Geology and organic petrology of some selected Permian and Jurassic coals of Western Australia

Krishna K. Sappal

Sappal Krishna K 1996. Geology and organic petrology of some selected Permian and Jurassic coals of Western Australia. *Palaeobotanist* **45** : 33-40.

The commercial coal resources of Western Australia occur in sediments ranging in age from Permian to Jurassic. The coal from each period has distinctive geographical, biological and geological characteristics which effects its utilization in industry and power generation. Currently the Permian intracratonic Collie Basin is the only producing coalfield in Western Australia. The annual production from this coalfield is approximately 6 million tonnes, which is mostly used for power generation. Another Permian coal deposit in the Vasse Shelf, located in the southern part of the Perth Basin has potential for export to Asian markets. The Early Jurassic coal of the Hill River area in the northern Perth Basin has been fully explored and is ready for mining as a source for power generation. All three coal deposits represent a measured *in situ* resource in excess of 1500 million tonnes for Western Australia.

Similar to the Gondwana coals of Australia, the coals are finely banded and the dominant lithotypes are dull and dull banded with minor bright and bright banded types. The maceral composition of the coals is variable, however, the macerals of vitrinite and inertinite groups dominate, and the exinite and mineral matter contents are low, particularly in the Permian coals. On the basis of petrology of coal and the inter-seam sediments the depositional environment for the Permian coal was braided fluvial and fluvio-lacustrine, with marked fluctuations in the water table. The low water table accounts for fusain and inertodetrinite in the coal. The depositional environment for the Jurassic coal was of a low delta with some marine influence, supported by the presence of framboidal pyrite and acritarchs in the coal measures.

Key-words—Macerals, Minerals, Depositional environment, Permian, Jurassic, Western Australia.

Krishna K. Sappal, Curtin University of Technology, Perth, Western Australia.

साराँश

पश्चिमी ऑस्ट्रेलिया के कुछ छाँटे गये परमियन एवं जुरेसिक कोयलों का भूवैज्ञानिक एवं कार्बनिक शैलिकीय अध्ययन

कृष्ण के. सप्पल

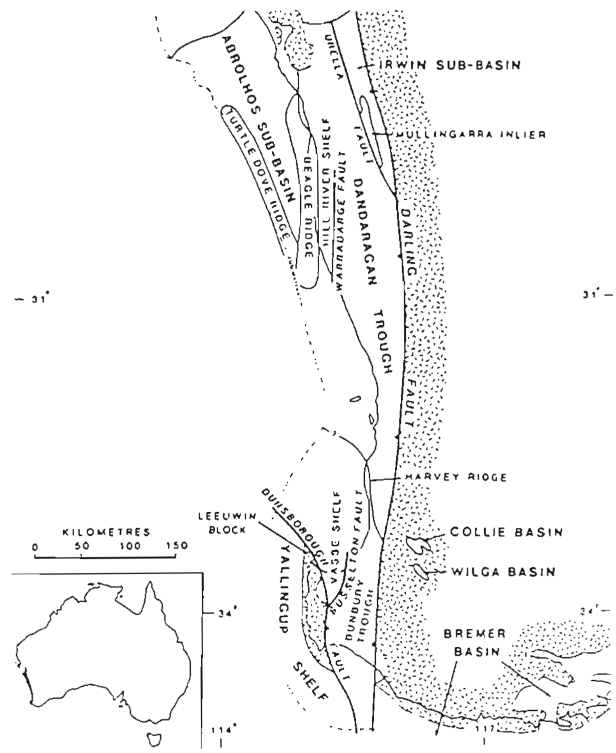
पश्चिमी ऑस्ट्रेलिया में व्यावसायिक कोयले के स्रोत परमियन से जुरेसिक आयु के अवसादों में मिलते हैं। प्रत्येक कल्प के कोयले के अलग-अलग गुण होने के कारण इनका उद्योग और विद्युत उत्पादन में भिन्न-भिन्न दृष्टि से प्रयोग होता है। इस समय पश्चिमी ऑस्ट्रेलिया में परमियन इन्ट्राक्रेटोनिक कोली द्रोणी से ही कोयला प्राप्त किया जाता है तथा विद्युत उत्पादन में इसका उपयोग किया जाता है। इसके अतिरिक्त वासे शेल्फ में भी परमियन कोयले के भंडार हैं जो एशिया में निर्यात करने योग्य हैं। दक्षिणी पर्थ द्रोणी में हिल नदी क्षेत्र के प्रारम्भिक जुरेसिक युगीन कोयले भी विद्युत उत्पादन हेतु उपयुक्त हैं। पश्चिमी ऑस्ट्रेलिया में ये तीनों कोयले के भंडार 1500 मिलियन टन से भी अधिक हैं।

