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Preliminary studies of Cleat Fractures and Matrix Porosity in Lakhra and Thar coals, Sindh, Pakistan

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Abstract

Cleats are joints and fractures or linear discontinuities forming a structural fabric that develops in coal as a result of physical and chemical changes and tectonic stresses during coalification. The cleats are known to influence the occurrence, migration, and production of coal bed methane. Cleats provide the permeability for fluid flow and successful recovery of coal bed methane gas. Micro pores (matrix) in coal are responsible for the porosity in coal.

Lakhra and Thar coal has been investigated with Scanning Electron Microscopy and results show that in Lakhra coal reticulate cleats and micropores are well developed and has the chance of having methane gas, while Thar coal due to minute size of micro pores and occurrence of micro cleat the chance of coal bed methane diminishes.

However; detailed study of cleat geometry and porosity percentage will further investigate potentials of CBM in lignitic coal of Sindh.

Keywords: Cleats; CBM; Micropores; adsorption and absorption ratio

1. Introduction

Coal consists of cleats and matrix (micropores). Cleats are natural opening-mode fractures in coal beds that produce permeability in coal; the matrix is capable of storing gas by adsorption and flow of gas by diffusion (Laubach et al., 1998). Coal Bed Methane (CBM) is generated either through chemical reactions or bacterial action (Rice, 1993). Chemical changes referred to as thermogenic, occurs over time as heat and pressure are applied to coal in a sedimentary basin. While biogenic reactions in coal produce methane as a by product (SanFilipo et al., 2000). Lignite coal is formed as a result of bacterial decomposition of the organic matter; during coalification process a large amount of methane gas is also produced in coal, and cleats produce permeability in coal which became saturated with methanogenic water that is pumped out from the coal beds in large quantity (Cobb, 2003). There are three basic states of CBM in coal; as a free gas; as gas dissolved in water within coal; and as gas ‘adsorbed’ on the solid surface of coal.

The network of fractures and cleats in coal determines the permeability of the coal, which plays very important role in generation and migration of coal bed methane (CBM). Cleats are linear discontinuities forming a structural fabric developed in coal as a result of physical changes and tectonic stresses during coalification. Cleats are classified as (a) Face cleats or primary cleats and (b) Butt cleats or secondary cleats (Laubach et al., 1998).

Face cleats are the continuous fissures extending in the direction of maximum in situ stress. The primary cleats are long (50-500µm) having wide aperture openings (5-20µm). Face cleats usually give directional permeability towards their orientation. The Secondary cleats extend in the direction of maximum in situ stress, and are discontinuous, shorter in extent and localized between adjacent cleats. Face cleats has larger contact area with the matrix as compared to the butt cleats, therefore, capable to drain out water from large areas of coal seams. The Face cleats provide main pathways for gas flow into the well bore.

2. Lakhra coalfield

The Lakhra coalfield covering an area of 680 Km^2 is located 225 km North East of Karachi in Jamshoro district of Sindh province. It lies between latitudes 25° 32' and 25°50' N and longitudes 68° 0' and 68° 15' E (Fig. 1).

The Lakhra coalfield area is underlain by a sedimentary sequence belonging to Ranikot Group, comprised of Sonhari Member (Early Eocene), Laki Limestone (Early Eocene) and Manchar Formation (Pliocene) (Table 1). The thickness of the minable coal seam in the area varies between 1.5 to 3.35 meters (Khan et al., 1988).

3. Thar coalfield

The Thar coalfield spread over 9100 sq km is located between latitudes 24^o 30' N & 25^o 00' N and longitudes 70^o10' E & 70^o 30' E in the south eastern part of Sindh. It is connected with a 667 km metalled road upto Islamkot from Karachi via Hyderabad-Mirpur khas-Naukot.

