# LITHOTYPE AND CHEMICAL CHARACTERISTICS OF THE SOUTH WALKER CREEK COALS, BOWEN BASIN, AUSTRALIA

## *LITOTIPE DAN KARAKTERISTIK KIMIA BATUBARA SOUTH WALKER CREEK, BOWEN BASIN, AUSTRALIA*

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Abstract

Lithotype analysis is very useful for guidance in microscopic analysis, predominantly maceral studies. However, the lithotype analysis may also contribute to identify mineral matter occurrence and chemical characteristics. The South Walker Creek coal occurs in a single seam 10.5 to 14 m in thickness and is dominated by dull and bright (40-60% bright), and dull with numerous bright bands (10-40% bright) lithotypes, along with minor dull (< 1% bright) coal. In vertical profile the lithotype content of the seams show an irregular pattern from the top to the bottom. The bright and banded coal tends mainly to occur in or around the middle of the seam. Carbonaceous shale and claystone are the most common clastic bands. The occurrence of clastic dirt bands is mostly associated with the duller plies in the coal seam. Duller lithotypes are mostly associated with a high proportion of inertinite and mineral matter content which is suggests the coal was formed in deep-water conditions. Proximate and fixed carbon analysis shows that the coal seam has relatively higher grade in the middle of the seam and decreases markedly in the top and bottom of the seam. This indicates that the middle of the seam associated with the bright and banded coal lithotype, however in the top and bottom of the seam in association with the duller plies or claystone and carbonaceous shale. This paper is developed from MSc thesis at the University of New South Wales, Australia.

Keywods: coal lithotype, chemical characteristics, South Walker Creek, Bowen Basin



*Abstrak*

*Analisis litotipe pada batubara sangat berguna dalam analisis mikroskopi, terutama dalam studi maseral, tetapi dalam perkembangannya litotipe analisis pada batubara juga berguna untuk mengidentifikasi kehadiran mineral matter dan karakteristik geokimia. Batubara South Walker Creek terbentuk berupa satu lapisan batubara dengan ketebalan berkisar antara 10,5 m sampai 14 m, dimana secara umum didominasi oleh litotipe dull-bright (40-60% bright), dull dengan dominan lapisan bright (10-40% bright), dan sedikit dull (< 1% bright). Secara vertikal komposisi litotipe dalam lapisan batubara menunjukkan pola yang tidak teratur dari bawah sampai keatas, dimana litotipe bright dan banded lebih banyak terbentuk pada bagian tengah lapisan batubara. Lapisan batulanau dan serpih karbonan merupakan batuan klastika yang sering terbentuk bersamaan dengan lapisan batubara. Kehadiran dari lapisan klastika pada lapisan batubara sering berasosiasi dengan litotipe dull. Litotipe dull juga sering berasosiasi dengan tingginya komposisi inertinit dan mineral matter, hal ini menunjukkan bahwa kemungkinan batubara ini terbentuk pada kondisi basah atau deep water condition. Analisa proksimat karbon padat menujukkan bahwa pada bagian tengah lapisan batubara memiliki peringkat lebih tinggi dan selanjutnya menurun pada bagian atas dan bawah seam. Hal ini menunjukkan bahwa bagian tengah dari lapisan batubara berasosiasi dengan litotipe bright dan banded, sedangkan bagian atas dan bawah dari lapisan batubara berasosiasi dengan litotipe dull atau batulanau dan serpih karbonan. Makalah ini dikembangkan berdasarkan data dari thesis MSc di Universitas New South Wales, Australia.*

Kata Kunci: litotipe batubara, karakteristik kimia, South Walker Creek, Bowen Basin.

## Introduction

Coal is a heterogenous sedimentary rock characterized by many variations in physical and chemical properties. The different physical and chemical properties of individual samples are important in determining the overall characteristics of the coal seams. Macroscopic and chemical examination of coal samples is a fundamental key for further interpretation and analysis, such as mineralogical studies for coal utilization.

Macroscopic analysis such as coal lithotype data provides useful information for further observation,

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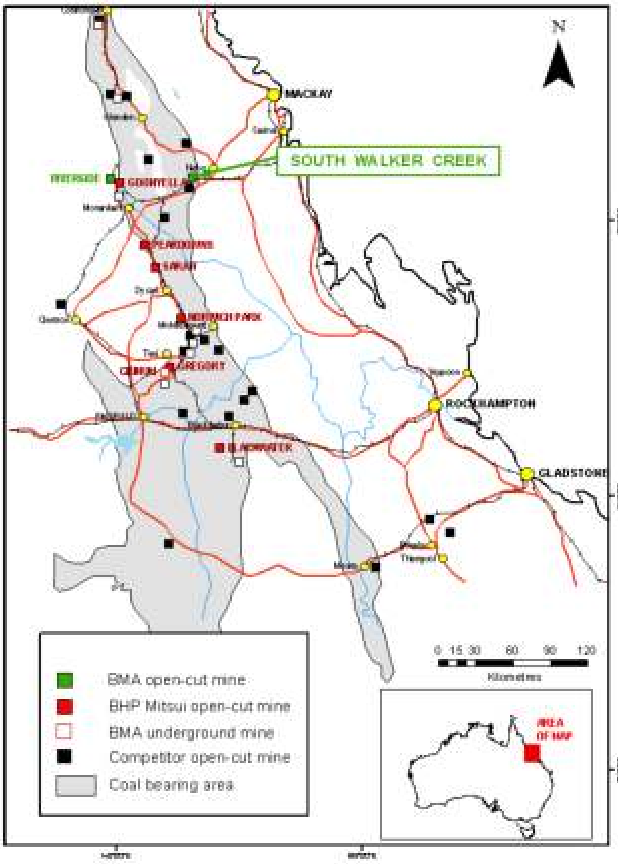


Figure 1. Location of the study area.


