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PALAEODEPOSITONAL CONDITIONS AND HYDROCARBON SOURCE CHARACTERISTICS OF LIGNITES FROM BIKANER-NAGAUR BASIN (RAJASTHAN) WESTERN INDIA BASED ON ORGANIC PETROGRAPHIC STUDIES

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ABSTRACT: In Indian subcontinent Cenozoic lignites are found at several places along the boundary of Indian plate which was the shoreline of palaeotethys. However, the western part of the Indian subcontinent is particularly rich in lignites and shales along with hydrocarbon reserves. Thus, this location of the country is an important producer of hydrocarbon and lies at a significant position in the mineral map of the country. In the north western state of Rajasthan, lignites are reported in associated with the Cenozoic sedimentary rocks extending an area of 70,000 sq.kms in Bikaner, Barmer, Nagaur, Jalore and Jaisalmer districts. The present study focuses on the lignite bearing sequence exposed in the Matasukh and Barsingsar lignite mines of Bikaner-Nagaur Basin, Rajasthan. The lignite belongs to the Palana Formation of early Palaeocene age (~66-56 Ma). The lignite seam extends over an area of 2.50 sq.kms and is estimated to have consisted of 10.10 million tonnes of lignites.The lignites of Matasukh and Barsingar lignite mines are studied based on organic petrographic data to elucidate the palaeodepositional conditions and the hydrocarbon source potential. The lignites of Matasukh are predominantly composed of huminite macerals (av. 60 vol. %), followed by moderate liptinite content (av. 23 vol. %). Inertinite macerals (av. 9 vol. %) and mineral matter (av. 8 vol. %) are in lesser proportions. However, in Barsingsar, the lignites are predominantly composed of huminite macerals (av. 74 vol. %), followed by Inertinite macerals (av. 10 vol. %), liptinite content (av. 9 vol.%) and mineral matter (av. 6 vol. %). The dominance of detrohuminite (attrinite + densinite) concerning telohuminite (textinite + ulminite) suggests that the organic matter has undergone a higher degree of degradation; as is also indicated by the frequent occurrence of funginite. In Matasukh, Low TPI and GI values indicate limno-telmatic and mesotrophic-rherotrophic conditions of the palaeomire during the deposition of the lignite forming peat. The deposition took place in varying depositional settings. However, in Barsingsar, the lignites are formed in limnic and rheotrophic conditions. The deposition took place possibly in a marshy depositional setting. Matasukh lignite has huminite reflectance values (av. VR_o= 0.26%) indicating that the studied lignites attained ‘brown coal’ as German Standard or 'lignitic’ stage/rank (ASTM) and is of low rank B (ISO: 7404-5, 2009). Altogether, the lignites of Bikaner-Nagaur Basin show varying petrographic characteristics indicating the variation in the source floral composition, microbial degradation and depositional conditions in different parts of the basin.

INTRODUCTION

Lignite is an important fossil fuel consisting of organic matter which reflects the change in paleoclimatic and paleoenvironmental conditions over geological time (Mitroviae *et al.,* 2016). Microscopic constituents in lignite/coal like maceral and microlithotype were used in various

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studies to estimate depositional conditions and peatification of land plant material (Diessel, 1986; Calder *et al.,* 1991; Kalkreuth *et al*., 1991; Bechtel *et al*., 2003; Petersen and Ratanasthien, 2011; Bechtel *et al.,* 2014; Stock *et al*., 2016). Progressive coalification causes not only the rank changes but also chemical composition and properties of the macerals also changes. Oil and gas reserve of the basin is related to source rock, tectonic structure, depositional condition and thermal maturity of the organic matter. Because macerals are the building blocks of coal, it essential to have a proper understanding of their chemical composition, structure, and their decompositional products (Sun *et al.*,1998; Wilkins and George, 2002). Low-rank coals are dominantly composed of huminite which is isotropic in nature, and anisotropy increases with increase in coal rank. In low-rank coals, huminite significantly influences the technological properties, and this is related to the degree of humification and gelification (Sy´korova´ *et al.,* 2005).

In the Indian subcontinent, the north-western region of Rajasthan is already considered as a highly potential for natural resources especially fossil fuel. The sediments of this region are enriched in carbonaceous sediments such as lignites and shale aong with the hydrocarbon reserves. For this reason, this part of the country is an important producer of oil and gas. Lignites from Jalore, Bikaner, Barmer and Jaisalmer districts of Rajasthan are repoted from Cenozoic sediments extending an area of 17,000 km^2. The Matasukh lignite is being commercially exploited by the Rajasthan State Mines and Minerals Limited (RSMML) since 2003 and Barsingsar Lignite exploited by Neyveli Lignite Corporation Limited (NLC) The present study deals with the lignite bearing sequence exposed in Barsingsar mine located in the Bikaner district of Rajasthan and Matasukh mine located in Nagaur district of central Rajasthan. The most used method for evaluation and evolution of coal/lignite deposit is petrographic analysis (Diessel, 1983; Diessel, 1986; Calder *et al*., 1991; Taylor *et al.,* 1998; Suárez-Ruiz *et al*., 2012; Stock *et al*., 2016). Multiproxy analysis of organic matter in lignite has occurred in the last few years which shows most significance in term of economic evaluation and palaeoenvironmental reconstruction (e.g. Bechtel *et al*., 2005, 2007; Zdravkov *et al*., 2011; Singh *et al.*, 2013; Stefanova *et al.,* 2013; Životić *et al.,* 2013). The aim of the present study focused on the depositional conditions and hydrocarbon source characterization during peatification of lignite by organic petrography.

