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Construct a Paleo-Limnological Environment Based on Coal Petrography; Case Study, Two Selected Coal Seams, North Crowsnest Open-Pit Mine, Canada

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Abstract

The Crowsnest coalfield is a separated structural coalfield at the East Kootenay basin within southeast British Columbia. Selected Jurassic-Cretaceous two coals seam S-10 and S-C of the Mist-Mountain formation were investigated from the points of coal petrography to construct a Paleo-limnological setting. Twenty-two channel coal samples were assembled and measured from S-10 and S-C coal seams. Vitrinite reflectance measuring of the S-10 coal concern to low-volatile bituminous (1.61, on average). While the vitrinite reflectanc measurements of S-C coal seam show an average value of 0.98 related to high-volatile bituminous. Petrographic analysis demonstrates that the S-10 coal seam appears to be rich in inertinite than the S-C coal seam that appears rich in vitrinite. Applying coal facies indices of Tissue Preservation Index, Gelification Index, Ground Water Index, Vegetation Index and coal facies diagrams for the studied coal seams aid to suggest a condition of the depositional Paleo-environments. The results promote Paleo-depositional sites of telmatic to limno-telmatic setting of rheotropic systems swamp. The obtained results show a trend of increase in both herbaceous flora and anoxic waterlogged limo-telmatic setting toward the younger coal seam S-C than the older S-10 coal seam.

Keywords: Petrography; Paleo-limnology; Peat swamp; Coal indices; Maceral analysis; Crowsnest

1. Introduction

The coal has been a source of energy in Canada since the 18th century. According to British Petroleum statistical review of world energy (2020), total proved coal reserves at Canada 6582 million tons, roughly 0.6% of the world total. This represents more energy than all the oil and gas in the country combined. Canada's coal resources occur in 16 sedimentary basins or groups of basins and range in age from Devonian to Tertiary. The Western Canada Sedimentary Basin (WCSB), which contains the vast majority (about 90%) of the nation's coal resources of immediate interest, underlies a large area in the provinces of British Columbia, Alberta, Saskatchewan and Manitoba (Smith et al., 1994; BCCIO, 2018). The Kootenay Group is one of the most important coal-bearing sequences in southeast British Colombia and other places in western Canada. From which the Jurassic-Cretaceous Mist-Mountain Formation was chosen. It is the main coal-bearing formation of economic interest in the western territory of Canada. It covers a considerable rank range from high-volatile bituminous to semi-anthracite. The generalized

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sedimentary sequence of the Mist-Mountain formation attains ≈ 650 m of vertical thickness and involves over 30 coal seams embody $\approx 12\%$ of the total stratigraphic thickness (Gibson, 1985; Grieve, 1993; Vessey, 1998; Kalkreuth, 2004; Goodarzi et al., 2009). The S-10 coal seam represents part of a package of the Late-Jurassic coal seams that compose the base of the considered formation. Whereas, the S-C coal seam represents capped coals of the Mist-Mountain formation of Early-Cretaceous time. Earlier studies establish a significant change in the rank and geochemical characteristic of Jurassic against Cretaceous coals of the Mist-Mountain formation, while it discloses little to focus on the role of maceral composition of these differences. The variations in rank reflect the coalification pattern with systematic changes in the maceral composition of coal seams had a profound effect on coal quality. Facies that depend on coal maceral types have an essential significance to distinguish the conditions and sedimentary environment of peat accumulation and deposition (Lin et al., 2011; Alkhafaji et al., 2021). Also, it shows a prominent task in the progress of the limnological environment under which the coal was preserved (Silva and Kalkreuth, 2005; Sun et al., 2010). Thus, the aim of the present study is to identify the maceral composition of the two selected coal seams as a case study, and to document progress development in coal facies to detect the suggested model of the Paleo-environment of the investigated coal seams mire system through time.

The East Kootenay coalfields of southeastern British Columbia comprise three structurally separated remnants of the Jurassic-Cretaceous Kootenay Group in the front ranges of the Canadian Rockies southeast of the British Columbia province (Fig. 1). One of which is Crowsnest coalfield, which is pear-shaped (about 50 km long, 20 km wide). It occupies a structural depression referred to as the Fernie Basin (Pearson and Grieve, 1985). Crowsnest area involves three categories of coal-seams ranks started by low-volatile bituminous seams from the base and covered by a high volatile bituminous coal seam. During the Late-Jurassic time, the package of the lowering coal seams of low- and medium-volatile bituminous. Whereas, the Early-Cretaceous coal seams are comprising fewer coal seams that cover the formation. (Pearson and Grieve, 1985; Bustin and England, 1989; Minnes and Mucalo, 2008).