The Thar coalfield is covered by sand dunes with an average thickness of over 80 meters resting upon the structural platform formed of granitic basement in the eastern part of the desert (Fig. 2). The granite complex dips down abruptly beneath the western part of the Thar Desert and is highly faulted (Fesset and Durrani, 1994). Over 3 km thick sedimentary sequence occurring 60 kms north of Singharo-Bhithro Block of Thar coalfield, consists of Mesozoic–Cenozoic succession (Table 2). Thinning eastward across the Thar Desert, with average thickness of 250 meters in the Thar coalfield area (Khan & Khan, 1994).

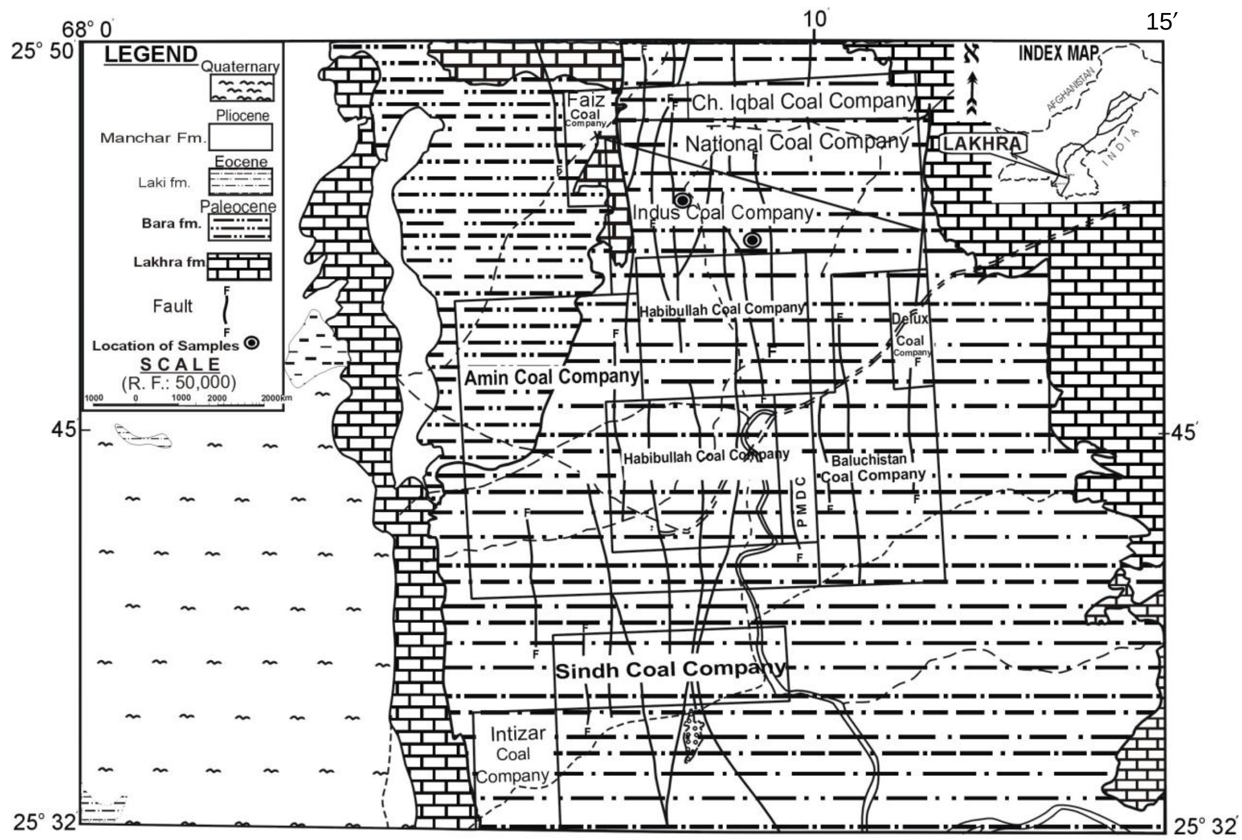


Fig. 1. Geological map of Lakhra coalfield showing locations of samples (after Khan, R.A., 1994).

Table 1. General Stratigraphic Sequence in the Lakhra area (Khan et al., 1988).