GEOLOGICAL SETTING

Barsingsar and Matasukh lignite belong to the Palana Formation of Bikaner-Nagaur Basin. The Barsingsar block is located about 25Kms in a south-west direction from Bikaner city in the State of Rajasthan and falls on the toposheet No.45E/1 of Survey of India having latitude 27˚48’ 59 ‘’ -27˚51’02’’N and longitude 73˚11’20’’-73˚11’58’’E. The Matasukh lignite mine is located at a distance of about 42 km from Nagaur town between latitude 27˚00’N and longitude 74˚00’E belongs to the Nagaur-Merta sub-basin of central Rajasthan. This sub-basin is the southern part of the Bikaner-Nagaur Basin with Palana-Kolayat being the northern sub-basin. Bikaner-Nagaur Basin of Rajasthan is elongated in shape and falls in Bikaner and Nagaur districts. The two districts are separated by ‘Arenaceous High’ belonging to Marwar Supergroup. The basin extends for nearly 200 km in E-W direction while its maximum width is 50 km. The northern and southern boundaries the basinare marked by E-W trending faults with basement hight at Dulmera, Suratgarh and the surrounding region. The rocks of Neoproterozoic Nagaur Group (Marwar Supergroup) are overlain by the Cenozoic sediments of continental and marine origin in this basin. These Cenozoic sediments occur, in conformable contacts as Palana, Marh and Jogira formations in ascending order.

The Palana Formation is the sole repository of lignite in this basin and is comprised of grey to dark grey, greenish grey and variegated clays intercalated with fine to medium grained sandstone. Marh Formation is chiefly composed of sandstone having ferruginous stains and alternate clay beds. La Touche (1902) was first to map the geology of the Palana area and mention the occurrence of lignite (1.2–2.0 m thick) encountered in a dug well. Subsequently, the geological study was carried out by a number of workers and mineral potential was estimated (Heron, 1935; Sethi, 1951; Dutta, 1971). A comprehensive account of the geology of north-western Rajasthan has been provided by Pareek (1984). Based on the study made on the Cenozoic sediments of the Bikaner-Nagaur basin, the geological map has been revised by Dasgupta *et al.* (1988). Geological Survey of India (GSI) has carried out detailed exploration of the lignite bearing sequence in the basin (Jodha, 2009). The lignite seams with variable thickness have been reported in different boreholes drilled by GSI, Department of Mines and Geology, Rajasthan (DMGR) and Mineral Exploration Corporation Ltd. (MECL). The lignite seams of 0.5–12 m thickness have been intersected in Raneri Block at a depth of 50–150 m (Jodha, 2009). In few boreholes, lignite horizons have also been intersected at a shallower depth. For a better understanding of basin configuration gravity and magnetic surveys were carried out by GSI which has revealed the presence of gravity low having thick lignite bearing Cenozoic sediments. Besides, few more gravity highs and lows have also been identified in the basin by their geophysical survey. The details of the geological succession of Bikaner-Nagaur Basin along with lithology are furnished in Table 1 and the geological map is shown in Figure 1.

Table 1: General stratigraphic succession in the Bikaner-Nagaur basin, Rajasthan (Modified after Ghose 1983)

Age	**Formation**	**Lithounits**	**Thickness (m)**
Pleistocene to Recent	Kolayat Formation	Sand and sandy alluvium ironstone nodule,	5-11 m
		Sandy calcareous grit kankar, gypsite, ferruginous band, semi-consolidated conglomerate Erratic boulder of quartzite	1–2 m
		Unconformity	
Early to Middle Eocene	Jogaria Formation (Calcareous facies)	Shaly and Marly limestone with foraminifers (Alveolina, Discocyclina Nummulities)	5-10 m
		Unfossiliferous, white clayey marl	1 m
		Dirty brown impure limestone with broken shells of Ostrea and foraminifers (Assilina).	1.5 m
		Fuller's earth with shale partings having casts of lamellibranchs and gastropods.	14 m
		Cream and yellowish white limestone full of smaller foraminifers (Nummulites and Assilina) with a thin band of fuller's earth (1–2 m) near base.	75 m
		Yellow shales ochers, marl, etc., with smaller foraminifers (Nummulites, Assilina)	20 m
		Angular unconformity	
Palaeocene to Lower Eocene	Marh Formation (Arenaceous facies)	Upper clay horizon with one clay bed.	3-10 m
		Ferruginous sandstone, gritty sandstone and sugary sandstone with white glass sand (local).	60 m
		Middle clay horizon with five clay beds and sandstone partings.	50 m
		Ferruginous sandstone, gritty sandstone, grit, siltstone.	70 m
		Lower clay horizon with one clay bed. Ferruginous sandstone, gritty sandstone,	1-3 m
		various siltstone with leaf impressions (base not exposed).	20 m
		(?) Gradational contact	
Palaeocene	Palana Formation (Carbonaceous facies)	Fine grained sandstone, carbonaceous shale and lignite.	120 m
		Base not encountered	

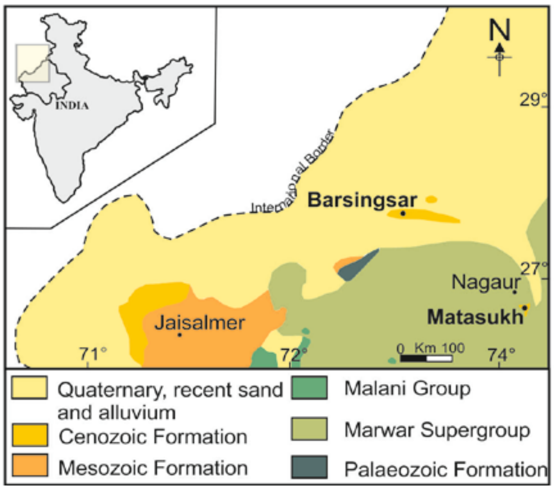

Figure 1: Location and geological map of western Rajasthan, India showing Barsingsar and Matasukh lignite mines (Modified after Roy and Jakhar, 2002).

