitrinite reflectance basis described in Chapter 4, due to the high mineral matter content which decreases the value of specific energy in the coal. The classification of the coal in the Seyler chart is sub-hydrous to per-hydrous in the bright coal band (Figure 7.6, page 283).

CHAPTER 8. DEPOSITIONAL ENVIRONMENT

8.1. Introduction

The petrographic data are used to interpret depositional environment of the coal. The depositional environment for the coal from the Vasse Shelf is more detailed in comparison to the Collie and Irwin River coals due to the availability of particulate samples only of the latter two, and lack of the Irwin River coal samples for trace element analyses.

8.2. The Vasse Shelf Coal

The depositional environment of the Vasse Shelf coal is interpreted on the basis of lithotypes, macerals, microlithotypes analyses and the trace elements distribution.

8.2.1. Lithotypes

For the Vasse Shelf coal, the lithotype analyses were completed on the seams A to P of drill holes RBCH 5, RBCH 6, RB 3, CRCH 1 and CRCH 2. The dominant lithotypes are dull and dull banded, followed by bright banded and banded, with minor bright lithotypes. This indicates predominance of wet conditions over relatively dry conditions during the deposition of the coal.

The depositional environment of the seam L from the drill hole CRCH 1 is given in Figure 8.1. The coal shows an abundance of the dull and dull banded lithotypes, with minor bright and bright banded lithotypes. There is a transition of bright banded type upward into dull banded type for the

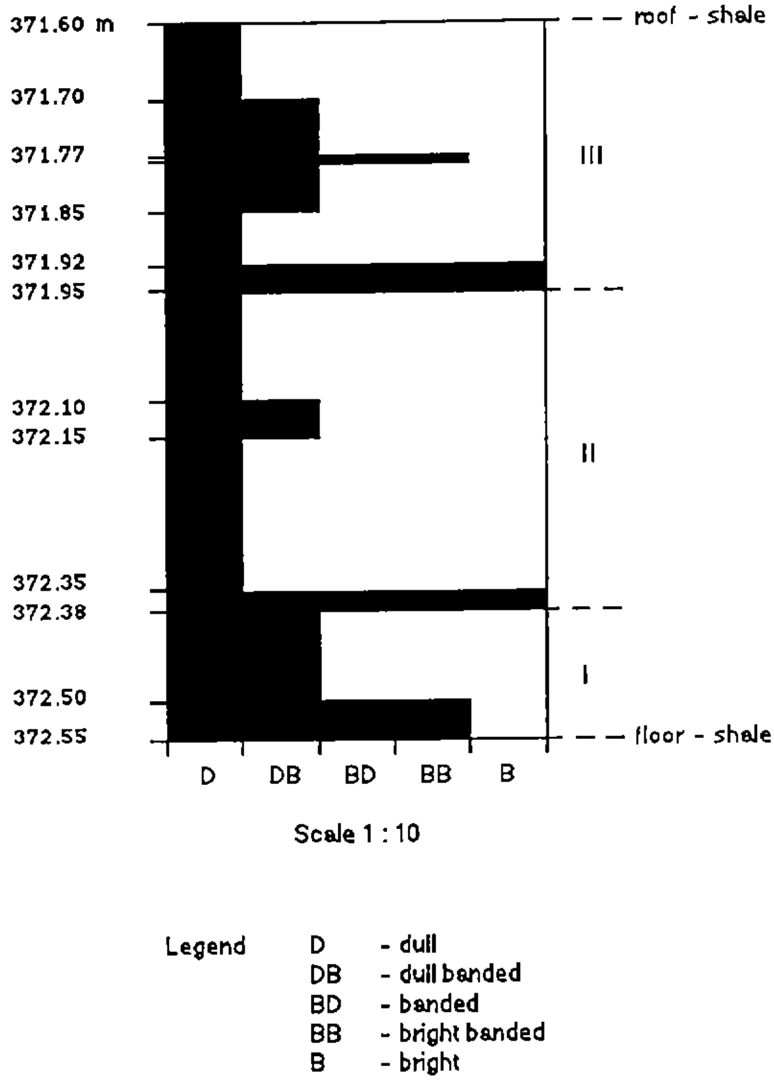


Figure 8.1. Lithotype profile of seam L, CRCH 1, Vasse Shelf, Western Australia.

interval 372.55 m to 372.38 m, reflecting a transition of wet swamp (bright banded lithotype) to open water (dull banded lithotype). A similar trend from wet swamp to open water is repeated three times in the seam. The variation in the depositional environment of the coal is also present in other seams of the shelf as presented in Appendix I.2.

8.2.2. Macerals

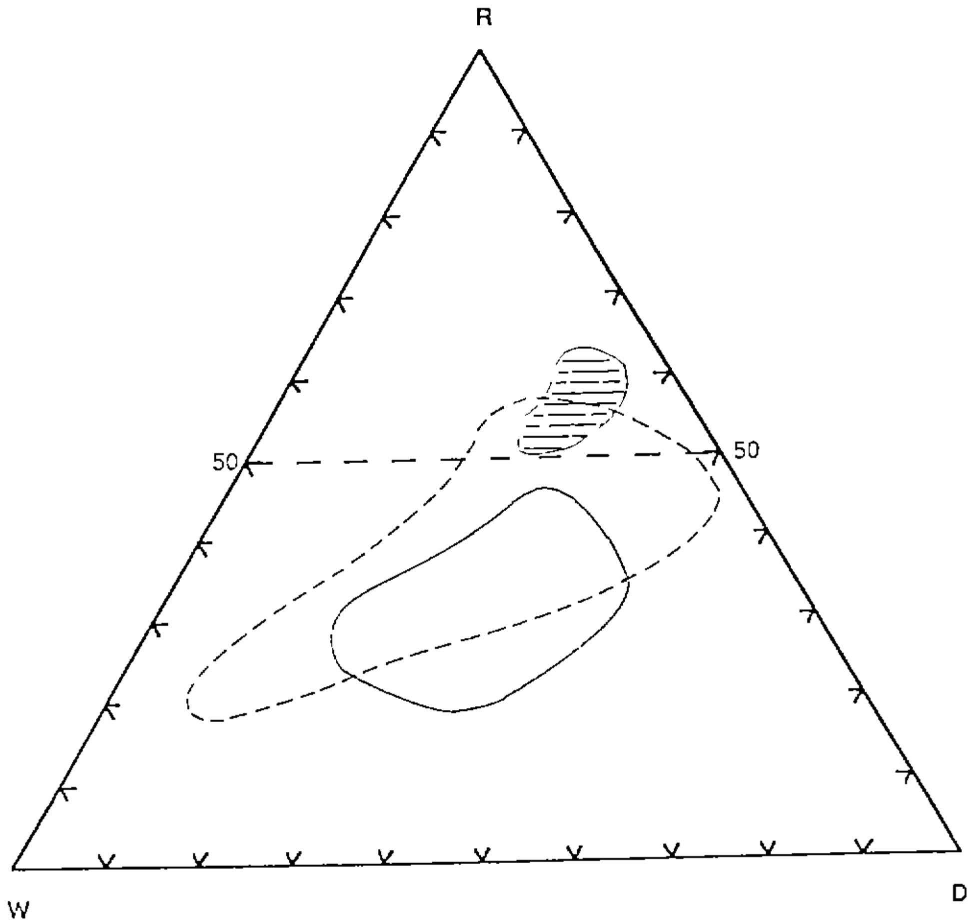
The interpretation of the depositional environment of the coal on the basis of maceral analyses, uses models proposed by Diessel (1982 a, 1986), modified by Lamberson, Bustin and Kalkreuth (1991).

The maceral compositions of the seams from the five drill holes are plotted onto the DWR and DTF ternary diagrams as shown in Tables 8.1, 8.2 and 8.3, and depicted in Figures 8.2 and 8.3. The construction of the diagrams is explained in Chapter 3. The DWR (Table 8.1 and Figure 8.2) shows that five of the seams from the drill holes RBCH 5 (D, H and J) and CRCH 2 (M and O) contain less than 50% diagnostic macerals, supporting the deposition in a mixed environment without a strong tendency towards either forest moor or limnic conditions. These five seams do not require investigation in the DTF diagram. Rest of the seams are plotted on the DTF diagram (Figure 8.3).

Tables 8.2 and 8.3 and Figure 8.3 show that twenty one seams from the drill holes RBCH 5 (all the seams, except E), RBCH 6 (A, B and K), CRCH 1 (A, C, E and M) and CRCH 2 (all the seams, except N) contain less than 1 (T+F)/D ratios, indicating the deposition in an open moor. Rest of the seams are plotted on the (T+F)/D ratios of greater than 1, supporting the deposition in forest moors. In addition, all the seams of the RB 3 (A to I) and five

DRILL HOLES	SEAMS	D(dispersed) % (alginite, sporinite, inertodetrinite)	W(woody) % (telinite, telocollinite, semifusinite, fusinite)	R(remainder) % (other macerals)
RBCH 5	A	36.1	18.5	45.4
	B	29.9	22.5	47.6
	C	35.5	20.7	43.8
	D	28.8	18.8	52.4
	E	31.8	29.5	38.7
	F	35.5	26.7	37.9
	G	32.4	23.2	44.4
	H	44.6	4.0	51.4
	I	37.8	16.0	46.2
	J	28.8	19.2	52.0
RBCH 6	A	36.0	22.7	41.3
	B	31.8	23.2	45.0
	G	25.4	25.6	49.0
	K	35.0	17.2	47.8
RB 3	A	20.2	53.8	26.0
	B	22.8	47.6	29.6
	C	25.7	46.1	28.2
	D	20.0	48.2	31.8
	E	30.4	41.3	28.3
	F	26.4	37.4	36.2
	G	27.4	38.9	33.7
	H	24.6	46.4	29.0
	I	28.0	42.3	29.8
CRCH 1	A	34.2	30.6	35.2
	B	28.0	33.4	38.6
	C	46.2	16.8	37.0
	D	30.0	40.8	29.2
	E	38.4	33.0	28.6
	F	25.7	46.4	27.9
	G	24.4	51.1	24.5
	H	18.7	50.7	30.5
	I	16.4	54.9	28.7
	J	38.2	36.7	25.1
	K	12.4	66.8	20.8
	L	17.5	63.2	19.3
	M	42.0	26.8	31.2
CRCH 2	A	38.8	19.8	41.4
	J	52.0	5.2	42.8
	M	22.4	20.0	57.6
	N	30.8	29.8	39.4
	O	27.6	16.4	56.0
	P	41.4	16.9	41.7

Table 8.1. DWR-maceral composition (%) of the Vasse Shelf coal.



Legend: Vasse Shelf coal (42 samples)
Collie coal (27 samples)
Irwin River coal (7 samples)

D : alginite, sporinite and inertodetrinite
W : telinite, telocollinite, semifusinite and fusinite
R : remaining macerals (principally desmocollinite)

Figure 8.2. Maceral composition of the Vasse Shelf, Collie and the Irwin River coals, plotted on a facies diagram (DWR).

DRILL HOLES	SEAMS	D % (alginite, sporinite, inertodetrinite)	T % (telinite, telocollinite)	F % (fusinite, semifusinite)
RBCH 5	A	66.1	12.1	21.8
	B	57.1	18.3	24.6
	C	63.2	21.4	15.5
	D	60.5	24.4	15.1
	E	51.9	21.4	26.8
	F	57.1	20.7	22.2
	G	58.3	29.5	12.2
	H	91.8	3.3	4.9
	I	70.3	22.7	7.1
	J	60.0	20.8	19.2
RBCH 6	A	61.3	25.6	13.1
	B	57.8	15.6	26.6
	G	49.8	12.6	37.7
	K	67.1	7.3	25.7
RB 3	A	27.3	27.0	45.7
	B	32.4	25.9	41.8
	C	35.8	18.9	45.3
	D	29.3	30.5	40.2
	E	42.4	22.6	35.0
	F	41.4	19.1	39.5
	G	41.4	20.3	38.3
	H	34.7	22.0	43.4
	I	39.9	22.6	37.5
CRCH 1	A	52.8	23.2	24.1
	B	45.6	23.1	31.3
	C	73.3	16.5	10.2
	D	42.4	31.6	26.0
	E	53.8	23.5	22.7
	F	35.7	43.1	21.2
	G	32.3	27.7	40.0
	H	27.0	31.8	41.3
	I	23.0	47.8	29.2
	J	50.9	26.7	22.3
	K	15.7	47.7	36.6
	L	21.7	38.0	40.3
	M	61.1	8.4	30.5
CRCH 2	A	66.2	13.0	20.8
	J	90.9	4.6	4.6
	M	52.8	38.7	8.5
	N	50.8	25.7	23.4
	O	62.7	12.7	24.5
	P	71.0	5.5	23.5

Table 8.2. DTF-maceral composition (%) of the Vasse Shelf coal.

DRILL HOLES	SEAMS	T/F	(T+F)/D	GI	TPI
RBCH 5	A	0.6	0.5	0.9	0.3
	B	0.7	0.8	1.0	0.4
	C	1.4	0.2	1.0	0.4
	D	1.6	0.7	1.4	0.4
	E	0.8	1.0	0.9	0.6
	F	0.9	0.8	0.9	0.5
	G	2.4	0.7	1.3	0.4
	H	0.7	0.1	0.9	0.1
	I	3.2	0.4	1.1	0.2
	J	1.1	0.7	1.2	0.3
RBCH 6	A	2.0	0.6	1.0	0.4
	B	0.6	0.8	1.0	0.4
	G	0.3	1.0	1.1	0.5
	K	0.3	0.5	0.8	0.3
RB 3	A	0.6	3.0	0.8	1.8
	B	0.6	2.5	0.9	1.3
	C	0.4	2.1	0.7	1.3
	D	0.8	3.4	1.2	1.5
	E	0.7	1.6	0.6	1.0
	F	0.5	1.6	0.9	1.0
	G	0.5	1.6	0.8	1.0
	H	0.5	1.9	0.7	1.3
	I	0.6	1.6	0.7	1.1
CRCH 1	A	1.0	0.9	0.9	0.6
	B	0.7	1.2	0.9	0.7
	C	1.6	0.4	0.7	0.3
	D	1.2	1.4	0.9	1.1
	E	1.0	0.9	0.7	0.7
	F	2.0	2.2	1.5	1.5
	G	0.7	2.0	0.7	1.4
	H	0.8	2.9	1.0	1.5
	I	1.6	3.4	1.6	1.9
	J	1.2	1.1	0.8	0.8
	K	1.3	5.6	1.5	3.1
	L	0.9	3.5	0.9	2.5
	M	0.3	0.6	0.4	0.5
CRCH 2	A	0.6	0.6	1.0	0.3
	J	1.0	0.1	0.7	0.1
	M	4.6	0.9	4.3	0.4
	N	1.1	1.0	1.0	0.6
	O	0.5	0.6	1.2	0.3
	P	0.2	0.4	0.6	0.2

T/F = Telinite+Telocollinite/Semifusinite+Fusinite

(T+F)/D = Telinite+Telocollinite+Semifusinite+Fusinite/Inertodetrinite+Sporinite+Alginite

GI = Vitrinite+Macrinite/Semifusinite+Fusinite+Inertodetrinite

TPI = Telinite+Telocollinite+Semifusinite+Fusinite/Desmocollinite+Macrinite+Inertodetrinite

Table 8.3. Petrographic indices of the Vasse Shelf coal.

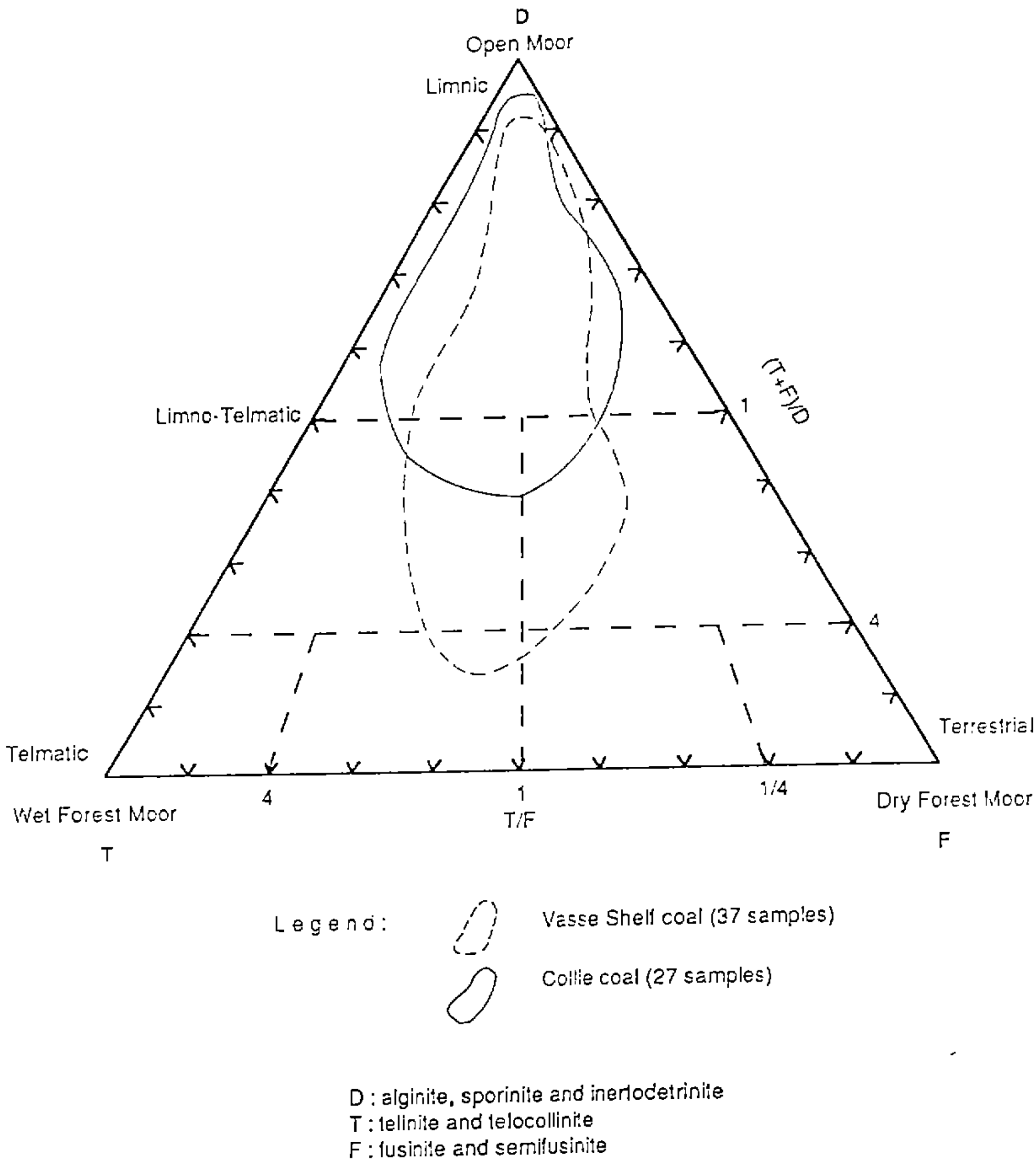


Figure 8.3. Maceral composition of the Vasse Shelf and Collie coals, plotted on a facies diagram (DTF). Note: The Irwin River coal contains less than 50% diagnostic macerals, thence no DTF plot.

seams of the CRCH 1 (B, G, H, L and M) have the T/F ratio of less than 1, suggesting the deposition in relatively dry forest moor conditions. The five seams of CRCH 1 (D, F, I, J and K) have the T/F ratio of greater than 1, suggesting the deposition in relatively wet forest conditions.

In summary, the conditions for the deposition of the coal interpreted from the DWR and DTF ternary diagrams are of a mixed coal-forming environment without a strong tendency towards either forest moor or limnic conditions.

Figure 8.4 and Table 8.3 show maceral compositions plotted on the TPI and GI diagram of Diessel (1986), modified by Lamberson, Bustin and Kalkreuth (1991). Thirteen of the seams from the drill holes RBCH 5 (A, E, F and H), RBCH 6 (K), CRCH 1 (A, B, C, E, J and M) and CRCH 2 (J and P), plot close together and are characterized by less than 1 TPI and GI values. The maceral content of the coal is dominated by inertinite over vitrinite and inertodetrinite over structured inertinite. These seams represent deposition in an open marsh swamp.

Thirteen seams of the drill holes RBCH 5 (B, C, D, G, I and J), RBCH 6 (A, B and G) and CRCH 2 (A, M, N and O), plot in the field of clastic marsh with limited influx, as these are characterized by high GI (>1) but low TPI (<1). These seams are characterized by the predominance of vitrinite over inertinite and degraded vitrinite over structured vitrinite.

Five seams of the drill holes RB 3 (D) and CRCH 1 (F, H, I and K) plot in the wet forest swamp having high TPI and GI values of greater than 1, and characterized by the predominance of vitrinite over inertinite and structured vitrinite over degraded vitrinite.

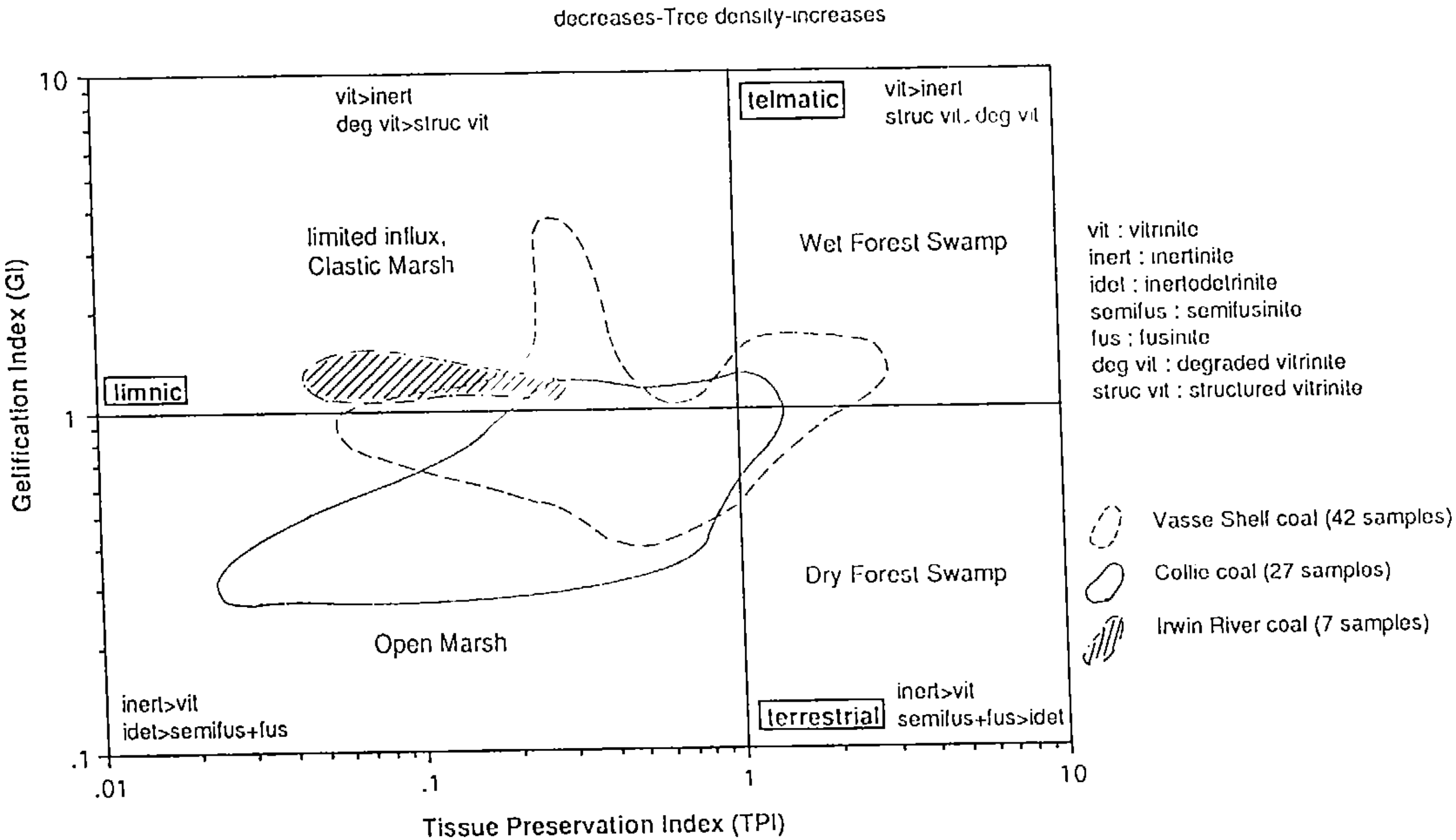


Figure 8.4. TPI and GI facies diagram of the Vasse Shelf, Collie and the Irwin River coals.

Eleven seams of the drill holes RB 3 (all the seams, except D) and CRCH 1 (D, G and L) plot in the dry forest swamp, being characterized by high TPI (>1) but low GI values (<1). The maceral content is dominated by the inertinite over vitrinite and structured inertinite over inertodetrinite. In summary, the Vasse Shelf coal was deposited in an open and clastic marsh with limited influx, and also in dry and wet forest swamps.

8.2.3. Microlithotypes

The microlithotype analyses and 'bandwidth' of the microlithotypes of the coal are used on ternary diagrams of Hunt and Hobday (1984) and Smyth (1979, 1989) to interpret depositional environment.

Figure 8.5 shows that the 'bandwidths' are located in the medium banded zone, followed by finely banded zone and the coarsely banded zone. Thus, the distribution pattern of 'bandwidth' curves supports that the coal was deposited in a braided fluvial to upper delta environment.

In Figure 8.6, microlithotype composition of the coal from the drill holes RBCH 5 (A to J), RBCH 6 (A, B, G and K), RB 3 (A to I), CRCH 1 (A to M) and CRCH 2 (A, J, M, N, O and P) is plotted on the ternary diagram of Smyth (1979, 1989). The microlithotype compositions of the coal in the figure occupy A, B, D and E areas supporting the interpretation that the depositional environment for the coal was fluvial, lacustrine to deltaic without any brackish or marine influence, due to the absence of plots in the area C of the diagram.