Group	Formation/Member	Age	Thickness	Lithological Description
R A	Alluvium Manchar Formation	Recent Pliocene	Thin 18.28 m	Silt and Sand Composed of ferruginous dark brown, red and yellow colored laterite and Pebbles mixed with sand, Silt and Clay.
		Unconformity		
N I	Laki limestone Member	Early Eocene	20.7 m	In the area two units (Sonhari Member and Laki Limestone member) of the Laki Formation are exposed. The limestone is fossiliferous, creamy, white and light grey with yellow to brown stains, weathers to light grey.
	Sonhari Member	Early Eocene	7.62 m	Consists of lateritic clay and ferruginous sandstone of yellow, red and brown colour.
K		Unconformity		
	Lakhra	Late Paleocene	137.16 m	The unit consists of light grey, dark brown, yellow sandstone, limestone, clay stone, shale and siltstone. It is fine to coarse with sub angular to sub rounded grains calcareous and fossiliferous.
O T	Bara Formation	Early Paleocene	20.7 m exposed	**C O A L S EA M S.**

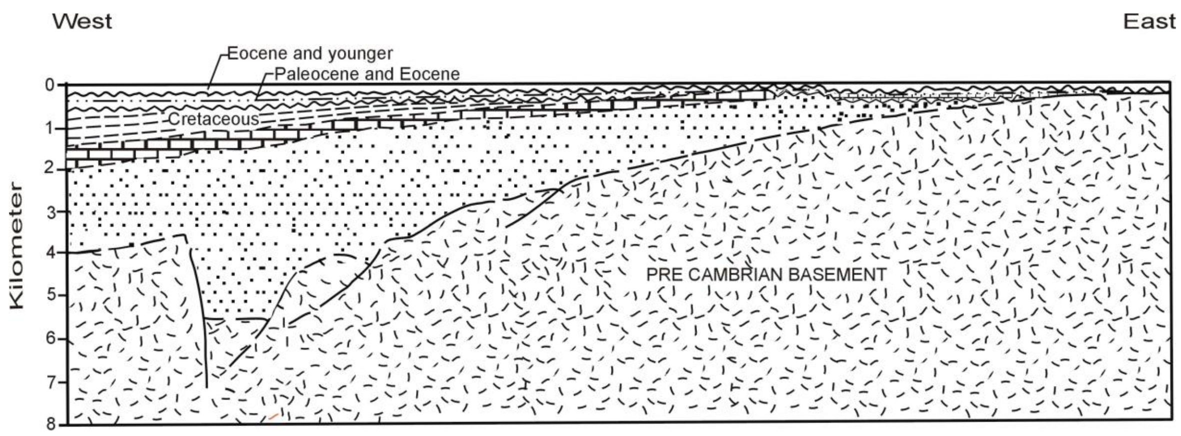


Fig. 2. Structural cross section of Thar coalfield, showing granitic basement and sedimentary rocks (after Fessett and Durrani, 1994).

4. Materials and Methods

As a part of this study, samples were collected from coal mines of the Lakhra coalfield and drill core samples from block VIII of the Thar coalfield (Fig. 3). The morphology of cleats of selected coal samples of Lakhra and Thar coalfield were investigated by JEOL (6490 LV model) Scanning Electron Microscope. The smooth chips of coal were prepared and their plane surfaces were polished on a dry and neat plane glass surface. These polished chips were mounted on stub with double sided carbon solution tape.

For acquiring optimum conductive surface of the coal, chips were coated with carbon in the vacuum value of an ideal pressure condition of 10^{-4} Pa., and placed under the bell jar of Vacuum Evaporator (JEOL JEE-420 model), for observation under SEM. The microanalysis was performed by Energy Dispersive X-Ray Spectrometer (EDX Bruker Gmb XFLASH), connected with SEM, after attaining an ideal magnification of x120 to x1000 (Table 3).

Table 2. The Generalized stratigraphic sequence of the Thar coalfield (Jaleel et al., 2002).