SAMPLING AND METHODOLOGY

Twenty one lignite samples were analyzed in this study. Samples were taken from the open-pit mine Barsingsar, operated by NLC and open-pit mine Matasukh, operated by RSMML. Among 21 samples, 11 lignites were from Barsingsar, andten lignite samples were from Matasukh. Four samples of lignite were collected from the top seam-1 (ca. 8 m) and seven lignite samples from the bottom seam-2 (ca. 15 m, Figure2) of Barsingsar mines. The upper seam is overlain by clay of variable thickness. A shale layer of ca. 3 m separates both lignite seams. Out of the ten samples from Matasukh, four lignite samples were collected from the top seam-1 (ca. 2 m) and sixfrom the bottom seam-2 (ca. 2.75 m, Figure2). Grey shales of variable thickness underlay both the lignite seams in this area and a sand layer of ca. 0.75 m lies in between both lignite seams.

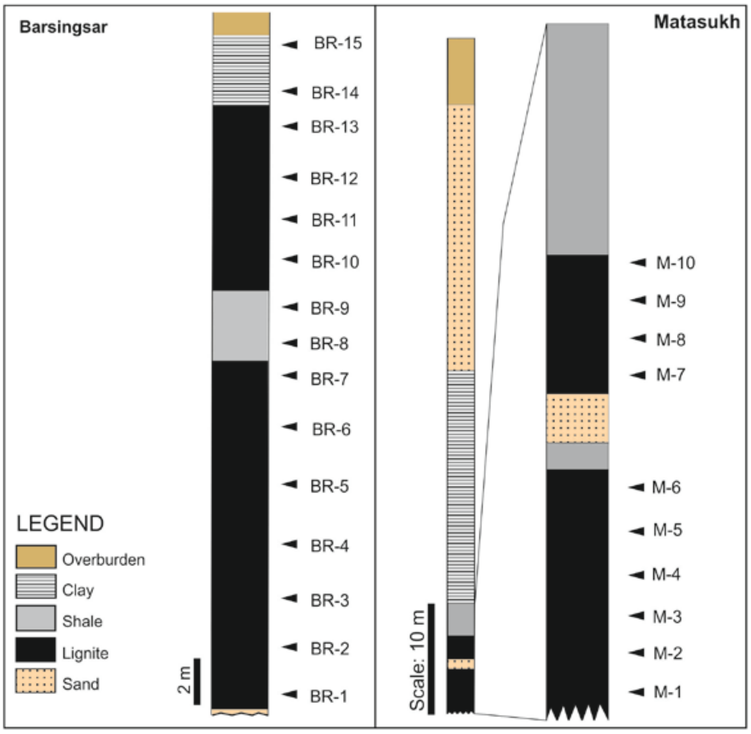

Figure 2: Litholog of the studied Barsingsar and Matasukh mines section.

Petrography

Specifications of ISO 7404-2 (2009) for the micropetrographical analysis were followed. Standards of ISO 7404-3 (2009) and ISO 7404-5 (2009)were followed to carry out maceral analyses and reflectance measurements. Study of macerals was done by using a Leica DM 4500P microscope, at the same time under the normal incident and fluorescence (blue light) under an oil immersion objective (50×) to distinguish the liptinite maceral. The descriptions and nomenclature as provided by Stach *et al*., (1982) and Taylor *et al.* (1998) and Sýkorová *et al.* (2005), are used in this study. With the help of software Petroglite 2.35., counts of 500 macerals were done for the maceral analysis. Measurements of reflectance (100 readings/sample) were made on maceral huminite with the help of Sapphire(0.594% Ro) standard, immersion oil method (Rf:1.518), photometry system (PMT III) and the software MSP 200.

RESULTS AND DISCUSSION

The Palaeocene lignites of the Bikaner-Nagaur Basin have a thermal maturity indicated by Vitrinite Reflectance (VR_o) between 0.26 and 0.34% which put them as 'low rank C' coals as per ISO-11760 (2005). The megascopic seam profiles reveal that these lignites have mostly stratified bands, except a few non-stratified bands, of brown to black colour.

Petrographic characteristics

The lignites of Bikaner-Nagaur Basin are dominantly composed of huminite group macerals with subordinate amounts of the liptinite and inertinite groups. Ulminite is sometimes characterised by prominent fractures which are filled up with argillaceous mineral matter or remain empty. Textinite occurs in very low concentrations, especially in Matasukh lignite. Among liptinite macerals mainly liptodetrinite and resinite are recorded though in a few regions show in abundance. The cutinite is represented chiefly by small cutinites. The abundance of sporinite having well developed cell fillings is also observed. Oval to rounded resin bodies sometimes irregular in shape are also noticed which vary in size from less than ten µm to over 100 µm. Few patches of fusinite, with well-preserved cell structure, have also been observed especially in Barsingsar lignites. The cell lumens are sometimes filled with mineral matter and on a few occasions by framboidal pyrites. At times, the cells are elongated and even oriented. Inertodetrinite is common in both the lignite samples. Argillaceous minerals occupy the cell lumens and fractures. Framboidal pyrite occurs as single grain as well as clusters. The carbonates are mainly represented by siderite. Characteristic macerals are shown in the photomicrographs (Figure 3).

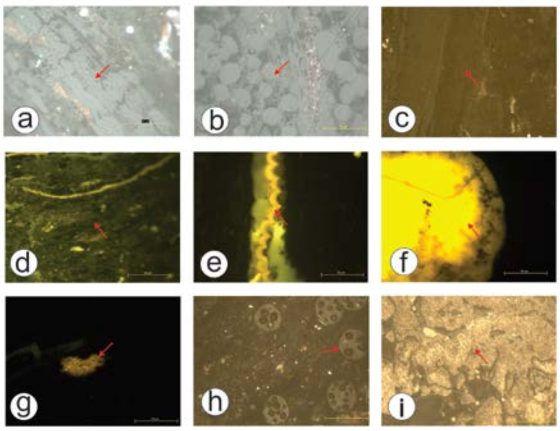

Figure 3: Representative photomicrograph of macerals and associated mineral matter in the studied lignite: a) textinite b) corpohuminite c) densinite d) perhydrous huminite e) cutinite f) resinite g) spores (cluster of) h) funginite i) pyrite.