ऑस्ट्रेलिया के गोंडवाना कोयलों की तरह, ये कोयले पट्टीदार हैं तथा प्रभावी शैलप्ररूप हल्के, पट्टीदार तथा कुछ हल्की सी चमक वाली पट्टी से युक्त हैं तथापि इनमें विट्रीनाइट एवं इनर्टीनाइट की बाहुल्यता है एवं एक्जीनाइट एवं खनिज पदार्थ कम हैं, विशेषतया पर्मियन कोयले में। कोयले एवं अन्तरसीम अवसादों के शैलिकीय अध्ययन के आधार पर परमियन कोयले का निक्षेपणीय वातावरण नदीय से नदीय सरोवरी प्रस्तावित किया गया है। निक्षेपण के समय पानी के तल में भी उतार चढ़ाव होता रहा है। निम्न पानी के तल के कारण इनमें फ्यूज़ेन एवं इनर्टोडिट्रीनाइट हैं। जुरेसिक कोयले के निक्षेपण के समय समुद्री प्रभाव के साथ-साथ निम्न डेल्टा वाला वातावरण विद्यमान था, जिसकी पुष्टी फ्रेम्बॉयडल पाइराइट एवं एक्रीटार्कों की उपस्थिति से होती है।

THE coal was first discovered at Collie, located 160 SSE of Perth, in 1883. Since the commencement of mining in 1898, the Collie Basin has been the site of only commercial coalfield in Western Australia. Kristensen and Wilson (1986) reviewed coal resources of Western Australia and stated that the Early to Late Permian coal occurs at mineable depth in the Vasse Shelf, 180 km South of Perth as proved by the extensive exploration drilling in the area. The Jurassic coal in the Hill River area, 250 km North of Perth in the Perth Basin, was first intersected in 1964 during the drilling for oil. Since 1982, the CRA Exploration Pty Ltd has been active in exploration in the Hill River area. The exploration has been directed mainly towards evaluating the potential in power generation, and in 1990 the company submitted a tender to supply coal based power to the State Energy Commission of Western Australia based on this coal with a capacity of 600 megawatts. The samples for this study were collected from the Open Cut Mine and the drill holes drilled in the areas. The particulate samples of coal were prepared and examined according to the Standard Association of Australia codes (1977, 1981, 1982). This study forms a component of the major research program being undertaken at the Coal Research Laboratory, Curtin University of Technology, towards petrographic and geochemical characterisation of Western Australian coals.

The industry sponsored project on Petrology of Permian Coal from the Collie Basin was undertaken by Sappal (1986), followed by the studies on the Hill River coal and the Vasse Shelf coal by Suwarna (1993) and Santoso (1994) respectively.

The coal from the three areas is classified as sub-bituminous suitable for power generation and the vitrinite reflectance of the coal has a range between 0.42 to 0.62 per cent. The specific energy of the coal varies between 20.0 to 25 MJ/kg as received basis.



Text-figure 1—Locality plan and subdivisions, Perth Basin

GEOLOGY OF THE AREAS

The regional settings of the Collie Basin, Vasse Shelf and the Hill River area is given in Text-figure 1. The Collie Basin is located east of the Darling Fault in the Yilgarn Craton of Western Australia. The Vasse Shelf is located in the southern part of the Perth Basin, and the Hill River area containing Early Jurassic coal in the northern part of the basin.