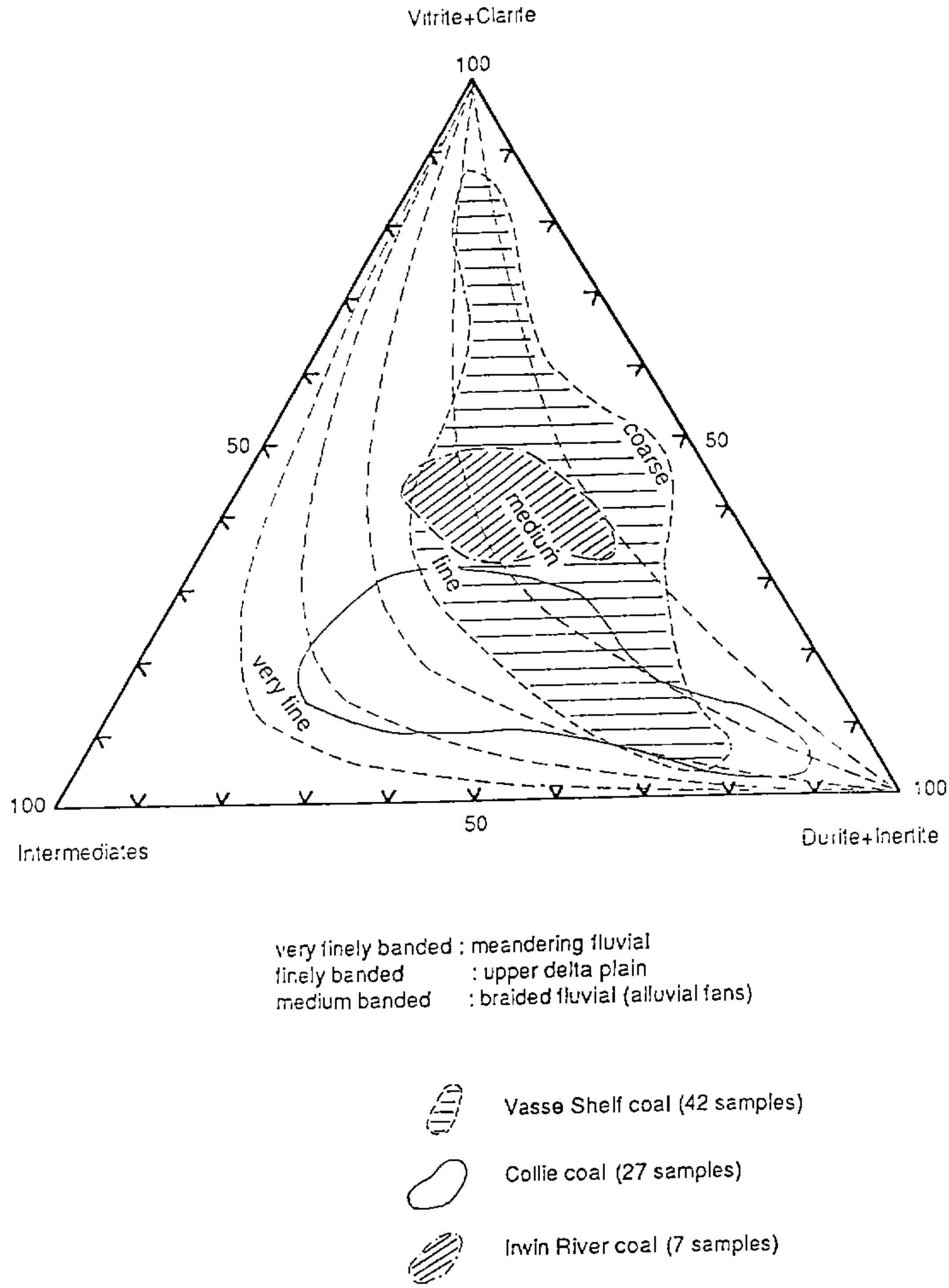


Figure 8.5. Bandwidth curves of microlithotype facies of the Vasse Shelf, Collie and the Irwin River coals.

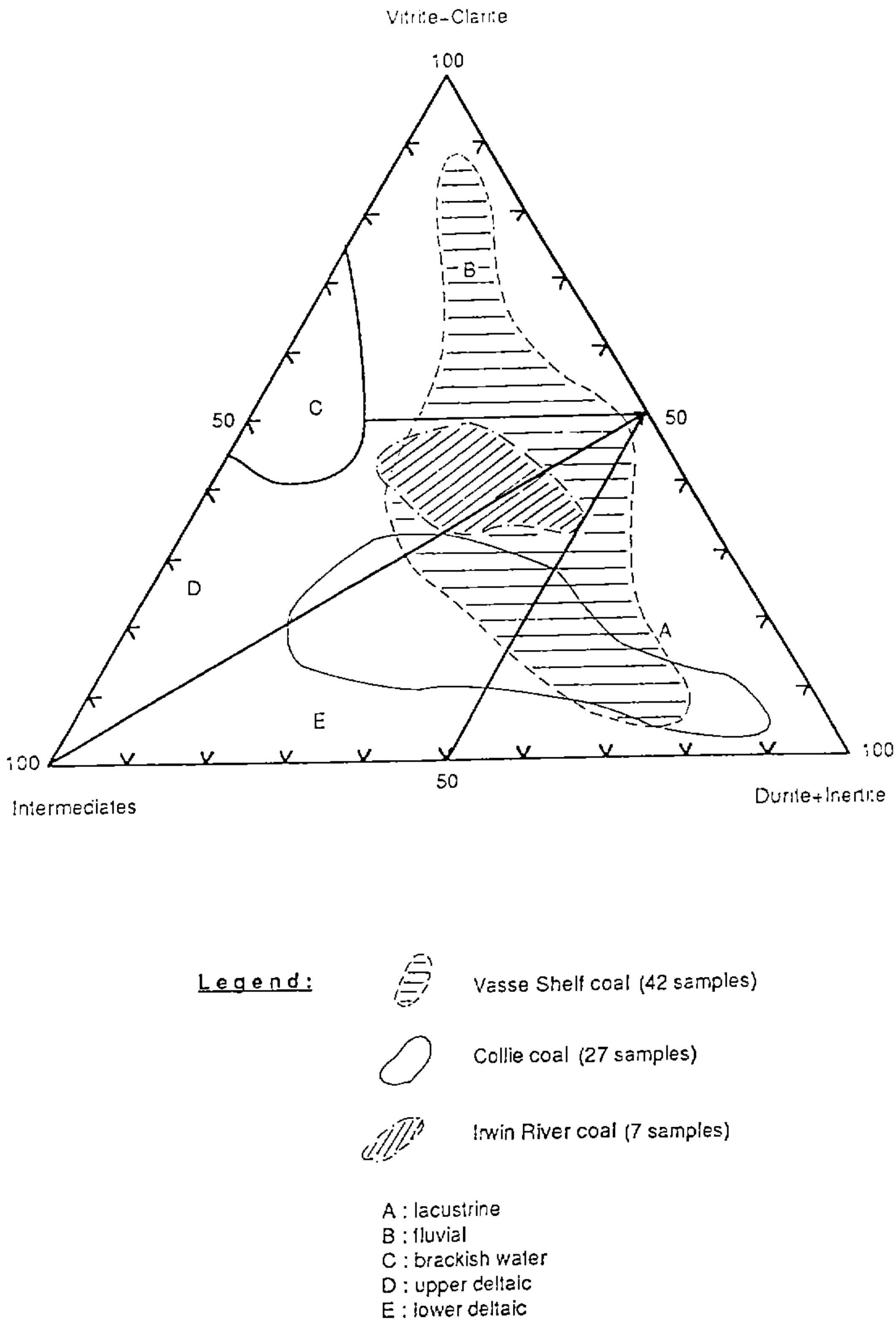


Figure 8.6. Depositional environment related to microlithotype composition of the Vasse Shelf, Collie and the Irwin River coals.

8.2.4. Trace Elements

As mentioned in the chapter 7 that thirteen coal samples from the seams A, B and G were analysed for trace elements. The trace elements analysed are B, Be, Co, Cr, Cu, Ga, Ge, Mn, Mo, Ni, Pb, Sb, Sn, Sr, Ti, U, V, Zn and Zr.

The trace elements are associated with the inorganic matter, being present within mineral structures or adsorbed onto the surface of minerals in the coal or associated with organic entities of the coal forming flora.

According to Rimmer and Davis (1986) and Rimmer (1991), Cr, Cu and V commonly found in aluminosilicate minerals suggest that these trace elements are distributed in the influx of clay-rich sediment along the basin margins or are formed in the fresh water environments along the basin margins. Zr is transported into the peat swamp with detrital quartz and clays. Smyth (1966) suggested that Mn is transported into the swamp in association with clays. Mukherjee *et al.* (1992) indicated that Cu, Cr, V, Ni, B and Ga are associated with a high influx of fresh water or fluvio-lacustrine Lower Gondwana coals of India. Bouska (1981) stated that Pb, Zn, Cu and Ni are formed in a reducing environment and Ge is predominantly restricted to the limnic basins. Lyons *et al.* (1989) suggested that coal having a boron content ranging between 400 ppm to 450 ppm indicates marine-influenced environment, whereas a boron concentration varying from 10 ppm to 50 ppm accumulates in fresh-water environment, as outlined by Degens (1965).

The trace elements helpful as indicators of depositional environment in the coal, consist of B, Cr, Cu, Ga, Ge, Mn, Ni, Pb, V, Zn and Zr. The shelf seams containing these trace elements are interpreted to have been deposited in the peat swamp of fluvio-lacustrine environment in association with clays, pyrite and quartz. In addition, on the basis of boron content (43 ppm to 141 ppm), the coal is interpreted to have accumulated in a fresh-water environment.

8.2.5. Sedimentary Structures

Interpretation of the depositional environment of the Vasse Shelf coal on the basis of sedimentary structures from the drill hole RBCH 5 is described earlier in Chapter 2 (page 16). The presence of the sedimentary structures like massive, parallel and cross laminations in the sequence indicates that the sediments were deposited in the point bars of a meandering fluvial environment (Kristensen and Wilson, 1986).

In summary, the depositional environment of the Vasse Shelf coal, on the basis of lithotypes, macerals, microlithotypes, trace elements and the sedimentary structures, is braided and meandering deltaic-river systems.

8.3. The Collie Coal

The depositional environment for the coal is interpreted on the basis of maceral and microlithotype analyses, and the distribution of trace elements.

8.3.1. Macerals

The maceral compositions of the coal for the five drill holes are plotted on the DWR, DTF and the TPI and GI diagrams , as given in Tables 8.4, 8.5 and 8.6, and illustrated in Figures 8.2, 8.3 and 8.4 (pages 305, 308 and

DRILL HOLES	SEAMS	D(dispersed) % (alginite, sporinite, inertodetrinite)	W(woody) % (telinite, telocollinite, semifusinite, fusinite)	R(remainder) % (other macerals)
BUC 213	E 50	37.5	33.3	29.2
	E 60	43.7	21.4	34.9
	E 70	40.7	18.6	40.7
	E 80	24.4	42.6	33.0
	E 90	41.1	30.2	28.7
BUC 215	E 9	52.4	19.2	28.4
	E 10	24.3	48.2	27.5
	E 15	46.5	25.3	28.3
	E 20	33.5	35.6	30.8
	E 30	32.2	30.5	37.3
	E 35	73.4	1.8	24.8
BUC 212	P 89	29.8	34.0	36.2
	P 90	27.9	43.3	28.8
	E 20	38.0	29.8	32.2
	E 30	31.3	36.7	32.0
	E 40	36.7	35.3	28.0
	E 50	36.8	25.0	38.2
	E 60	33.2	37.8	29.0
	E 80	50.1	28.1	21.8
BUC 217	E 10	42.4	38.4	19.2
	E 22	50.6	20.8	28.6
	E 25	46.4	27.4	26.2
	E 30	34.9	34.2	30.9
BUC 214	E 9	40.6	31.8	27.6
	E 10	27.6	43.8	28.6
	E 20	38.5	37.4	24.1
	E 22	30.7	38.4	30.9
	E 25	34.5	37.3	28.2
	E 30	33.0	37.2	29.8

Table 8.4. DWR-maceral composition (%) of the Collie coal.

DRILL HOLES	SEAMS	D % (alginite, sporinite, inertodetrinite)	T % (telinite, telocollinite)	F % (fusinite, semifusinite)
BUC 213	E 50	53.0	24.3	22.8
	E 60	67.1	21.4	11.5
	E 70	67.9	19.0	13.1
	E 80	36.5	33.3	30.2
	E 90	57.6	29.4	13.1
BUC 215	E 9	73.2	24.2	2.6
	E 10	33.5	32.7	33.8
	E 15	64.8	15.5	19.7
	E 20	48.5	28.8	22.7
	E 30	51.3	18.5	30.2
	E 35	97.7	1.5	0.9
BUC 212	P 89	46.7	28.5	24.8
	P 90	50.9	25.2	24.0
	E 20	56.0	26.9	17.0
	E 30	46.0	25.9	28.1
	E 40	51.0	31.9	17.1
	E 50	59.5	18.7	21.8
	E 60	46.8	31.4	21.9
	E 80	64.0	32.7	3.3
BUC 217	E 10	52.5	26.6	20.9
	E 22	70.9	11.4	17.7
	E 25	62.8	9.3	27.9
	E 30	50.5	22.4	27.2
BUC 214	E 9	55.5	25.7	18.8
	E 10	38.6	33.9	27.5
	E 20	50.7	17.0	32.3
	E 22	44.5	22.8	32.7
	E 25	48.1	23.5	28.4
	E 30	47.0	26.5	26.5

Table 8.5. DTF-maceral composition (%) of the Collie coal.

DRILL HOLES	SEAMS	T/F	(T+F)/D	GI	TPI
BUC 213	E50	1.1	0.9	0.9	0.6
	E60	1.9	0.5	1.0	0.3
	E70	1.4	0.5	1.1	0.3
	E80	1.1	1.9	1.2	0.9
	E90	2.3	0.7	1.0	0.6
BUC 215	E 9	9.2	0.4	1.0	0.3
	E10	1.0	2.0	1.0	1.4
	E15	0.8	0.5	0.5	0.4
	E20	1.3	1.1	1.0	0.6
	E30	0.6	0.9	0.8	0.6
	E35	1.7	0.1	0.3	0.1
BUC 212	E20	1.6	0.8	0.9	0.6
	E30	0.9	1.2	1.0	0.7
	E40	1.9	1.0	1.1	0.6
	E50	0.9	0.7	1.1	0.4
	E60	1.4	1.1	1.1	0.8
	E80	9.9	0.6	0.9	0.5
BUC 217	E10	1.3	0.9	0.6	0.8
	E22	0.6	0.4	0.5	0.3
	E25	0.3	0.6	0.3	0.5
	E30	0.8	1.0	0.8	0.7
BUC 214	E 9	1.4	0.8	0.8	0.6
	E10	1.2	1.6	0.9	1.1
	E20	0.5	1.0	0.5	0.7
	E22	0.7	1.3	0.7	0.9
	E25	0.8	1.1	0.7	0.7
	E30	1.0	1.1	0.9	1.0

T/F = Telinite+Telocollinite/Semifusinite+Fusinite
(T+F)/D = Telinite+Telocollinite+Semifusinite+Fusinite/Inertodetrinite+Sporinite+Alginite
GI = Vitrinite+Macrinite/Semifusinite+Fusinite+Inertodetrinite
TPI = Telinite+Telocollinite+Semifusinite+Fusinite/Desmocollinite+Macrinite+Inertodetrinite

Table 8.6. Petrographic indices of the Collie coal.

310, respectively).

The DWR diagram (Table 8.4 and Figure 8.2) shows that all the seams from the drill holes contain more than 50% diagnostic macerals, requiring investigation in the DTF diagram. Tables 8.5 and 8.6 and Figure 8.3 show that fifteen seams from all the drill holes have the (T+F)/D ratio of less than 1, supporting the deposition in an open moor environment. The twelve seams have the (T+F)/D ratio of greater than 1, indicating deposition in a forest moor. Additionally, five seams of the drill holes BUC 212 (E 30), BUC 217 (E 30) and BUC 214 (E 20, E 22 and E 25) contain the T/F ratio of less than 1, reflecting the deposition in the dry forest condition. On the other hand, seven seams (E 80 of BUC 213, E 10 and E 20 of BUC 215, E 40 and E 60 of BUC 212 and E 10 and E 30 of BUC 214) have the T/F ratio of greater than 1, suggesting the deposition in the wet forest moors.

Figure 8.4 and Table 8.6 show plots of the coal on the TPI and GI facies diagram. The fourteen seams from the drill holes are characterized by less than 1 TPI and GI values and these plot in the open marsh area of the diagram. The maceral content is dominated by inertinite over vitrinite and inertodetrinite over structured inertinite.

The ten seams of the drill holes BUC 213 (E 60, E 70, E 80 and E 90), BUC 215 (E 9 and E 20) and BUC 212 (E 30, E 40, E 50 and E 60), occupy the area of clastic marsh, as these are characterized by high GI (>1) but low TPI (<1). These seams are characterized by the predominance of vitrinite over inertinite and degraded vitrinite over structured vitrinite, supporting the deposition in a clastic marsh with limited influx of sediments.

One seam of the drill hole BUC 215 (E 10) plots in the wet forest swamp area, because it has high TPI and GI values (>1) and is characterized by the predominance of vitrinite over inertinite and structured vitrinite over degraded vitrinite.

One of the seams from BUC 214 (E 10) is the only coal seam plotting in the dry forest swamp, which is characterized by high TPI (>1) but low GI (<1). The maceral content is dominated by inertinite over vitrinite and structured inertinite over inertodetrinite. In summary, the coal was deposited in open, clastic, wet and dry forest swamp environments.

8.3.2. Microlithotypes

The interpretation of depositional environment of the coal based on microlithotype analysis is discussed by using ternary diagrams of Hunt and Hobday (1984) and Smyth (1979, 1989), similar to the Vasse Shelf coal. Figure 8.5 shows that the coal occupies the very fine to medium zones, and its precursor was deposited in a braided to meandering fluvial systems.

The microlithotype associations of the coal are also plotted on ternary diagram of Smyth (1979, 1989) as illustrated in Figure 8.6. In this diagram, most of the seams are mainly situated in the area A, followed by areas E and D, and therefore, the coal predominantly accumulated in lacustrine and upper to lower delta plain environments.

8.3.3. Trace Elements

The sixteen coal samples were selected from the seams E 10, E 20, E 30, E 50, E 60 and E 80 for the trace element analyses. The elements analysed were B, Be, Co, Cr, Cu, Ga, Ge, Mn, Mo, Ni, Pb, Sb, Sn, Sr, Ti, U, V, Zn, and

Zr, as mentioned earlier in chapter 7. The results of the trace elements analyses in the coal indicate that most of the trace elements have inorganic affinity and lesser affinity with the organic matter.

The trace elements helpful as indicators of depositional environment in the coal, include B, Cr, Cu, Ga, Mn, Ni, Pb, V, Zn and Zr, similar to the Vasse Shelf coal. The coals containing these trace elements are interpreted to have been formed in the peat swamp within fluvio-lacustrine environment in association with clays, pyrite and quartz. The lower boron content (10 ppm to 71 ppm) in the coal, like the Vasse Shelf coal, supports the absence of marine influence during the deposition.

In summary, the depositional environment of the coal on the basis of macerals, microlithotypes and trace elements distribution, is interpreted to be lacustrine, braided to meandering fluvial system, without the influence of marine influx.

8.4. The Irwin River Coal

Similar to the Vasse Shelf and Collie coals, the depositional environment for the Irwin River coal is interpreted based on the maceral and microlithotype analyses.

8.4.1. Macerals

The maceral analyses of the sub-seams G1 to G7 from the drill hole IRCH 1 are plotted on the DWR triangle (Table 8.7 and Figure 8.2). The figure shows that all the sub-seams occupy the upper field, as they contain less than 50% diagnostic macerals, and thus the sub-seams do not require further investigation in the DTF triangle. The coal was formed in a mixed coal forming environment without a strong tendency towards either forest moor or limnic conditions.

The maceral analyses data plotted on the TPI and GI diagram (Table 8.7 and Figure 8.4), show that sub-seams G1 to G7 occupy the field of clastic marsh, as these are characterized by high GI (>1) and low TPI (<1), predominance of vitrinite over inertinite and degraded vitrinite over structured vitrinite.

8.4.2. Microlithotypes

Figure 8.5 (page 312) depicts 'bandwidth' curves of the microlithotypes for the sub-seams G1 to G7 from the drill hole IRCH 1 plotted on the diagram of Hunt and Hobday (1984). The coal occupies the finely banded to medium banded zones, and thus, the coal is interpreted to have accumulated in a braided fluvial to upper delta-plain environment.

Figure 8.6 (page 313) illustrates microlithotype composition of the coal plotted on ternary diagram of Smyth (1979, 1989) and it shows that sub-seams G1 to G7 occupy areas D and E, which represent upper delta and lower delta-plain environments.

The depositional environment of the Irwin River coal based on the maceral and microlithotype analyses is interpreted to be braided fluvial to deltaic.

The depositional environments based on the petrographic data of the Vasse Shelf, Collie and the Irwin River coals are summarized in Table 8.8. The depositional environments of the all three coals are braided,

SUB-SEAMS	D	W	R	GI	TPI
G 1	38.8	4.8	56.4	1.3	0.1
G 2	29.1	20.8	50.1	1.2	0.3
G 3	31.6	15.0	53.4	1.1	0.2
G 4	35.2	4.2	60.6	1.5	0.1
G 5	32.2	11.3	56.5	1.3	0.1
G 6	31.1	7.8	61.1	1.6	0.1
G 7	34.4	14.0	51.6	1.1	0.2

D = Alginite+Sporinite+Inertodetrinite

W = Telinite+Telocollinite+Semifusinite+Fusinite

R = Other macerals (principally desmocollinite)

GI = Vitrinite+Macrinite/Semifusinite+Fusinite+Inertodetrinite

TPI = Telinite+Telocollinite+Semifusinite+Fusinite/Desmocollinite+Macrinite+Inertodetrinite

Table 8.7. DWR-maceral composition (%) and petrographic indices of the Irwin River coal.

was undertaken on sedimentology of core samples for the Vasse Shelf coal to supplement petrology of coal in the interpretation of depositional environment. However, this was outside the scope of the thesis due to objectives being on petrology. The inconsistencies in the depositional environments for the coals are obvious because different models developed for coal from Eastern Australia are used. If only one model is used, then the discrepancies will not be present in the interpretations.

The depositional environments based on the petrographic data of the Vasse Shelf, Collie and the Irwin River coals are summarized in Table 8.8. The depositional environments of the all three coals are braided, meandering lacustrine deltaic river systems, without any marine influences, as depicted in Table 8.8.

CRITERIA	DEPOSITIONAL ENVIRONMENT		
	VASSE SHELF	**COLLIE**	**IRWIN RIVER**
DTF	Open moor Dry forest moor Wet forest moor	Open moor Dry forest moor Wet forest moor	The coal contains less than 50% diagnostic macerals, thence no DTF plot
TPI-GI	Open marsh Clastic marsh (Wet&dry forest swamps)	Open marsh Clastic marsh (Wet&dry forest swamps)	Clastic marsh
Bandwidth	Braided fluvial-Upper delta plain	Braided to meandering fluvial	Braided fluvial-Upper delta plain
Microlithotypes	Fluvial, lacustrine to delta	Lacustrine to deltaic	Upper-lower deltaic

Key

DTF - D: alginite, sporinite,telocollinite
T : telinite, telocollinite
F : fusinite, semifusinite
TPI - Tissue Preservation Index
GI - Gellification Index

Table 8.8. Summary of depositional environments of the Vasse Shelf, Collie and the Irwin River coals.

CHAPTER 9. CONCLUSIONS

The thesis has achieved its aim and objectives in establishing detailed petrology of the Early Permian Vasse Shelf coal. The petrology of the selected coal samples from the Premier and the Irwin Sub-basins, Western Australia has also been established. The comments on petrology of Western Australian coal with the selected Gondwana coals are also included. The following conclusions are made from the petrological study:

Vasse Shelf

1. The Perth Basin in Western Australia contains coal ranging in age from Early to Late Permian, but the thickest and most extensive seams are found in the Early Permian rocks. The Early Permian coals are present in subsurface of the basin, however, the coals only occur at mineable depths in two structural subdivisions, namely the Vasse Shelf in the southern Perth Basin and the Irwin Sub-basin in the north. The coal measures of the Vasse Shelf are described as the Sue Coal Measures which consist of sixteen coal seams and carbonaceous shale units in cyclic sequences of point bar deposits. The thickness of the individual seams ranges from 20 cm to 195 cm.

2. Macroscopically, the coal is finely banded and the dominant lithotypes are dull (12.2% to 100.0%) and dull banded (4.5% to 98.3%) lithotypes followed by bright banded (1.7% to 78.3%) and banded (2.0% to 48.9%) lithotypes, with minor bright lithotype (1.0% to 44.5%).

3. The maceral composition of the coal is predominated by inertinite, followed by vitrinite, and minor exinite. The inertinite content has a range of

14.8% to 63.0%, and it consists mainly of inertodetrinite, followed by fusinite and semifusinite, with low micrinite, sclerotinite and macrinite. The vitrinite in the coal consists of desmocollinite, telocollinite, vitrodetrinite and very low corpocollinite and telinite contents, and the vitrinite content varies from 19.6% to 64.2%. The exinite content in the coal varies between 5.3% to 18.0%, and it is represented by sporinite, cutinite, liptodetrinite and very low resinite and alginite. The semifusinite ratio of the coal is very low to medium and the vitrinite content is low to high. On the basis of the vitrinite content, the vitrinite group in the coal was formed in anaerobic conditions, moderate subsidence and wet environment, and on the basis of the semifusinite ratio, the coal was deposited in a slightly oxidizing environment. Overall the coal could be interpreted to be formed in an anaerobic wet environment with some degree of oxidation during its deposition. The reflectance values of vitrinite between 0.58% to 0.63% indicate a coalification stage at sub-bituminous to high volatile bituminous levels of the Australian standard or sub-bituminous A to high volatile bituminous of the ASTM classification.

4. The maceral and mineral matter distributions in coal size fractions show that the vitrinite content has a slight increase followed by a decrease with declining size fractions, and the reverse is true for the inertinite content in the size fractions. The exinite and mineral matter contents in the size fractions follow the similar trends that of vitrinite and inertinite.