Formation	Age	Thickness	Lithology
Dune Sand	Recent	14m to 93m	Sand, Silt and Clay
	……………………….	Unconformity	……………………………
Alluvial Deposits	Sub Recent	11m to 209m	Sandstone, Siltstone, Claystone
	…………………………….	Unconformity	………………………………
Bara Formation	Paleocene to Early Eocene	+52m (variable)	Claystone, shale, sandstone, coal, carbonaceous clay-stone
	…………………………	Unconformity	………………………………
Basement Complex	Pre-Cambrian	----	Granite and quartz diorite

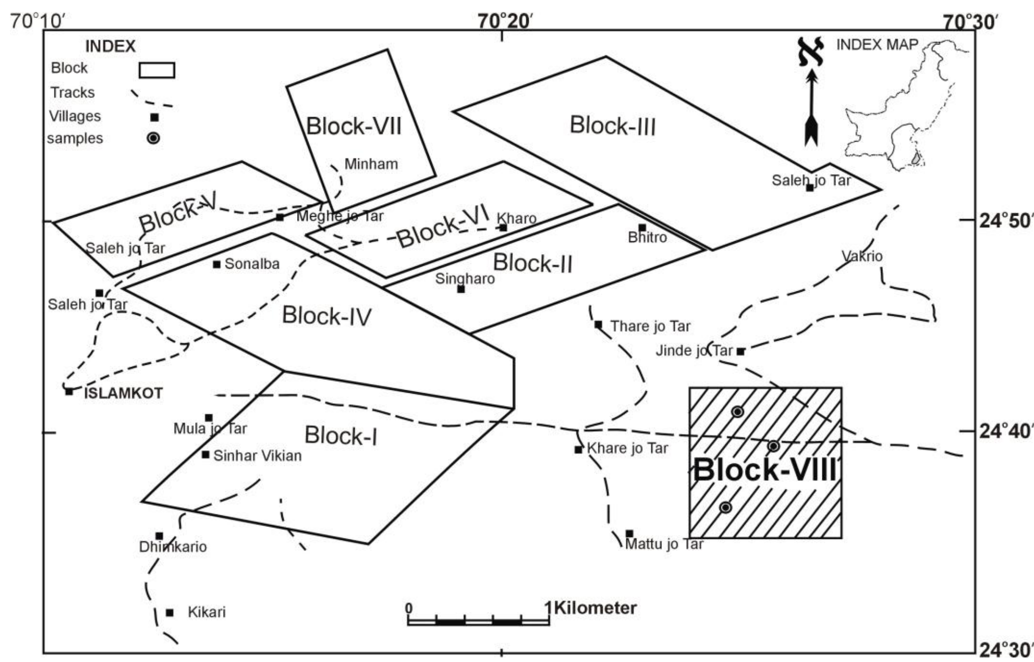
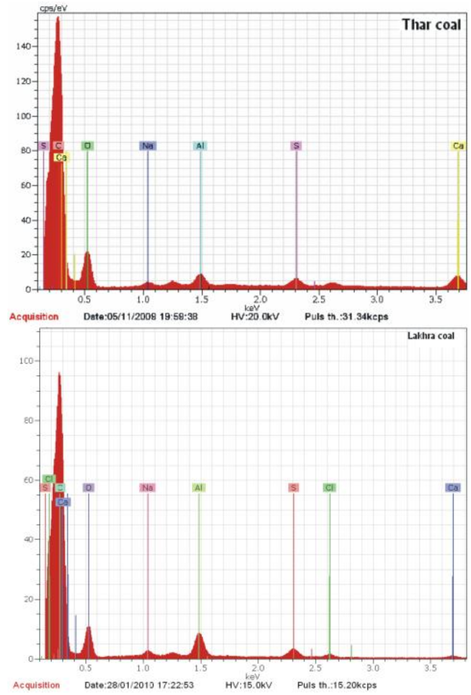


Fig. 3. Location of Thar Coalfield showing various blocks in coalfield.