East Kootenay basin involved the Crowsnest area accumulates a huge thickness of terrestrial clastic deposits reach for about 1112 m thick that formed a so-called the Kootenay Group (Gibson, 1985; Can't and Stockmal, 1989). The Group subdivided into three formations as follows from base to top (Fig. 2): The Morrissey Fm of the Lower-Jurassic contains the lower Weary Ridge member overlain by the Moose Mountain members. Both members reach a vertical thickness ranges between 20-80 m; The Mist-Mountain formation of accumulated thickness varies between 25 and 665 m of Upper-Jurassic-Lower-Cretaceous contains economic coal seams; and the Elk formation of the Lower Cretaceous conglomerates of 0 up to 590 m thick (Grieve, 1985; Dunlop and Bustin, 1987; Vessey, 1998). In the Crowsnest area, the Mist-Mountain formation reaches 665 m in thickness. It forms a syncline fold structural. The older Jurassic coal seam appears along the periphery of the area, whereas the core of the Crowsnest area the younger Cretaceous coal seams is declared. The coal-bearing formation composed of an alternation of economic coal, shale, sandstone and siltstone. The Mist-Mountain formation conformable overlain the Moose Mountain member and unconformably overlay by conglomerates of Elk formation (Gibson, 1985; Dunlop and Bustin, 1987; Grieve, 1993). During the Jurassic to Early-Cretaceous, the Mist-Mountain coal-bearing formation is deposited according to global compressional tectonic orogeny of so-called (Columbia 1) within the east-Kootenay basin. These stages are after the next Columbia 2 and Laramide orogenies that extended until the Early-Tertiary periods (Gibson and Hughes, 1981; Cant and Stockmal 1989). The post-depositional folds and thrust faults structures that influenced the coal sequence in the Crowsnest area are formed during the Columbia 2 and Laramide stages (Bustin and England, 1989). They form a broad plunging syncline fold structure of the Crowsnest Area. The hinge-line of these broad fold plunges toward a southwest direction. The broad fold affected by a list of thrust faults that duplicate coal seams and thicken them to valuable economic thickness, especially at the western side of the present area. Post-Tertiary the compressional force replaced by an

extensional force that responsible for a dip-slip displacement along the old thrust faults and form a new normal fault affect the Crowsnest area (Grieve and Kilby, 1989; Hacquebard and Cameron, 1989).

Fig. 1. Location map of the study area

2. Materials and Methods

Channel samples regularly gathered from two selected coal seams, S-10 and S-C of Mist-Mountain Fm in the mining area. 10 channels samples from a vertical 15 m thickness S-10 coal seam. The sampling interval was 1.5 m to cover the entire coal seam thickness and ordered by a numerical number from base to top. Whilst twelve channel samples are collected from a 5 m vertical thickness of seam S-C with a sample interval of 0.5 m. The coal fragments are numbered numerically in ascending order from base to top. The collection and shipping of samples took place under the permission of teck resources limited of about 20Kg of each coal seams in two boxes, shipping with the annual imported coking coal to El-Nasr Coking Company in Egypt for academic researches purpose. For the preparation of the polished block samples, the coal was firstly crushed to size between 1 and 2 cm that mounted in epoxy resin. A course of multiple polishing at certain polished powder sizes from coarser to finer under a standard condition of coal sample preparation (ISO-7404/1, 2016; ISO-7404/2, 2009). Vitritine Reflectance (R_o) measuring by determining the reflective intensity of light reflected from the polished surface of collotelinite maceral under incident, monochromatic light, reflected light microscope (Nikon-Eclipse) using oil immersion $n = 1.518$ with a magnification according to ISO-7404-5 (2009) and ISO-7404-3 (2009)

Fig. 2. Generalized lithostratigraphic section of the Mist-Mountain Formation at North of Crowsnest Coalfield (British Columbia Coal Industry Overview, 2018)

An yttrium-aluminum-garnet standard is applied to calibrate reflectance equal to 0.894. Measuring the random reflectance is driven out by a count of fifty counted points per sample. The general classification of macerals is done according to the ICCP System (1998; 2001; 2017). The maceral identity of each sample carried out by a minimum of 500 counted and express as volume percentages in reflected light microscope from two polished blocks for each sample at the laboratory of organic geochemistry of the Egyptian Petroleum Researches Institute (EPRI). The maceral indices of Gelification Index (GI), Tissue Preservation Index (TPI) corresponding to Diessel (1982) are operated in the present study. Also, indices of the Ground Water Index (GWI) and Vegetation Index (VI) corresponding to Calder et al. (1991) are handled as well. Coal facies of T-D-F triangular according to Kalkreuth et al. (1991), Kalaitzidis et al. (2009), and facies diagrams of (GI vs. TPI) agree with those modified by Feng et al. (2019) and (GWI vs. VI) giving by Calder et al. (1991) are applied for plotted coal samples of the S-10 and S-C coal seams to highlight the former depositional conditions contemporary the peat swamp formation.