Figure 2. Core of borehole 11852 from the Mulgrave Pit, South Walker Creek.



such as coal petrology, seam correlation and other purposes. Lithotype analysis may be useful for guidance in microscopic analysis, mainly maceral studies. Some researchers indicate that the coal lithotypes can be correlated with maceral characteristics in a number of cases (Diessel, 1965; Smith, 1968; Shibaoka and Smyth, 1975; Cameron, 1978; Marchioni, 1980).

The South Walker Creek coal mine is located near Nebo in Central Queensland, Australia (Figure 1). The distribution of coal measures in the northern Bowen Basin is controlled by faulting and folding within the Nebo Synclinorium. The coal resources of this area are part of the Late Permian Rangal Coal Measures. The most economic seam at South Walker Creek is the “main seam”, which comprises 10.5 m to 14 m of dull to dull banded coal with rare thin stone beds. Permana (2011) indicates that the South Walker Creek Coals consist of a number of different clay and carbonate minerals. They occur macroscopically as lenses or nodules in fusain bands within the coal seam, or as fractures fillings or coating on joint surfaces and as “silickensides” associated with fault zones. However, the association of the mineral matter occurrence and coal lithotype within the South Walker Coals are poorly understood. This paper provides information about the coal seam characteristics in the South Walker Creek area, such as coal lithotype and geochemistry. It also describes the association of coal lithotypes with mineral matter occurrence within the coal seams, as well the association of coal lithotypes, chemical properties and coal rank stages.

## Methods

Two cored sections covering the main coal seam were made available from the Mulgrave Pit (boreholes 11424 and 11852) for more detailed macroscopic analysis or coal lithotype analysis (Figure 2). Hand specimens of coal were also collected from the exposed mine workings (Walker and Toolah Pits) during a visit to the site and used for this study. Twenty four short intervals of core (each approximately 100 mm long) from that study were subjected to further geochemical investigation. Row data within this paper were extracted from my MSc thesis, however new analysis and interpretation were developed.

Table 1. Comparison of the lithotype classification (Stopes, 1919; Schopf, 1960 and AS 2916, 2007)

| **Stopes (1919)** | **Schopf (1960) ASTM standard (1978)** | | **Australian Standard 2916** |
|---|---|---|---|
| Banded (humic) coals | | | |
| Vitrain | Vitrain | | Coal, bright (> 90% bright) |
| Clarain | Attrital coal | Bright | Coal, bright, dull bands (60-90% bright) |
| | | Moderately bright | Coal, dull and bright (40-60% bright) |
| | | Mid. lustre | Coal, mainly dull with numerous bright bands (10-40% bright) |
| | | Moderately dull | Coal, dull minor bright bands (1-10% bright) |
| | | Dull | |
| Fusain | Fusain | | Coal, dull (< 1% bright) |
| Nonbanded (sparopelic) coals | | | |
| Cannel coal | Cannel coal | | Coal, dull conchoidal (canneloid) |
| Boghead coal | Boghead coal | | |
| Impure coals | Bone coal | | Coal, stony (or sahley) |
| | Mineralised coal | | Coal, heat altered |
| | | | Coal, weathered |



*Lithotype Analysis*

Based on macroscopic appearance, such as colour, lustre, fracture and stratification in coal seams, Stopes (1919) proposed four basic lithotypes for describing banded (or humic) bituminous coal, as vitrain, clarain, durain and fusain. This terms are widely used for describing individual hand specimens or discrete horizons in coal seams. However, difficulties have arisen in using this terminology to describe coals in bore cores and coal seam exposures in mine faces. In practical application two of the four lithotypes (vitrain and fusain) occur as thin layers or lenses, usually only some millimetres in thickness, while the other two typically occur as thicker beds within the seam. Strict usage of this terminology would give extremely detailed descriptions, and is not particularly effective for practical purposes at the full-seam scale due to the number and variability of lithologically distinct units involved (Ward, 1984; Thomas, 2002).

Schopf (1960) introduced a coal lithotype system for use by the U.S Geological Survey, and this has been successfully used by many others for field use. The coal is described using three categories, vitrain, fusain and attrital coal. Attrital coal, as proposed in this terminology, is described as having five levels of lustre ranging from bright to dull. Vitrain and fusain are thus regarded as discrete units (bands) occurring within a matrix of finely divided attrital coal (Ward, 1984).