5. The inertite and vitrite are the dominant monomaceral microlithotypes occurring in the coal, and their contents vary between 4.4% to 50.6% and 4.6% to 57.8%, respectively. The major bimaceral microlithotypes in the coal are clarite with the range of 0.4% to 31.6%, followed by vitrinertite ranging between 2.0% to 27.8% and durite with the range of 0.8% to

36.4%. The duroclarite and clarodurite are the major trimaceral microlithotypes in the coal, which occur within a range of 1.2% to 12.8% and 0.4% to 7.6%, respectively. The carbominerites in the coal predominantly comprise carbargilite, carbopyrite and carbosilicate. The range of carbargilite content is between 0.6% to 6.2%, whereas carbopyrite shows a value of 0.2% to 2.2% and the carbosilicate has a range of 0.0% to 0.8%.

6. The mineral matter in the coal is predominantly composed of clay minerals and pyrite, with low quartz, and it is qualitatively associated with fusinite, semifusinite and desmocollinite. The clay minerals vary from 0.2% to 5.0%, which are the most dominant in the coal. The clay minerals identified under SEM in the coal are montmorillonite, kaolinite and illite. The pyrite is the second dominant mineral in the coal, and it has a range of 0.5% to 3.4%. The quartz content in the coal varies from 0.0% to 1.2%.

7. The relationship of lithotypes, macerals and microlithotypes in the coal shows that the dull and bright lithotypes are due to concentration of inertinite and inertite, and vitrinite and vitrite contents, respectively. Thus, the microlithotype composition of the coal follows the same pattern as the maceral content of the lithotypes.

8. The trace elements analysed in the selected coal are B, Be, Co, Cr, Cu, Ga, Ge, Mn, Mo, Ni, Pb, Sb, Sn, Sr, Ti, U, V, Zn and Zr. The elements of Cu, Ge and Sr occur in inorganic associations and are part of the mineral matter in the coal. The Be, Co, Cr, Ni, Pb, Sb, Ti, U and V have organic affinity, which points to the fact that these elements are inherent in the flora which provided the vegetable matter for the coal. The B, Ga, Mn, Mo, Sn, Zn and Zr are present in both organic and inorganic affinities in the coal.

9. On the basis of lithotypes, macerals, microlithotypes, trace elements and the sedimentary structures in the interseam sediments, the depositional environment for the Vasse Shelf coal is braided and meandering deltaic-river systems.

Collie Basin

1. The Collie Basin is an intracratonic and bilobate, fault controlled northwest trending depression within a basement complex of Archaean granite and gneiss. The basin is subdivided into Cardiff and the Premier Sub-basins. The coal samples for this study were collected from the Premier Sub-basin. The basin consists of two groups, namely the Stockton and Collie, overlying the Archaean basement. At the base, the earliest Permian Stockton Group is conformably overlain by the Early to Late Permian Collie Group, which are unconformably overlain by the Cretaceous Nakina Formation. The Collie Group comprises five formations from the top to bottom: Muja Coal Measures, Premier Coal Measures, Allanson Sandstone, Ewington Coal Measures and the Westralia Sandstone. The Ewington Coal Measures are stratigraphically equivalent to the Sue Coal Measures of the Vasse Shelf and the Irwin River Coal Measures of the Irwin Sub-basin.

2. The inertinite and vitrinite are the dominant maceral groups present in the coal, whereas exinite and mineral matter form minor components. The inertinite content has a range of 41.2% to 69.0%, it consists mainly of inertodetrinite with low fusinite and semifusinite and very low micrinite, sclerotinite and macrinite. The vitrinite in the coal consists mainly of desmocollinite and telocollinite, with minor vitrodetrinite, telinite and corpocollinite. The vitrinite content ranges between 15.2% to 47.4%. The

exinite content varies from 4.6% to 14.4%, and it consists mainly of sporinite, cutinite and liptodetrinite, with low alginite and resinite. The semifusinite ratio for the coal is very low to low and the vitrinite content is low to medium, which supports that the coal was formed in an aerobic dry to wet environment with some degree of oxidation during its deposition. The maximum reflectance of vitrinite ranges between 0.45% to 0.48%, which represents the coalification stage of sub-bituminous rank according to the Australian rank, and corresponds to sub-bituminous B of the ASTM classification.

3. The coal is mainly dominated by inertite (6.4% to 49.4%) and durite (5.6% to 36.2%), followed by vitrite (2.4% to 25.0%), vitrinertite (2.0% to 27.6%) and clarite (0.2% to 11.6%) and low vitrinertoliptite (0.0% to 2.8%), liptite (0.0% to 1.6%) and carbominerites (3.0% to 9.8%).

4. The mineral matter in the coal is predominantly composed of clay minerals (0.8% to 7.4%) and pyrite (1.2% to 3.0%), with low quartz (less than 1.0%). It is particularly associated with fusinite, semifusinite, inertodetrinite and desmocollinite.

5. The relationship of macerals and microlithotypes in the coal shows that the coal contains more inertinite and inertite compared with vitrinite and vitrite in most of the seams. The exinite and liptite contents are low and the mineral matter and carbominerite contents remain fairly constant. Thus, the microlithotype composition of the coal follows the same pattern as the maceral content.

6. The elements of B, Cr, Ga, Mo, Ni, Pb, Sb, U, V and Zr are present in inorganic affinity, whilst Mn and Zn occur in organic association in the coal.

The Be, Co, Cu, Sn, Sr and Ti are present in organic and inorganic associations.

7. The depositional environment of the Collie coal on the basis of macerals, microlithotypes and trace elements distribution is lacustrine, braided to meandering fluvial system.

Irwin Sub-basin

1. The Irwin River Coal Measures in the Irwin Sub-basin extend approximately 40 km from north to south. The coal measures vary in thickness from 60 m in the north and 120 m in the south, and contain up to 10 m cumulative thickness of coal in nine seams over a stratigraphic interval of 50 m. The coal seams range between 0.5 m and 6.0 m in thickness.

2. The maceral composition of the Irwin River coal is dominated by vitrinite (45.4% to 55.2%), followed by inertinite (35.2% to 44.4%), with minor exinite (4.8% to 8.6%) and mineral matter (2.8% to 8.2%). The vitrinite consists mainly of desmocollinite with low telocollinite, vitrodetrinite, corpocollinite and telinite. The inertinite in the coal comprises inertodetrinite, fusinite, semifusinite and very low micrinite, macrinite and sclerotinite. The exinite group in the coal consists mainly of sporinite, cutinite and liptodetrinite and low resinite and alginite. The semifusinite ratio of the coal is very low and the vitrinite content is medium to high. Based on the semifusinite ratio and vitrinite content, the coal was formed in an anaerobic wet environment with some degree of oxidation during its deposition in a rapidly subsiding area. The maximum reflectance (ROmax) of vitrinite has a range between 0.42% to 0.59%, and the rank of the coal is

sub-bituminous according to the Australian classification, and it corresponds to the sub-bituminous A to B of the ASTM rank.

3. The microlithotype composition of the coal is predominantly composed of vitrite (23.8% to 36.4%), inertite (15.6% to 36.6%) and vitrinertite (6.6% to 21.6%), followed by clarite (3.8% to 9.8%), durite (2.4% to 9.2%), duroclarite (5.2% to 11.0%) and clarodurite (2.6% to 8.2%) and low vitrinertoliptite (0.2% to 2.2%) and liptite (less than 0.4%). The carbargilite and carbopyrite are the dominant carbominerites in the coal, and their contents range between 0.8% to 5.8% and 1.0% to 5.2%, respectively. The carbosilicate is present in a low amount, ranging from 0.0% to 0.6%.

4. The mineral matter in the coal consists mainly of pyrite (0.8% to 5.8%), clay minerals (1.4% to 2.4%) and low amounts of quartz (0.2% to 0.8%). It is mainly associated with vitrinite and inertinite group of macerals.

5. The relationship between maceral and microlithotype compositions of the coal shows that most of the sub-seams are dominated by the vitrinite and vitrite contents, followed by the inertinite and inertite with minor exinite and liptite, and mineral matter and carbominerites. Thus, the microlithotype composition of the coal follows the same pattern as the maceral content.

6. The depositional environment of the coal based on macerals and microlithotypes contents is braided fluvial to deltaic.

7. The petrological comparisons of Vasse Shelf, Collie and Irwin River coals show that the vitrinite content of the Irwin River coal is highest (49.1%) and of the Collie coal is lowest 37.3%) of the three. The inertinite content is highest in Collie coal (49.1%), followed by Vasse Shelf (46.4%) and Irwin

River (39.2%) coals. The exinite content is low in Irwin River coal (6.3%) as compared with Vasse Shelf (9.0%) and Collie (8.3%) coals. The mineral matter content is relatively similar for all the three coals. On the basis of semifusinite ratio and vitrinite content values, the Vasse Shelf and Irwin river coals were formed in an anaerobic and wet condition, whereas for Collie coal somewhat drier condition prevailed. The vitrinite reflectance values of Vasse Shelf coal are high as compared with Collie and Irwin River coals, either due to tectonic uplift after the deposition in post-Permian in the southern Perth Basin, or due to the average depth of burial over Vasse Shelf is much thicker than that of Collie and Irwin River coals.

8. The Vasse Shelf coal contains more monomaceralic microlithotypes (56.2%) than coals from the Irwin River (54.4%) and Collie (42.7%). The bimaceralic content is highest in the Collie coal (31.5%) and lowest in the Irwin River coal (26.0%). The trimaceralic content is high in the Collie coal (20.4%) as compared with the Irwin River (12.4%) and Vasse Shelf (10.3%) coals. The carbominerites are highest in Irwin River coal (6.2%) and lowest in Vasse Shelf coal (4.1%).

9. On the basis of maceral and microlithotype compositions, the depositional environment of the Vasse Shelf coal is braided and meandering deltaic-river systems, lacustrine, braided to meandering fluvial system for the Collie coal and braided fluvial to deltaic for the Irwin River coal.

10. The comparisons of the petrology of the coal from Western Australia with selected Gondwana coals shows the predominance of inertinite over vitrinite contents (Vasse Shelf and Collie Basin), otherwise the Brazilian, eastern Australian (all the three basins), Indian (all the three basins) and

Western Australian (Irwin Sub-basin) coals are dominated by vitrinite over inertinite. The exinite content is highest in the Indian coal and lowest in the eastern Australian coals. The mineral matter content is highest in the Brazilian and Indian coals, and lowest in Western Australian (Vasse Shelf) and eastern Australian (Sydney Basin) coals. The rank of the coals varies from sub-bituminous to medium volatile bituminous as per the Australian classification.

The experience gained by the author during the research for this thesis will be useful and equally applicable to the petrological study of Indonesian coals and their utilization.

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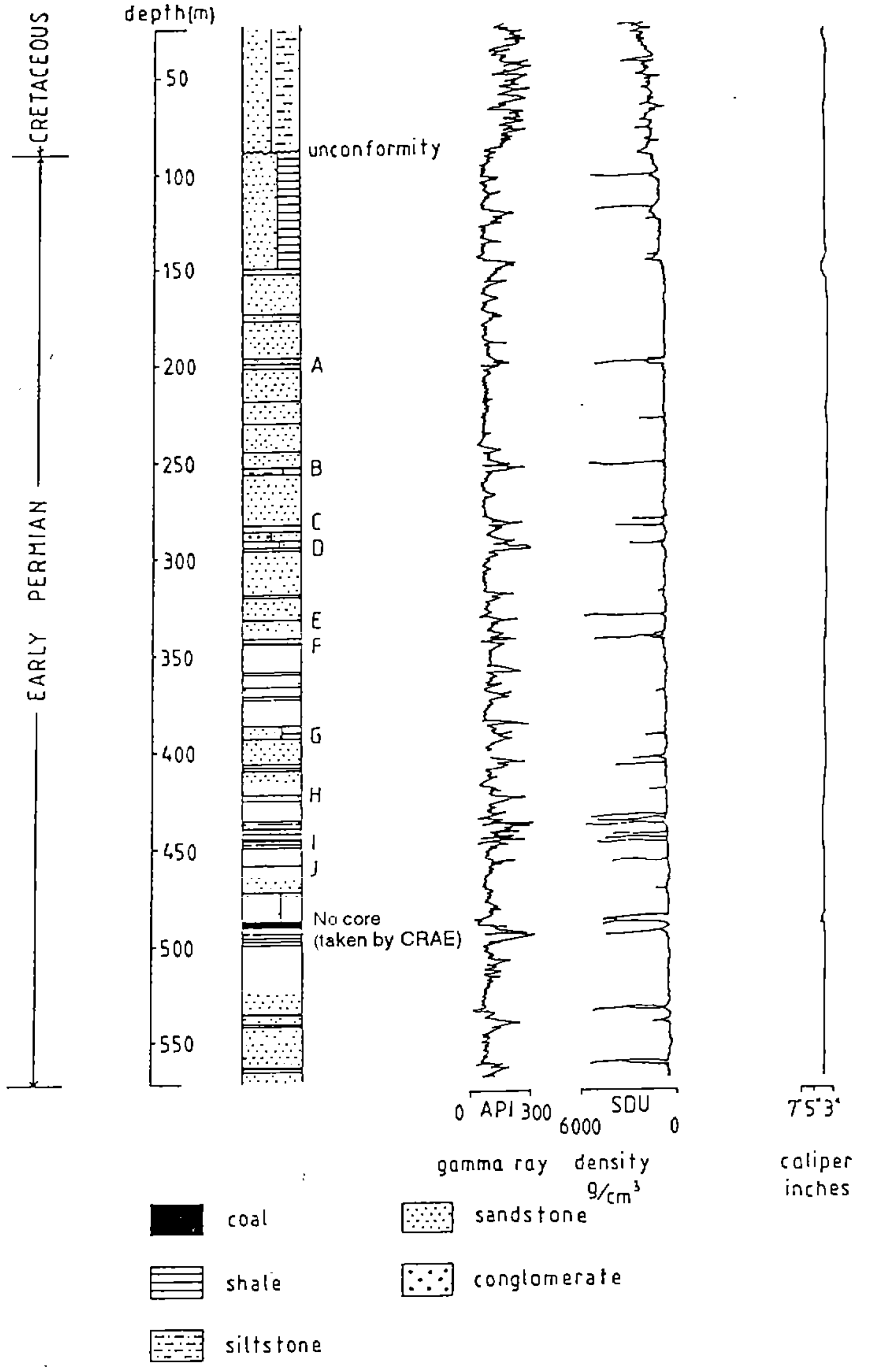
APPENDIX I

Appendix I.1. Lithology log of the drill holes, Vasse Shelf, Perth Basin, Western Australia.

Appendix I.1.1. Lithology log of RBCH 5.
Appendix I.1.2. Lithology log of RBCH 6.
Appendix I.1.3. Lithology log of RB 3.
Appendix I.1.4. Lithology log of CRCH 1.
Appendix I.1.5. Lithology log of CRCH 2.

Appendix I.2. Lithotype profile of coal seams, Vasse Shelf, Perth Basin, Western Australia.

APPENDIX I.1. Lithology log of the drill holes, Vasse Shelf, Perth Basin, Western Australia.



Appendix 1.1.1. Lithology log of RBCH 5, A to J coal seams, Vasse Shelf, Perth Basin, Western Australia (after CRAE, 1984).

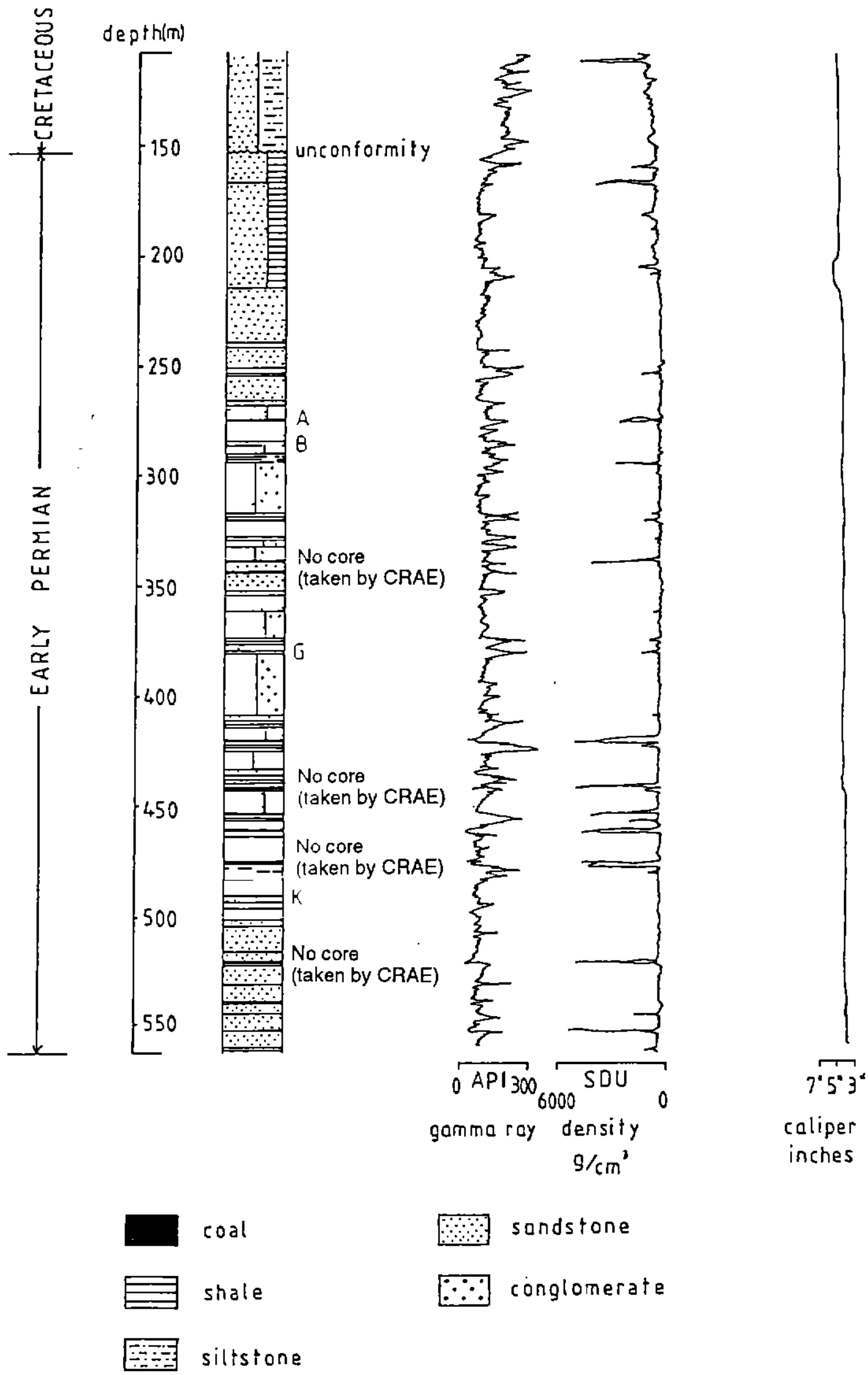
APPENDIX I.1.1. LITHOLOGY LOG OF RBCH 5, VASSE SHELF, PERTH BASIN, WESTERN AUSTRALIA.

ROCK TYPE	DEPTH RANGE (m)	THICKNESS (m)	DESCRIPTION
SANDSTONE and SHALE	149.55-154.60	5.05	Interlamination sandstone with shale. Sandstone (60%), brownish-grey, fine-medium grained, well-sorted, parallel, ripple and cross laminations, slump, very hard. Shale (40%), dark grey, carbonaceous, mica, pyrite, brittle.
SANDSTONE	154.60-167.00	12.4	Grey, medium-pebble, very poorly-sorted, mica, pyrite, massive, very hard.
SHALE	167.00-167.35	0.35	Dark grey, carbonaceous, soft.
SANDSTONE	167.35-173.34	5.99	Brownish-grey, coarse-granule, very poorly-sorted, slightly parallel lamination, very hard.
SANDSTONE	173.34-178.70	5.36	Grey, fine, well-sorted, parallel, cross and ripple laminations, carbonaceous, pyrite, mica, very hard.
SANDSTONE	178.70-188.60	9.90	Grey, fine-coarse, very poorly-sorted, coal fragments, parallel lamination, very hard.
CONGLOMERATE	188.60-188.70	0.10	Brownish-grey, coarse-pebble, very poorly-sorted, very hard.
SANDSTONE	188.70-192.30	3.60	Dark grey, coarse-granule, very poorly-sorted, parallel lamination, carbonaceous, very hard.
SANDSTONE	192.30-201.40	9.10	Interbedded sandstone with shale. Sandstone (55%), grey, medium-coarse, poorly sorted, massive, carbonaceous, very hard. Shale (45%), dark grey, carbonaceous, brittle.
COAL	201.40-201.94	0.54	Seam A, black, pyrite, brittle.
SANDSTONE	201.94-206.25	4.31	Dark grey, fine-grained, well-sorted, parallel lamination, mica, very hard.
SANDSTONE	206.25-210.60	4.35	Brownish-grey, very coarse-granule, very poorly-sorted, massive, very hard.
SANDSTONE	210.60-219.00	8.40	Grey, very coarse-granule, very poorly-sorted, parallel lamination, carbonaceous, very hard.
CONGLOMERATE	219.00-219.50	0.50	Grey, coarse-pebble, very poorly-sorted, very hard.
SANDSTONE	219.50-226.81	7.31	Brownish-grey, coarse-granule, very poorly-sorted, carbonaceous, massive, very hard.
SANDSTONE	226.81-237.43	10.62	Dark grey, very coarse-pebble, poorly-sorted, massive, very hard.
SANDSTONE	237.43-244.85	7.42	Grey, fine-coarse, poorly-sorted, massive, very hard.
SANDSTONE	244.85-252.27	7.42	Grey, fine-granule, very poorly-sorted, massive, very hard.
SILTSTONE	252.27-252.82	0.55	Blackish-grey, parallel and cross laminations, brittle.
COAL	252.82-253.60	0.78	Seam B, black, brittle.
SILTSTONE	253.60-255.60	2.00	Dark grey, parallel and cross laminations, carbonaceous, hard-brittle.

SANDSTONE	255.60-261.00	5.40	Grey, fine-coarse, poorly-sorted, slump, parallel and cross laminations, carbonaceous, very hard.
SANDSTONE	261.00-267.05	6.05	Grey, very coarse-pebble, very poorly-sorted, massive, very hard.
SANDSTONE	267.05-269.37	2.32	Grey, fine, well sorted, parallel and cross laminations, carbonaceous, very hard.
SANDSTONE	269.37-282.00	12.63	Grey, fine-pebble, very poorly-sorted, massive, very hard.
SANDSTONE	282.00-282.60	0.60	Grey, fine, well-sorted, parallel and cross laminations, very hard.
COAL	282.60-283.00	0.40	Seam C, black, pyrite, hard-brittle.
SHALE	283.00-283.70	0.70	Blackish-grey, carbonaceous, pyrite, brittle.
SANDSTONE and SHALE	283.70-293.58	9.88	Interbedded sandstone with shale. Sandstone (70%), fine-coarse, poorly-sorted, carbonaceous, parallel, cross and ripple laminations, hard. Shale (30%), blackish-grey, carbonaceous, hard-brittle.
COAL	293.58-294.17	0.59	Seam D, black, brittle.
SANDSTONE and SHALE	295.17-301.00	5.83	Interbedded sandstone with shale. Sandstone (60%), grey, fine-medium, moderately-sorted, massive, very hard. Shale (40%), dark grey, carbonaceous, brittle.
SANDSTONE	301.00-307.90	6.90	Grey, medium-granule, very poorly-sorted, massive, very hard.
SANDSTONE	307.90-319.20	11.30	Grey, medium-very coarse, poorly-sorted, parallel lamination, very hard.
SILTSTONE	319.20-319.60	0.40	Dark grey, massive, hard.
SANDSTONE	319.60-331.30	11.70	Grey, fine-pebble, very poorly-sorted, parallel and cross laminations, graded bedding, very hard.
COAL	331.30-332.15	0.85	Seam E, black, brittle.
SANDSTONE and SHALE	332.15-343.23	11.08	Interbedded sandstone and shale. Sandstone (55%), grey, fine-pebble, very poorly-sorted, slump, graded bedding, parallel and cross laminations, very hard. Shale (45%), black, carbonaceous, brittle.
COAL	343.23-344.27	1.04	Seam F, black, brittle-hard.
SANDSTONE	344.27-358.63	14.36	Sandstone, grey, medium-pebble, very poorly-sorted, parallel, cross and ripple laminations, graded bedding, massive, very hard.
SANDSTONE	358.63-361.78	3.15	Grey to dark grey, fine-granule, very poorly-sorted, parallel and cross laminations, graded bedding, very hard.
SANDSTONE	361.78-370.81	9.03	Grey, fine-pebble, very poorly-sorted, massive, graded bedding, parallel lamination, very hard.
SANDSTONE and SHALE	370.81-374.33	3.52	Interlaminated sandstone with shale. Sandstone (55%), grey, fine-coarse, poorly-sorted, massive, hard. Shale (45%), black, carbonaceous, brittle.
SANDSTONE	374.33-385.80	11.47	Grey, medium-granule, very poorly-sorted, graded bedding, parallel lamination, massive, very hard.
SANDSTONE	385.80-393.38	7.58	Interbedded sandstone with shale. Sandstone (60%), grey, fine-pebble, very poorly-sorted, parallel and cross laminations, hard. Shale (40%), black, carbonaceous, brittle.
COAL	393.38-393.66	0.28	Seam G, black, brittle.