Barsingsar lignite seam

Huminite is the most abundant maceral group (60–86%; av. 76 vol. %) and consists mainly of detrohuminite followed by telohuminite. Detrohuminiteis represented by densinite (35–81%; av. 68 vol. %) and attrinite (1-8%; av. 4 vol. %) while telohuminite is mainly contributed by ulminite (1–18%; av. 4 vol. %). Textinite was almost absent. Gelohuminite mainly composed of corpohuminite (1-2%; av. 0.3 vol. %) and gelinite was absent. Inertinite has a relatively low percentage (3–23%; av. 9 vol %) and liptinite shows low content (3–18%; av. 10 vol. %) in these lignites. The mineral matter varies from 2–18% (av. 6 vol. %). The maceral composition is given in Table 2 and the overall composition of Barsingsar lignite is given in the Figure.4.

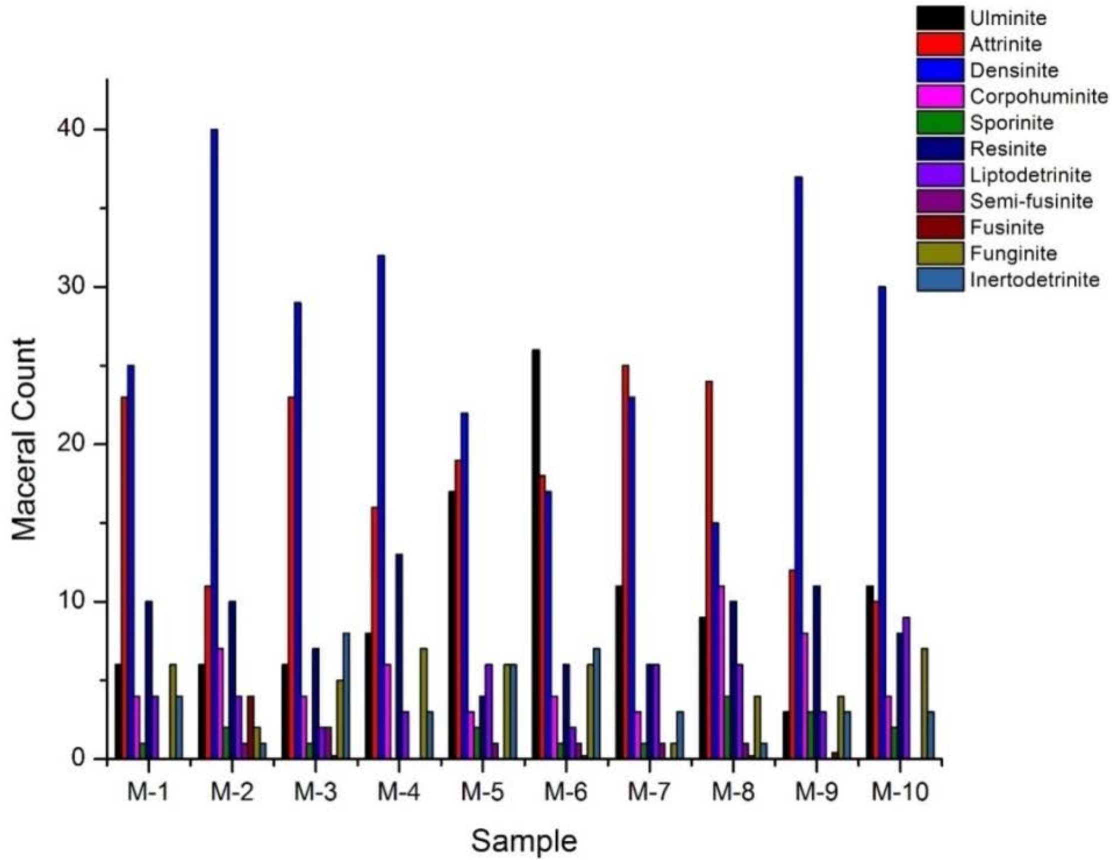

Figure 4: Abundance of different macerals in the Barsingsar lignite.

Matasukh lignite seam

Huminite is the most abundant maceral group (60–68%; av. 63 vol. %) and consists mainly of detrohuminite followed by telohuminite. Detrohuminiteis represented by densinite (15–40%; av. 27 vol. %) and attrinite (10-23%; av. 18 vol. %) while telohuminiteis mainly contributed by ulminite (6-26%; av. 10 vol. %). Textinite occurs in very low concentration (0-6%; avg. 3 vol. %). Gelohuminite mainly composed of corpohuminite (3-11%; av. 5 vol. %) and gelinite was absent. Inertinite has a relatively low percentage (5-15%; av. 10 vol. %) and liptinite shows low content (15-28%; av. 21 vol. %) in these lignites. The mineral matter varies from 4–10% (av. 6.00 vol. %). The maceral composition is given in Table 3 and the overall composition of Barsingsar lignite is given in the Figure 5.