Collie Basin

The Collie Basin covers an area of about 230 km^2, located 160 km SSE of Perth. The basin is intracratonic and bilobate, fault controlled northwest-trending depression within a basement complex of Archaean granite and gneiss of the Yilgarn Craton. The basin has been subdivided into two unequal units, named Cardiff and Premier Sub-basins, Text-figure 2. The

PLATE 1 →

1. Vitrinite A (grey) and resinite (black), Collie coal x 300.
2. Sporinite (dark grey), vitrinite (grey) and inertinite (white) Vasse Shelf coal x 300.
3. Semi-fusinite with pyrite, Collie coal x 300.
4. Framboidal pyrite (white) with vitrinite and inertinite Hill River coal x 300.

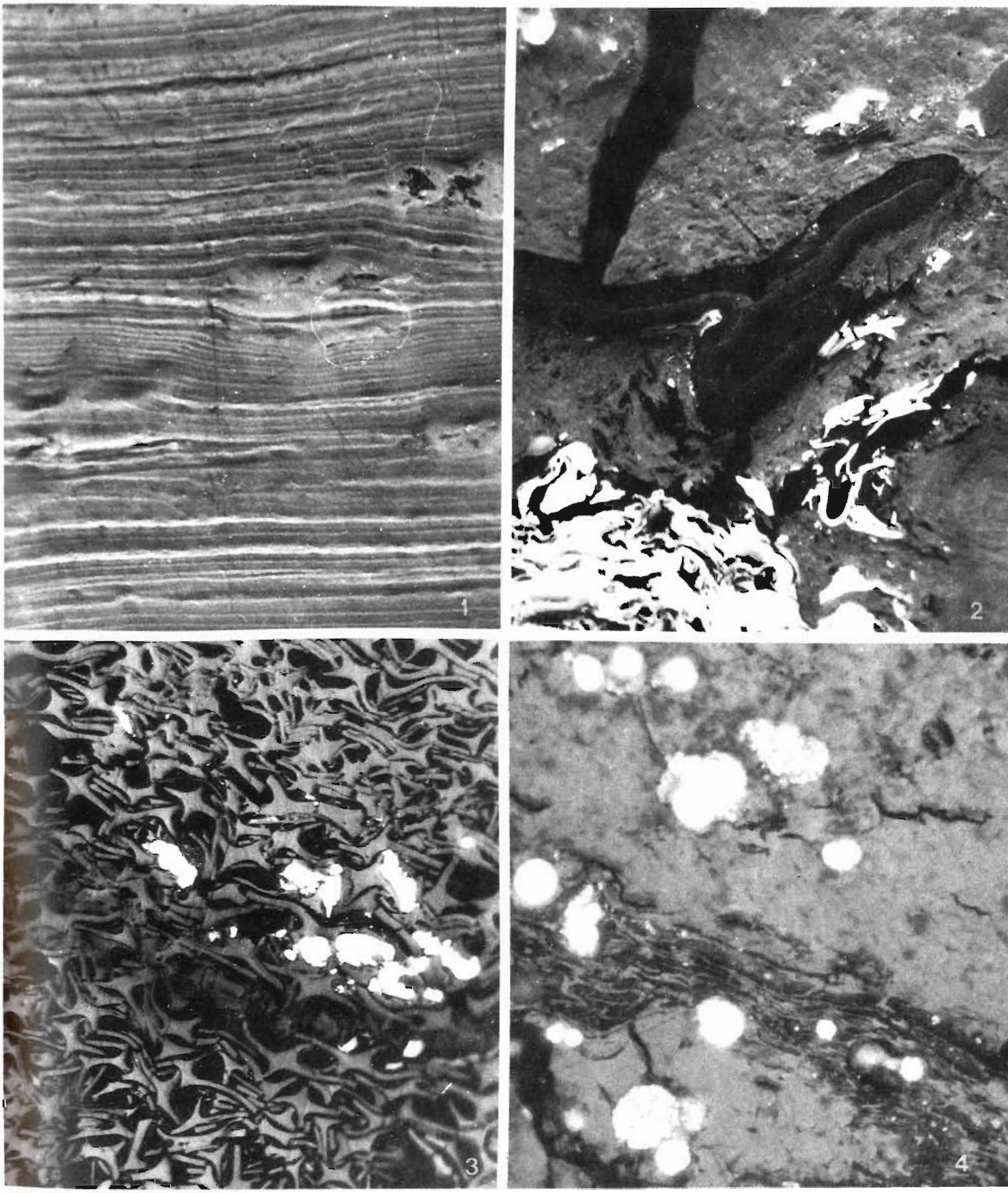
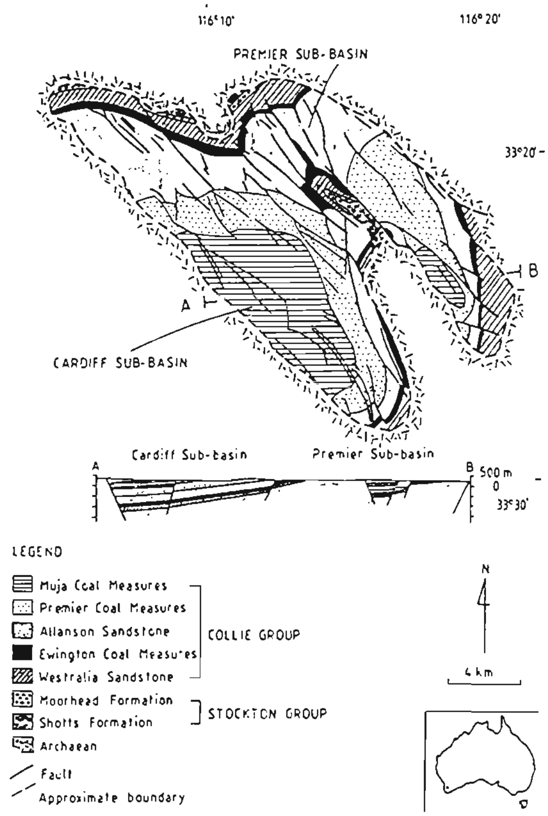