SANDSTONE	393.66-407.20	13.54	Grey, fine-pebble, very poorly-sorted, mostly massive, parallel and cross laminations, graded bedding, very hard.
SANDSTONE and SHALE	407.20-409.92	2.72	Interlaminated sandstone and shale. Sandstone (60%), grey, fine, very well-sorted, parallel and cross laminations, hard. Shale (40%), blackish-grey, carbonaceous, brittle.
SANDSTONE	409.92-422.26	12.34	Grey, medium-pebble, very poorly-sorted, graded bedding, mostly massive, parallel lamination, very hard.
COAL	422.26-422.61	0.35	Seam H, black, brittle-hard.
SANDSTONE and SHALE	422.61-427.60	4.99	Interbedded sandstone and shale. Sandstone (55%), grey, fine, very well-sorted, coal lamination (5%), parallel lamination, very hard. Shale (40%), dark grey, carbonaceous, coal fragments, brittle-hard.
SANDSTONE	427.60-435.20	7.60	Grey, medium-pebble, very poorly-sorted, graded bedding, fining upwards, massive, very hard.
	435.20-439.14	3.94	Gap (no core).
SHALE and SANDSTONE	439.14-445.18	6.04	Interbedded shale and sandstone. Shale (55%), blackish grey, carbonaceous, coal lamination (5%), brittle. Sandstone (40%), grey, very well-sorted, graded bedding, fining upwards, massive, very hard.
COAL	445.18-445.63	0.45	Seam I, black, pyrite, brittle-hard.
	445.63-446.18	1.00	Gap (no core).
SHALE	446.18-446.98	0.80	Blackish-grey, carbonaceous, brittle.
	446.98-448.18	1.20	Gap (no core).
SANDSTONE	448.18-458.73	10.55	Grey, fine-pebble, very poorly-sorted, fining upwards, parallel and cross laminations, carbonaceous, very hard.
COAL	458.73-459.20	0.47	Seam J, black, pyrite, hard.
SANDSTONE	459.20-462.00	2.80	Grey, fine, very well-sorted, parallel and cross laminations, slump, reworking, very hard.
SANDSTONE upwards,	462.00-469.53	7.53	Grey, fine-pebble, very poorly-sorted, mostly massive, graded bedding, fining parallel lamination, very hard.
SANDSTONE	469.53-487.60	18.07	Grey, medium-granule, very poorly-sorted, mostly massive, graded bedding, fining upwards, parallel and cross laminations, carbonaceous, very hard.
	487.60-491.86	4.26	Gap (no core).
SANDSTONE	491.86-494.00	2.14	Grey, fine, very well-sorted, parallel and cross lamination, very hard.
	494.00-496.00	2.00	Gap (no core).
SHALE and SANDSTONE	496.00-498.00	2.00	Interlaminated shale and sandstone. Shale (60%), dark grey, carbonaceous, brittle. Sandstone (40%), grey, fine, very well-sorted, parallel and cross laminations, hard.
SANDSTONE	498.00-507.30	9.30	Grey, fine (upper part), very well-sorted, medium-granule (lower part), very poorly-sorted, carbonaceous, graded bedding, fining upwards, massive, parallel and cross laminations, very hard.

SANDSTONE	507 30-517.88	10.58	Grey, medium-pebble, very poorly-sorted, graded bedding, fining upwards, mostly massive, parallel lamination, carbonaceous, very hard.
SANDSTONE	517 88-534.42	16.54	Grey, medium-granule, very poorly-sorted, graded bedding, fining upwards, carbonaceous, coal fragments, very hard.
	534.42-536.42	1.00	Gap (no core).
SANDSTONE	536.42-540.00	3.58	Dark grey, medium-coarse, moderately sorted, massive, very hard.
	540.00-541.20	1.20	Gap (no core).
SHALE	541.20-542.56	1.36	Black, carbonaceous, pyrite, mica, hard-brittle.
SANDSTONE	542.56-547.80	5.24	Dark grey, fine (upper part), very well-sorted, fine-coarse (lower part), moderately-sorted, carbonaceous, coal fragments, parallel and cross laminations, massive, very hard.
SANDSTONE	547.80-562.55	14.75	Grey, fine-coarse, moderately-sorted, mostly massive, coal fragments, carbonaceous, parallel, cross and ripple laminations, very hard.



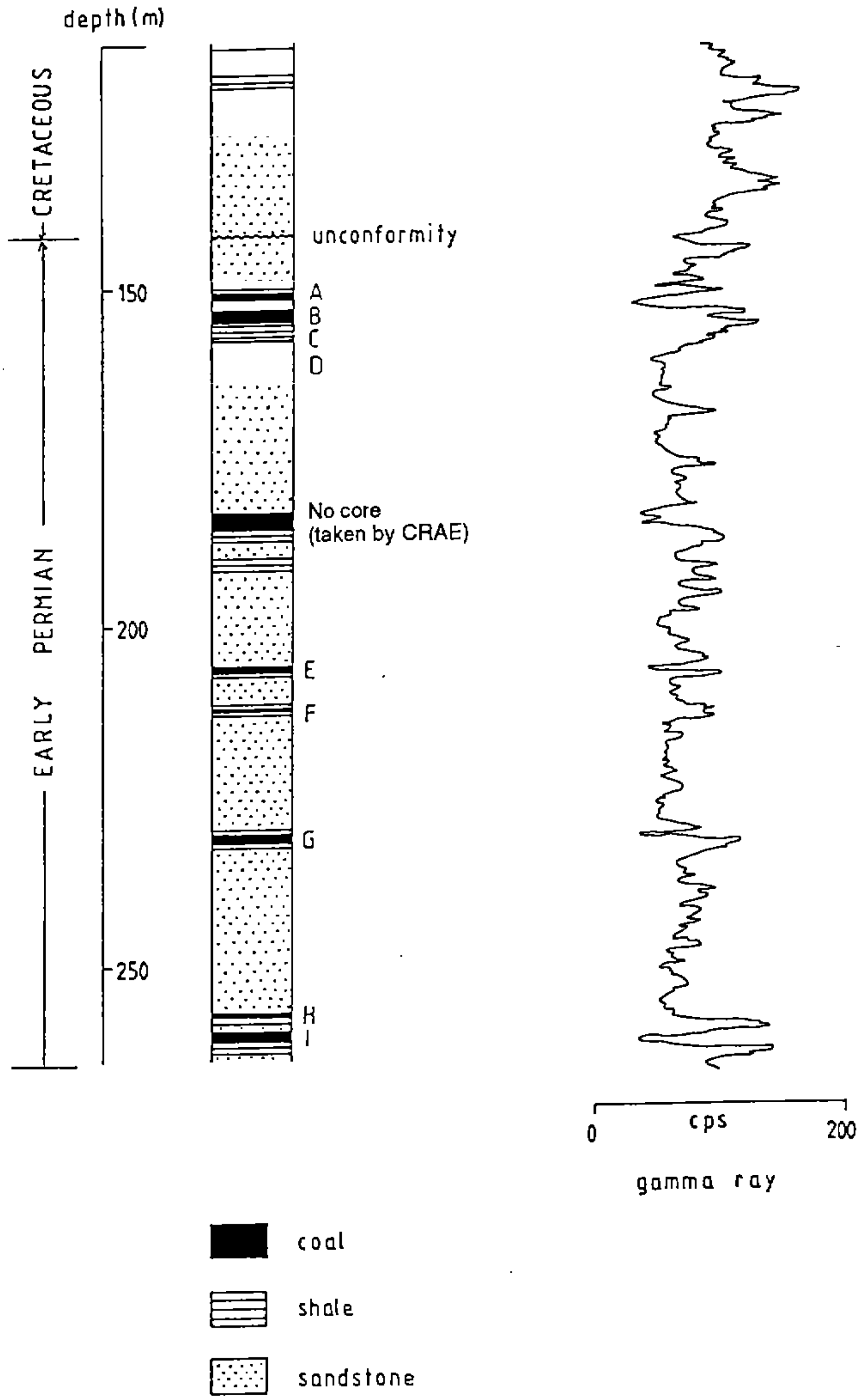
Appendix I.1.2. Lithology log of RBCH 6, A, B, G and K coal seams, Vasse Shelf, Perth Basin, Western Australia (after CRAE, 1984).

APPENDIX I.1.2. LITHOLOGY LOG OF RBCH 6, VASSE SHELF, PERTH BASIN, WESTERN AUSTRALIA.

ROCK TYPE	DEPTH RANGE (m)	THICKNESS (m)	DESCRIPTION
SANDSTONE	214.00-229.31	15.31	Greenish-grey, fine-granule, very poorly-sorted, graded bedding, fining upwards, mostly massive, parallel lamination, carbonaceous, shaly, shale fragments, very hard.
SANDSTONE	229.31-241.53	12.22	Grey, medium-coarse (upper part), moderately-sorted, medium-granule (lower part), poorly-sorted, graded bedding, fining upwards, massive, parallel lamination, very hard.
SANDSTONE	241.53-250.46	8.93	Grey, fine-very coarse, poorly-sorted, mostly massive, parallel lamination, very hard.
SHALE and SANDSTONE	250.46-254.43	3.97	Interlaminated shale with sandstone. Shale (60%), blackish-grey, carbonaceous, coal fragments, brittle-hard. Sandstone (40%), grey, very fine, well-sorted, parallel and cross laminations, very hard.
SANDSTONE	254.43-265.74	11.31	Grey, fine-very coarse (upper part), very poorly-sorted, medium-granule (lower part), very poorly-sorted, graded bedding, fining upwards, massive, very hard.
SHALE	265.74-265.82	0.08	Blackish-grey, carbonaceous, coal fragments, brittle.
SANDSTONE	265.82-274.18	8.36	Grey, fine-medium (upper part), moderately to well sorted, medium-pebble (lower part), very poorly-sorted, graded bedding, fining upwards, parallel and cross laminations, coal and shale fragments, very hard.
COAL	274.18-274.85	0.67	Seam A, black, fractured, pyrite, brittle-hard.
SANDSTONE	274.85-284.28	9.43	Grey, fine (upper part), very well-sorted, medium-pebble (lower part), graded bedding, fining upwards, massive, cross lamination, very hard.
SANDSTONE and SHALE	284.28-293.68	9.40	Interbedded sandstone with shale. Sandstone (55%), grey, fine-very coarse, poorly-sorted, graded bedding, coal fragment, mostly massive, parallel lamination, very hard. Shale (40%), dark grey, carbonaceous, coal lamination (5%), brittle.
COAL	293.68-294.02	0.34	Seam B, black, fractured, brittle.
SANDSTONE	294.02-317.00	22.98	Grey, fine-very coarse (upper part), poorly-sorted, medium-pebble (lower part), very poorly-sorted, mostly massive, graded bedding, fining upwards, parallel lamination, coal fragments, very hard.
SHALE, SANDSTONE and COAL	317.00-320.40	3.40	Interlamination of shale, sandstone and coal. Shale (50%), blackish-grey, carbonaceous, pyrite, plant remains, brittle. Sandstone (40%), grey, very fine, well-sorted, parallel and cross laminations, carbonaceous, hard. Coal (10%), black, pyrite, brittle-hard.
SANDSTONE	320.40-327.71	7.31	Grey, fine-granule, very poorly-sorted, mostly massive, parallel lamination, carbonaceous, very hard.
SILTSTONE	327.71-328.30	0.59	Dark grey, massive, hard, coal lamination (5 cm).

SANDSTONE	328.30-337.82	9.52	Grey, fine (upper part), very well-sorted, medium-pebble (lower part), very poorly-sorted, fining upwards, mostly massive, parallel and cross laminations, carbonaceous, very hard.
	337.82-339.04	1.22	Gap (no core).
SANDSTONE	339.04-351.70	12.66	Grey, fine-very coarse (upper part), poorly-sorted, coarse-pebble (lower part), very poorly-sorted, mostly massive, parallel and cross laminations, carbonaceous, very hard.
SHALE and SANDSTONE	351.70-353.84	2.14	Interlaminated shale with sandstone. Shale (60%), blackish-grey, mica, pyrite, carbonaceous, brittle. Sandstone (40%), grey, fine, very well-sorted, parallel and cross laminations, hard.
SANDSTONE	353.84-361.08	7.24	Grey, medium-granule, very poorly-sorted, massive, graded bedding, fining upwards, very hard.
SANDSTONE	361.08-373.62	12.54	Grey, fine-very coarse (upper part), poorly-sorted, medium-pebble (lower part), very poorly-sorted, massive, graded bedding, fining upwards, parallel lamination, very hard.
SHALE, SANDSTONE and COAL	373.62-378.80	5.18	Interlamination of shale, sandstone and coal. Shale (50%), blackish-grey, carbonaceous, coal fragments, brittle. Sandstone (45%), grey, fine-medium, moderately-sorted, parallel and cross laminations, very hard. Coal (5%), black, pyrite.
COAL	378.80-379.02	0.22	Seam G, black, fractured, brittle
SHALE	379.02-380.10	1.08	Blackish-grey, carbonaceous, coal fragments, brittle.
SANDSTONE	380.10-390.00	9.90	Grey, fine-coarse, moderately-sorted, mostly massive, fining upwards, massive, very hard.
SANDSTONE	390.00-408.02	18.02	Grey, medium-pebble, very poorly-sorted, graded bedding, fining upwards, shale and coal fragments, massive, very hard.
SANDSTONE	408.02-411.65	3.63	Grey, fine-pebble, very poorly-sorted, graded bedding, fining upwards, shale and coal fragments, massive, very hard.
SANDSTONE	411.65-414.30	2.65	Grey to dark grey, fine, very well-sorted, massive (upper part), parallel and cross laminations, carbonaceous, very hard.
SANDSTONE	414.30-418.70	4.40	Grey, medium-pebble, very poorly-sorted, shale fragments, massive, very hard.
	418.70-420.35	1.65	Gap (no core).
SANDSTONE	420.35-422.06	1.71	Grey to dark grey, medium-granule, very poorly-sorted, graded bedding, massive, coal fragments, hard.
SHALE	422.06-424.60	2.54	Blackish-grey, carbonaceous, coal fragments, coal lamination (3 cm), brittle.
SANDSTONE	424.60-432.66	8.06	Grey, fine-pebble, very poorly-sorted, graded bedding, fining upwards, massive, hard.
SANDSTONE and SHALE	432.66-440.25	7.59	Interbedded sandstone and shale. Sandstone (60%), grey, medium-coarse, moderately-sorted, coal fragments, massive, very hard. Shale (40%), blackish-grey, carbonaceous, coal fragments, brittle.
	440.25-441.77	1.52	Gap (no core).
SANDSTONE	441.77-444.05	2.28	Interbedded sandstone and shale. Sandstone (55%), grey, fine, very well-sorted,

and SHALE			carbonaceous, parallel lamination, very hard. Shale (45%), blackish-grey, carbonaceous, mica, pyrite, brittle.
SANDSTONE	444.05-452.38	8.33	Grey, medium-pebble, very poorly-sorted, graded bedding, fining upwards, massive, very hard.
	452.38-454.30	1.92	Gap (no core).
SANDSTONE and SHALE	454.30-459.50	5.20	Interbedded sandstone with shale. Sandstone (70%), grey, fine, very well-sorted, massive, hard. Shale (30%), blackish-grey, carbonaceous, brittle.
	459.50-461.20	1.70	Gap (no core).
SANDSTONE	461.20-473.40	12.20	Grey, fine-medium (upper part), moderately-sorted, medium-pebble (lower part), very poorly-sorted, graded bedding, fining upwards, massive, very hard.
	473.40-476.20	2.80	Gap (no core).
SHALE and SANDSTONE	476.20-480.84	4.64	Interbedded shale and sandstone. Shale (55%), blackish-grey, carbonaceous, coal lamination (5%), brittle. Sandstone (40%), grey, fine, very well-sorted, parallel and cross laminations, carbonaceous, hard.
SANDSTONE	480.84-498.73	17.89	Grey, fine-very coarse (upper part), poorly-sorted, medium-pebble (lower part), very poorly-sorted, mostly massive, graded bedding, fining upwards, parallel lamination, very hard.
SANDSTONE	498.73-515.11	16.38	Grey, fine-granule (upper part), very poorly-sorted, medium-pebble (lower part), very poorly-sorted, fining upwards, mostly massive, parallel lamination, shale fragments, coal lamination (1 cm), mica, very hard.
SANDSTONE	515.11-519.64	4.53	Grey, medium-pebble, very poorly-sorted, massive, graded bedding, fining upwards, coal fragments, very hard.
	519.64-520.70	1.06	Gap (no core).
SILTSTONE	520.70-521.20	0.50	Dark grey, carbonaceous, coal fragments, mica, hard.
SANDSTONE	521.20-529.89	8.69	Grey, fine (upper part), very well-sorted, medium-very coarse (lower part), poorly-sorted, mostly massive, parallel lamination, coal fragments, hard-very hard.
SANDSTONE	529.89-539.70	9.81	Grey, fine-medium (upper part), moderately-well sorted, medium-granule (lower part), very poorly-sorted, mostly massive, graded bedding, parallel lamination, shale lamination (41 cm), plant remains, hard.
SANDSTONE	539.70-545.07	5.37	Dark grey to grey, fine-granule, very poorly-sorted, parallel lamination, massive, hard.
COAL	545.07-545.35	0.28	Seam K, black, fractured, hard-brittle.
SHALE and SANDSTONE	545.35-?		Interlaminated shale and sandstone. Shale (70%), blackish-grey, carbonaceous, coal fragments, brittle. Sandstone (30%), dark grey, fine, very well-sorted, parallel and cross laminations, carbonaceous, hard.

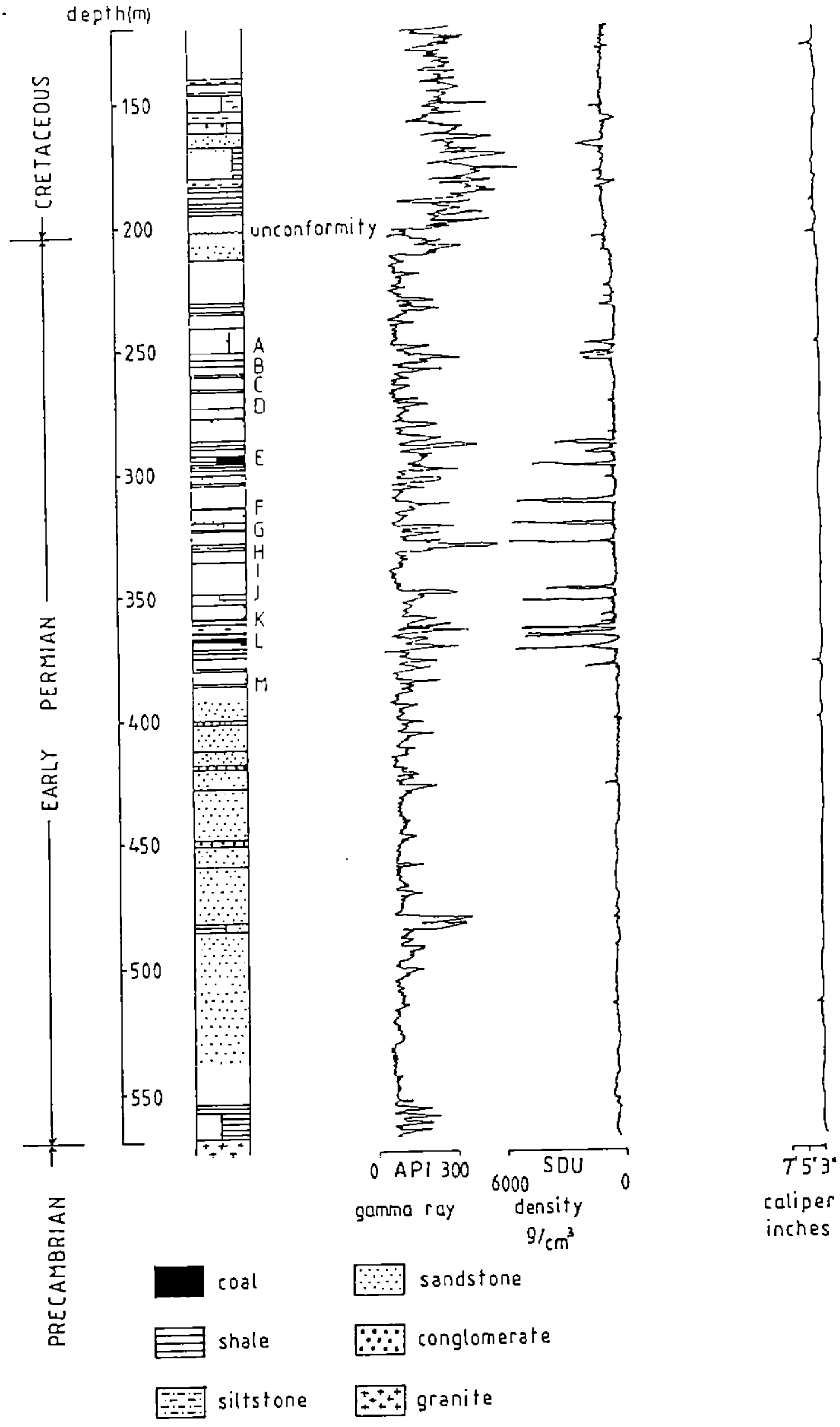


Appendix 1.1.3. Lithology log of RB 3, A to I coal seams, Vasse Shelf, Perth Basin, Western Australia (after CRAE, 1984).

APPENDIX I.1.3. LITHOLOGY LOG OF RB 3, VASSE SHELF, PERTH BASIN, WESTERN AUSTRALIA.

ROCK TYPE	DEPTH RANGE (m)	THICKNESS (m)	DESCRIPTION
SHALE	150.00-150.37	0.37	Dark grey, carbonaceous, brittle-hard.
COAL	150.37-150.55	0.18	Seam A, black, fractured, brittle.
SANDSTONE	150.55-150.62	0.07	Dark grey, very fine, very well-sorted, massive, very hard.
COAL	150.62-150.78	0.16	Seam B, black, fractured, brittle.
SHALE	150.78-151.00	0.22	Dark grey, carbonaceous, coal fragments, brittle.
COAL	151.00-151.60	0.60	Seam C, black, fractured, brittle.
SILTSTONE	151.60-152.04	0.44	Grey, parallel lamination, hard.
SANDSTONE	152.04-153.18	1.14	Yellowish-grey, fine, very well-sorted, parallel, cross and ripple laminations, mica, carbonaceous, load structure, very hard.
	153.18-154.80	1.62	Gap (no core).
SHALE and SANDSTONE	154.80-157.94	3.14	Interbedded shale and sandstone. Shale (70%), blackish-grey, carbonaceous, brittle. Sandstone (30%), yellowish-grey, fine, very well-sorted, mica, parallel and cross laminations, hard.
COAL	157.94-158.10	0.16	Seam D, black, fractured, pyrite, brittle.
SANDSTONE	158.10-169.38	11.28	Yellowish-grey to light-grey, fine-medium (upper part), moderately-sorted, medium-granule (lower part), graded bedding, fining upwards, massive, cross lamination, very hard.
SANDSTONE	169.38-183.42	14.04	Yellowish-grey, fine-medium (upper part), moderately-sorted, coarse-pebble (lower part), very poorly-sorted, graded bedding, parallel and cross laminations, massive, very hard.
	183.42-185.75	2.33	Gap (no core).
SANDSTONE	183.75-191.29	7.54	Yellowish grey to light grey, fine (upper part), very well-sorted, medium-granule (lower part), poorly-sorted, silty, clayey, parallel and cross laminations, brittle-friable.
SANDSTONE	191.29-207.16	15.87	Light grey to greenish grey, coarse-pebble (upper part), very poorly-sorted, medium-pebble (lower part), massive, graded bedding, mica, brittle-hard.
COAL	207.16-208.16	1.00	Seam E, brownish-black, fractured, brittle-hard.
SHALE	208.16-208.67	0.51	Black, coaly, silty, brittle.
SANDSTONE	208.67-212.04	3.37	Brownish-grey, fine-medium (upper part), moderately-sorted, medium-granule (lower part), massive, graded bedding, mica, parallel and cross laminations, very hard.
SHALE	212.04-212.13	0.09	Blackish-grey, carbonaceous, brittle.
COAL	212.13-212.32	0.19	Seam F, brownish-black, fractured, brittle-hard.

SHALE	212.32-212.43	0.11	Blackish-grey, carbonaceous, brittle-soft.
SILTSTONE	212.43-212.62	0.19	Dark grey, carbonaceous, mica, massive, hard.
SANDSTONE	212.62-216.28	3.66	Grey, fine-medium (upper part), moderately to well-sorted, medium-pebble (lower part), very poorly-sorted, parallel and cross laminations, massive, fining upwards, very hard.
SANDSTONE	216.28-230.16	13.88	Light grey to brownish-grey, fine-medium (upper part), moderately to well-sorted, coarse-granule (middle part), very poorly-sorted, coarse-pebble (lower part), very poorly-sorted, fining upwards, mostly massive, graded bedding, parallel and cross laminations, coal streaks (2 cm), carbonaceous, very hard.
SHALE	230.16-231.20	1.04	Blackish-grey, carbonaceous, brittle.
COAL	231.20-232.18	0.98	Seam G, brownish-black, shale band (17 cm), fractured, brittle-hard.
SHALE	232.18-232.38	0.20	Blackish-grey, carbonaceous, brittle.
SILTSTONE	232.38-233.02	0.64	Dark grey, parallel lamination, mica, hard.
SANDSTONE	233.02-238.98	5.96	Grey to brownish-grey, fine-medium (upper part), moderately to well-sorted, medium-pebble (lower part), very poorly-sorted, fining upwards, mostly massive, cross lamination, carbonaceous, mica, very hard.
SHALE	238.98-239.09	0.11	Blackish-grey, carbonaceous, pyrite, brittle.
SANDSTONE	239.09-249.85	10.76	Yellowish-grey, fine-medium (upper part), moderately to well-sorted, coarse-pebble (lower part), very poorly-sorted, fining upwards, mostly massive, cross lamination, mica, very hard.
SANDSTONE	249.85-254.93	5.08	Brownish-grey, fine-coarse (upper part), poorly-sorted, medium-granule (lower part), very poorly-sorted, graded bedding, fining upwards, mostly massive, parallel lamination, carbonaceous, very hard.
SHALE and SANDSTONE	254.93-257.15	2.22	Interbedded shale with sandstone. Shale (70%), blackish-grey, carbonaceous, hard. Sandstone (30%), grey, fine-coarse, poorly-sorted, massive, very hard.
COAL	257.15-257.47	0.32	Seam H, brownish-black, fractured, hard.
SHALE and SANDSTONE	257.47-259.56	2.09	Interlaminated shale and sandstone. Shale (60%), blackish-grey, carbonaceous, pyrite, brittle. Sandstone (40%), dark grey, fine, very well-sorted, parallel and cross lamination, hard-brittle.
COAL	259.56-261.51	1.95	Seam I, black, pyrite, brittle-hard.
SHALE and	261.51-264.48	2.97	Interlaminated shale with sandstone. Shale (70%), blackish-grey, carbonaceous, coal band (8 cm), brittle. Sandstone (30%), dark grey, fine, well-sorted, massive, parallel and cross laminations, carbonaceous, brittle-very hard.



Appendix 1.1.4. Lithology log of CRCH 1, A to M coal seams, Vasse Shelf, Perth Basin, Western Australia (after CRAE, 1984).