Another classification has been established by Diessel (1965), and has since been widely employed in the Australian coal industry. Diessel's terminology is based on the relative brightness of layers within the coal seams, divided into five categories, namely bright coal, banded bright coal, banded coal, banded dull coal and dull coal. There are many similar classification systems in the world, and all of them can be used for broad and particular purposes, such as the lithotype classification for soft brown coal (Taylor, 1998; ICCP, 1993), and macroscopic description of lignites (Bustin *et al.,* 1983)

In this study, the Australian system was used for describing the coal lithotype, following Australian Standard 2916 (Standards Australia,2007; Table 1). This system is very suitable for field use, with more detail in physical description. Although the terms are similar to the Schopf' classification, this terminology is much more descriptive, the “attrital coals” are divided into five categories based on major and minor constituent of each end member (Thomas, 2002).

Result of Investigation

*Lithotype log*

Lithotype characterisation of the South Walker Creek coals was carried out on core samples from boreholes 11424 and 11852 in the Mulgrave Pit. The coal in these cores (especially 11852) was re-logged in terms of lithotype, including partings or dirt bands within the coal seams. The lithotype profile for each borehole was then used to identify the pattern of vertical variation in the coal seam.

Detailed megascopic examination of borehole 11424 indicates that the coal is moderately banded and bright in lustre. Based on the Australian Standard 2916 the coal is dominantly the dull and bright (40-60% bright) or minor dull (< 1% bright) lithotype. Although bright coal with dull bands dominantly occurs in the middle of the seam, in general the lithotype profile shows an irregular pattern from the top to the bottom of the main coal seam (Figure 3).

Lithotype analysis of core 11852 shows that the coal is finely banded and moderate in lustre, with cleats or fractures mostly filled by clay and carbonate minerals (3-5 mm in thickness). In general the lithotype of core 11852 is less bright than that of core 11424, and is dominantly composed of dull coal with numerous bright bands (10-40% bright) and dull coal with bright bands (40-60% bright), together with minor dull coal (<1% bright). In the vertical

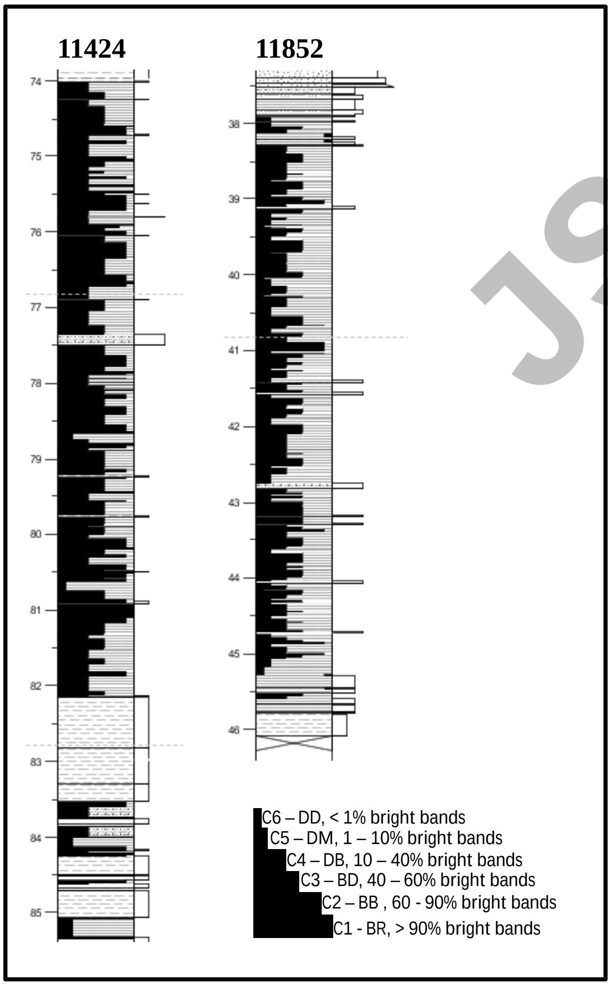


Figure 3. Lithotype profiles of boreholes 11424 and 11852 from the Mulgrave Pit (based on Australian Standard-2916)