PLATE 1



Text-figure 2—Permian geology, Collie Basin.

Cardiff Sub-basin contains at least 1,100 m of Early to Late Permian sediments inclusive of the coal measures. The Premier Sub-basin in the eastern lobe of the basin and it contains 850 m and 580 m of Permian sediments in the Muja and Shotts areas, respectively.

The stratigraphy of the Collie Basin consists of the Stockton Group and the Collie Group. The Stockton Group with its earliest Permian Shotts Formation overlies the Archaean basement unconformably. And it is conformably overlain by the Early to Late Permian Collie Group consisting of three coal measures namely, Ewington, Premier and the Muja. The coal seams from all three coal measures are being mined either by open cut mine or subsurface mining methods. The Muja Coal Measures of Late Permian age are unconformably overlain by the lacustrine Nakina Formation of Cretaceous age. Detailed geology and stratigraphy of the Collie Basin is described by Ashton *et al.* (1995).

Vasse Shelf

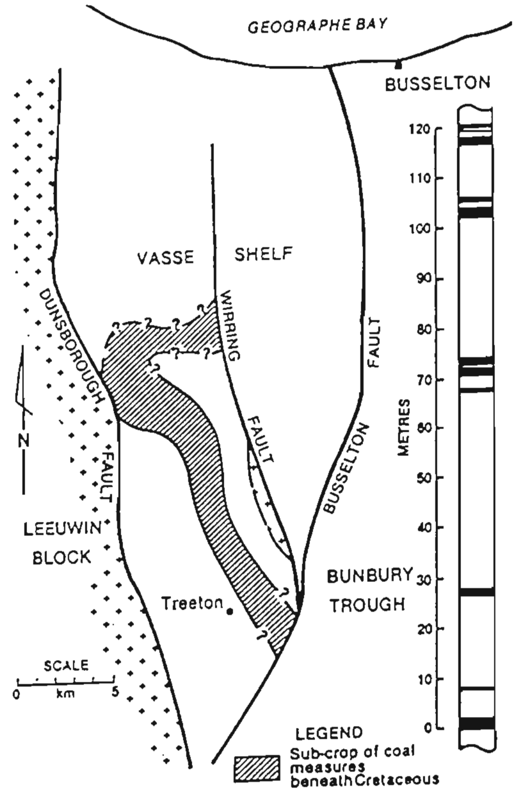
The Vasse Shelf is a sub-division of the Perth Basin, which was first named by Andrews (1938), Text-figure 1. The basin is a deep linear polycyclic trough containing 15,000 m of Phanerozoic sediments ranging in age from Silurian to Quaternary. It has an area of about 45,000 km^2, extending in north-south direction for 1000 km. The eastern boundary of the basin is defined by a major tectonic feature of Western Australia, named the Darling Fault. The western and the southern limits of the basin lie under the continental shelf. The Vasse Shelf is a faulted block of Permian sediments, delineated to the east by the Busselton Fault and to the west by the Dunsborough Fault, Text-figure 3. The two faults coverage to the south.