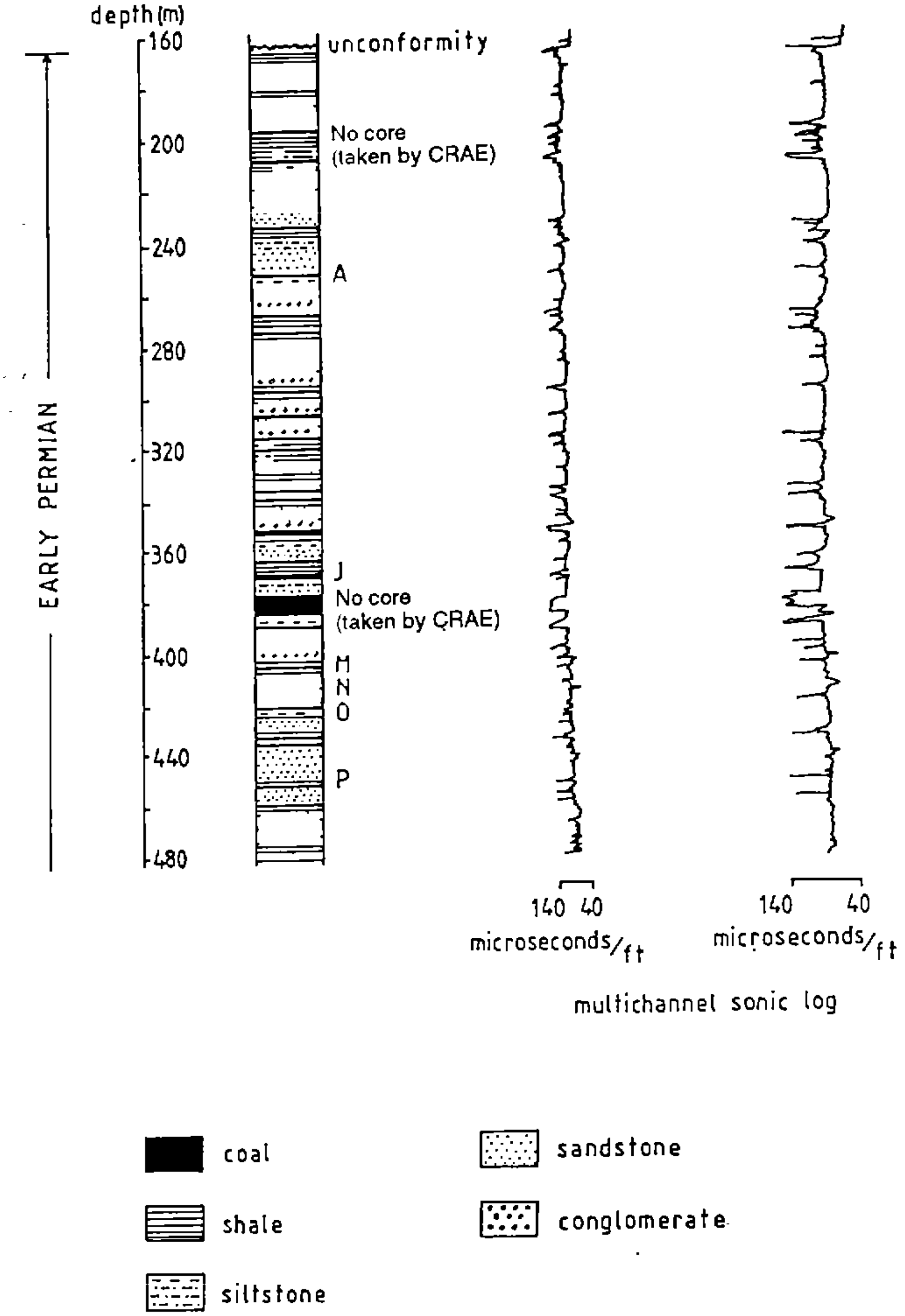
APPENDIX I.1.4. LITHOLOGY LOG OF CRCH 1, VASSE SHELF, PERTH BASIN, WESTERN AUSTRALIA.

ROCK TYPE	DEPTH RANGE (m)	THICKNESS (m)	DESCRIPTION
CONGLOMERATE	200.00-202.50	2.50	Brownish-reddish grey, sub-rounded to rounded, very poorly-sorted, quartz, sandy, brittle-very hard. Unconformity.
SANDSTONE	202.50-213.00	10.50	Light grey to greenish-grey, fine-medium (upper part), moderately to well-sorted, medium-pebble (lower part), very poorly-sorted, graded bedding, fining upwards, kaolinitic, mica, chloritic, massive, parallel lamination, hard-friable.
SANDSTONE	213.00-224.10	11.10	Greenish-grey to brownish-grey, medium-coarse (upper part), moderately-sorted, medium-pebble (lower part), very poorly-sorted, mica, kaolinitic, chloritic, coal lamination (2 cm), massive, parallel lamination, hard-very hard.
SANDSTONE	224.10-231.30	7.20	Light grey to greenish-grey, medium-granule, very poorly-sorted, graded bedding, fining upwards, chloritic, mica, mostly massive, parallel lamination, hard.
SHALE	231.30-231.38	0.08	Blackish-grey, carbonaceous, coal band (5 cm), soft-brittle.
SILTSTONE	231.38-231.90	0.52	Dark to blackish-grey, carbonaceous, parallel and ripple laminations, mica, brittle.
SANDSTONE	231.90-234.20	2.30	Light to dark grey, medium, very well-sorted, parallel and cross lamination, mica, quartz, massive, silty, very hard.
SHALE	234.20-234.70	0.50	Dark to blackish grey, coal streaks, carbonaceous, brittle.
SILTSTONE	234.70-235.40	0.70	Dark grey, carbonaceous, parallel lamination, hard.
SANDSTONE	235.40-240.70	5.30	Dark to light grey, fine-medium (upper part), well-sorted, medium-pebble (lower part), graded bedding, fining upwards, conglomeratic, shaly, parallel and cross lamination, very hard.
SANDSTONE	240.70-250.20	9.50	Light grey, medium-granule, very poorly-sorted, fining upwards, conglomeratic, mainly massive, parallel lamination, very hard.
COAL	250.20-250.50	0.30	Seam A, brownish-black, pyrite, brittle.
SHALE	250.50-251.00	0.50	Blackish-grey, carbonaceous, silty, brittle-hard.
SANDSTONE	251.00-253.70	2.70	Dark to light grey, fine-coarse, poorly-sorted, graded bedding, shaly, parallel and cross laminations, very hard.
COAL	253.70-254.05	0 35	Seam B, brownish-black, pyrite, brittle.
SHALE and SANDSTONE	254.05-255.74	1 69	Interlaminated shale and sandstone. Shale (70%), blackish-grey, carbonaceous, coaly, brittle. Sandstone (30%), grey, fine, very well-sorted, parallel and cross lamination, hard.
COAL	255.74-256.15	0.41	Seam C, brownish-black, pyrite, fractured, brittle.
SANDSTONE	256.15-260.70	4.55	Interbedded sandstone with shale. Sandstone (60%), dark to light grey, fine-coarse,

and SHALE			poorly -sorted, silty, carbonaceous, bioturbation (?), coal band (2 cm), parallel and cross laminations, massive, hard. Shale (40%), blackish-grey, carbonaceous, silty, brittle.
SANDSTONE	260.70-273.00	12.30	Brownish-grey to grey, medium-coarse (upper part), poorly-sorted, medium-granule (middle part), very poorly-sorted, medium-pebble (lower part), very poorly-sorted, fining upwards, shaly, coal lamination (2 cm), mica, carbonaceous, kaolinitic, mostly massive, parallel lamination, hard.
SANDSTONE	273.00-281.12	8.12	Brownish-grey to blackish-grey, medium-coarse (upper part), moderately-sorted, medium-pebble (lower part), very poorly-sorted, bioturbation (?), coal band (7 cm), conglomeratic, mostly massive, parallel lamination, very hard.
SANDSTONE	281.12-285.73	4.61	Brownish-grey, fine-coarse (upper part), moderately-sorted, medium-very coarse (lower part), poorly-sorted, fining upwards, parallel and cross laminations, massive, hard.
SHALE	285.73-287.80	2.07	Blackish-grey, silty, carbonaceous, brittle.
SILTSTONE	287.80-288.40	0.60	Dark grey, clayey, parallel and cross laminations, carbonaceous, hard.
SANDSTONE	288.40-289.45	1.05	Brownish-grey, medium-coarse, moderately-sorted, massive, very hard.
COAL	289.45-289.86	0.41	Seam D, black, hard.
SANDSTONE and SHALE	289.86-292.68	2.82	Interbedded sandstone and shale. Sandstone (60%), dark grey, fine, well-sorted, parallel lamination, carbonaceous, hard. Shale (35%), blackish-grey, carbonaceous, coal band (14 cm), brittle.
COAL	292.68-293.00	0.32	Seam E, black, brittle-hard.
SHALE and SANDSTONE	293.00-297.73	4.73	Interbedded shale and sandstone. Shale (60%), blackish-grey, carbonaceous, coal streaks, brittle. Sandstone (40%), grey to yellowish-grey, fine, well-sorted, mica, parallel and cross laminations, hard.
COAL	297.73-298.63	0.90	Seam F, black, pyrite, fractured, brittle.
SANDSTONE, SHALE and COAL	298.63-305.00	6.37	Interbedded sandstone with shale and coal. Sandstone (50%), brownish-grey to grey, fine, very well-sorted, coal fragments, parallel and cross laminations, hard. Shale (45%), blackish-grey, carbonaceous, pyrite, coal streaks, brittle. Coal (5%), black, fractured, hard-brittle.
SANDSTONE	305.00-312.98	7.98	Light grey, fine-medium (upper part), moderately-sorted, medium-granule (lower part), very poorly-sorted, graded bedding, fining upwards, parallel and cross laminations, massive, very hard.
COAL	312.98-313.86	0.88	Seam G, brownish-black, pyrite, brittle-hard.
SHALE and SANDSTONE	313.86-314.50	0.64	Interlaminated shale with sandstone. Shale (60%), blackish-grey, carbonaceous, brittle. Sandstone (40%), yellowish-grey, fine, very well-sorted, parallel to cross laminations, very hard.
SANDSTONE	314.50-322.02	7.52	Light grey, light grey to grey, fine-medium (upper part), moderately-sorted, medium-granule (lower), very poorly-sorted, conglomeratic, fining upwards, massive, very hard.

COAL	322.02-323.02	1.00	Seam H, black, fractured, brittle-hard.
SHALE	323.02-323.60	0.58	Blackish-grey, carbonaceous, hard.
SANDSTONE	323.60-328.64	5.04	Light grey, medium-pebble, very poorly-sorted, graded bedding, fining upwards, conglomeratic, parallel and cross lamination, very hard.
SHALE and SANDSTONE	328.64-329.63	0.99	Interlaminated shale with sandstone. Shale (60%), blackish-grey, carbonaceous, brittle. Sandstone (40%), grey, fine-medium, moderately-sorted, parallel lamination, very hard.
COAL	329.63-330.27	0.64	Seam I, brownish-grey, pyrite, brittle-hard.
SHALE	330.27-331.45	0.18	Blackish-grey, carbonaceous, sandy, hard.
SANDSTONE	331.45-336.22	4.77	Dark to light grey, fine (upper part), very well-sorted, medium-granule (lower part), graded bedding, bioturbation (?), massive, parallel and cross laminations, conglomeratic, very hard.
COAL	336.22-336.33	0.11	Black, pyrite, hard.
SANDSTONE	336.33-348.52	12.19	Dark to light grey, fine-medium (upper part), moderately-sorted, medium-granule (lower part), very poorly-sorted, graded bedding, fining upwards, conglomeratic, carbonaceous, coal streaks, massive, parallel and cross laminations, very hard.
COAL	348.52-349.32	0.80	Seam J, black, pyrite, hard-brittle.
SHALE	349.32-349.43	0.11	Blackish-grey, carbonaceous, coaly, brittle.
SANDSTONE	349.43-352.90	3.47	Dark to light grey, fine, very well-sorted, silty, parallel and cross laminations, hard.
SHALE	352.90-353.00	0.10	Blackish-grey, coaly, hard.
COAL	353.00-353.36	0.36	Seam K, black, hard.
SHALE	353.36-353.56	0.20	Blackish-grey, carbonaceous, hard.
SANDSTONE	353.56-356.00	2.44	Light grey, fine-medium, moderately to well-sorted, parallel and cross laminations, hard.
SANDSTONE	356.00-358.86	2.86	Light grey, fine-medium, moderately-sorted, massive, hard.
SHALE	358.86-359.22	0.36	Blackish-grey, carbonaceous, coal band (6 cm), brittle.
SANDSTONE and SHALE	359.22-361.70	2.48	Interlaminated sandstone with shale. Sandstone (60%), dark grey, fine, well-sorted, parallel and cross laminations, carbonaceous, hard. Shale (40%), blackish-grey, carbonaceous, brittle.
COAL	361.70-361.83	0.13	Brownish-black, fractured, brittle-hard.
SHALE	361.83-362.50	0.67	Dark grey, sandy, carbonaceous, brittle.
SANDSTONE	362.50-363.47	0.97	Grey, very fine, very well-sorted, cross lamination, hard.
COAL	363.47-363.60	0.13	Black, fractured, pyrite, brittle.
SANDSTONE	363.60-363.72	0.12	Light grey, fine-very coarse, poorly-sorted, massive, very hard.
	363.72-368.38	4.66	Gap (no core).

SHALE and SANDSTONE	368.38-371.60	3.22	Interlaminated shale with sandstone. Shale (60%), blackish-grey, carbonaceous, coaly, pyrite, sandy, brittle Sandstone (40%), grey, fine, well-sorted, parallel and cross laminations, hard
COAL	371.60-372.55	095	Seam L, brownish-black, pyrite, hard-brittle.
SHALE	372.55-372.69	0.14	Blackish-grey, coaly, carbonaceous, sandy, brittle.
SANDSTONE	372.69-378.66	5.97	Light grey, medium-granule, very poorly-sorted, graded bedding, fining upwards, parallel and cross laminations (upper part), massive (lower part), very hard.
SHALE	378.66-378.77	0.11	Dark grey, carbonaceous, pyrite, brittle.
COAL	378.77-379.00	0.23	Seam M, brownish-black, hard.
SHALE	379.00-379.50	0.50	Blackish-grey, carbonaceous, brittle.
SANDSTONE	379.50-384.94	5.44	Light grey, fine-granule, very poorly-sorted, graded bedding, fining upwards, conglomeratic, coal streaks, cross lamination, very hard.
SHALE	384.94-385.12	0.18	Dark grey, silty, carbonaceous, brittle.
SILTSTONE	385.12-385.87	0.75	Dark grey, ripple, cross and parallel laminations, carbonaceous, hard.
SANDSTONE	385.87-401.31	15.44	Light grey to brownish-grey, fine-medium (upper part), moderately-sorted, medium-granule (lower part), very poorly-sorted, coal fragments, conglomeratic, mostly massive, fining upwards, parallel, cross and ripple laminations, very hard.
SANDSTONE	401.31-413.00	11.61	Grey to dark grey, fine-very coarse (upper part), poorly-sorted, medium-granule (lower part), coal fragments, conglomeratic, mostly massive, graded bedding, fining upwards, coal streaks, parallel lamination, very hard.
SANDSTONE	413.00-427.76	14.76	Light grey, fine-very coarse (upper part), poorly-sorted, medium-granule (lower part), very poorly-sorted, massive, coal fragments, coal band (5 cm), conglomeratic, very hard.
COAL	427.76-427.97	0.21	Brownish-black, fractured, brittle.
SHALE	427.97-428.00	0.03	Blackish-grey, carbonaceous, brittle.
SILTSTONE	428.00-428.20	0.20	Dark grey, carbonaceous, pyrite, parallel lamination, brittle.
SANDSTONE	428.20-442.00	13.8	Dark grey to brownish-grey, fine (upper part), very well-sorted, medium-coarse (lower part), moderately-sorted, graded bedding, fining upwards, coal lamination (1 cm), carbonaceous, parallel lamination, very hard.



Appendix 1.1.5. Lithology log of CRCH 2, A, J, M, N, O and P coal seams, Vasse Shelf, Perth Basin, Western Australia (after CRAE, 1984).

APPENDIX I.1.5. LITHOLOGY LOG OF CRCH 2, VASSE SHELF, PERTH BASIN, WESTERN AUSTRALIA.

ROCK TYPE	DEPTH RANGE (m)	THICKNESS (m)	DESCRIPTION
SANDSTONE	153.00-158.05	5.05	Interbedded sandstone and shale. Sandstone (60%), grey, fine, very well-sorted, mostly massive, parallel lamination, coal fragments, hard. Shale (40%), blackish-grey, carbonaceous, coal fragments, brittle.
SANDSTONE	158.05-166.65	8.60	Brownish-grey to greenish-grey, fine-medium (upper part), moderately to well sorted, medium-granule (lower part), very poorly-sorted, shaly, mostly massive, graded bedding, fining upwards, parallel lamination, chloritic, very hard.
SANDSTONE	166.65-168.40	1.75	Greenish-grey to yellowish-grey, medium, very well-sorted, coal and shale fragments, massive, hard.
SHALE	168.40-170.10	1.70	Blackish-grey, coal fragments, carbonaceous, sandy, brittle.
SANDSTONE	170.10-182.65	12.55	Grey to pinkish-grey, fine-coarse (upper part), poorly-sorted, medium-granule (lower part), graded bedding, fining upwards, massive, parallel and cross laminations, very hard.
COAL and SHALE	182.65-182.87	0.22	Interlaminated coal and shale. Coal (60%), brownish-black, brittle. Shale (40%), blackish-grey, carbonaceous, coal fragments, brittle.
SANDSTONE	182.87-184.40	1.53	Grey, coarse-pebble, very poorly-sorted, shale fragments, massive, hard.
SANDSTONE	184.40-197.67	13.27	Grey to pinkish-grey, fine (upper part), very well-sorted, medium-granule (lower part), very poorly-sorted, graded bedding, fining upwards, shale and coal fragments, massive, very hard.
	197.67-198.42	0.75	Gap (no core).
SHALE, SANDSTONE and COAL	198.42-209.07	10.65	Interlaminated shale with sandstone and coal. Shale (50%), blackish-grey, carbonaceous, coal fragments, brittle. Sandstone (40%), grey, fine, very well-sorted, parallel and cross laminations, coal fragments, hard. Coal (10%), 1 cm to 9 cm, black, pyrite, brittle.
	209.07-210.84	1.77	Gap (no core).
SHALE and SANDSTONE	210.84-213.70	2.86	Interlaminated shale with sandstone. Shale (60%), blackish-grey, carbonaceous, coal fragments, brittle. Sandstone (40%), dark grey, fine, very well-sorted, parallel and cross laminations, hard.
SANDSTONE	213.70-228.10	14.40	Grey, fine-medium, moderately-sorted, fining upwards, coal and shale fragments, mostly massive, parallel lamination, coal band (3 cm), hard.
SANDSTONE	228.10-234.83	6.73	Grey, fine-very coarse, very poorly-sorted, graded bedding, fining upwards, mostly massive, parallel lamination, very hard.

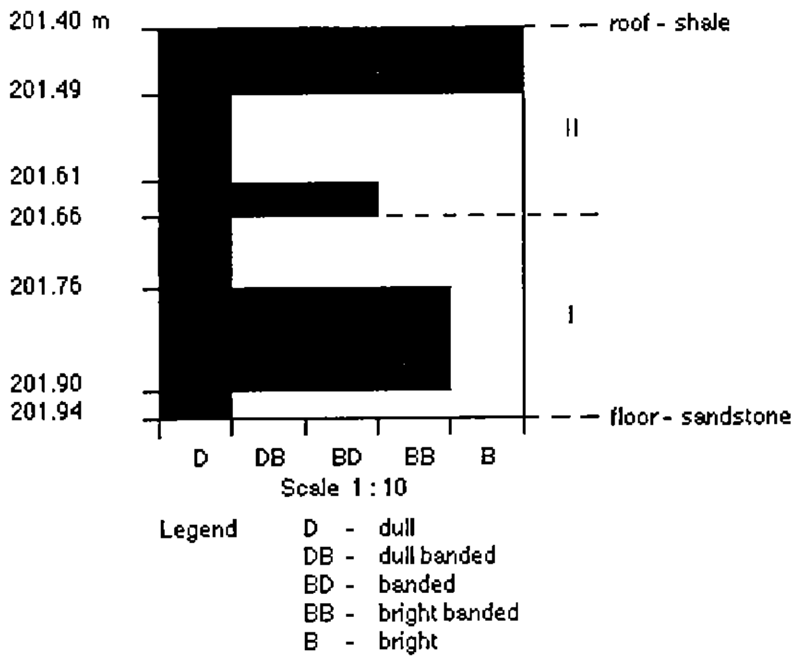
SHALE, SANDSTONE and COAL	234.83-243.80	8.97	Interbedded shale with sandstone and coal. Shale (50%), blackish-grey, carbonaceous, coal fragments, brittle. Sandstone (40%), grey, fine, very well-sorted, massive, parallel lamination, hard. Coal (10%), 3 cm to 9 cm, brownish-black, brittle.
SILTSTONE	243.80-244.33	0.53	Dark grey, massive, hard.
SANDSTONE	244.33-252.76	8.43	Grey, fine-very coarse (upper part), poorly-sorted, medium-granule (lower part), graded bedding, massive, parallel lamination, shaly, hard.
COAL	252.76-253.02	0.26	Seam A, brownish-black, pyrite, brittle.
SILTSTONE	253.02-253.32	0.30	Dark grey, carbonaceous, massive, hard.
SANDSTONE	253.32-269.69	16.37	Grey to greenish-grey, fine-very coarse (upper part), poorly-sorted, medium-granule (middle part), very poorly-sorted, coarse-pebble (lower part), very poorly-sorted, fining upwards, mostly massive, graded bedding, parallel lamination, coal fragments, very hard.
	269.69-270.23	0.54	Gap (no core).
SHALE and SANDSTONE	270.23-276.99	6.76	Interlaminated shale and sandstone. Shale (60%), blackish-grey, carbonaceous, mica, pyrite, coal band (8 cm), brittle. Sandstone (40%), dark grey, fine, well-sorted, massive, parallel lamination, hard.
	276.99-277.70	0.71	Gap (no core).
SHALE and SANDSTONE	277.70-279.34	1.64	Interlaminated shale with sandstone. Shale (60%), blackish-grey, carbonaceous, brittle. Sandstone (40%), grey, fine, well-sorted, massive, parallel lamination, hard.
SANDSTONE	279.34-284.55	5.21	Light grey, fine (upper part), well-sorted, medium-very coarse (lower part), poorly-sorted, graded bedding, fining upwards, massive, shaly, very hard.
SHALE	284.55-284.70	0.15	Blackish-grey, carbonaceous, coal fragments, brittle.
SANDSTONE	284.70-288.03	3.33	Grey, medium-pebble, very poorly-sorted, graded bedding, fining upwards, shale fragments, massive, very hard.
SHALE and SANDSTONE	288.03-289.03	1.00	Interlaminated shale and sandstone. Shale (60%), blackish-grey, carbonaceous, brittle. Sandstone (40%), dark grey, fine, well-sorted, massive, hard.
SANDSTONE	289.03-299.13	10.10	Grey, medium-pebble, very poorly-sorted, graded bedding, fining upwards, shale fragments, mica, very hard.
	299.13-299.72	0.59	Gap (no core).
SHALE	299.72-300.80	1.08	Blackish-grey, carbonaceous, brittle.
SANDSTONE	300.80-308.46	7.66	Grey, medium (upper part), very well-sorted, medium-pebble (lower part), very poorly-sorted, conglomeratic, graded bedding, fining upwards, mostly massive, parallel lamination, hard.
SANDSTONE	308.46-317.36	8.90	Grey, fine-granule, very poorly-sorted, graded bedding, fining upwards, shaly, massive, very hard.
	317.36-318.04	0.68	Gap (no core).
SANDSTONE	318.04-323.96	5.92	Interbedded sandstone with shale. Sandstone (70%), grey, fine, very well-sorted,

and SHALE			parallel lamination, hard. Shale (40%), blackish-grey, carbonaceous, coal fragments, brittle.
SANDSTONE	323.96-331.75	7.79	Grey, medium-coarse (upper part), poorly-sorted, medium-granule (lower part), very poorly-sorted, graded bedding, fining upwards, mostly massive, parallel lamination, carbonaceous, very hard.
SHALE	331.75-332.05	0.30	Blackish-grey, carbonaceous, coal fragments, plant remains, mica, brittle.
SANDSTONE	332.05-334.12	2.07	Grey, medium-pebble, very poorly-sorted, conglomeratic, graded bedding, fining upwards, massive, very hard.
SANDSTONE	334.12-337.34	3.22	Grey, medium (upper part), very well-sorted, medium-granule (lower part), very poorly-sorted, graded bedding, fining upwards, shale fragments, mica, mostly massive, parallel lamination, very hard.
	337.34-338.31	0.97	Gap (no core).
SHALE and SANDSTONE	338.31-340.66	2.35	Interlaminated shale with sandstone. Shale (60%), blackish-grey, carbonaceous, brittle. Sandstone (40%), grey, fine, very well-sorted, parallel lamination, hard.
	340.66-341.86	1.20	Gap (no core).
SANDSTONE and SHALE	341.86-343.93	2.07	Interlaminated sandstone with shale. Sandstone (60%), grey, fine, very well-sorted, parallel lamination, hard. Shale (40%), blackish-grey, coaly, coal band (8 cm), brittle.
SANDSTONE	343.93-354.47	10.54	Grey, fine-granule (upper part), very poorly-sorted, medium-pebble (lower part), very poorly-sorted, graded bedding, fining upwards, massive, parallel and cross laminations, very hard.
	354.47-355.70	1.23	Gap (no core).
SILTSTONE	355.70-358.03	2.33	Blackish-grey, carbonaceous, massive, hard.
SANDSTONE	358.03-366.93	8.90	Grey, fine-very coarse (upper part), poorly-sorted, medium-granule, very poorly-sorted, graded bedding, fining upwards, mostly massive, parallel lamination, coal lamination (2 mm), conglomeratic, very hard.
SANDSTONE and SHALE	366.93-371.62	4.69	Interbedded sandstone with shale. Sandstone (70%), grey to dark grey, fine-medium (upper part), moderately-sorted, coarse (lower part), well-sorted, parallel, cross and ripple laminations, massive, hard. Shale (30%), blackish-grey, carbonaceous, coal fragments, coal band (4 cm), brittle.
	371.62-372.99	1.37	Gap (no core).
SILTSTONE	372.99-374.80	1.81	Dark grey, parallel lamination, carbonaceous, hard.
SANDSTONE	374.80-381.20	6.40	Grey, medium-granule (upper part), very poorly-sorted, medium-pebble (lower part), very poorly-sorted, graded bedding, fining upwards, mostly massive, parallel and cross laminations, shale fragments, very hard.
COAL	381.20-381.45	0.25	Seam J, brownish-black, pyrite, brittle.
SHALE	381.45-381.88	0.43	Blackish-grey, carbonaceous, brittle-soft.
	381.88-386.62	4.74	Gap (no core).