3. Results

3.1. Maceral compositions

Forty-four block polished samples are examined microscopically for the selected twenty-two coals (using two blocks polished for each sample) of the S-10 and S-C coal seams. The maceral identity was determined and counted. Besides, mineral matter (clay, calcite, pyrite, quartz, etc.) were distinguished and counted too (Tables 1 and 2; Figs. 3 and 4). The maceral contents of the studied S-10 coal samples show roughly an equal amount of the vitrinite and inertinite macerals of about 50.5% and 49.15%, respectively. The minor amounts of the liptinite macerals are show a minimal percentage of 0.35%. Collodetrinite is the most common vitrinite macerals in the S-10 coal samples with an average value of

45.0%. The collodetrinite marked in the examined coal as a groundmass binding other coal macerals (Fig. 3; a, b, f, h). The subsequent maceral of well-preserved tissue is the collotelinite maceral, less frequently marked with 4.24%. Vitrodetrinite occurrence is limited by 1.26%; on average (Table 1). The inertinite macerals are the second most abundant maceral group (49.15%) in the S-10 coal seam (Table 1). In which, semifusinite is the dominance maceral displays an average amount of 35.4%. It appears in the studied coal samples either as spindle shape with high reflectance or high reflectance tissues less than fusinite. Fusinite maceral present in subsequent order shows an average value of 11.3%, identified by a high reflectance well-preserved cellular tissue with cell lumen either empty or full with micrinite or resinite macerals (Fig. 3: c, d, e, g). The uncommon occurrence of each micrinite, macrinite, inertodetrinite, and funginite macerals are recorded with a lesser amount < 1%. (Fig. 3; b, g) (Table 1). The (MM) mineral matter contents of the S-10 coal seams are of 4.67% on average, that comprises clay minerals (3.2%) quartz (1.1%) and pyrite (0.4%) (Table 1; Fig. 3; h).

In opposition, the maceral content of the S-C coal seam revealed a most common of vitrinite macerals with an average value of 69.4% then Inertinite of 29.7% and the liptinite of 0.9%. As same as the S-10 coal samples, the collodetrinite (Cd), is the most common of S-C coal samples with an average of 51% (Fig. 4; c, d, e), Collotelinite (Ct) maceral is less common with an amount of 11.2%. It appears as a thin to thick band of intact tissues of homogenous tone with poor structure of absent cell lumen (Fig. 4; c). Vitrodetrinite (Vd), is an uncommon represents of an amount equals 4.0% that occur as small tiny detrital particles with varying shapes (Fig. 5; a, b, f). Telinite maceral (T) is presence with minor amounts of 2.4%, with well-preserved cellular structure.

Table 1. Main maceral composition and indices of the studied (S-10) coal samples; Vitrinite, V; Inertinite, I; Liptinite, L; Collotelinite, C; Collodetrinite, Cd; Vitrodetrinite, Vd; Fusinite, F; Semifusinite, Sf; Macrinite, Mac; Micrinite, Mic; Inertodetrinite, Id; Secretinite, Sc; Sporinite, Sp; Cutinite, Cut; Resinite, R; Liptodetrinite, Ld; Alginate, Alg; Clay, Cly; Pyrite, Py; Quartz, Qz; Mineral Matter, MM; mineral matter free (mmf), Tissue Preservation Index, TPI; Gelification Index, GI; Ground Water Index, GWI; Vegetation Index, VI.