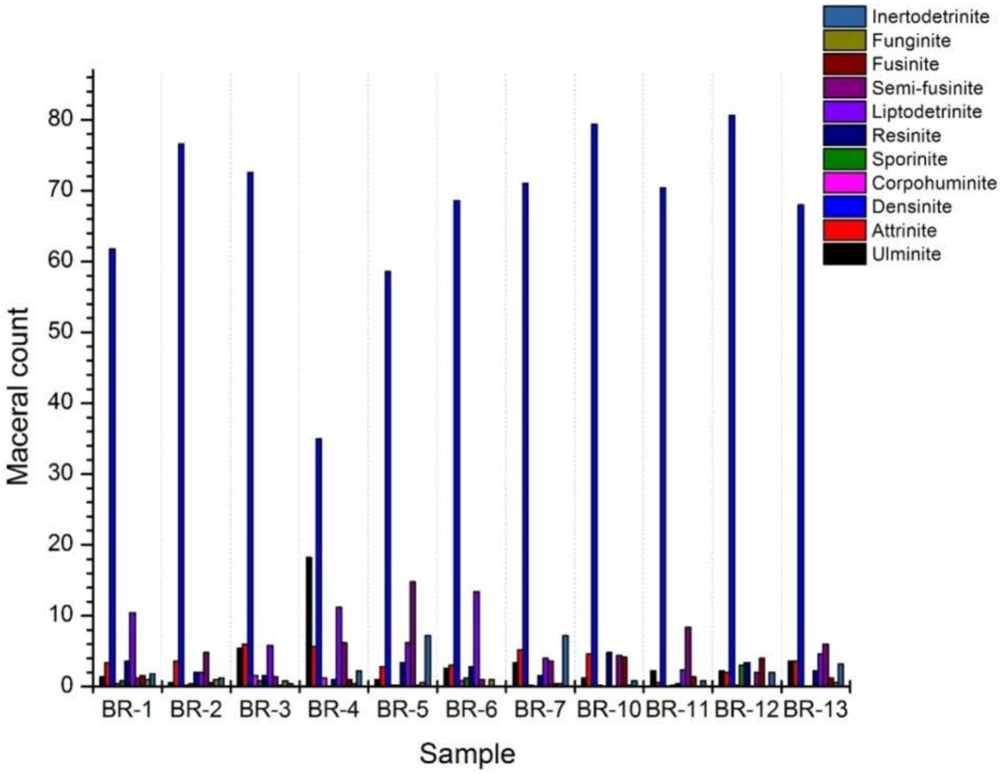

Figure 5: Abundance of different macerals in the Matasukh lignite

Depositional conditions

On the basis of maceral grouping mentioned above, diagnostic macerals as palaeoenvironmental indicators are interpreted. The abundance of huminite group macerals (Figure 6) in the studied lignites suggests that the lignites originated in a wet forest swamp environment (Teichmüller and Teichmüller1982; Bustin *et al*. 1983), mainly from arborescent vegetation (Rimmer and Davis 1988). The high amount of huminite macerals with a general predominance of detrohuminite also indicates that alteration of these peats was mainly controlled by suboxic to anoxic condition and deposition in the peat-forming mires, whilst the relatively low content of inertinite indicates the occurrence of low levels of peat (forest) fire and/ or oxidation and the coal having been deposited in waterlogged

conditions (Stach *et al*. 1982; Diessel 1992; Flores 2002; Sykorova *et al*. 2005; Scott and Glasspool 2007; Petersen *et al.* 2009; Erik 2011). In the present case, large amounts of detrohuminite in the

studied lignites are considered to be related to both the dominance of herbaceous plants in the palaeomires and the poor preservation of woody substance due to prolonged humification in slowly subsiding palaeomires (Diessel1992; Petersen *et al*. 2009; Súarez-Ruiz *et al*. 2012). In general, the herbaceous plants are consistent to those reported by Ahmed (2004) who described high contributions of dicots and herbaceous monocots and a complete absence of gymnospermic pollen.The presence of large amounts of liptinite group macerals (i.e.,liptodetrinite and resinite) suggests an accumulation within forested wet-raised bogs (Ratanasthien *et al*. 1999; Erik 2011).

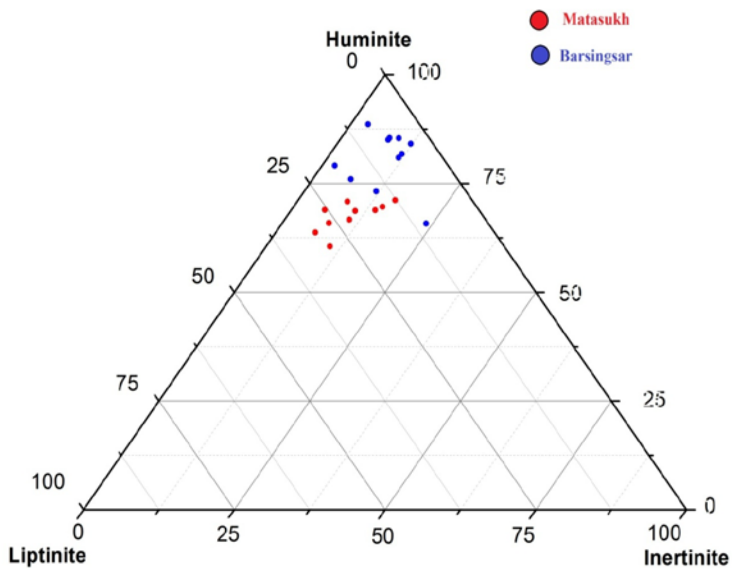

Figure 6: Ternary diagram of maceral group composition (huminite-liptinite-inertinite) for analysed Barsingsar and Matasukh lignites.

Petrographic facies could also reflect, to some extent, differences in the type of peat-forming plant communities. On the basis of Tissue Preservation Index (TPI) and Gelification Index (GI), the ratio can be used to determine particular peat-forming environment conditions (e.g. Diessel1986, 1992; Calder *et al.* 1991; Kalkreuth *et al.* 1991; Siavalaset *et al*. 2009; Jasper *et al*. 2010; Koukouzas *et al*. 2010; Životić *et al*. 2013 and many others). The GI-TPI diagram was firstly proposed by Diessel (1986) for high-rank Australian Permian coals. The type of vegetation and degree of humification may be known through TPI regarding less humified structured and strongly humified unstructured tissue derived macerals (Diessel, 1992). Accordingly, a high TPI indicates high subsidence rate of the basin and predominance of wood derived tissues whereas a low TPI is an expression of the lowrate of subsidence and enhanced humification because of the predominance of herbaceous vegetation in the mire. GI is the manifestation of the degree of gelification of huminite macerals. Gelification requires a continuous presence of water. Fluctuation of water table influences GI due to the formation of inertinites during the drier periods. The Ground Water Index(GWI) indicates the level of ground water (and relative rainfall) during the peat accumulation. According to Amijaya and Littke (2005), there are mainly three types of hydrological condition responsible for fomation of mires such as ombrotrophic, mesotrophic and rheotrophic.If the value of GWI < 0.5, 0.5-1 and >1, indicatesan ombrotrophic, mesotrophic and rheotrophic hydrological condition, respectively. Type of vegetation present in the mire indicates vegetation index (VI) which depends on the type of peat-forming plant communities (e.g., bushes and trees).To calculate GI, TPI, GWI and VI, It was decided to follow the formula given by Kalaitzidis *et al.* (2000) which is shown below:

GI = (ulminite+gelohuminite+densinite)/(textinite+attrinite+inertinite)

TPI=(telohuminite+corpohuminite+fusinite+semifusinite)/(attrinite+densinite+gelinite+inertodetrinite)

GWI=(corpohuminite+gelinite+densinite+mineral matter)/(textinite+ulminite+attrinite)

VI=(telohuminite+resinite+suberinite+fusinite+semifusinite)/(detrohuminite+inertodetrinite+cutinite+sporinite+alginite+bituminite+liptodetrinite)

The GI vs. TPI plot and the GWI vs. VI plot for the studied samples are provided in the Figure 7a and b. A high GI (2.34-14.4, avg.6.65) and low TPI (0.06-0.62, avg. 0.16) values in the lignite of Barsingsar mine are indicative of continuous wet conditions in the basin with a slow rate of subsidence during the decay of organic matter. Lignite of Matasukh showing moderate GI (0.90.-2.30, avg. 1.50) and low TPI (0.27-0.77, avg. 0.40) values are indicative of a moderate water column level in the basin with a slow rate of subsidence during the decay of organic matter and represent predominantly topogenous mire conditions. This is well corroborated with higher proportions of huminite over inertinite macerals in the lignites of Barsingsar and Matasukh mine. An estimate of GWI (2.28-29.71, avg. 14.11) and VI (0.07-0.49, avg. 0.17) values in the lignite of Barsingsar mine and estimate of GWI (0.54-2.80) and VI (0.28-0.72) values in the lignite of Matasukh mine are found. Both lignite samples have average GWI value more than one which is indicating the rheotrophic condition. VI value of Matasukh mine is relatively more than the Barsingsar mine which is showing more terrestrial herbaceous plant input in the Matasukh than Barsingsar mine.

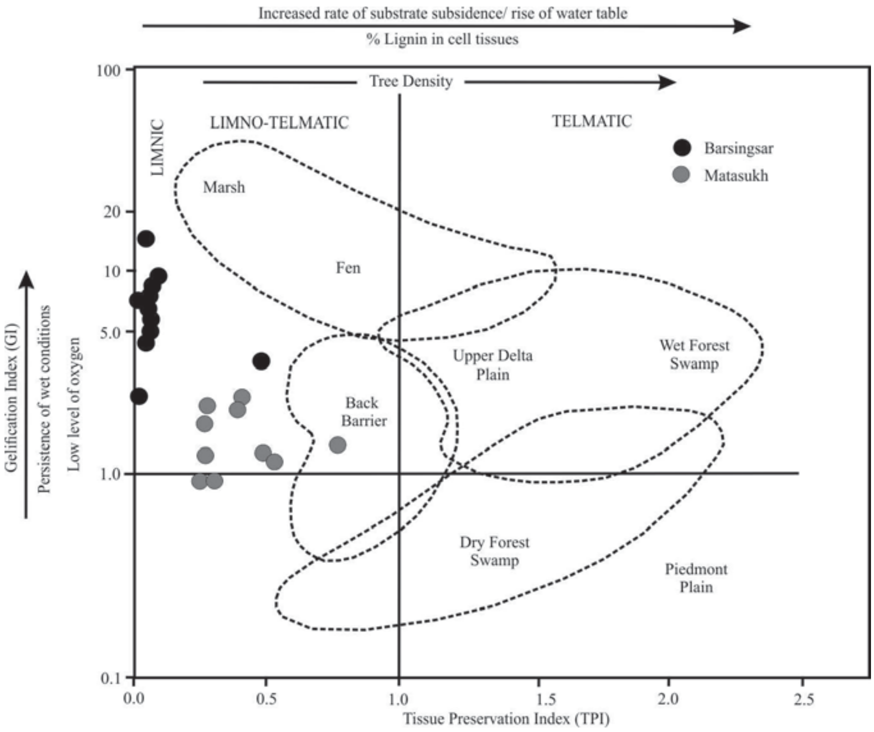

Figure 7a: Diagram of GWI and VI indices of the Barsingsar and Matasukh lignites showing palaeoenvironment conditions (Calder *et al*., 1991).

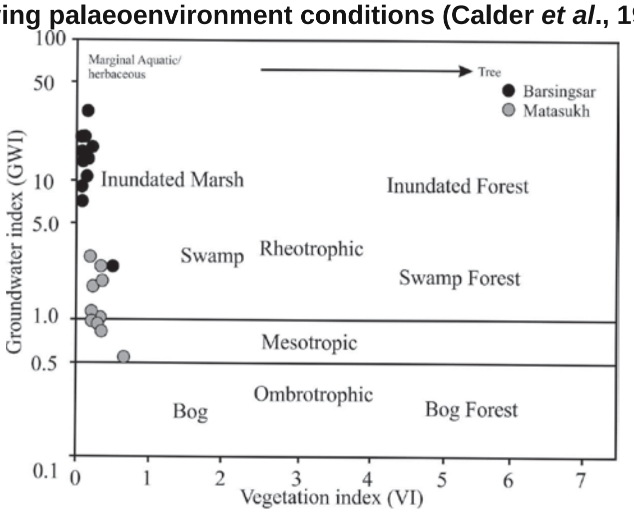

Figure 7b: GI and TPI diagram indicating the relation of hydrological conditions and the type of mire in Western Rajasthan, India (Diessel 1986, 1992).