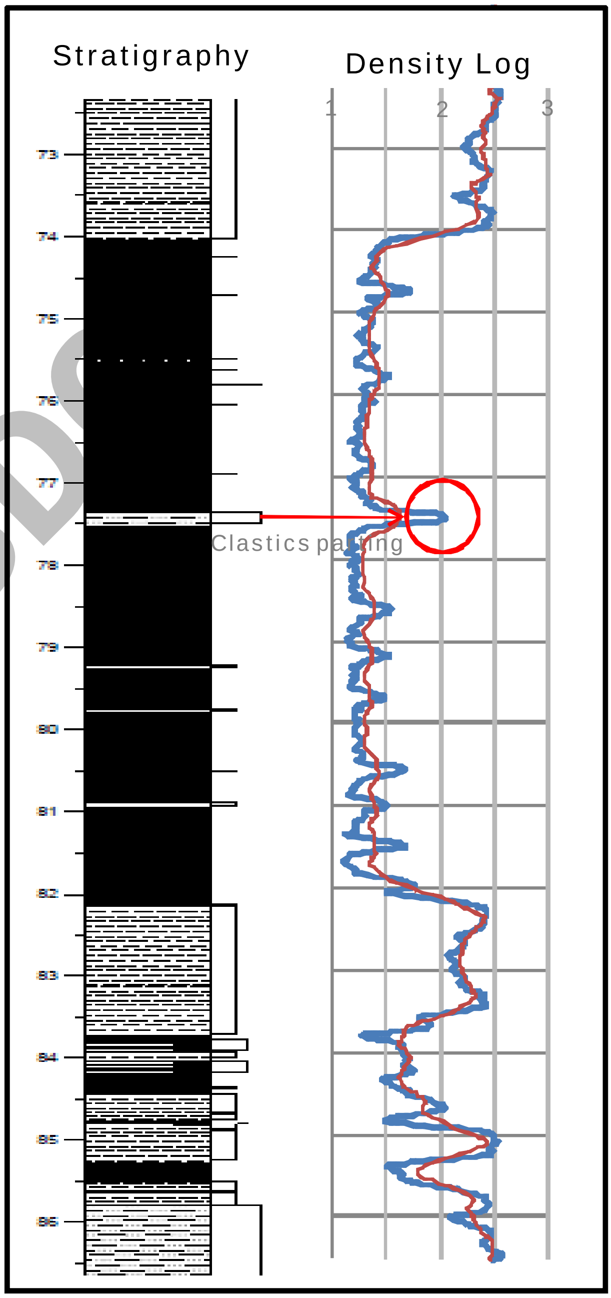


Figure 4. Comparison between the stratigraphic profile and density log of borehole 11424 (Mulgrave Pit)

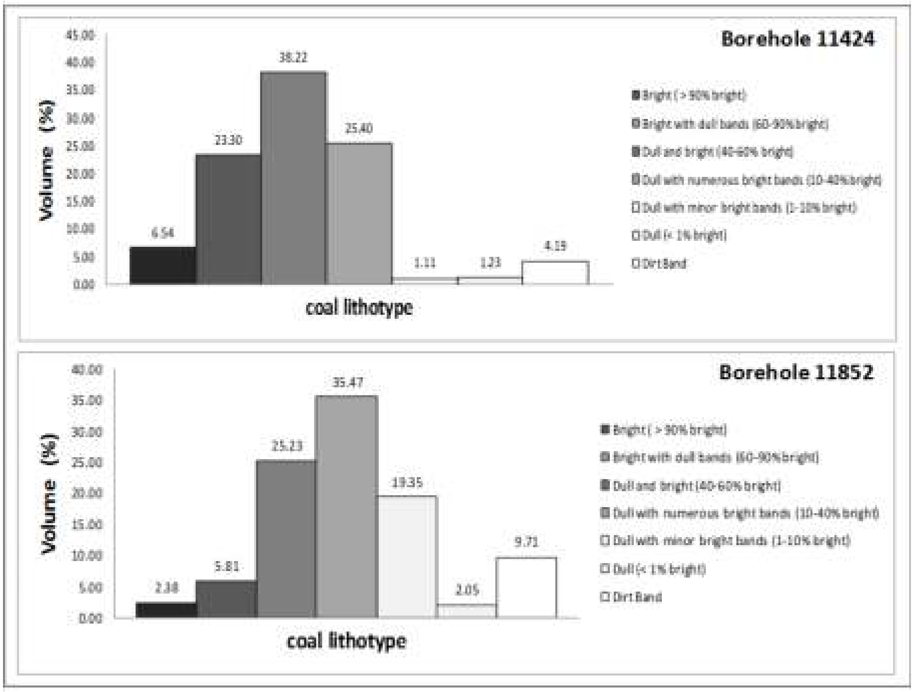


Figure 5. Abundance of coal lithotypes and dirt bands in the coal seams (boreholes 11424 and 11852)

variation of the lithotype profile, the bright coals also occur mainly in the middle of the seam (Figure 3).

Partings or dirt bands in the coal section are dominantly composed of claystone and carbonaceous shale. They mostly occur in association with the duller coal plies. It may sometimes be difficult to distinguish between dull bands and carbonaceous shale; physically they have similar characteristics, being both dull and hard. The density log from the geophysical data would probably help to distinguish the shale parting from the dull coal. The carbonaceous shale would give a high density on the log data. Figure 4 shows the comparison between density log and core description for borehole 11424, indicating that the shale partings have a high kicks in the log pattern within the coal seam. Thus, the density log pattern can assist to identify the distribution of partings or dirt bands within the individual coal seams in this study.

In vertical profile the lithotype content of the seams in borehole 11424 and 11852 show an irregular pattern from the top to the bottom. However, the bright and banded coal tends mainly to occur in or around the middle of the seam. Carbonaceous and claystone are the most common clastic bands. The occurrence of clastic dirt bands is mostly associated with the duller plies in the coal seam.

*Lithotype variation*

The variation in coal lithotype has been further investigated by calculating the aggregate thickness of each lithotype layer or band, including the non-coal partings within the seams. The sum of each coal lithotype thickness was calculated as a percentage of the full seam. The proportions of each lithotype were then plotted on a bar graph to examine their distribution in boreholes 11424 and 11852 (Figure 5).

Figure 5 shows that there is a slight difference in coal lithotype distribution between the boreholes. The coal seam in borehole 11424 is much brighter than that in 11852. In borehole 11424, the seam is dominated by dull coal with bright bands (40-60% bright), which represents around 38% of the total seam thickness. This followed by dull coal with numerous bright bands (10-40% bright) and bright coal with dull bands (60-90% bright) at around 25% and 23% respectively. Around 6.5% of the total thickness of the coal seam is composed of bright coal (> 90% bright), while duller coal plies make up less than 2% (1.1% of dull coal with minor bright bands (1-10% bright) and 1.2% of dull coal (< 1% bright)).