Sample no.	Vitrinite					Inertinite						Liptinite					Mineral Matter					Coal Facies							
	Vol, % (mmf)					Vol, % (mmf)						Vol, % (mmf)					Vol, %												
	Ct	Cd	Vd	ΣV	F	Sf	Mac	Mic	Id	SC	ΣI	Cut	R	Ld	Alg	ΣL	Cly	Py	Qz	ΣMM	TPI	GI	GWl	VI	T	D	F		
10	3.2	54.0	4.6	61.8	9.0	26.1	0.0	2.0	0.0	0.6	37.7	0.5	0.0	0.0	0.0	0.5	14.0	0.8	0.0	14.8	0.63	1.68	21.5	0.70	3.2	73.1	35.1		
9	3.5	56.1	2.3	61.9	10.0	27.7	0.0	0.0	0.0	0.0	37.7	0.0	0.0	0.0	0.4	0.4	1.5	0.5	3.5	5.5	0.71	1.64	17.6	0.73	3.5	63.8	37.7		
8	5.3	53.8	1.7	60.8	5.0	30.6	0.0	1.6	2.0	0.0	39.2	0.0	0.0	0.0	0.0	0.0	3.2	0.0	2.8	6.0	0.69	1.55	11.3	0.73	5.3	63.5	35.6		
7	3.8	47.0	1.0	51.8	0.0	45.1	0.0	1.5	0.0	0.0	46.6	0.0	0.0	1.6	0.0	1.6	1.7	0.5	2.8	5.0	0.99	1.11	13.7	1.01	3.8	54.1	45.1		
6	4.1	42.5	0.4	47.0	3.7	42.6	3.8	1.9	0.0	1.0	53.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1	0.0	3.1	1.02	1.08	11.1	1.19	4.1	46	46.3		
5	5.0	51.0	0.0	56.0	28.2	11.9	1.0	0.0	2.9	0.0	44.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5	0.82	1.33	10.3	0.84	5	54	40.1		
4	4.8	31.0	1.2	37.0	19.6	41.3	1.9	0.2	0.0	0.0	63.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0	2.9	5.3	1.92	0.64	7.6	2.12	4.8	37.5	60.9		
3	4.6	20.2	1.2	26.0	16.9	55.0	0.5	1.4	0.0	0.1	73.9	0.0	0.1	0.0	0.0	0.1	1.0	0.5	2.8	4.3	3.27	0.36	5.3	3.8	4.6	25.3	71.9		
2	4.0	50.7	0.0	54.7	0.0	42.5	0.2	1.7	0.2	0.5	45.1	0.0	0.2	0.0	0.0	0.2	2.8	0.6	2.5	5.9	0.87	1.25	14.2	0.92	4	56.4	42.5		
1	4.1	43.8	0.0	47.9	20.2	31.1	0.0	0.0	0.0	0.0	51.3	0.0	0.8	0.0	0.0	0.8	2.3	0.5	3.5	6.3	1.26	0.94	12.2	1.28	4.1	50.4	51.3		
Avg	4.2	45.0	1.2	50.5	11.3	35.4	0.7	1.0	0.5	0.2	49.1	0.05	0.1	0.1	0.04	0.3	3.2	0.4	2.1	5.67	1.22	1.16	12.5	1.33	4.2	52.4	46.7		

Table 2. Main maceral composition and indices of the studied (S-C) coal samples; Vitrinite, V; Inertinite, I; Liptinite, L; Collotelinite, C; Collodetrinite, Cd; Vitrodetrinite, Vd; Fusinite, F; Semifusinite, Sf; Macrinite, Mac; Micrinite, Mic; Inertodetrinite, Id; Secretinite, Sc; Sporinite, Sp; Cutinite, Cut; Resinite, R; Liptodetrinite, Ld; Alginate, Alg; Clay, Cly; Pyrite, Py; Quartz, Qz; Mineral Matter, MM; mineral matter free (mmf), Tissue Preservation Index, TPI; Gelification Index, GI; Ground Water Index, GWI; Vegetation Index, VI.