The self contains an Early to Late Permian coal measure sequence of 1800 m, overlying unconformably on an irregular Archaean basement. The sequence is correlated with the Sue Coal Measures of the Bunbury Trough, and these are unconformably overlain by Early Cretaceous sequence of the Leederville Formation. The most extensively explored area is the southern part of the shelf, where the coal measures have been drilled at 2 km intervals by CRA Exploration Pty Ltd, and the sixteen coal seams with thickness of 20 cm to 2 m have been encountered. The detailed geology and stratigraphy of Permian and Jurassic coal measures is described by Kristensen (1995).

Hill River Area

The Hill River is located in the northern part of the Perth Basin. The geology and coal measures of the Hill River area were first described by Willmott (1964), followed by Kristensen (1989, 1995). The area and the coalfield occupy the Hill River Shelf of the northern Perth Basin. The shelf is located at the western flank of the Dandargan Trough, bounded by the Lesuer-Peron Faults in the west and the Warradarge Fault in the east, Text- figure 4.

The economic coal seams in the Hill River area occur at an interval 70 to 100 m thick parting within the upper part of the Early Jurassic Cockleshell Gully Formation. This upper coal bearing sequence is described as the Cattamarra Coal Measures. The coal



Text-figure 3—Geology and tectonic setting, Vasse Shelf.

measures are the most extensively explored coal measures in Western Australia, which extend to a width of 5 to 10 km and length of at least 80 km in the north-south direction. Three major economic deposits have been delineated, namely Eneabba in north, Gairdner Range and Wongondarra in the south of the region. The Cockleshell Gully Formation and the coal measures have been generally considered to be entirely of terrestrial origin, however exploratory drilling for coal and studies of Sappal and Islam (1992) revealed the presence of several marine incursions in the Cattamarra Coal Measures.

PETROLOGY

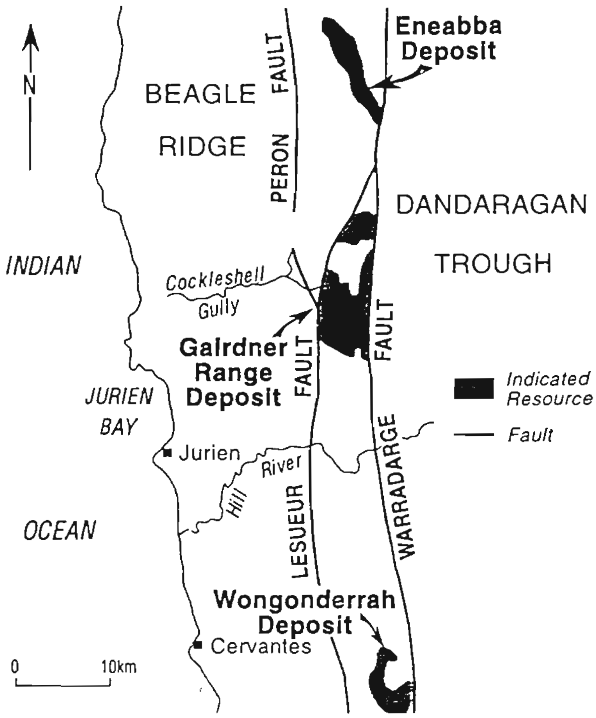
The macroscopic (lithotypes) and microscopic (macerals and mineral matter) characters of the selected Permian and Jurassic coals of Western Australia are briefly described. The data on maceral, mineral matter and vitrinite reflectance of the selected samples is given in Table 1.