The seam in borehole 11852 predominantly consists of dull coal with numerous bright bands (10-40% bright), making up around 35% of the total thickness. The bright and dull coal lithotype (60-90% bright) is the second highest proportion with around 25%.

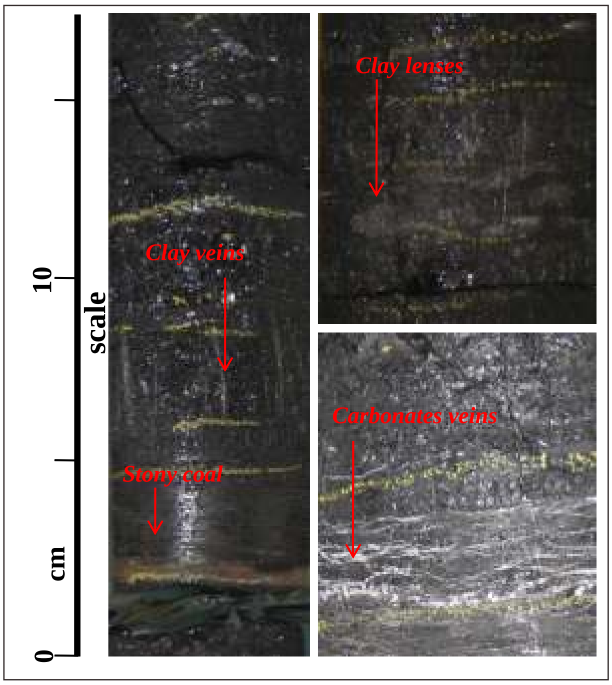


Figure 6. Macroscopic appearance of mineral matter in different modes of occurrence within the coal seam (Borehole 11852)

Figure 7. Outcrop view of nacrite mineral coating on silickenside surfaces associated with fault zones in the Toolah Pit

The proportion of dull bands is higher than bright bands; the dull coal proportion is around 21% compared to the bright coal lithotype, which makes up about 8% of the total coal thickness. The proportion of clastic partings or dirt bands in borehole 11852 is higher than in borehole 11424, being 9.7% and 4.2% respectively.

*Cleat development*

As well as lithotype bands, cleats are very important features to be considered in macroscopic analysis. The major set of cleats is termed the "face cleat", and the shorter, less continuous set is the "butt cleat". Individual fractures of the latter are usually curved, and may even end up in the face cleat planes.

Based on core log observations, the South Walker Creek coals have moderately developed cleat systems. The face and butt cleat can be recognized from the top to the bottom of the seam, with both open and closed apertures. The brighter coal lithotypes have lower cleat spacings than the duller coal bands. The cleats are often infilled by mineral matter, mostly carbonate and clay minerals (Figure 6).

Nacrite, one of the kaolinite polymorphs, also occurs as cleat and fracture infillings or coatings on silickensided surfaces associated with a fault zone at the Toolah Pit (Figure 7). Face cleat spacing is between 2 cm and 18 cm and cleat aperture ranges from 0.5 cm to 2 cm. The occurrence of this kaolinite polymorph is possibly due to the influence of the hot fluid circulation associated with tectonic deformation.

*Chemical analysis*

Apart from the macroscopic features, the chemical properties of the coal are also important in the present study. As well as representing the organic matter, however, the chemical constituents of coal may also represent inorganic material, including both moisture and mineral impurities.

Data on chemical properties of the coal in this study, including proximate analysis, ash analysis, and similar properties are mainly derived from samples taken from borehole 11424 in the Mulgrave Pit area.

Table 2. Proximate and the ash content of the South Walker Creek coals from the Mulgrave Pit (borehole 11424)