Table 3. Chemical analysis of studied coal (in wt %).

Element	Thar coal		Lakhra coal
	Sample-I	Sample -II	
Carbon	57.58	47.16	58.75
Oxygen	38.54	32.88	34.5
Sulphur	0.75	0.67	1.50
Nitrogen	ND	16.06	ND
Chlorine	ND	ND	0.61
Aluminum	0.82	1.06	2.63
Calcium	1.64	1.47	0.74
Sodium	0.67	0.69	1.17

ND = Not Detected



5. Results and Discussion

Su et al (2001) classified cleats into three patterns; (a) Reticulate (b) Isolated and (c) Random. The reticulate pattern of cleats have further been classified as (i) Regular reticulate sub-pattern and (ii) irregular reticulate sub-pattern, while Isolated cleat pattern is further classified as Isolated sub-pattern and Isolated 'S' pattern (Fig. 4). These patterns play very important role in production of CBM, as cleats produce permeability in coal, through which water moves and locks methane in coal. In Lakhra coal regular reticulate sub-pattern and isolated sub-pattern have been identified by SEM (Fig. 5).

The SEM micrograph examination of Lakhra coal shows stress related exogenic as well as endogenic types of cleats, which had further produced reticulate and isolated 'S' sub-patterns of cleats. Hence stress related cleats in coal enhance reservoir porosity and permeability. At the maximum magnification x1000 examination of the SEM micrograph shows that Lakhra coal exhibits granular matrix of >10µm. The examination of micrographs of Thar coal samples also shows that the size of micropores is of <0.1µm. The observation of SEM micrographs shows that in Thar coal due to tectonic activity microcleats of random and isolated 'S' patterns had been developed (Fig. 5).

The coal has dual pore system of macropores and micropores. The micropores (known as matrix) are responsible for the porosity in coal. Gamson and Beamish (1992) has classified matrix porosity into three forms: (i) in between a coarse granular matrix (10-50µm), (ii) Within a chaotic mass of minute angular to sub-rounded particles collectively known as micromite (1-5µm) and (iii) as microcavities in between clay particles of 0.1µm to 2µm size.

The microanalysis performed by micro analyzer (i.e. EDX), connected with scanning electron microscope shows that beside carbon, oxygen, and nitrogen; chlorine has also been detected in Lakhra coal in very low concentration i.e. 0.6%, but in Thar coal it could not be detected (Table 3). The presence of chlorine in Lakhra coal indicates presence of small amount of water-soluble chlorides as pore moisture in coal. The higher percentage of sulphur (i.e. 1.50%) in Lakhra coal indicates that this sulphur deposited from secondary sulphide mineral (pyrite and marcasite) as cleat fillings.