HYDROCARBON POTENTIAL

Hydrocarbon generation from source rock is associated with the generation of lighter molecules from the heavy molecules in the original organic matter. In general, the potential to generate hydrocarbon is found to increase from Carboniferous to Cenozoic coals which is related to the evolution of more complex plant communities. However, the depositional condition also plays a major role (Petersen, 2005). The chemical composition of source rock is very important in determining the hydrocarbon potential. The kinds of source vegetation determine this chemical composition. In the present study, the maceral composition of Bikaner-Nagaur Basin lignites is compared with the general chemical composition of macerals which is already known (Mastalerz *et al.,* 2013). One of the limiting factors for hydrocarbon generation potential of any organic matter is the amount of hydrogen-rich macerals incorporated in it. Aliphatic chains in the organic matrix lead to the formation of hydrocarbons. The organic matter derived from marine and lacustrine source rocks (type I and II respectively) are geochemically uniform and contains an abundance of long-chain *n*-alkanes, a prerequisite for oil formation. Coaly organic matter (mainly type III kerogen), is composed of heterogeneous and complex higher land plant materials which are richer in oxygen and have fewer long chain *n*-alkanes leading to its lower oil generation potential (Petersen, 2005).However, during deposition, the paralic coals are dominant in hydrogen which is affected by the seawater (Petersen and Rosenberg 1998; Sykes 2001), and incorporation of the hydrogen into aliphatic chains may increase the generation capacity.

Aliphaticity of the organic matter apparently shows the richness of hydrogen content in the macerals. Aliphaticity is an important parameter in hydrocarbon potential as higher aliphatic composition of organic material means more the hydrocarbon potential. Qualitative analysis on the functional groups of different liptinite macerals showed defined and prominent aliphatic stretching bands, lower absorbance of aromatic carbon whereas huminite macerals showed prominent aromatic absorption bands (Mastalerz *et al.,* 2013). These are expected differences and result from the aliphatic character of liptinite group macerals in contrast to more aromatic huminite (*e.g.* Mastalerz and Bustin, 1993). Alginite showed prominent aliphatic stretching bands, their narrow peaks resulting from an overwhelming contribution of CH_2 and a very minor CH_3 contribution in this region, suggesting long and straight aliphatic chains (Lin and Ritz, 1993). The petrographic studies of the lignites of Bikaner-Nagaur Basin indicate that these lignites are mainly composed of huminite group macerals, particularly detrohuminite. Huminite group macerals are of higher aromaticity within which ulminite and corpohuminite have the lowest and highest aromaticity, respectively (Mastalerz *et al*., 2013). Liptinite macerals subdominate in the studied lignites. The higher aliphaticity of liptinite macerals and its abundance point to higher oil potential. However, relatively less abundance of liptinite macerals and higher abundance of huminite macerals in Bikaner-Nagaur lignites point to its gaseous potential. Along with the maceral composition, maturity is another important factor determining the ability of hydrocarbon source rock potential. The huminite reflectance (VR_o) study of Matasukh lignite ranges from 0.26 to 0.34 suggesting an immature nature (Singh *et al*., 2017).

Table 2: Maceral contents (vol. %), mineral matter content (vol. %) and petrographic indices (GI, TPI, GWI, VI) of the studied Barsingsar lignite.

Sample No. Macerals		BR-1	BR-2	BR-3	BR-4	BR-5	BR-6	BR-7	BR-10	BR-11	BR-12	BR-13	Avg.
Huminite(H)		67	81	86	60	63	75	80	85	73	85	76	**75**
Telohuminite		1	1	5	18	1	3	3	1	2	2	4	**3**
	Textinite	0	0	0	0	0	0	0	0	0	0	0	
	Ulminite	1	1	5	18	1	3	3	1	2	2	4	
Detrohuminite		65	80	79	41	61	72	76	84	71	83	72	**71**
	Attrinite	3	4	6	6	3	3	5	5	1	2	4	
	Densinite	62	77	73	35	59	69	71	79	70	81	68	
Gelohuminite		0	0	2	1	0	1	0	0	0	0	0	**0.4**
	Corpohuminite	0	0	2	1	0	1	0	0	0	0	0	
	Gelinite	0	0	0	0	0	0	0	0	0	0	0	
Liptinite (L)		16	6	8	12	10	18	6	5	3	7	7	**10**
	Sporinite	1	0	1	0	0	1	0	0	0	3	0	
	Cutinite	0	1	0	0	0	0	0	0	0	0	0	
	Suberinite	0	0	0	0	0	0	0	0	0	0	0	
	Resinite	4	2	2	1	3	3	2	5	0	3	2	
	alginite	0	0	0	0	0	0	0	0	0	0	0	
	Bituminite	0	0	0	0	0	0	0	0	0	0	0	
	Fluorinite	0	0	0	0	0	0	0	0	0	0	0	
	Exsudatinite	0	0	0	0	0	0	0	0	0	0	0	
	Liptodetrinite	10	2	6	11	6	13	4	0	2	0	5	
Inertinite (I)		6	8	3	10	23	2	12	10	11	8	11	**9**
	Semifusinite	1	5	1	6	15	1	4	4	8	2	6	
	Fusinite	2	1	0	1	0	0	0	4	1	4	1	
	Funginite	1	1	1	0	1	1	0	0	0	0	1	
	Secretinite	0	0	0	0	0	0	0	0	0	0	0	
	Macrinite	0	0	0	0	0	0	0	0	0	0	0	
	Micrinite	0	0	0	0	0	0	0	0	0	0	0	
	Inertodetrinite	2	1	0	2	7	0	7	1	1	2	3	
Mineral Matter (TOTAL)		11	5	3	18	4	5	2	0	13	0	6	**6**
	Mineral matter	11	5	3	18	4	5	2	0	4	0	0	
	Pyrite	0	1	0	0	1	0	0	0	9	0	0	
Fluorescing H		42	40	49	23	52	17	19	55	40	53	34	**39**
Non-fluorescing (H)		25	41	37	37	11	58	60	30	34	32	41	
Total Fluorescing (H+L)		58	46	57	35	61	35	26	60	43	60	41	
Non-fluorescing (H+I+M)		42	54	43	65	39	65	74	40	57	40	59	
H (mmf)		76	85	89	73	66	79	82	85	84	85	81	
L (mmf)		18	7	8	15	10	19	6	5	4	7	7	
I (mmf)		6	8	3	12	24	2	12	10	12	8	12	
GI		7.07	6.91	9.05	3.53	2.34	14.40	4.44	5.69	6.48	8.30	4.93	**6.65**
TPI		0.07	0.08	0.11	0.62	0.24	0.06	0.09	0.12	0.17	0.10	0.14	**0.16**
GWI		15.25	19.52	6.81	2.28	16.53	13.32	8.53	13.72	29.71	19.24	10.33	**14.11**
VI		0.10	0.09	0.10	0.49	0.26	0.07	0.10	0.17	0.17	0.13	0.16	**0.17**