Lithotypes

Macroscopically the northern hemisphere Carboniferous coals have been described on the basis of Stopes (1935) terminology; Vitrain, Clarain, Durain and Fusain. However, these terms are not equally applicable to Permian coals of Australia because of fine laminations, and vitrain bands are usually less 10 mm thick unlike the thicker bands of northern hemisphere coals. Due to finer laminations, a smaller limit of a minimum 5 mm thickness is used. The terms applicable to lithotypes are dull, dull banded, banded, bright banded, bright and fusain for fibrous coal, as per definitions of Diessel (1965). The terms are based on thickness of laminae and their brightness. The bright component of dull coal is 0-10 per cent, dull banded coal 10-40 per cent, banded coal 40-60 per cent, bright banded coal 60-90 per cent and the bright coal 90-100 per cent.

Table 1—Maceral, mineral matter and vitrinite reflectance of the selected Permian and Jurassic coals. Data from Sappal (1986), Suwarna (1993) and Santoso (1994)

Locations Seams	Vitrinite %	Exinite %	Inertinite %	Minerals %	RO_{max} %
Jurassic					
Hill River					
CPCH I - G1	61	13	22	4	0.47
G2	62	12	22	4	0.49
G3	63	14	16	7	0.50
G4	52	20	19	9	0.49
G5	56	16	15	13	0.50
Permian					
Collie Basin Ceres	61	4	33	2	0.43
Diana	60	7	30	3	0.42
Flora	25	3	69	3	0.45
Hebe	54	4	39	3	0.44
Iona	64	3	31	2	0.45
BUC.214					
E9	37	9	49	5	0.46
E10	38	7	50	5	0.45
E20	26	7	61	6	0.46
E25	36	6	52	6	0.46
E30	39	9	47	5	0.47
Vasse Shelf					
RBCH5-A	41	5	48	6	0.58
C	43	8	45	4	0.59
F	38	8	49	5	0.61
G	48	9	41	2	0.62
I	45	5	46	4	0.62



Text-figure 4—Tectonic setting, Hill River Area.

A number of lithotype analyses of Permian and Jurassic coals record the subdued luster due to fine laminations and finely dispersed mineral matter within dull and bright types. The dominant lithotypes in the coals are dull banded and banded with minor bright and bright banded lithotypes. Lenses of fusain less than 5 mm in thickness are also present in the coals.

Macerals

Similar to lithotypes in coal, the macerals are the products of peat forming flora, depositional environment and post depositional coalification in a sedimentary basin. Some macerals are the result of contributions from specific plants or parts of plants, and others may form from a wide range of source materials. The proportions of maceral groups and minerals have been calculated from the sub-sections of the individual seams selected from Collie Basin, Vasse Shelf and the Hill River area of Western Australia.

Table 1 gives the average maceral group composition, mineral matter content and the vitrinite reflectance of the selected seams of the three areas. The vitrinite group occurs as microbands, disintegrated and fragmentary shreds in the coal. The group consists of Vitrinite A (telocollinite and telinite) and Vitrinite B (desmocollinite, corpocollinite and minor vitrodetrinite). Plate 1, figure 1 illustrates Vitrinite A, showing wood cells and resinite in the Permian coal.