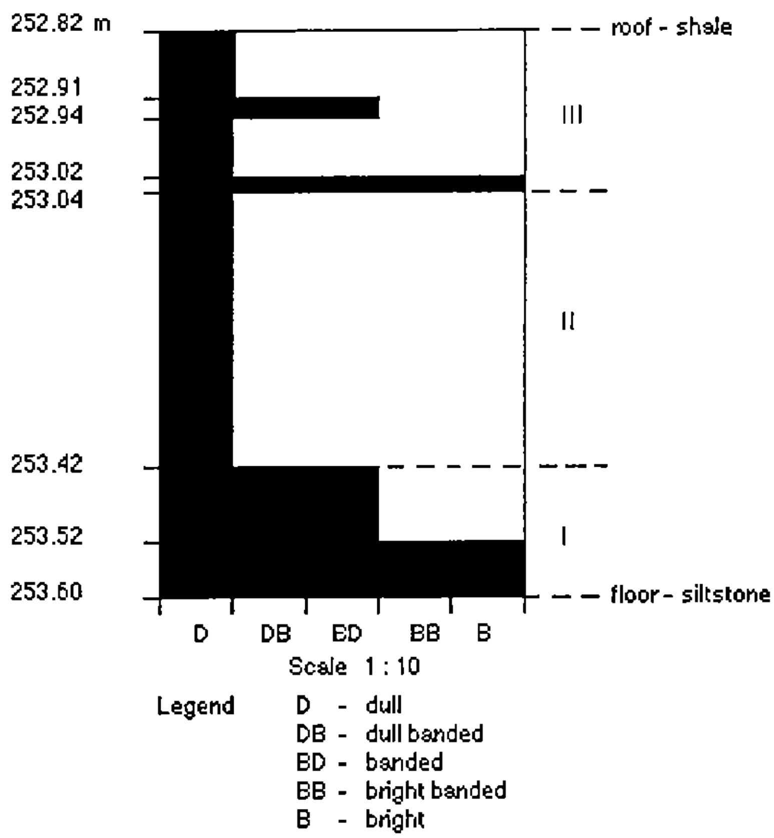
SILTSTONE	386.62-387.80	1.18	Dark grey, carbonaceous, parallel lamination, hard.
SANDSTONE and SHALE	387.80-391.00	3.20	Interlaminated sandstone and shale. Sandstone (60%), dark grey, fine, very well-sorted, massive, parallel lamination, hard. Shale (40%), blackish-grey, carbonaceous, brittle.
	391.00-393.04	2.04	Gap (no core).
SANDSTONE	393.04-399.62	6.58	Grey to dark grey, fine (upper part), very well-sorted, coarse-pebble (lower part), very poorly-sorted, graded bedding, fining upwards, massive, parallel lamination, carbonaceous, very hard.
SHALE	399.62-399.78	0.16	Dark grey, carbonaceous, brittle.
COAL	399.78-400.00	0.22	Seam M, brownish-black, pyrite, brittle-hard.
SHALE	400.00-400.21	0.21	Blackish-grey, carbonaceous, sandy, coal fragments, brittle.
SANDSTONE	400.21-402.23	2.02	Grey, medium, very well-sorted, parallel lamination, carbonaceous, hard.
COAL and SHALE	402.23-402.53	0.30	Interlaminated coal with shale. Seam N (65%), black, brittle-hard. Shale (35%), blackish-grey, carbonaceous, brittle.
SANDSTONE	402.53-407.26	4.73	Grey, medium (upper part), very well-sorted, medium-coarse (lower part), poorly-sorted, graded bedding, fining upwards, massive, parallel laminated, very hard.
SHALE and SANDSTONE	407.26-408.15	0.89	Interlaminated shale with sandstone. Shale (60%), blackish-grey, carbonaceous, coal fragments, brittle. Sandstone (40%), fine, very well-sorted, massive, hard.
SANDSTONE	408.15-420.85	12.70	Grey to dark grey, fine (upper part), very well-sorted, coarse (middle part), well-sorted, medium-granule (lower part), graded bedding, fining upwards, massive, parallel and cross laminations, coal fragments, very hard.
COAL	420.85-421.10	0.25	Seam O, brownish-black, pyrite, hard.
SHALE	421.10-421.40	0.30	Blackish-grey, carbonaceous, silty, brittle.
SANDSTONE	421.40-433.55	12.15	Grey, medium (upper part), very well-sorted, medium-very coarse (middle part), poorly-sorted, medium-granule (lower part), very poorly-sorted, graded bedding, fining upwards, massive, parallel lamination, shale fragments, very hard.
SHALE, SANDSTONE and COAL	433.55-436.82	3.27	Interlaminated shale with sandstone and coal. Shale (50%), blackish-grey, carbonaceous, brittle. Sandstone (45%), grey, medium, well-sorted, massive, hard. Coal (5 cm and 6 cm), black, brittle.
SANDSTONE	436.82-452.31	15.49	Grey, fine-coarse (upper part), poorly-sorted, medium-granule (middle part), very poorly-sorted, coarse-pebble (lower part), very poorly-sorted, graded bedding, fining upwards, conglomeratic, coal and shale fragments, coal streaks, massive, parallel lamination, very hard.
SHALE	452.31-452.36	0.05	Blackish-grey, carbonaceous, brittle.
COAL	452.36-452.81	0.45	Seam P, brownish-black, hard.
SANDSTONE	452.81-459.41	6.60	Purple-grey to grey, fine, very well-sorted, mostly massive, parallel lamination, shale fragments, hard.

SHALE	459.41-459.51	0.10	Blackish-grey, carbonaceous, coal band (4 cm), brittle.
SANDSTONE	459.51-470.00	10.49	Grey, fine-coarse (upper part), poorly-sorted, fine-very coarse (lower part), poorly-sorted, graded bedding, fining upwards, mostly massive, parallel and cross laminations, very hard.
SANDSTONE	470.00-481.95	11.95	Grey, fine-coarse (upper part), poorly-sorted, fine-granule (lower part), very poorly-sorted, graded bedding, fining upwards, shale fragments, mostly massive, parallel lamination, very hard.
SANDSTONE and SHALE	481.95-483.00	1.05	Interlaminated sandstone and shale. Sandstone (60%), dark grey, fine-medium, moderately-sorted, parallel and cross lamination, carbonaceous, hard. Shale (40%), dark grey, carbonaceous, brittle.
SANDSTONE	483.00-485.00	2.00	Grey, medium, very well-sorted, massive, very hard.

APPENDIX I.2. Lithotype profile of coal seams, Vasse Shelf, Perth Basin, Western Australia.



Appendix I.2.1. Lithotype profile of seam A, RBCH 5, Vasse Shelf, Western Australia.



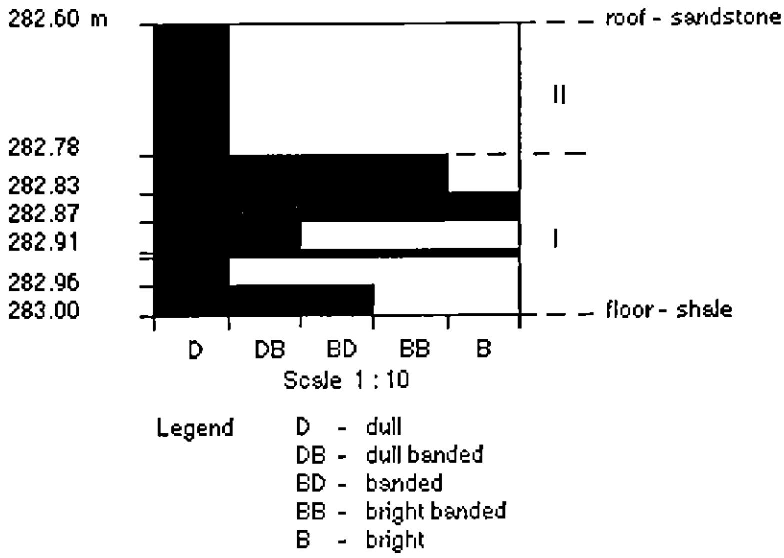
Appendix I.2.2. Lithotype profile of seam B, RBCH 5, Vasse Shelf, Western Australia.

Lithotype log of seam A, RBCH 5, Vasse Shelf, Western Australia.

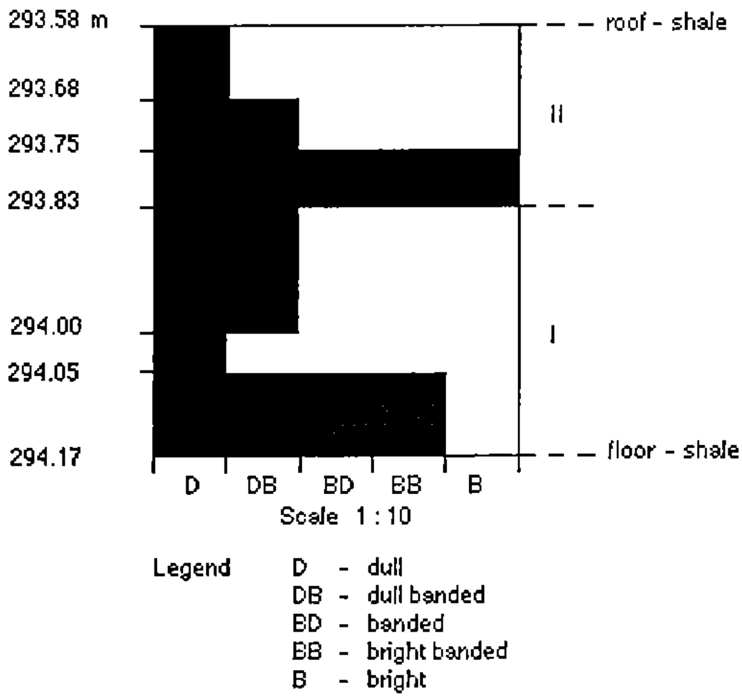
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.09	201.49	B
	0.12	201.61	D
	0.05	201.66	BD
	0.10	201.76	D
	0.14	201.90	BB
	0.04	201.94	D
Sandstone		Floor	

Lithotype log of seam B, RBCH 5, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.09	252.91	D
	0.03	252.94	BD
	0.08	253.02	D
	0.02	253.04	B
	0.38	253.42	D
	0.10	253.52	BD
	0.08	253.60	B
Siltstone		Floor	



Appendix I.2.3. Lithotype profile of seam C, RBCH 5, Vasse Shelf, Western Australia.



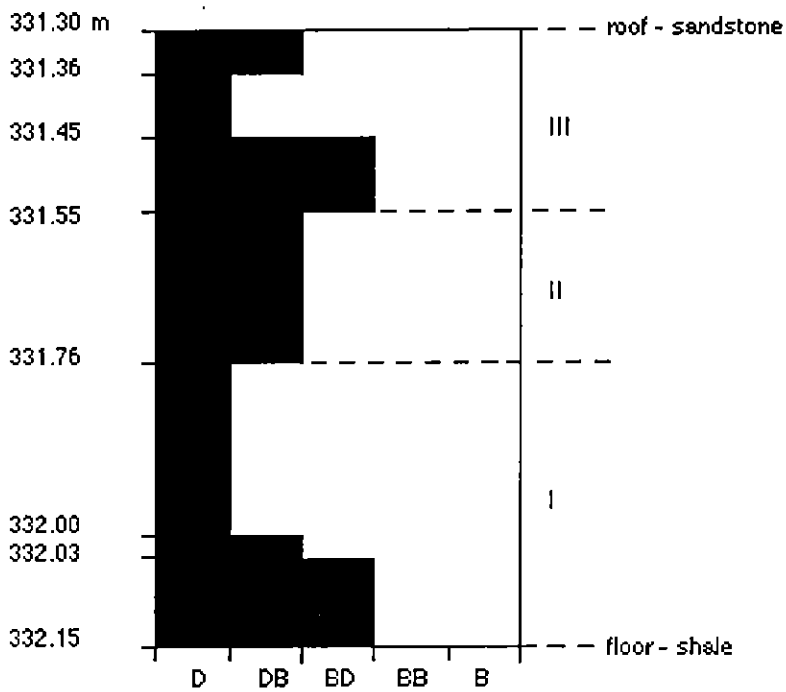
Appendix I.2.4. Lithotype profile of seam D, RBCH 5, Vasse Shelf, Western Australia.

Lithotype log of seam C, RBCH 5, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.18	282.78	D
	0.05	282.83	BB
	0.04	282.87	B
	0.04	282.91	DB
	0.05	282.96	D
	0.04	283.00	BD
Shale		Floor	

Lithotype log of seam D, RBCH 5, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.10	293.68	D
	0.07	293.75	DB
	0.08	293.83	B
	0.17	294.00	DB
	0.05	294.05	D
	0.12	294.17	BB
Shale		Floor	



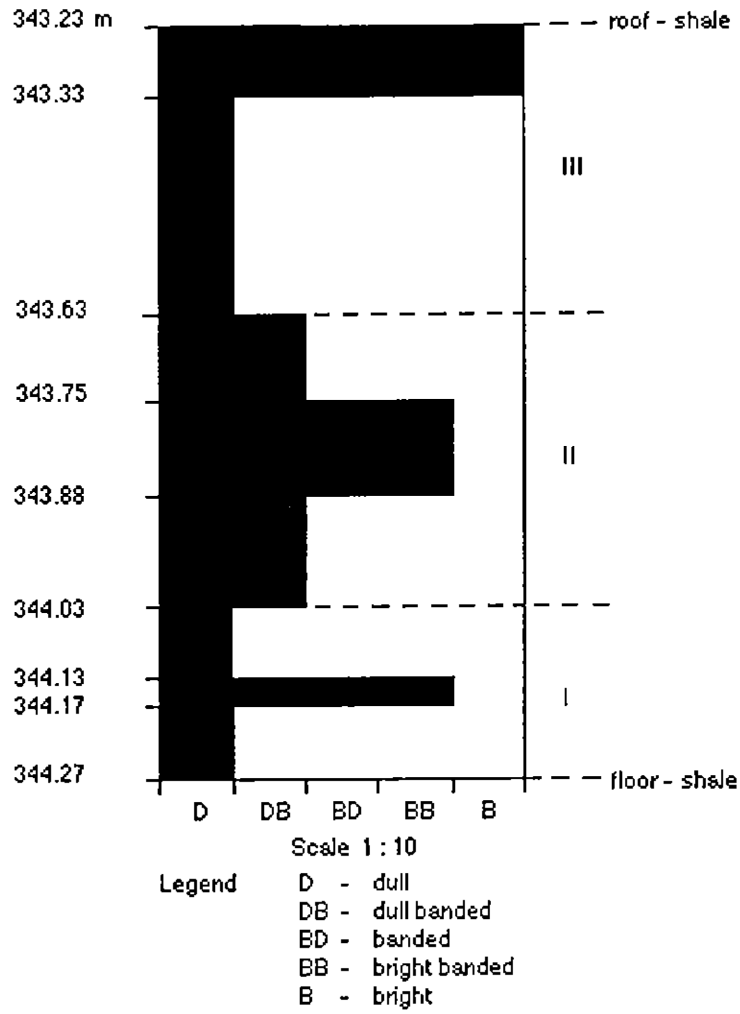
Scale 1 : 10

Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

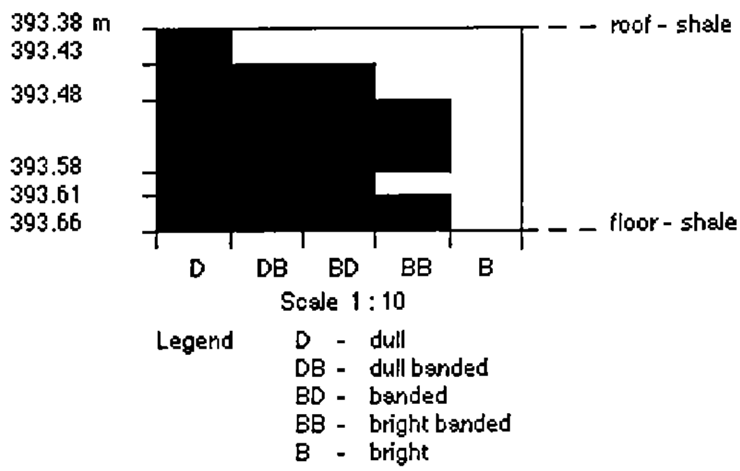
Appendix I.2.5. Lithotype profile of seam E, RBCH 5, Vasse Shelf, Western Australia.

Lithotype log of seam E, RBCH 5, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.06	331.36	DB
	0.09	331.45	D
	0.10	331.55	BD
	0.21	331.76	DB
	0.24	332.00	D
	0.03	332.03	DB
	0.12	332.15	BD
Shale		Floor	



Appendix I.2.6. Lithotype profile of seam F, RBCH 5, Vasse Shelf, Western Australia.



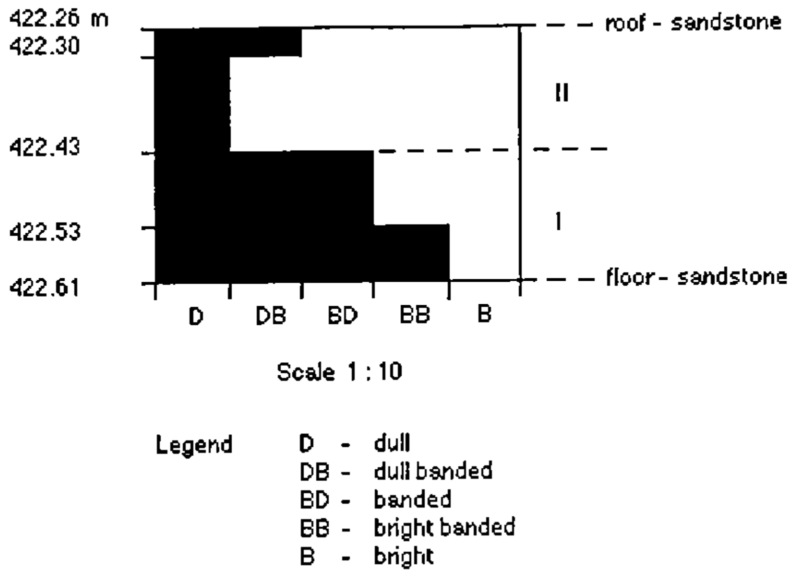
Appendix I.2.7. Lithotype profile of seam G, RBCH 5, Vasse Shelf, Western Australia.

Lithotype log of seam F, RBCH 5, Vasse Shelf, Western Australia.

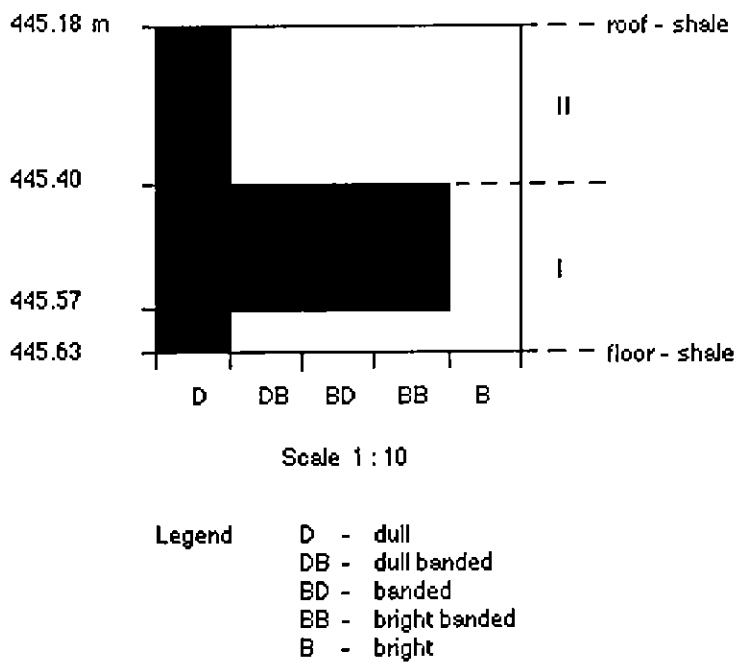
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.10	343.33	B
	0.30	343.63	D
	0.12	343.75	DB
	0.13	343.88	BB
	0.15	344.03	DB
	0.10	344.13	D
	0.04	344.17	BB
	0.10	344.27	D
Shale		Floor	

Lithotype log of seam G, RBCH 5, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.05	393.43	D
	0.05	393.48	BD
	0.10	393.58	BB
	0.03	393.61	BD
	0.05	393.66	BB
Shale		Floor	



Appendix I.2.8. Lithotype profile of seam H, RBCH 5, Vasse Shelf, Western Australia.



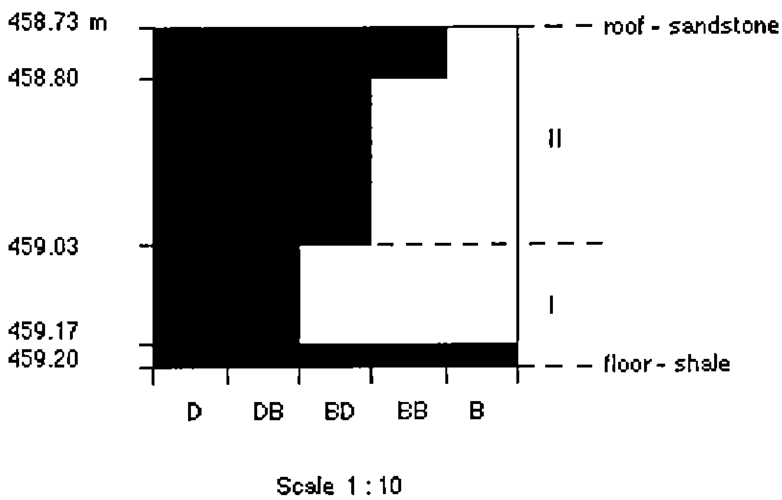
Appendix I.2.9. Lithotype profile of seam I, RBCH 5, Western Australia.

Lithotype log of seam H, RBCH 5, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.04	422.30	DB
	0.13	422.43	D
	0.10	422.53	BD
	0.08	422.61	BB
Sandstone		Floor	

Lithotype log of seam I, RBCH 5, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.22	445.40	D
	0.17	445.57	BB
	0.06	44563	D
Shale		Floor	

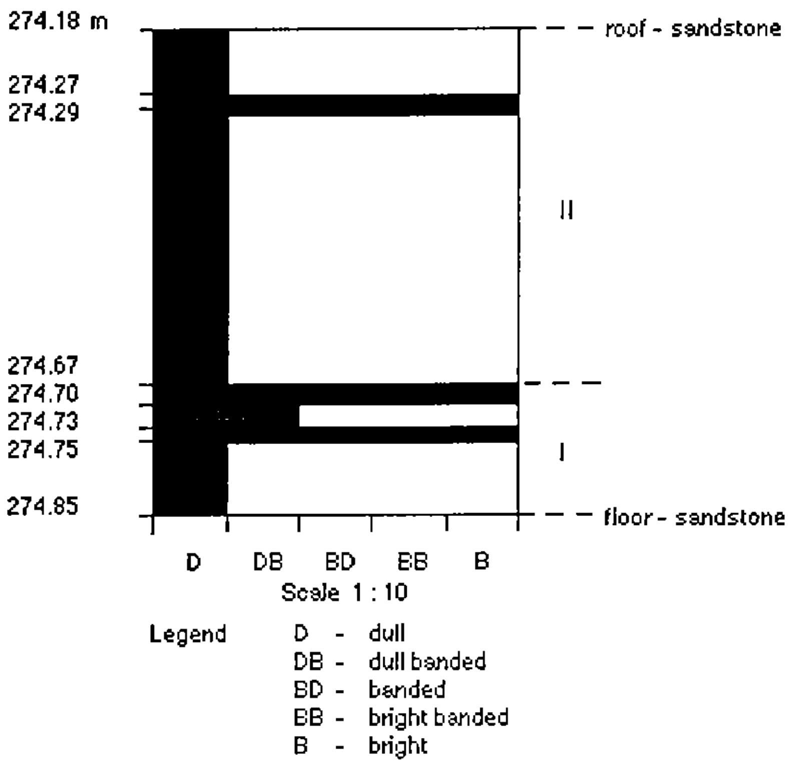


Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

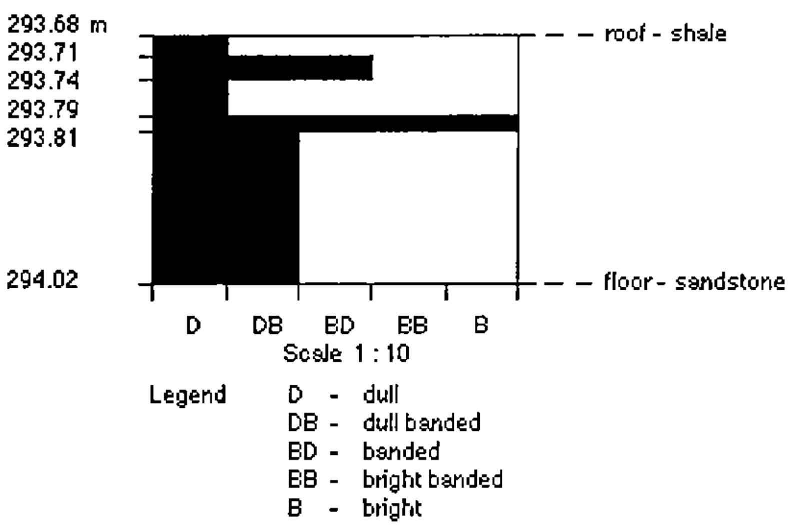
Appendix I.2.10. Lithotype profile of seam J, RBCH 5, Vasse Shelf, Western Australia.