Table 3: Maceral contents (vol. %), mineral matter content (vol. %), huminite reflectance (VR_o %) and petrographic indices (GI, TPI, GWI, VI) of the studied Matasukh lignite

Sample No. Macerals		M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	M-9	M-10	Avg.
Huminite(H)		64	68	67	62	64	67	62	60	63	57	**63**
Telohuminite		12	10	11	8	20	28	11	10	6	13	**13**
	Textinite	6	4	5	0	3	2	0	1	3	2	
	Ulminite	6	6	6	8	17	26	11	9	3	11	
Detrohuminite		48	51	52	48	41	35	48	39	49	40	**45**
	Attrinite	23	11	23	16	19	18	25	24	12	10	
	Densinite	25	40	29	32	22	17	23	15	37	30	
Gelohuminite		4	7	4	6	3	4	3	11	8	4	**5**
	Corpohuminite	4	7	4	6	3	4	3	11	8	4	
	Gelinite	0	0	0	0	0	0	0	0	0	0	
Liptinite (L)		19	20	12	21	16	15	23	28	25	27	**21**
	Sporinite	1	2	1	0	2	1	1	4	3	2	
	Cutinite	1	2	2	0	2	1	0	1	2	2	
	Suberinite	2	1	0	3	0	1	1	1	2	0	
	Resinite	10	10	7	13	4	6	6	10	11	8	
	alginite	0	0	0	0	0	0	8	0	0	0	
	Bituminite	1	1	0	2	2	4	1	6	4	6	
	Fluorinite	0	0	0	0	0	0	0	0	0	0	
	Exsudatinite	0	0	0	0	0	0	0	0	0	0	
	Liptodetrinite	4	4	2	3	6	2	6	6	3	9	
Inertinite (I)		10	8	15	10	13	14	5	6	7	10	**10**
	Semifusinite	0	1	2	0	1	1	1	1	0	0	
	Fusinite	0	4	0	0	0	0	0	0	0	0	
	Funginite	6	2	5	7	6	6	1	4	4	7	
	Secretinite	0	0	0	0	0	0	0	0	0	0	
	Macrinite	0	0	0	0	0	0	0	0	0	0	
	Micrinite	0	0	0	0	0	0	0	0	0	0	
	Inertodetrinite	4	1	8	3	6	7	3	1	3	3	
Mineral Matter (TOTAL)		7	4	6	6	7	4	10	6	5	6	**6**
	Mineral matter	6	2	6	5	7	4	7	5	5	4	
	Pyrite	1	2	0	1	0	0	3	1	0	2	
Fluorescing H		19	21	25	15	18	15	12	11	19	10	**17**
Non-fluorescing (H)		45	47	42	47	46	52	50	49	45	47	
Total Fluorescing (H+L)		38	41	37	36	34	30	35	39	44	38	
Non-fluorescing (H+I+M)		62	59	64	63	66	70	65	61	57	63	
H (mmf)		69	71	71	67	69	70	69	64	66	61	
L (mmf)		21	21	13	23	17	16	26	30	26	29	
I (mmf)		11	8	16	11	14	15	6	7	8	11	
$R_{r\ mean\ \%}$		0.34	0.29	0.28	0.32	0.31	0.30	0.32	0.28	0.27	0.26	
GI		0.90	2.30	0.90	1.77	1.20	1.37	1.23	1.12	2.14	2.05	**1.5**
TPI		0.31	0.40	0.25	0.27	0.49	0.77	0.27	0.53	0.28	0.40	**0.4**
GWI		1.03	2.43	1.16	1.83	0.83	0.54	1.00	0.94	2.80	1.74	**1.43**
VI		0.41	0.43	0.31	0.43	0.42	0.72	0.28	0.39	0.30	0.34	**0.4**

CONCLUSIONS

The following observations have been made from the study on lignites from Matasukh and Barsingsar lignites of the Bikaner-Nagaur Basin: The Bikaner-Nagaur lignites are dominantly composed of huminite macerals with the sub dominance of liptinites suggesting prolific inputs from the woody forest vegetation. The high amount of detrohuminte suggests inputs form herbaceous vegetation and the highly active microbial degradation of the peat biomass. Based on the maceral composition and faceis diagrams, it is evident that the lignites of the Bikaner-Nagaur Basin are formed generally in mesotrophic to rheotrophic and limnic to limnotelmatic conditions. However, the differences in the maceral composition from both lignites indicate that there were variations in the source vegetation composition, degree of humification, exposure of the peat biomass, microbial activity and the hydrological conditions experienced in both the mires in space and time. The occurrence of ornamented sporinite and pyrite suggesting near shore conditions of formation. The huminite reflectance indicates the immaturity of the organic matter. However, these paralic coals are potential source rocks for gaseous hydrocarbons on maturity.

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