Sample no.	Vitrinite					Inertinite							Liptinite				Mineral Matter					Coal Facies								
	Vol,% (mmf)					Vol, % (mmf)							Vol,% (mmf)				Vol, %													
	T	Ct	Cd	Vd	ΣV	F	Sf	Ma	c	Mic	Id	SC	ΣI	Sp	Cut	R	ΣL	Cly	Py	Qz	ΣM	M	TPI	GI	GW	I	VI	T	D	F
12	0.0	18.1	49.7	3.9	71.7	15.0	11.9	0.6	0.1	0.2	0.0	27.8	0.0	0.0	0.5	0.5	3.6	0.0	1.5	5.1	0.83	2.66	3.0	0.91	18	59.4	0.83			
11	2.2	12.8	59.8	3.2	78.0	7.0	12.6	0.4	0.1	0.4	0.1	20.7	0.0	0.0	1.3	1.3	2.0	1.7	1.0	4.7	0.54	3.91	4.3	0.6	15	67.7	0.54			
10	2.3	7.4	53.9	1.8	65.4	4.0	28.4	0.9	0.1	0.2	0.0	33.6	1.0	0.0	0.0	1.0	1.0	1.4	0.0	2.4	0.74	2.03	5.8	0.76	9.7	58	0.74			
9	0.0	12.1	51.2	7.9	71.2	2.2	24.5	1.7	0.1	0.0	0.0	28.5	0.0	0.0	0.3	0.3	2.6	0.0	0.8	3.4	0.64	2.72	4.5	0.76	12	62.8	0.64			
8	0.0	13.8	63.0	3.5	80.3	6.7	10.5	0.8	0.2	0.3	0.0	18.5	0.6	0.6	0.0	1.2	1.7	1.2	0.0	2.9	0.46	4.58	4.8	0.48	13.8	69.7	0.46			
7	0.0	18.7	48.8	4.2	71.7	13.8	10.7	0.7	0.2	0.2	1.9	27.6	0.0	0.0	0.7	0.7	1.8	1.5	1.5	4.8	0.77	2.97	2.9	0.9	18.7	57.3	0.77			
6	7.6	5.7	44.2	4.1	61.6	2.3	30.5	2.4	1.4	0.1	0.1	36.8	0.0	0.0	1.6	1.6	0.0	1.5	0.5	2.0	0.88	1.87	3.5	1.08	13.3	50.5	0.88			
5	7.6	4.0	43.1	3.9	58.6	5.0	34.0	2.1	0.2	0.1	0.0	41.4	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.5	1.02	1.55	3.9	1.17	11.6	49.6	1.02			
4	0.0	10.6	36.9	5.0	52.5	2.0	36.6	1.6	2.0	1.5	1.0	44.7	2.8	0.0	0.0	2.8	1.0	0.0	2.0	3.0	1.03	1.31	3.8	1.19	10.6	49.2	1.03			
3	0.0	11.3	62.8	2.9	77.0	7.5	15.1	0.0	0.4	0.0	0.0	23.0	0.0	0.0	0.0	0.0	1.5	0.0	1.5	3.0	0.51	3.35	5.8	0.54	11.3	68.7	0.51			
2	9.6	17.6	41.5	4.6	73.3	0.0	24.3	0.0	1.1	0.0	0.0	25.4	0.0	1.3	0.0	1.3	3.0	0.4	0.0	3.4	1.09	2.89	1.6	1.2	27.2	50.4	1.09			
1	0.0	12.1	55.5	3.5	71.1	12.1	14.5	0.5	1.1	0.2	0.0	28.4	0.0	0.0	0.5	0.5	4.4	0.0	1.2	5.6	0.64	2.57	5.1	0.7	12.1	65.3	0.64			
Avg.	2.4	12.0	50.9	4.0	69.4	6.5	21.1	1.0	0.6	0.3	0.3	29.7	0.37	0.16	0.4	0.90	1.9	0.6	1.0	3.6	0.76	2.7	4.1	0.86	14.4	59	27.6			

The most common of the inertinite macerals in the S-C coal seams is the semi fusinite that shows an average value of 21.1% (Fig. 4; b, d, e, f, g). It appears as a broken spindle shape commonly associated with a pyrite mineral. Degraded fusinite is considered in S-C coal samples as semifusinite maceral according to ICCP classification system. A less common fusinite maceral (about 6.5%) have been occurred either in the shape of a high reflectance, well-preserved sieve cellular structure (Fig. 4; d, e, g). Funginite (sclerotinite) is present in minor amounts of an average of 0.25%. As well, the inertodetrinite tiny particle size of 2-10 microns is commonly rare $\approx 0.25\%$, occurring as disseminated tiny inertinite fragments of varying shape with no recognizable structure. It appears derived from fragmentation of larger fusinite maceral (Fig. 4; d, e). Micrinite occurs in minimal amounts with an average of 0.6%. It observed as tiny dispersed of high reflectance powder < 2 microns in size. Macrinite is the lowest minor appearance maceral in the S-C coal seam showing an average value of $< 1\%$.

The liptinite macerals in both the S-10 and the S-C coal seams are measured in a very low percentages mostly $< 1\%$, a variety of liptinite macerals is recorded in both the studied section. Sporinite occurs as elongated thread-like or spindle-shaped dark bodies or megaspores (Fig. 4; c, h). A thin-walled cutinite (tenuicutinite) is also recorded as a narrow thread, having one serrated edge with dark grey to black tone. Resinite founded as filler of cell lumens in telinite, fusinite, and semifusinite or as isolated oval-shaped bodies (Fig. 3; d, e). Alginate recorded as a small waxy elongated body in a groundmass of collodetrinite (Fig. 3; f). Liptodetrinite maceral also appears as a fine degradation remains of dark liptinite associated with clay minerals. The content of the MM of the S-10 and the S-C coal seams occur in small percentages of (4.67% and 3.11%) in respective order (Tables 1, 2). The MM contents of the S-C coal samples composed of clay minerals (3.2%, on average), quartz (1.1%, on average), and pyrite (0.81%, on average). The amounts of clay, pyrite, and quartz of the S-C coal seams are 1.9%, 0.81%, and 0.4% in respective order.