| SAMPLE | DEPTH | | Air Dried Moisture | Volatile matter | | | Fixed Carbon | | | Ash |
|---|---|---|---|---|---|---|---|---|---|---|
| | From | To | (%) | ad | d | daf | ad | d | daf | (%) |
| **11424-2** | 73.7 | 73.8 | 1.9 | 6.4 | 6.5 | 84.2 | 1.2 | 1.2 | 15.8 | 91 |
| **11424-3** | 74.4 | 74.5 | 1 | 15 | 14.8 | 16.8 | 73 | 73.7 | 83.2 | 11 |
| **11424-4** | 74.6 | 74.7 | 1 | 12 | 12.3 | 15.4 | 66.9 | 67.6 | 84.6 | 20 |
| **11424-5** | 74.7 | 74.8 | 1 | 11 | 10.6 | 12.7 | 71.9 | 72.6 | 87.3 | 17 |
| **11424-6** | 75.2 | 5.3 | 1 | 9.8 | 9.9 | 10.9 | 79.7 | 80.5 | 89.1 | 9.5 |
| **11424-7** | 75.3 | 75.4 | 0.9 | 11 | 10.8 | 11.9 | 79 | 79.7 | 88.1 | 9.4 |
| **11424-8** | 75.5 | 75.5 | 0.9 | 14 | 13.8 | 15.2 | 76.4 | 77.1 | 84.8 | 9 |
| **11424-9** | 75.8 | 75.9 | 0.9 | 13 | 12.9 | 15.5 | 69.6 | 70.2 | 84.5 | 17 |
| **11424-10** | 76.2 | 76.4 | 0.9 | 14 | 14 | 15.2 | 77.6 | 78.3 | 84.8 | 7.6 |
| **11424-11** | 76.5 | 76.5 | 0.9 | 14 | 14.2 | 15.5 | 76.7 | 77.4 | 84.5 | 8.3 |
| **11424-12** | 76.7 | 76.8 | 1 | 11 | 10.7 | 11.5 | 81.2 | 82 | 88.5 | 7.2 |
| **11424-13** | 77 | 77 | 1 | 11 | 10.9 | 11.2 | 85.4 | 86.3 | 88.8 | 2.8 |
| **11424-14** | 77.8 | 77.9 | 1 | 11 | 10.6 | 11.1 | 83.9 | 84.7 | 88.9 | 4.6 |
| **11424-15** | 78.1 | 78.2 | 1 | 10 | 10.5 | 11.1 | 83.2 | 84 | 88.9 | 5.4 |
| **11424-16** | 78.5 | 78.6 | 0.7 | 24 | 24.6 | 31.2 | 53.7 | 54.1 | 68.8 | 21 |
| **11424-17** | 79.6 | 79.8 | 0.7 | 19 | 19.4 | 23.3 | 63.5 | 63.9 | 76.7 | 17 |
| **11424-18** | 80 | 80.3 | 0.9 | 14 | 13.9 | 14.8 | 79.4 | 80.1 | 85.2 | 5.9 |
| **11424-19** | 80.7 | 80.8 | 0.9 | 14 | 14 | 15.2 | 77.5 | 78.2 | 84.8 | 7.7 |
| **11424-20** | 80.9 | 81 | 1.2 | 11 | 11.1 | 12.7 | 75.8 | 76.7 | 87.3 | 12 |
| **11424-21** | 81.1 | 81.2 | 1.3 | 9.8 | 9.9 | 10.7 | 81.8 | 82.9 | 89.3 | 7.1 |
| **11424-22** | 81.7 | 81.9 | 1.1 | 10 | 10.1 | 12.8 | 68.2 | 69 | 87.2 | 21 |
| **11424-23** | 82.2 | 82.3 | 1.9 | 8.1 | 8.3 | 75 | 2.7 | 2.8 | 25 | 87 |
| **11424-24** | 82.5 | 82.5 | 1.6 | 12 | 12.2 | 73.2 | 4.4 | 4.5 | 26.8 | 82 |
| **11424-25** | 84.1 | 84.2 | 1.6 | 12 | 11.9 | 29.5 | 27.9 | 28.4 | 70.5 | 59 |
| **11424-26** | 84.4 | 84.5 | 1.2 | 14 | 13.8 | 28.3 | 34.4 | 34.8 | 71.7 | 51 |
| **11424-27** | 84.6 | 84.7 | 1.4 | 10 | 10.3 | 24.6 | 31.2 | 31.6 | 75.4 | 57 |
| **11424-28** | 84.8 | 85 | 1.4 | 9.1 | 9.2 | 22.9 | 30.7 | 31.1 | 77.1 | 59 |



*Proximate analysis*

Proximate analysis ideally provides a measure of the relative amount of light volatile compounds (volatile matter) to non-volatile organic compounds (fixed carbon) released from the coal at high temperature in the absence of oxygen. From a practical point of view, the analysis includes measurement of the moisture, volatile matter, fixed carbon, and ash percentages. Proximate analysis data for the South Walker Creek coals (borehole 11424) are presented Table 2.

The inherent moisture content of the coal seam is very low, ranging from 0.7% to 1.9%. It appears to be relatively high (up to 1.9%) in the top and the bottom parts of the seam, where the ash also increases substantially, but there is no significant variation of moisture content with depth in the main, lower-ash part of the coal seam (Figure 8). The low moisture in the middle of the seam is consistent with the high rank of the coal (Table 3); the higher moisture at the top and bottom of the seam may reflect the presence of additional moisture in clay minerals associated with the high ash values.

The ash yield (air-dried basis) varies from 2.8% to 91%. Higher ash percentages occur at the top and bottom of the profile (Figure 8), mainly in association with an abundance of (clay-rich) clastic sediment. Within the main part of the seam, from 74.421 m to 81.891 m, the ash yield is relatively low, ranging from 2.8% to 21%, with an average of 11%. The stony coals and non-coal materials at the top and in the lower part of the seam have much higher ash percentages.

The coal seam would be categorized as having a low to moderate level of ash (Graese *et al.,* 1992). However, according to the more recent classification from the International Organization for Standardization (ISO-11760, 2005), the main part of the seam, which is mostly less than 11% ash, falls to a low ash level or high grade coal.