Lithotype log of seam J, RBCH 5, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.07	458.80	BB
	0.23	459.03	BD
	0.14	459.17	DB
	0.03	459.20	B
Shale		Floor	



Appendix I.2.11. Lithotype profile of seam A, RBCH 6, Vasse Shelf, Western Australia.



Appendix I.2.12. Lithotype profile of seam B, RBCH 6, Vasse Shelf, Western Australia.

Lithotype log of seam A, RBCH 6, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.09	274.27	D
	0.02	274.29	B
	0.38	274.67	D
	0.03	274.70	B
	0.03	274.73	DB
	0.02	274.75	B
	0.10	274.85	D
Sandstone		Floor	

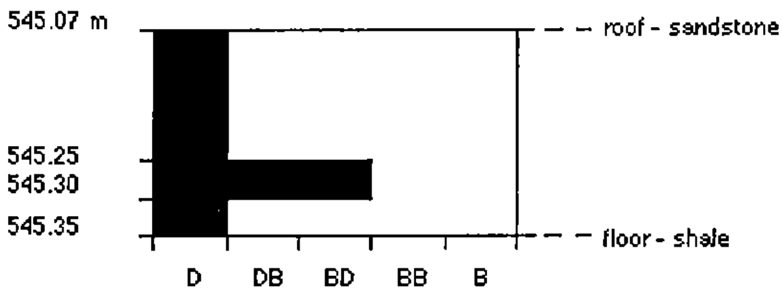
Lithotype log of seam B, RBCH 6, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.03	293.71	D
	0.03	293.74	BD
	0.05	293.79	D
	0.02	293.81	B
	0.21	294.02	DB
Sandstone		Floor	

Scale 1 : 10

Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.13. Lithotype profile of seam G, RBCH 6, Vasse Shelf, Western Australia.



Scale 1 : 10

Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.14. Lithotype profile of seam K, RBCH 6, Vasse Shelf, Western Australia.

Lithotype log of seam G, RBCH 6, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.10	378.90	DB
	0.07	378.97	BD
	0.05	379.02	D
Shale		Floor	

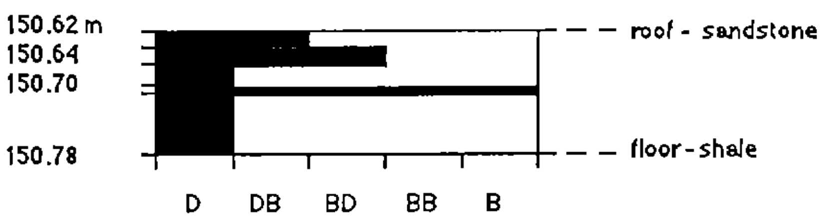
Lithotype log of seam K, RBCH 6, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.18	545.25	D
	0.05	545.30	BD
	0.05	545.35	D
Shale		Floor	

Scale 1: 10

Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.15. Lithotype profile of seam A, RB 3, Vasse Shelf, Western Australia.



Scale 1 : 10

Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

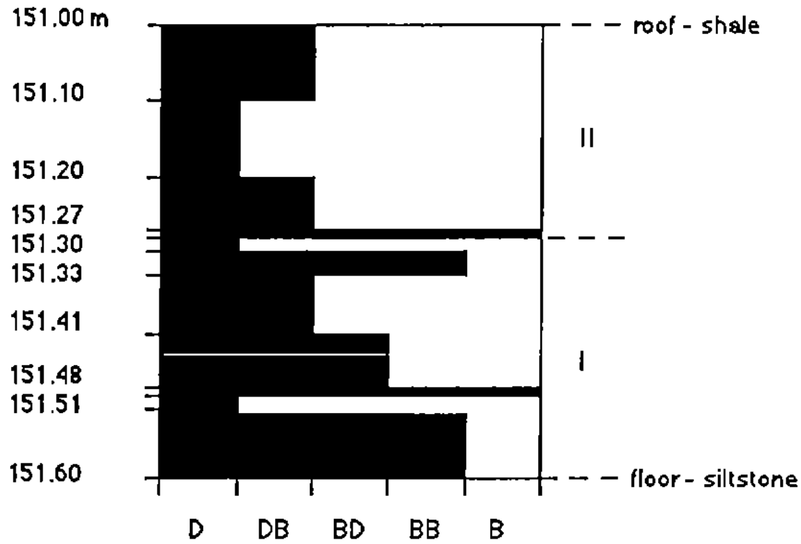
Appendix I.2.16. Lithotype profile of seam B, RB 3, Vasse Shelf, Western Australia.

Lithotype log of seam A, RB 3, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.07	150.44	DB
	0.03	150.47	BD
	0.05	150.52	B
	0.03	150.55	D
Sandstone		Floor	

Lithotype log of seam B, RB 3, Vasse Shelf, Western Australia.

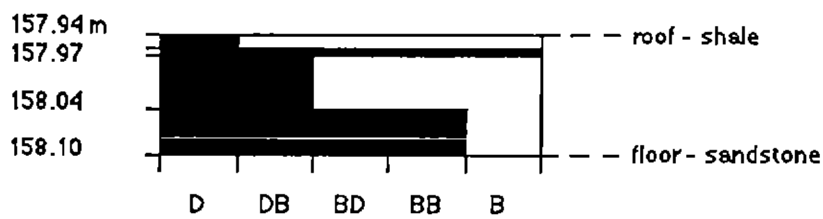
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.02	150.64	DB
	0.02	150.66	BD
	0.04	150.70	D
	0.02	150.72	B
	0.06	150.76	D
Shale		Floor	



Scale 1 : 10

Legend D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.17. Lithotype profile of seam C, RB 3, Vasse Shelf, Western Australia.



Scale 1 : 10

Legend D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

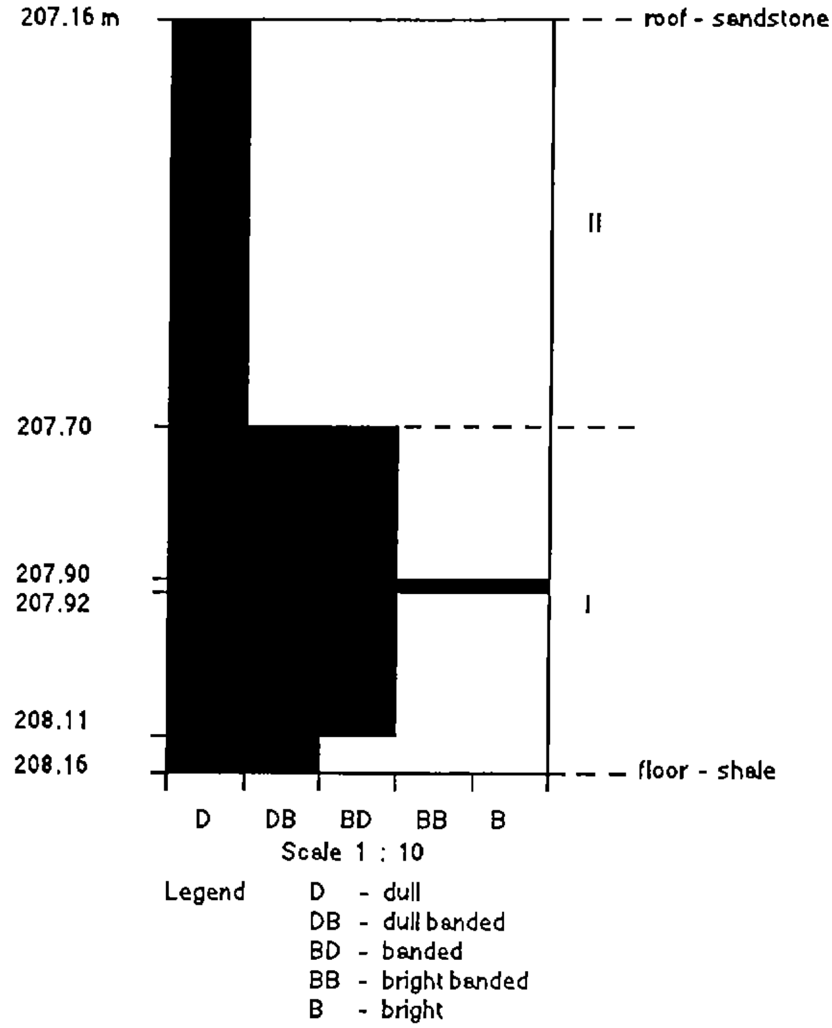
Appendix I.2.18. Lithotype profile of seam D, RB 3, Vasse Shelf, Western Australia.

Lithotype log of seam C, RB 3, Vasse Shelf, Western Australia.

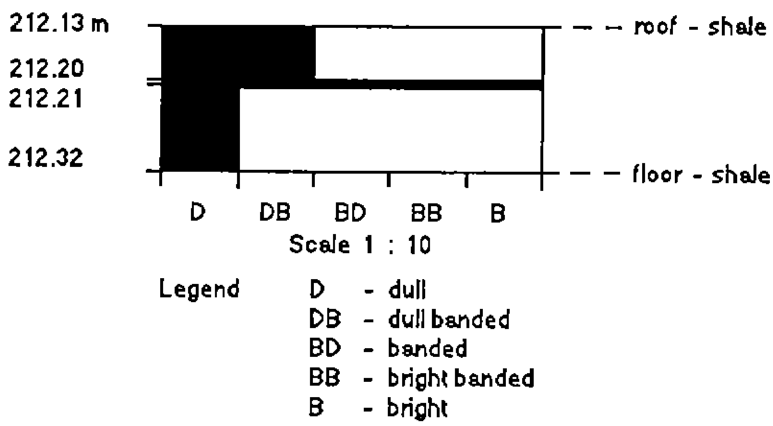
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.10	151.10	DB
	0.10	151.20	D
	0.07	151.27	DB
	0.01	151.28	B
	0.02	151.30	D
	0.03	151.33	BB
	0.08	151.41	DB
	0.07	151.48	BD
	0.01	151.49	B
	0.02	151.51	D
	0.09	151.60	BB
Siltstone		Floor	

Lithotype log of seam D, RB 3, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.02	157.96	D
	0.01	157.97	B
	0.07	158.04	DB
	0.06	158.10	BB
Sandstone		Floor	



Appendix I.2.19. Lithotype profile of seam E, RB 3, Yasse Shelf, Western Australia.



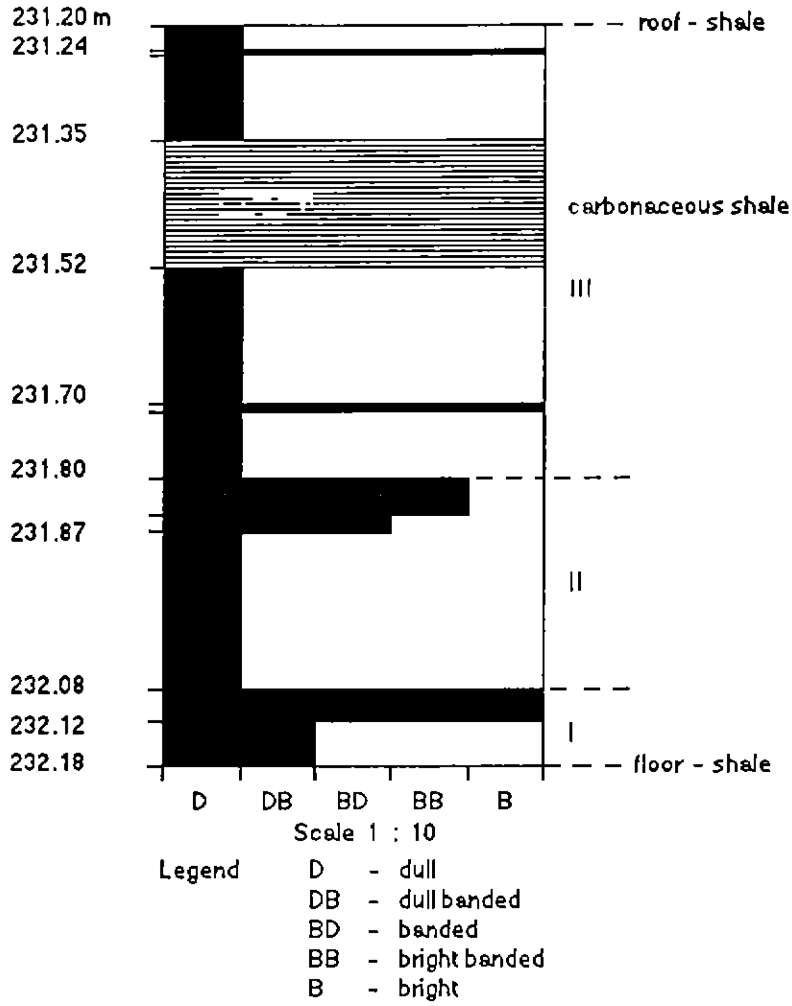
Appendix I.2.20. Lithotype profile of seam F, RB 3, Yasse Shelf, Western Australia.

Lithotype log of seam E, RB 3, Vasse Shelf, Western Australia.

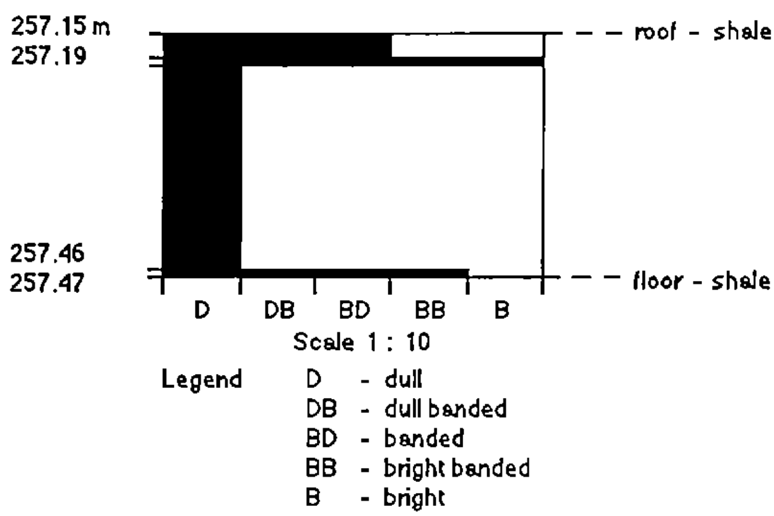
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.54	207.70	D
	0.20	207.90	BD
	0.02	207.92	B
	0.19	208.11	BD
	0.05	208.16	DB
Shale		Floor	

Lithotype log of seam F, RB 3, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.07	212.20	DB
	0.01	212.21	B
	0.11	212.32	D
Shale		Floor	



Appendix I.2.21. Lithotype profile of seam G, RB 3, Vasse Shelf, Western Australia.



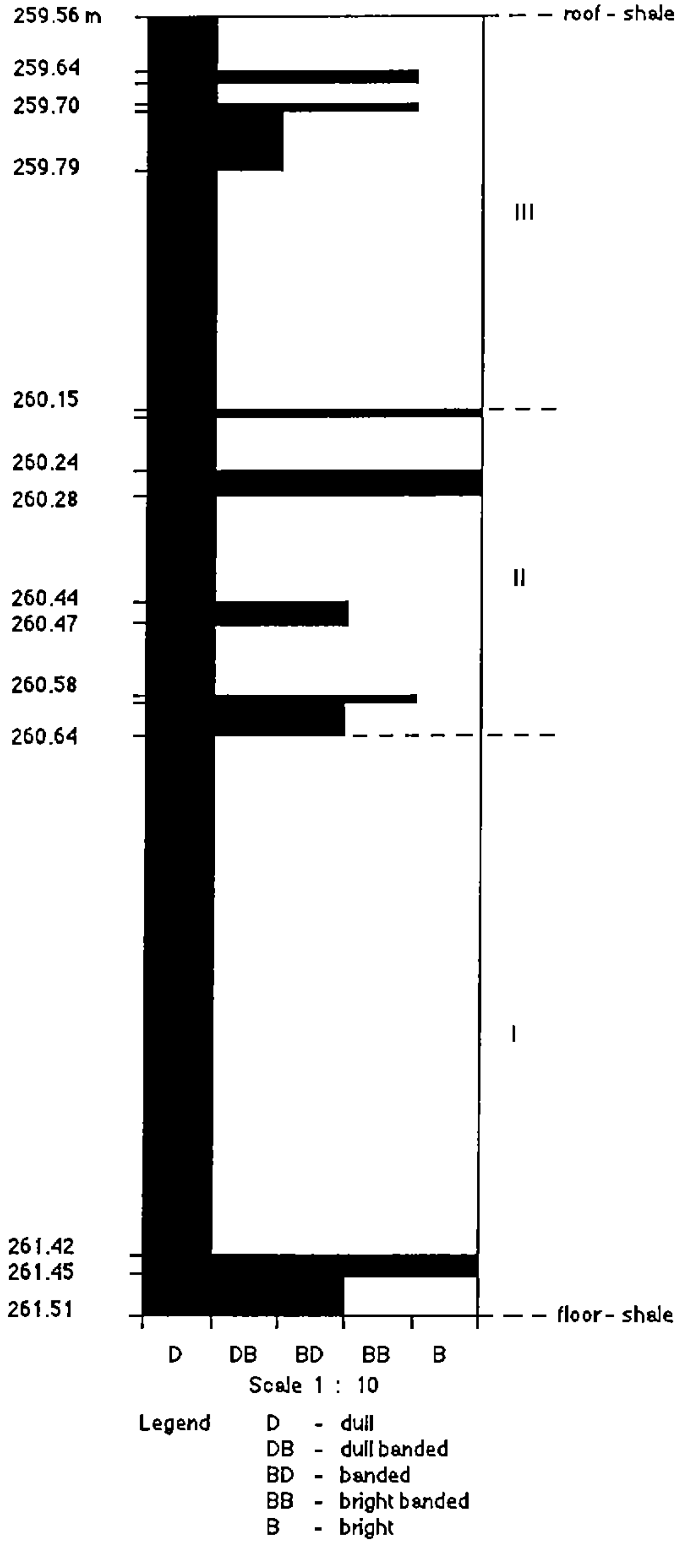
Appendix I.2.22. Lithotype profile of seam H, RB 3, Vasse Shelf, Western Australia.

Lithotype log of seam G, RB 3, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.04	231.24	D
	0.01	231.25	B
	0.10	231.35	D
Shale	0.17	231.52	
Coal	0.18	231.70	D
	0.01	231.71	B
	0.09	231.80	D
	0.05	231.85	BB
	0.02	231.87	BD
	0.21	232.08	D
	0.04	232.12	B
	0.06	232.18	DB
Shale		Floor	

Lithotype log of seam H, RB 3, Vasse Shelf, Western Australia.

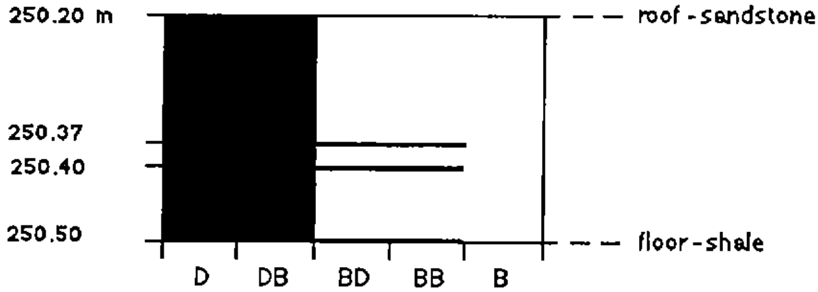
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.04	257.19	BD
	0.01	257.20	B
	0.26	257.46	D
	0.01	257.47	BB
Shale		Floor	



Appendix I.2.23. Lithotype profile of seam I, RB 3, Vasse Shelf, Western Australia.

Lithotype log of seam I, RB 3, Vasse Shelf, Western Australia.

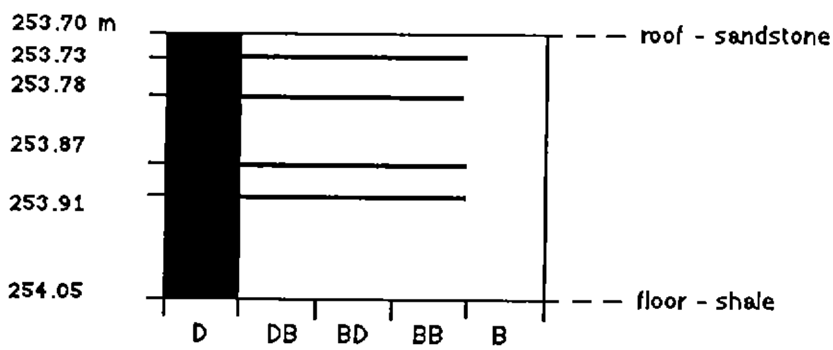
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.08	259.64	D
	0.02	259.66	BB
	0.04	259.70	D
	0.01	259.71	BB
	0.08	259.79	DB
	0.36	260.15	D
	0.01	260.16	B
	0.08	260.24	D
	0.04	260.28	B
	0.16	260.44	D
	0.03	260.47	BD
	0.11	260.58	D
	0.01	260.59	BB
	0.05	260.64	BD
	0.78	261.42	D
	0.03	261.45	B
	0.06	261.51	BD
Shale		Floor	



Scale 1 : 10

Legend D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.24. Lithotype profile of seam A, CRCH 1, Vasse Shelf, Western Australia.



Scale 1 : 10

Legend D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

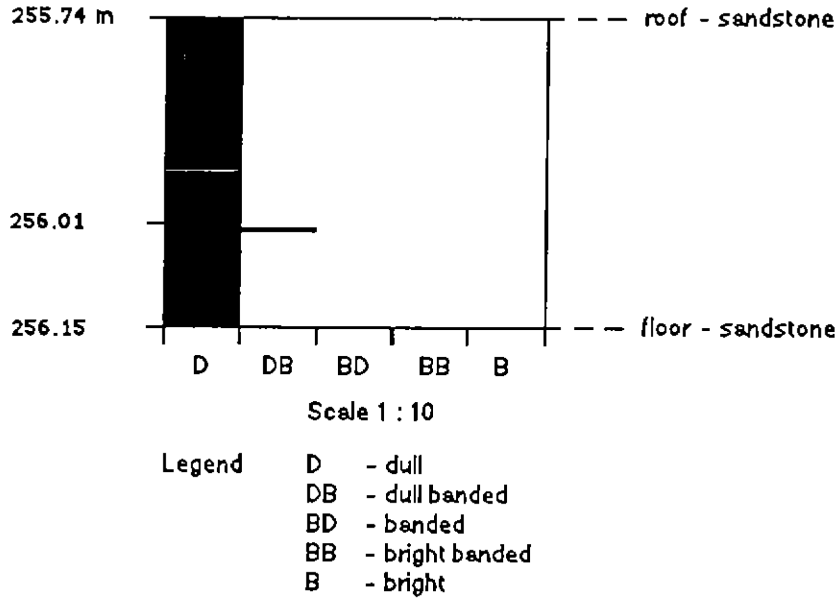
Appendix I.2.25. Lithotype profile of seam B, CRCH 1, Vasse Shelf, Western Australia.

Lithotype log of seam A, CRCH 1, Vasse Shelf, Western Australia.

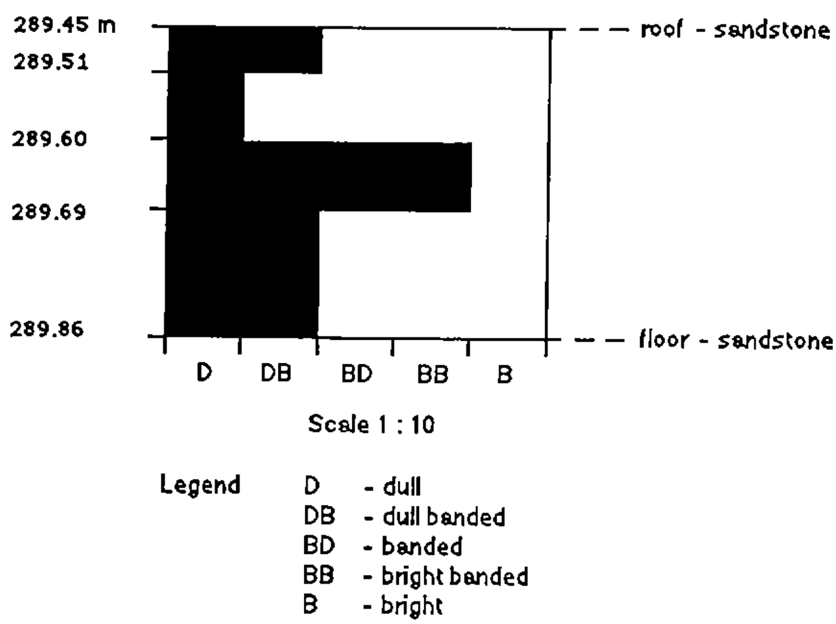
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.17	250.37	DB
	0.01	250.38	BB
	0.02	250.40	DB
	0.01	250.41	BB
	0.09	250.50	DB
Shale		Floor	

Lithotype log of seam B, CRCH 1, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.03	253.73	D
	0.01	253.74	BB
	0.04	253.78	D
	0.01	253.79	BB
	0.07	253.86	D
	0.01	253.87	BB
	0.04	253.91	D
	0.01	253.92	BB
	0.13	254.05	D
Shale		Floor	



Appendix I.2.26. Lithotype profile of seam C, CRCH 1, Vasse Shelf, Western Australia.



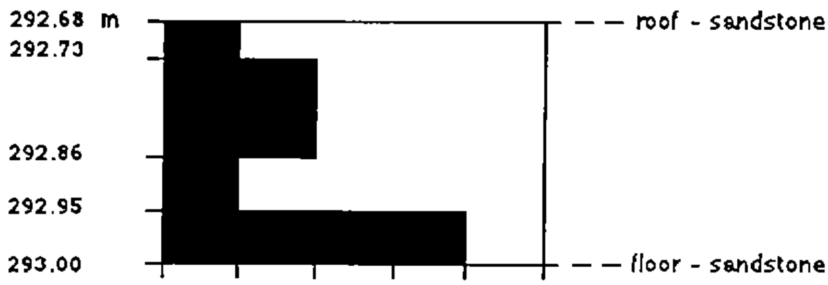
Appendix I.2.27. Lithotype profile of seam D, CRCH 1, Vasse Shelf, Western Australia.