Fig. 3. The maceral composition of the studied (S-10) coal samples; Collodetrinite, Cd; Fusinite, F; Semifusinite, Sf; Macrinite, Mac; Micrinite, Mic; Inertodetrinite, Id; Resinite, R; Alginite, Alg; Pyrite, Py.

Fig. 4. The maceral composition of the studied (S-C) coal samples; Collotelinite, Ct; Collodetrinite, Cd; Vitrodetrinite, Vd; Fusinite, F; Semifusinite, Sf; Macrinite, Mac; Inertodetrinite, Id; Resinite, R; Pyrite, Py

3.2. Maceral Indices and Paleo-Ecological Diagrams

3.2.1. GI versus TPI

The GI of the S-10 coal samples varies between 0.3 and 1.7 being 1.18 on average while, the TPI values lie between 0.6 and 3.2 (1.2; on average). The GI of the S-C coal samples range from 1.3 and 4.6 (2.7; on average), whereas The TPI values lie between values of 0.4 and 1.1 (0.76, on average). Plotting the coal samples concerning the S-10 and the S-C coal seam on the GI-TPI coal facies diagram of Feng et al. (2019) that modified from Diessel (1982; 1992) the S-10 samples are within the areas of the limno-telmatic marsh (70%; 7 samples) and in telmatic dry forest swamp (30%; 3 samples). While the S-C samples are taking place mostly in the limno-telmatic marsh (90%; 10 samples) and 10% represent by the rest of two samples fall within the telmatic wet-forest swamp region (Fig. 5).

3.2.2. GWI versus VI

The calculated GWI of the S-10 coal samples ranges from 7.13 to 22.2 (12.5; on average). The calculated values of VI range from 0.73 and 2.2 (1.17; on average). Whilst the GWI of S-C coal samples ranges from 1.65 to 5.82 (4.0; on average). VI is between 0.48 and 1.2 (0.86; on average). Plotting both studied coal samples on GWI-VI diagram of Calder et al. (1991), illustrates that 1/3 of samples of both coal seams have a VI > 1 and 2/3 of samples have VI < 1 (Fig. 6). The S-10 coal samples show a tendency to be in a rheotrophic mire system where the samples belong to the S-C coal seam has the same trend within the rheotrophic mire system (Fig. 6).

Fig. 5. The GI versus TPI diagram for coal facies types of S-10 and S-C coal seams; GI= (vitrinite+gelo-inertinite)/(telo-inertinite + detro-inertinite); TPI= (telovitrinite + telo-inertinite)/(detro-+gelovitrinite + detro- + geloinertinite)

3.2.3. TDF coal facies diagram

Plotting the coal samples on the TDF adopted by Mukhopadhyay (1989) and Kalkreuth et al. (1991) on TDF facies diagram (Fig. 7) show that, the samples are lying on the right arm of the triangle between open moor and terrestrial - forest moor environments. All the samples concern the S-10 and the S-C coals fall within a field that distinguished the limno-telmatic conditions.

4. Discussion

From peat to coal, the accumulation and preservation of vegetable material must be subjected to a subsequent series of the biochemical and geochemical coalifications (Diessel, 1992; Suarez-Ruiz and Crelling, 2008). Moreover, the depositional Paleo-environments during the progress of the coalification stages may play a significant role in change, the type, the quality, and the rank of the coal formed.

Fig. 6. GWI versus VI paleoenvironmental diagram for S-10 and S-C coal seams; $GWI = (\text{gelocollinite} + \text{corpocollinite} + \text{desmocollinite} + \text{mineral matter}) / (\text{telinite} + \text{telocollinite})$; $VI = (\text{telinite} + \text{telocollinite} + \text{fusinite} + \text{semifusinite} + \text{suberinite} + \text{resinite}) / (\text{desmocollonite} + \text{inertodetrinite} + \text{alginate} + \text{sporinite} + \text{cutinite} + \text{liptodetrinite})$

Fig. 7. TDF coal facies diagram of S-10 and S-C coal seams; T = Telovitrinite; F = Fusinite + Semifusinite. D = Detrovitrinite + Sporinite + Liptodetrinite + Resinite + Cutinite + Alginate + Inertodetrinite + Detrital minerals (Clay mineral + Quartz)

The coal type is a behave of the diversity constituent of its own macerals in the mire system where it was accumulated and preserved. This diversity of macerals depends on the pathway of the chemical, microbial, and/or biological decomposition that took place on plants of wood and herbaceous associated with a bulk ecosystem of fungus, algae, bacteria, insects and even digestive plant remains from herbivory

(Hower et al. 2009; Hower et al. 2011a). At least four-to-five pathways are recognized during the biochemical stage of coalification; humification-jellification pathway, mild oxidation pathway, fire-charred pathway; multiple non-fire degradation pathways, and fungal-bacterial degradation pathways (Scott, 2002; Scott and Glasspool, 2007; Hower et al., 2011; O'Keefe et al., 2013; Dai et al., 2020).