Table 3 Rank parameters for different coal rank stages (Diessel, 1992)

| RANK STAGES | % Carbon (daf) | % Volatile Matter (daf) | Specific Energy (gross in MJ/Kg) | % in situ Moisture | % Vitrinite Reflectance random | % Vitrinite Reflectance max |
|---|---|---|---|---|---|---|
| WOOD | 50 | > 65 | 11.7 | | | |
| PEAT | 60 | > 60 | 14.7 | 75 | 0.20 | 0.20 |
| BROWN COAL | 71 | 52 | 23.0 | 30 | 0.40 | 0.42 |
| SUB-BITUMINOUS COAL | 80 | 40 | 33.5 | 5 | 0.60 | 0.63 |
| HIGH VOLATILE BITUMINOUS COAL | 86 | 31 | 35.6 | 3 | 0.97 | 1.03 |
| MEDIUM VOLATILE BITUMINOUS COAL | 90 | 22 | 36.0 | < 1 | 1.49 | 1.58 |
| LOW VOLATILE BITUMINOUS COAL | 91 | 14 | 36.4 | 1 | 1.85 | 1.97 |
| SEMI-ANTHRACITE | 92 | 8 | 36.0 | 1 | 2.65 | 2.83 |
| ANTHRACITE | 95 | 2 | 35.2 | 2 | 6.55 | 7.00 |



In the top and bottom of the seam, the coal of higher ash level (up to 90%) under this latter classification would be categorized as carbonaceous rock.

The volatile matter ranges from 11.1% to 84.2% (dry, ash free basis). In the main coal seam the volatile matter is typically less than 16.8%, with 13.4% on average (dry, ash free), consistent with the high rank level. However, some values, mainly high ash coals with low fixed carbon contents (dry, ash free), the volatile matter is abnormally high up to 84.2% (Table 2). These may indicate that the volatile matter is derived from the carbonate minerals in the samples.

The fixed carbon ranges between 15.8% and 89.3%, with 83.3% on average (dry, ash free). The fixed carbon contents have a good inverse correlation with the ash and volatile matter contents. The higher fixed carbon contents are concomitant with the relatively low ash and volatile matter contents (Figure 8). This suggests that the relatively low fixed carbon contents, coupled with the abnormally high volatile matter (>70% VM, daf) and ash level (> 50%, ad) in the top and bottom of the seam, is consistent with carbonaceous rock associated with the roof and floor of the coal seam.

Discussions

*Coal lithotype and peat environment*

The lithotype profile provides information on changes in water table during the peat depositional processes. The thickness of the individual coal lithotypes indicates the relative duration of either submergence or emergence of the peat. Tasch (1960) proposed an association between the rate subsidence and coal lithotype. Fusain is formed during low rates subsidence, in relatively shallow water, frequently exposured to air in dry conditions combined with fires. Bright and bright banded coals (vitrain and clarain) are formed with flooding at relatively shallow depths. Dull coal (durain), however, may have been formed under deeper water conditions, and carbonaceous shale and dirt bands are thought to be formed in the wettest conditions. This concept seems to be successfully applied in particular areas, but can not be applied to other areas without verification from other analysis, such as microscopic analysis (Diessel, 1992).

Diessel (1992) has demonstrated that the dullness of many coal lithotype in Australian coal seams is basically due to the concentration of inertinite, with moderate contents of liptinite and minerals. The high proportion of inertinite in dull coal is probably due to the partially oxiding condition of the plant matter under relatively dry conditions. Lamberson *et al.* (1991) also indicate in a similar way that the increasing inertinite in the banded to dull banded plies of the high-inertinite Cretaceous coals has been regarded as due to indicating drier conditions, persistently lower water table and more intense oxidation.

The lithotype profiles indicate varying proportion of dull and bright lithotypes for the South Walker Creek coal seam. The dull lithotypes tend to be persistently observed at the top and bottom of the seam. Organic petrology indicates that the inertinite maceral are also predominantly found in the top and bottom of the coal seam associated with dull coal with bright bands (40-60% bright) and dull coal with numerous bright bands (10-40% bright). This may be a similar pattern to previous studies by Silva *et al.* (2008), the dull lithotypes associated with the high content of inertinite in part are a result of relatively drier conditions in the mire combined with freezing temperatures at winter time, where the ground water table relatively low. In this circumstance the peat was partially or totally exposed, oxidized and reworked.

Coal lithotype and mineral matter occurrence

Although a high percentage of the mineral matter is expected for dull coal, an association between mineral matter proportion and coal lithotype is difficult to identify. Mineral impurities in coal may be in the form of discrete bands, streaks or layers interbedded with the organic constituents, or they may occur as nodules or as vein infillings. Dull coal often contains clay minerals disseminated throughout the organic matter rather than in discrete layers, and veins or cleat infillings tend to be less common than in brighter lithotypes.

Mineral matter examination of the coal seam from the borehole 11852 indicates that macroscopic carbonates and clay minerals occur mainly as vein infillings, both parallel and perpendicular to bedding. In some cases clay minerals are found as lenses or layers (up to 1 cm) in fusain bands, or even as stony coal (Figure 5). This occurrence of mineral matter is dominantly found in the dull coal. The presence of a high amount of mineral matter in coal may indicate that the coal was formed in deep-water conditions. Cecil *et al.* (1979), however, suggest that the high concentration of mineral matter in coal may be due to sub-aerial ablation of the peat, or from excessive peat decay in swamp water of pH greater than 4.5.