The vitrinite content in the Jurassic coal ranges from 52 to 63 per cent and it is the dominant maceral in the coal. The Late Permian coal with the exception of the flora seam of the Collie Basin has also the dominance of vitrinite on other maceral groups. However, the vitrinite content in the Early Permian coal (BUC-214 and RBCH 5) of the Perth Basin has a range between 26 to 48 per cent, which is lower in comparison to the inertinite content. The vitrinite reflectance of the coals ranges between 0.42 to 0.62 per cent, which ranks as sub-bituminous as per the Australian classification and sub-bituminous A to C as per North American (ASTM) classification.

The exinite group recognised in the coals consists of sporinite, cutinite, alginite, liptodetrinite and resinite. The alginite content is relatively higher in the Jurassic coal than the Permian coal. This can be attributed to the differences in the depositional environments of the coals. The sporinite, cutinite and alginite are related to specific source material and have a considerable palaeo-environmental significance for the deposition of coal. Plate 1, figure 2 shows association of sporinite (megaspore) with inertinite (inertodetrinite, semi-fusinite and micrinite) and vitrinite.

The exinite content in the Jurassic coal has a range between 12 to 20 per cent which is relatively higher than the exinite content in the Permian coal with a range between 3 to 9 per cent . The higher exinite content in the Jurassic coal is due to depositional environment of the coal, which has an evidence of marine influences in a lower delta. This environment also imparts higher sulphur content to the coal due to the association of framboidal pyrite with the macerals (Pl. 1, figs 4, 8).

The maceral group intertinite in coals in mainly dominated by intertodetrinite, followed by fusinite and semi-fusinite, with minor micrinite, sclerotinite and macrinite. The macerals of this group are characterised as 'structured' and 'non-structured'.

The structured macerals consist of fusinite and semi- fusinite which are defined by the presence of botanical structure, and are considered to be originated from lignin and cellulose of plants. Plate 1, figure 3 shows cellular structure of semi-fusinite with the cell cavities partially filled with secondary pyrite and the Plate 1, figure 4 shows framboidal pyrite formed due to biogenic activity associated with semi-fusinite and vitrinite in the Jurassic coal. The non-structured macerals comprise inertodetrinite, micrinite, sclerotinite and macrinite. Figures 6 and 8 shows inertodetrinite and micrinite associations with vitrinite in the Permian and Jurassic coals respectively. The contents of inertinite in the Early Permian coal (BUC-214) and the Jurassic coal of the Vasse Shelf are higher than the corresponding vitrinite contents due to the process of oxidation following deposition of peat.

Minerals

In addition to the organic components (macerals), the coals also contain inorganic constituents as the mineral matter. Two groups of mineral constituents are analysed in the coal. The first group is inherent, which is present in the coal forming plants, and the constituents of this group are compounds of Ca, Mg, Fe, Al, Na, K, Mn, Ti, S, Si, Cl and P. The elements like Na, K, Mg and Cl are removed during the biochemical stage of coalification. The quantity of inherent mineral matter in the coal is relatively small but very significant in the utilization of coal and its impact on environment.

Nineteen trace elements namely B, Be, Co, Cr, Cu, Ga, Ge, Mn, Mo, Ni, Pb, Sb, Sn, Sr, Ti, U, V, Zn and Zr associated with macerals and minerals have been analysed in the Permian coal. These trace elements have concentrations between 10 to 1000 ppm. The lower boron concentration in the coal between the range 10-70 ppm supports the absence of marine influence during its deposition.

The trace elements analysed in the Jurassic coal within the range of 10-1000 ppm are; As, B, Be, Cd, Co, Cr, Cu, Ga, Mn, Mo, Ni, Pb, Sr, Th, U, V, Y, Zn and Zr. The high boron concentration within the range 60 to 410 ppm in this coal indicates the depositional environment influenced by the marine transgression.

The second group of mineral constituents in the coal is discrete and consists of adventitious mineral matter like clay minerals (kaolinite, montmorillonite, illite and gibbsite), carbonate minerals (calcite, dolomite, ankerite and siderite), pyrite minerals (pyrite and marcasite) and quartz grains impregnated in vitrinite and inertinite. Plate 1, figures 3 and 4 show pyrite associations with the semi-fusinite and framboidal pyrite with the vitrinite in the Permian and Jurassic coals, respectively. The clay and carbonate minerals are intimately associated in cellular structure and cleats of the coal. The concentrations of discrete minerals in the Jurassic coal is higher (4-13%) than the Permian coal (2-6%) mainly due to the Jurassic coal being deposited in the lower delta environment and subjected to marine influences.