Maceral analysis of the investigated coal samples shows the S-10 and the S-C coal seams have approximately 99% of vitrinite and inertinite macerals, with another of liptinite maceral lower than 1% (Tables 1 & 2). The S-10 Coal seam comes to be rich in the amount of inertinite than the S-C coal, and vice versa. This increasing in the inertinite maceral in the S-10 coal samples may imply that the S-10 coal seam was subjected to the circumstance of one or more of a fusinite producer pathways during their biochemical stage of the coalification before its final buried. That means, The S-10 coal seam may be subjected to an episode of dehydration and oxidation (desiccation) before its final burial in mire according to varying intensity of humification. Or the increasing in rank of coal toward the older S-10 coal seam may lead to convert some of its vitrinite macerals by increasing rate of coalification to inertinite one (like pseudo-vitrinite to semifusinite). In opposition, the increasing of the vitrinite maceral instead macerals of inertinite in the S-C coal seams may attribute a fast state of the conservation of soft and woody tissues in the mire with no relatively long span of oxidation and dehydration. The dominated of vitrinite macerals at both seams means that both coal seams (S-10 & S-C) were subjected to quite a little circumstance of fusinite produce pathway incomparable to dominate vitrinite produce pathway during their biochemical stage of coalification. The presence of vitrodetrinite macerals includes both collodetrinite and vitrodetrinite are the most dominated macerals in both the S-10 and S-C coal samples of (46.25% & 55%) respectively (Tables 1 and 2). The predominance of detrovitrinite in the coal seams may reflect the common multiple non-fire degradation pathways during the biochemical coalification stage than the fusinite paths, that accompany by the slightly alkaline water in swamp and relative oxidizing conditions of disintegrated fragments of cell tissues of either soft and woody material under intermediate humification - mineralization intensity before the final accumulation (Kalkreuth, 1991; Diessel, 1992; Taylor et al., 1998; Hower et al., 2011b; O'Keefe et al., 2013). To facilitate the recognition of the different circumstance combined with the conservation of the (S-10 & S-C) coal seams, the vitrinite/inertinite ratio as a deal of dominated vitrinite versus fusinite pathways during peat accumulation and preservation. For the S-10 coal samples the average vitrinite: inertinite ratio (50.5: 49.15) approximately 1: 1, while in coal samples belong to the S-C coal is (69.4: 29.7) 2.3: 1 (Tables 1, 2). These ratios agree with the pathways of the vitrinite producer macerals during the biochemical coalification construct a favourable preservation condition of vegetative material in coal than that conditions associated with the inertinite produced pathways of degradation and oxidation (Dai et al., 2002). The mineral contents of coal beside it gives evidence of the grade of coal. It refers indirectly to the shape of swamps (concave, flat, or convex) during the initial stages of peat accretion. The volumetric MM of coal measured of their ash contents. Diessel (1992) and Edress (2007) measured a relationship between the volumetric mineral matter and the ash contents of coal. They founded that the optical identification of MM approximately has a half amount of ash content in coal-based on the accuracy of the coal petrographer. So, with a caution, a tentative estimation of the amount of ash in the S-10 and the S-C based on the above mention assumption can be measured. The S-10 coal seam of MM equal to 4.67% may have an ash content of 9.34%. As the same as the MM of 3.11% concern, the S-C coal seams may refer indirectly to its 6.22% ash content. The measured percentage of Qz of 1.1% in the S-10 coal samples and 0.4% in the S-C coal samples and clay of 3.2%, and 1.9% in S-10 and S-C, respectively agree with early recorded of quartz sandstone and kaolinite assemblage associated the coal-bearing formation of the Mist-Mountain Fm in different localities (Legun, 1990; Grieve, 1993; Grieve et al., 1996; Riddell and Han, 2017) The topogenous mire setting based on its level of the water table and the types and intensity of its vegetations can be characterized into floating, marshes, fen, and swamps. Peat may be created by the sink of deadly floating plants and mosses, in marshes from normally submerged