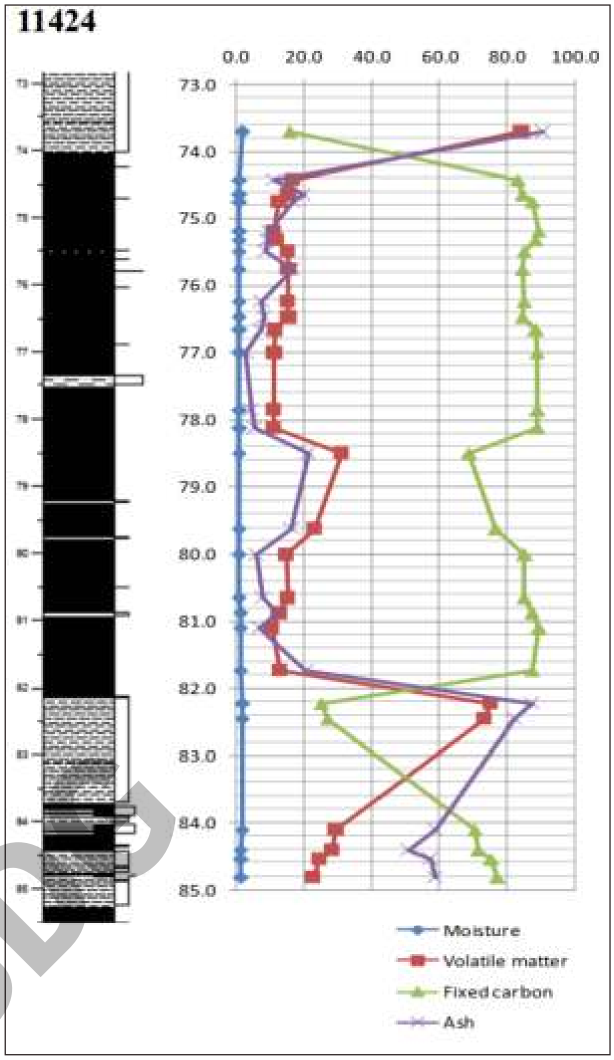


Figure 8. Variation of proximate analysis with depth in the Mulgrave Pit (Borehole 11424)

Considering variations of the rates of accommodation and peat accumulation, the increasing mineral content in the dull coal lithotype may also suggest an increase in the rate of energy during the peat accumulation, indicating a trend towards subaquatic conditions (Silva *et al.,* 2008). Another study also indicates that dull coal, which represents change in vegetation from arboreal to shrub and herbaceous, may be associated with higher mineral matter contents indicating a clastic marsh setting (Crosdale, 1995).

*Chemical properties and coal rank*

Diessel (1992) indicates that the various physical and chemical changes after deposition and during coalification constitute the basis for the concept of coal rank.

As a concept, rank cannot be measured, but it can be assessed by means of those physical and chemical properties which change most during coalification. Inherent moisture and dry, ash-free volatile matter both decrease with increasing rank, whereas dry, ash-free carbon content and specific energy increase with increasing coalification. The relations of these and other parameters to coal rank are shown in Table 3.

The present study suggests that the moisture content of just under 2% (ad) indicates a maximum reflectance around 1.03% to 1.56% or close to the 0.97% to 1.49% random vitrinite reflectance of the Diessel's classification. Other proximate analysis parameters, such as the relatively low volatile matter at around 13.4% in average (dry, ash free), and high fixed carbon at about 83.3% on average (dry, ash free), suggest that the South Walker Creek coal is consistent with a high coal rank level (volatile bituminous coal).

The proximate analysis data in the vertical sequence of the seam show a regular variation. The air dried moisture and volatile matter (dry, ash free) are consistently higher at the top and bottom of the seam, correlated with the ash yield. The fixed carbon (dry, ash free), however, is relatively low in this particular sequence. This suggests that the coal seam has relatively higher grade in the middle of the seam and decreases markedly in the top and bottom of the seam.

## Conclusions

Lithotype analysis of the South Walker Creek coals show them to be finely to moderately banded, dull and bright in lustre and highly cleated, with the cleats mostly filled by mineral matter. Based on Australian Standard terminology the coal in the cores is dominantly dull and bright (40-60% bright), and dull with numerous bright bands (10-40% bright), along with minor dull (< 1% bright) coal lithotypes.

Although coal with dull and bright bands (40-60% bright) dominantly occurs in the middle of the seam, the lithotype profile shows an irregular pattern from the top to the bottom in vertical section. Carbonaceous shale and claystone are the most common non-coal bands, and are mostly associated with duller plies in the coal seam. The fracture fillings are mostly carbonates and clay minerals; clay minerals in some cases are also found as lenses or layers (up to 1 cm) in fusain bands, or even as stony coal within the seam.

Duller lithotypes (10-40% bright and 40-60% bright) mostly associated with the high proportion of inertinite seen in the organic petrology studies. This suggests that the peat was partially or totally exposed, oxidized and reworked, as a result of relatively drier conditions in the mire and freezing temperatures during winter time, where the ground water table was relatively low.

The chemical properties of the South Walker Creek coals include relatively low moisture, low volatile matter (dry, ash-free) and low to moderate ash yield. If allowance is made for the effects of mineral components, the moisture and volatile matter are consistent with a low volatile bituminous rank.



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