DEPOSITIONAL ENVIRONMENT

The comments on the environment of deposition for the Permian coal are based on the presence of Glossopteris-Gangamopteris flora within the coal measures, low to medium semi-fusinite ratio, macerals of the non-structured intertinite group namely inertodetrinite and micrinite, low mineral matter and very low (10-70 ppm) boron in the coal. The pattern of sedimentation based on these parameters is essentially fluvial and fluvio-lacustrine, mostly with fluctuating water table. The nature of vitrinite A in the coal reflects formation from woody vegetation assigned to pteridophytes. The presence of high inertodetrinite and micrinite in the coal supports oxidation due to fluctuating water table with continuing net accumulation of peat in the basin, Hunt and Smyth (1989).

The presence of framboidal pyrite, boron in the range of 60-410 ppm and the acanthomorphs in the Hill River coal supports that the coal measures of the northern Perth Basin were deposited during a regressive phase of marine transgression possibly in an upper to lower delta environment (Sappal & Islam, 1992).

CONCLUSIONS

The petrology, palynology and the trace elements distribution of the coal are important aspects to understand the depositional environment of Jurassic and the Permian coals of Western Australia. These investigations also impact on the exploration and utilization of coal. The character, proportions and associations of mineral matter with lithotypes and the maceral are matters of concern to both producers and consumers of Western Australian coal.

REFERENCES

Andrews EC 1938. The structural history of Australia during the Palaeozoic. *Proc. R. Soc. New South Wales* **71**: 118-187.

Ashton PJ, Betlinski MT & Chapman DJ 1995. Collie and Wilga basin. *Geol. Soc. Australia Coal Geology Group Special Publ.* **1**: 369-386.

Diessel CFK 1965. Correlation of macro and micropetrography of some New South Wales coals. *Proc. Eighth Commonwealth Min. metall Congress* **6**: 669-677.

Hunt JW & Smyth M 1989. Origin of inertinite-rich coals of Australian cratonic basins. *Int. J. Coal. Geol.* **11**: 23-46.

Kristensen, SE & Wilson AC 1986. A review of coal and lignite resources of Western Australia. *Proc. Thirteenth Council of Min. metall. Institutions Congress* **2**: 87-97.

Kristensen SE 1995. Perth Basin. *Geol. Soc. Australia Coal Geol. Group Special Publ.* **1**: 387-394.

Santoso B 1994. Petrology of Permian coal, Vasse Shelf, Perth Basin, Western Australia, *PhD Thesis (unpublished), Curtin University of Technology.*

Sappal KK 1986. Petrography of Collie coal, Collie Basin, Western Australia. *Wampri project* **20**.

Sappal KK & Islam A 1992. Petrology and palynology of Cattamarra Coal Measures, Perth Basin, Western Australia. *Geol. Soc. Australia. Abstracts,* **32** *11th Australian Geological Convention*, p. 129.

Standards Association of Australia 1977. Code of practice for preparation of hard coal samples for microscopic examination by reflected light. *AS 2061.*

Standards Association of Australia. 1981. Determination of the maceral group composition of bituminous coal and anthracite (hard coal). *AS 2061.*

Standards Association of Australia 1982. Terms relating to the petrographic analysis of bituminous and anthracite (hard coal) *AS 2481*(5).

Stopes MC 1935. On the petrology of banded bituminous coals. *Fuel* **14**: 4-13.

Suwarna N 1993. Petrology of Jurassic coal, Hill River Area, Perth Basin, Western Australia. *Ph.D. Thesis (unpublished), Curtin University of Technology,* 339p.

Willmott SP 1964. Revisions to the Mesozoic stratigraphy of the Perth Basin. *Australia Bureau of Mineral Resources, Petroleum Search Subsidy Acts Publications* **54**: App. 1, 11p.