sedges and grasses of herbaceous vegetation, in fen from mixed herbaceous and arboreous (shrubs and trees vegetation), and in forest swamps from dominated arboreous vegetation (Calder, 1991; Diessel, 1992; Singh, 2016). The facies diagrams of the investigated S-10 and the S-C coal seams (Figs 5, 6 and 7) and calculated coal maceral indices are used in the present study to clarify both the amount of water cover and the types and intensity of the vegetations in peat-forming mire concern the studied coal seam sequence. The GI is reflecting the level of the water table above peat accumulation, whereas TPI represents the effects of the input from woody material and its preservation before the final deposition (Diessel, 1992). In comparing the obtained results of the TPI (1.09-0.78) and GI (1.18-2.7) of the S-10 and S-C coal seams in respective order. By comparing these values with the TPI and GI for coal within the Sydney Basin, according to Diessel (1992). The paleo depositional environments of the alluvial valley-braid plain within the upper delta facies are matched with the results of the studied coal measurements. Plotted the GI vs. TPI of the coal samples within the modified Diessel coal facies diagram (Feng et al., 2019) (Fig. 5), shows that the marsh and forest swamp vegetation setting of limno-telmatic and telmatic paleo-environment is dominated. The three samples belong to the S-10 coal seam are shifted to a dry forest swamp zone where may be indicate an episode of dropping water table during peat accumulation (Fig. 5). Calder et al. (1991) propose VI and GWI indices, to distinguish the ecosystem of the three types of mire settings related to Springhill coalfield, USA. They are the riverine zone (mixed arboreous and herbaceous vegetation of concave shape, limnic, mainly of inundated marshes), the inner mire (of arboreous dominant, swamp and fen of limno-telmatic peneplain mire, and the piedmont zone of a mixed arboreous swamp to the marsh of peneplain terrestrial mire. The GWI versus the VI diagram reveals that the considered coal samples have a variety of vegetation (Fig. 6). The 70% of coal samples related to the S-10 coal seam have a $VI < 1$ and 30% of samples have a $VI > 1$. While 66.66% of the S-C coal samples have a $VI < 1$ (8 samples) while nearly 33.33% of samples have a $VI > 1$ (4 samples) (Fig. 6). The above results show a type of vegetation of the S-10 and S-C coal seams involved a mixture of arboreous and herbaceous vegetation with a trend of dominance herbaceous vegetation toward the younger coal seam (S-C). Plotting the S-10 and the S-C coal samples on the TDF coal facies diagram illustrates that all samples lie on the right hand along the triangle arm in between open moor of marsh vegetation and terrestrial forest swamp of arborescent land forest vegetation (Fig. 7). The limno-telmatic setting is the area where all call samples have a waterlogged. All the representative coal samples of S-10 and S-C coal seam are in Limno-telmatic setting, the magnitude of marsh vegetation is exceed more than the land-forest swamp vegetation rather for S-C coal seam than S-10 coal seam. Depending on the peatland's hydrological models of Charman (2002), the two common models of the valley mire and /or floodplain mire models, where peat restricted to concave shape mire of valley bottom or the over-bank area receiving water from runoff river with seasonally groundwater table fluctuated are more acceptable sedimentary models in case of the considered coal seams. In such models, peat covered by considerable amounts of detrital and suspended sediments came from the annual flooding system (Riddell and Han, 2017). The above hydrologic models are in agreements with those circumstances associated the Paleo-deposition environments of the S-10 and S-C coal seams. From all the above mentioned results a tentative model including the types of vegetation and the hydrology water table level of mire system is illustrated by authors as show in Fig. 8, that give an easiest way to construct the old peat-forming mire system of both the investigated coal seams (S-10 & S-C) with considering the flora dominated in the Jurassic and Cretaceous times.

5. Conclusions

Petrographic analysis of coal seams is playing a profound effect to reveal the Paleo-limnology setting where those coal were accumulated and preserved. The domination of vitrinite than other inertinite and liptinite promote ordinary fast time span of accumulation and conservation. A slight increase in

inertinite macerals in the S-C coal seam may be attributed to a slight drop of water table during peat accretion.

Fig. 8. Proposal hydrogeological and vegetation model study coal forming mire developments; percentage taken as average data values from all previous indices and facies diagrams

The coal indices and diagram in the suggested study illustrate both vegetation types and the level of water cover in the precursor mire system. A variation of a mixture of arboreous and herbaceous plants are the precursor of the considered peat formation with a decrease in the percentage of woody tissues upward toward the S-C coal seam. Increase the GI toward the S-C coal seam related to full waterlogged associated peat accumulation and preservation. Coal indices and facies diagrams promote mainly a telmatic and limno-telmatic setting, where the swap is mainly of rheotrophic shapes.

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