Lithotype log of seam C, CRCH 1, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.27	256.01	D
	0.01	256.02	DB
	0.13	256.15	D
Sandstone		Floor	

Lithotype log of seam D, CRCH 1, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.06	289.51	DB
	0.09	289.60	D
	0.09	289.69	BB
	0.17	289.86	DB
Sandstone		Floor	



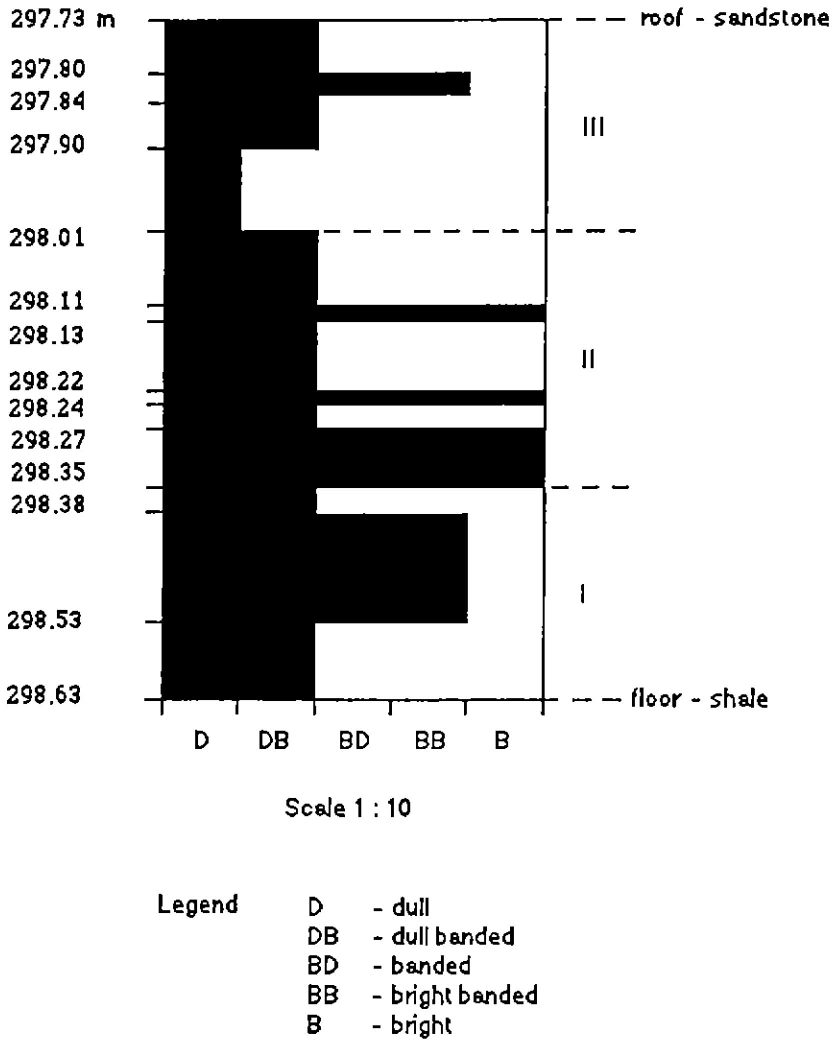
Scale 1 : 10

Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.28. Lithotype profile of seam E, CRCH 1, Vasse Shelf, Western Australia.

Lithotype log of seam E, CRCH 1, Vasse Shelf, Western Australia.

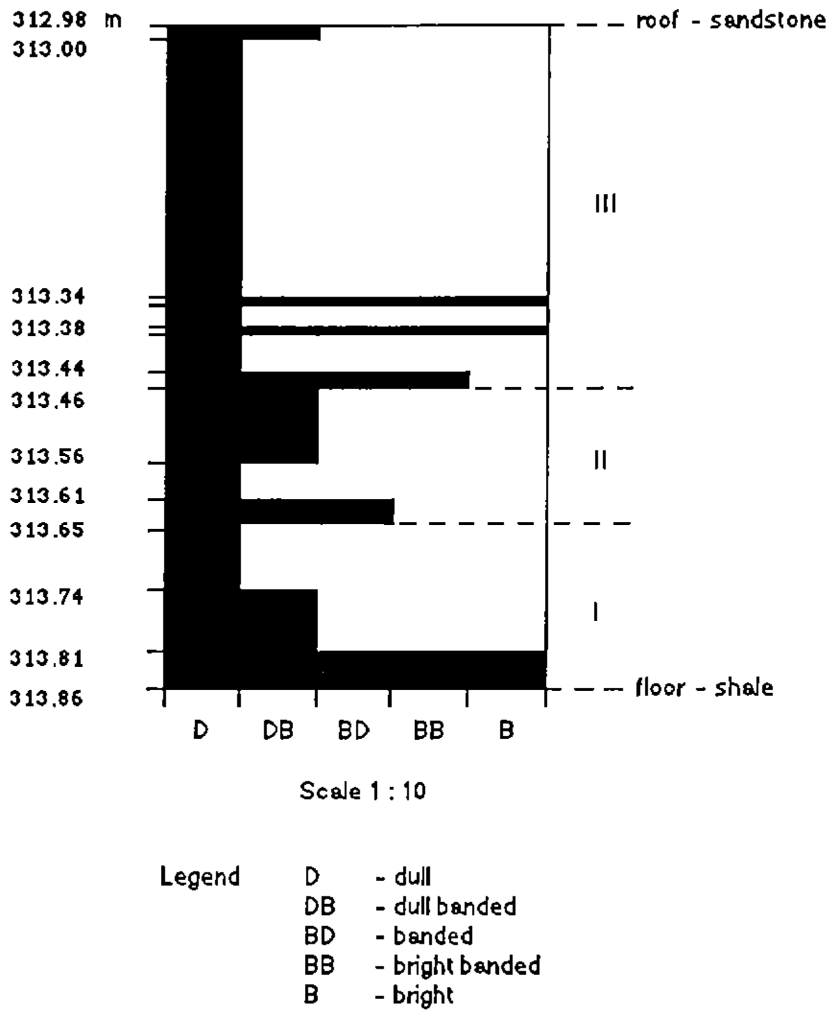
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.05	292.73	D
	0.13	292.86	DB
	0.09	292.95	D
	0.05	293.00	BB
Sandstone		Floor	



Appendix I.2.29. Lithotype profile of seam F, CRCH 1, Vasse Shelf, Western Australia.

Lithotype log of seam F, CRCH 1, Vasse Shelf, Western Australia.

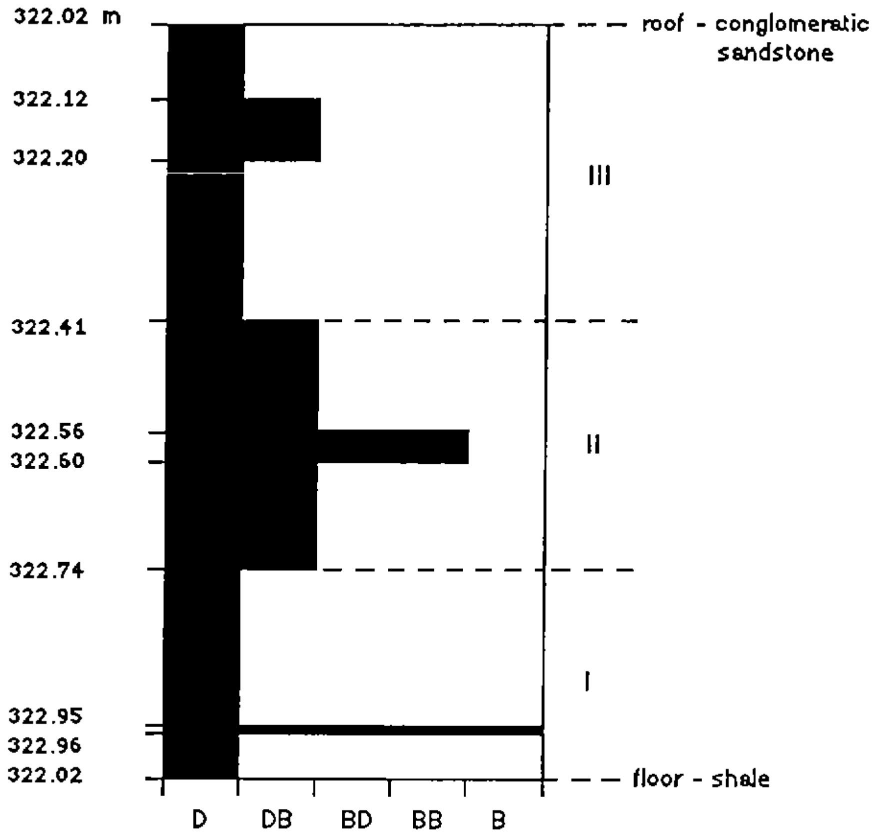
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.07	297.80	DB
	0.04	297.84	BB
	0.06	297.90	DB
	0.11	298.01	D
	0.10	298.11	DB
	0.02	298.13	B
	0.09	298.22	DB
	0.02	298.24	B
	0.03	298.27	DB
	0.08	298.35	B
	0.03	298.38	DB
	0.15	298.53	BB
	0.10	298.63	DB
Shale		Floor	



Appendix I.2.30. Lithotype profile of seam G, CRCH 1, Vasse Shelf, Western Australia.

Lithotype log of seam G, CRCH 1, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.02	313.00	DB
	0.34	313.34	D
	0.01	313.35	B
	0.03	313.38	D
	0.01	313.39	B
	0.05	313.44	D
	0.02	313.46	BB
	0.10	313.56	DB
	0.05	313.61	D
	0.04	313.65	BD
	0.09	313.74	D
	0.07	313.81	DB
	0.05	313.86	B
Shale		Floor	



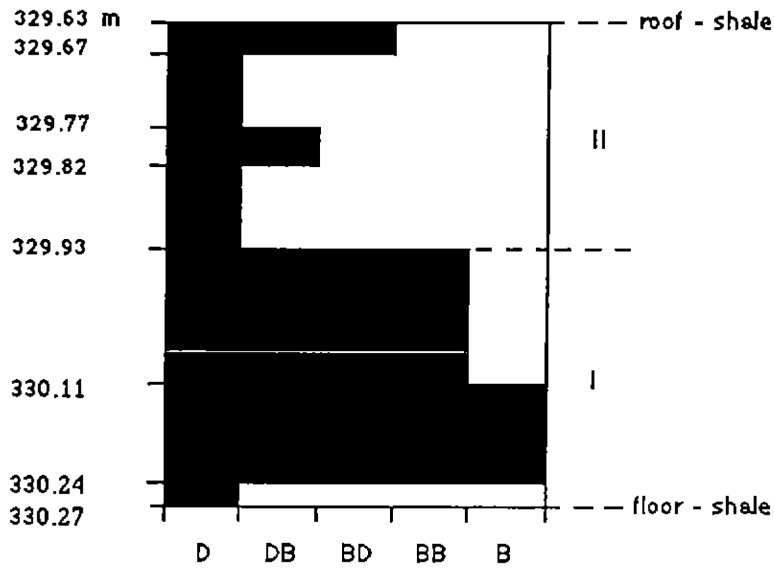
Scale 1 : 10

Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.31. Lithotype profile of seam H, CRCH 1, Vasse Shelf, Western Australia.

Lithotype log of seam H, CRCH 1, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.10	322.12	D
	0.08	322.20	DB
	0.21	322.41	D
	0.15	322.56	DB
	0.04	322.60	BB
	0.14	322.74	DB
	0.21	322.95	D
	0.01	322.96	B
	0.06	323.02	D
Shale		Floor	



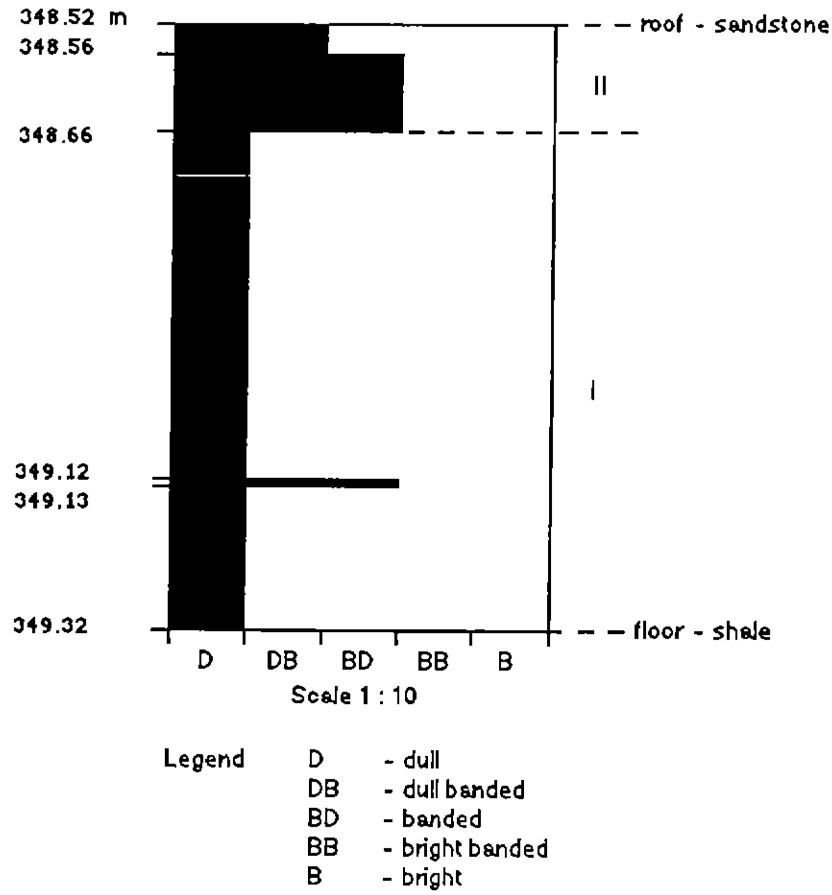
Scale 1 : 10

Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

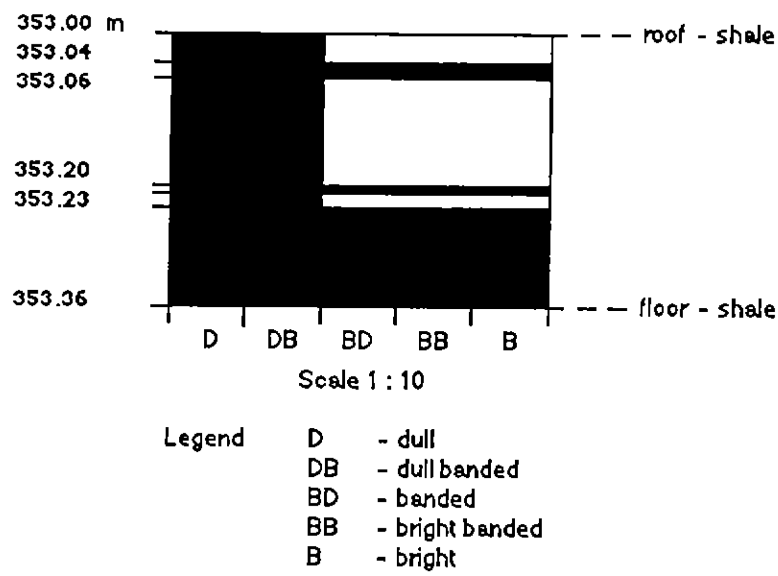
Appendix I.2.32. Lithotype profile of seam I, CRCH 1, Vasse Shelf, Western Australia.

Lithotype log of seam I, CRCH 1, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.04	329.67	BD
	0.10	329.77	D
	0.05	329.82	DB
	0.11	329.93	D
	0.18	330.11	BB
	0.13	330.24	B
	0.03	330.27	D
Shale		Floor	



Appendix I.2.33. Lithotype profile of seam J, CRCH 1, Vasse Shelf, Western Australia.



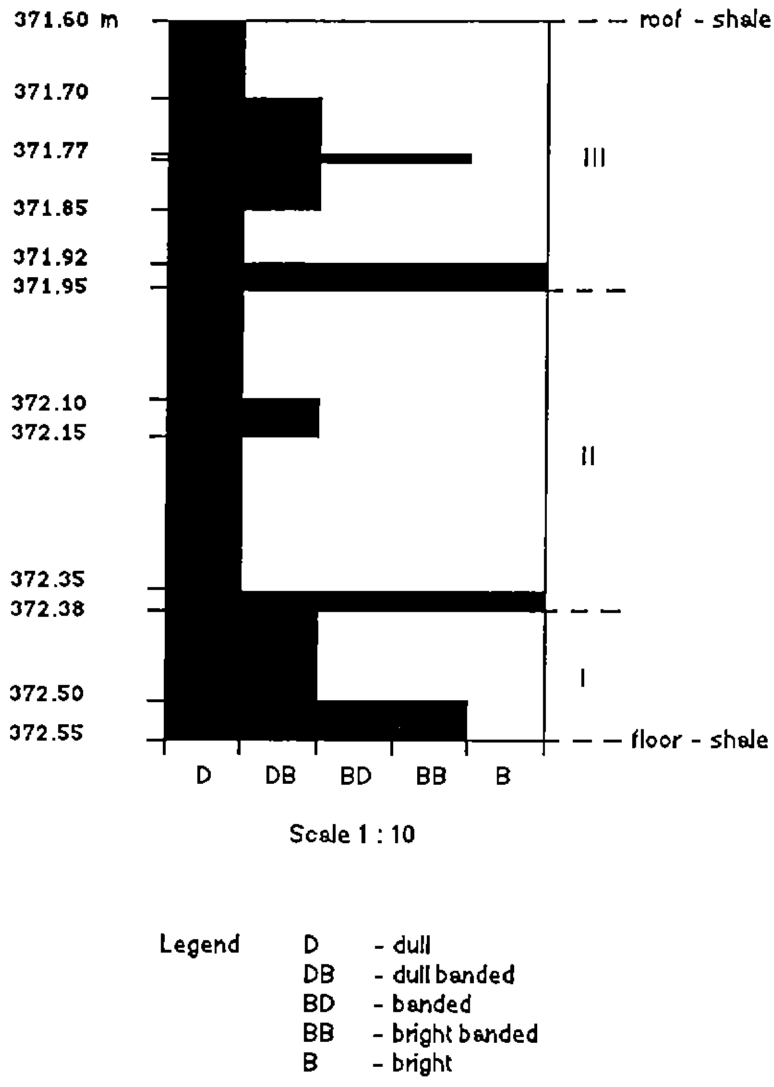
Appendix I.2.34. Lithotype profile of seam K, CRCH 1, Vasse Shelf, Western Australia.

Lithotype log of seam J, CRCH 1, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.04	348.56	DB
	0.10	348.66	BD
	0.46	349.12	D
	0.01	349.13	BD
	0.19	349.32	D
Shale		Floor	

Lithotype log of seam K, CRCH 1, Vasse Shelf, Western Australia.

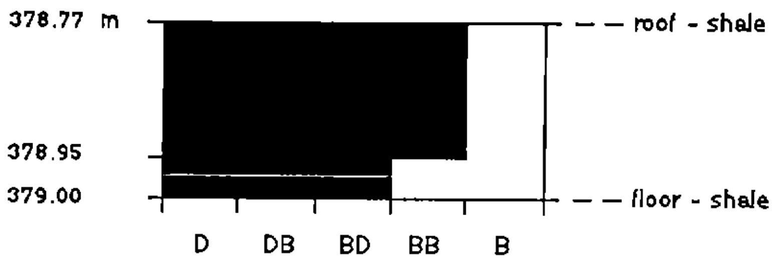
ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.04	353.04	DB
	0.02	353.06	B
	0.14	353.20	DB
	0.01	353.21	B
	0.02	353.23	DB
	0.13	353.36	B
Shale		Floor	



Appendix I.2.35. Lithotype profile of seam L, CRCH 1, Vasse Shelf, Western Australia.

Lithotype log of seam L, CRCH 1, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.10	371.70	D
	0.07	371.77	DB
	0.01	371.78	BB
	0.07	371.85	DB
	0.07	371.92	D
	0.03	371.95	B
	0.15	372.10	D
	0.05	372.15	DB
	0.20	372.35	D
	0.03	372.38	B
	0.12	372.50	DB
	0.05	372.55	BB
Shale		Floor	



Scale 1 : 10

Legend
- D - dull
- DB - dull banded
- BD - banded
- BB - bright banded
- B - bright

Appendix I.2.36. Lithotype profile of seam M, CRCH 1, Vasse Shelf, Western Australia.

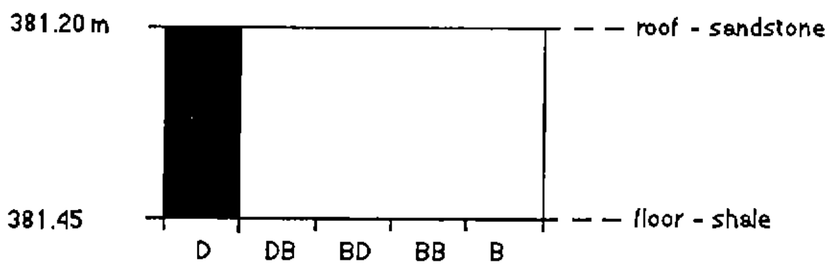
Lithotype log of seam M, CRCH 1, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.18	378.95	BB
	0.05	379.00	BD
Shale		Floor	

Scale 1: 10

Legend D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.37. Lithotype profile of seam A, CRCH 2, Vasse Shelf, Western Australia.



Scale 1 : 10

Legend D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

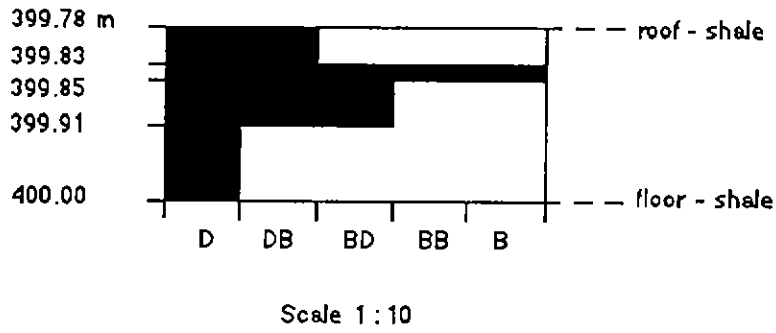
Appendix I.2.38. Lithotype profile of seam J, CRCH 2, Vasse Shelf, Western Australia.

Lithotype log of seam A, CRCH 2, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.04	252.80	B
	0.06	252.86	BD
	0.05	252.91	BB
	0.11	253.02	DB
Siltstone		Floor	

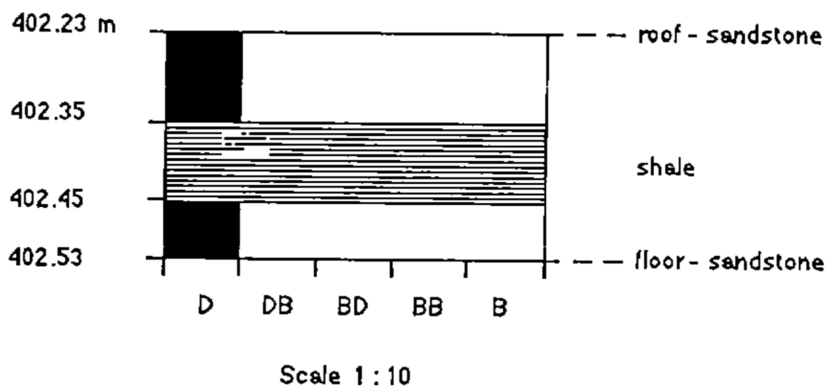
Lithotype log of seam J, CRCH 2, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.25	381.45	D
Shale		Floor	



Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.39. Lithotype profile of seam M, CRCH 2, Vasse Shelf, Western Australia.



Legend
D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.40. Lithotype profile of seam N, CRCH 2, Vasse Shelf, Western Australia.

Lithotype log of seam M, CRCH 2, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.05	399.83	DB
	0.02	399.85	B
	0.06	399.91	BD
	0.09	400.00	D
Shale		Floor	

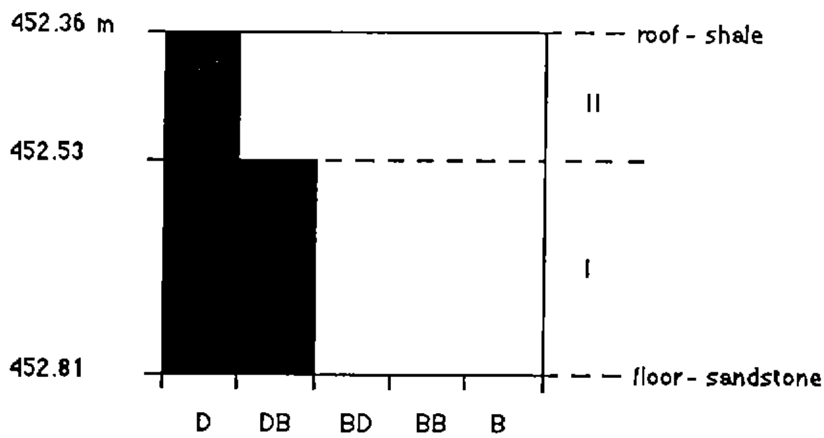
Lithotype log of seam N, CRCH 2, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.12	402.35	D
Shale	0.10	402.45	
Coal	0.08	402.53	D
Sandstone		Floor	

Scale 1 : 10

Legend D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.41. Lithotype profile of seam O, CRCH 2, Vasse Shelf, Western Australia.



Scale 1 : 10

Legend D - dull
DB - dull banded
BD - banded
BB - bright banded
B - bright

Appendix I.2.42. Lithotype profile of seam P, CRCH 2, Vasse Shelf, Western Australia.

Lithotype log of seam O, CRCH 2, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Sandstone		Roof	
Coal	0.06	420.91	DB
	0.05	420.96	BB
	0.07	421.03	D
	0.07	421.10	BD
Shale		Floor	

Lithotype log of seam P, CRCH 2, Vasse Shelf, Western Australia.

ROCK TYPE	THICKNESS (m)	DEPTH TO BASE (m)	DESCRIPTION
Shale		Roof	
Coal	0.17	452.53	D
	0.28	452.81	DB
Sandstone		Floor	