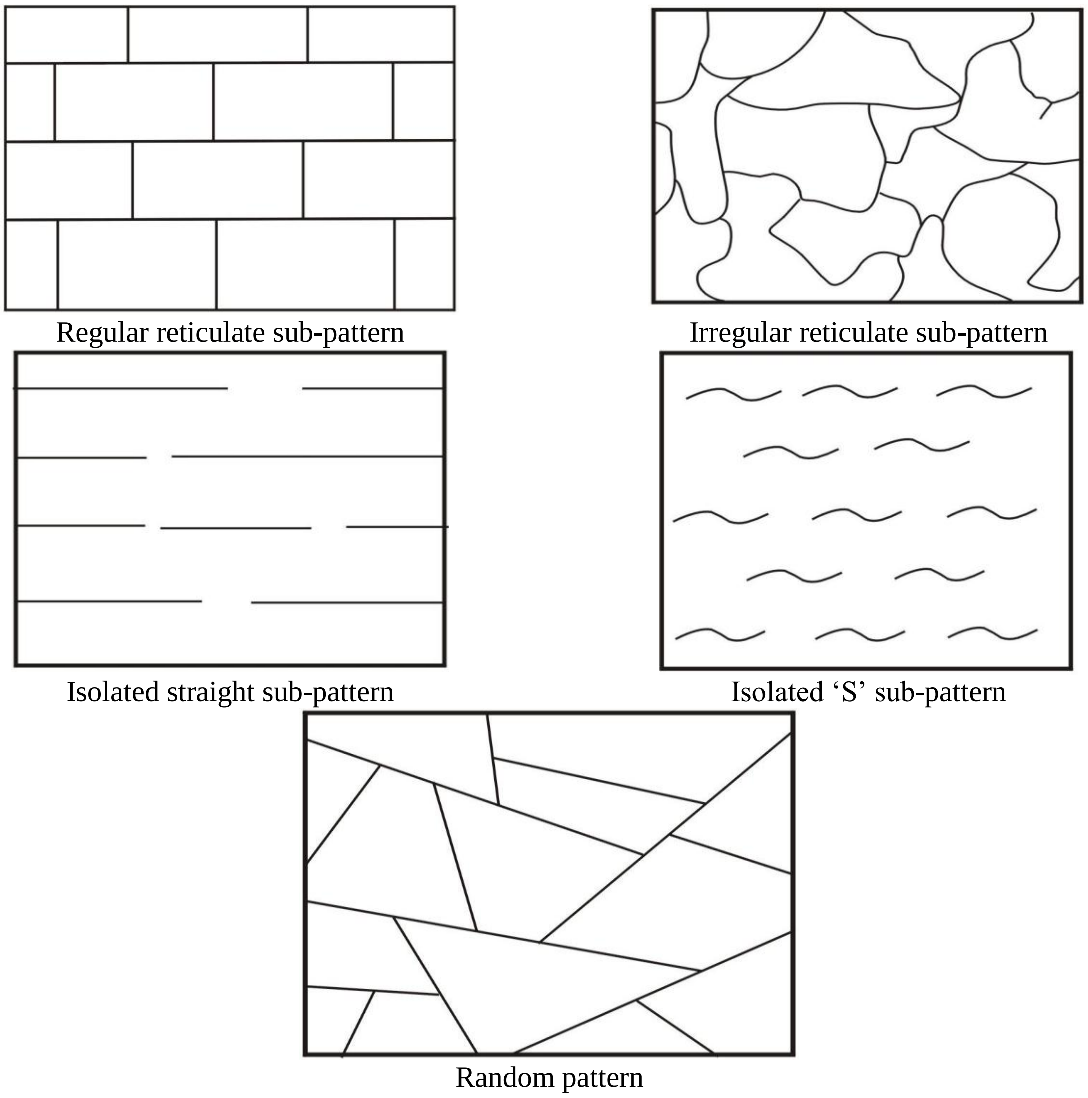


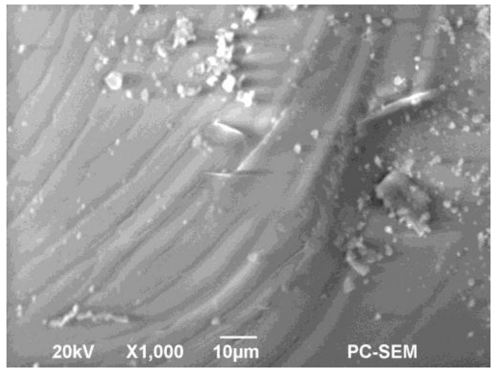
Fig. 4. Types of cleat patterns (after Su et al., 2001).

The concentration of aluminum in coal suggests; that it might have deposited as pore fillings from kaolinite mineral in coal. Calcium in coal either occurs as discrete mineral mater or organically associated cations. Calcium as shown in Table 3 varies from 1.47% to 1.64% in Thar coal and 0.74% in Lakhra coal, indicating that it had deposited from the movement of mineralized water through the cleats. Sodium in lignite is evenly dispersed throughout the coal matrix. The presence of sodium in cleats also indicates that saline or marine water had moved from one place to the other through the cleats.

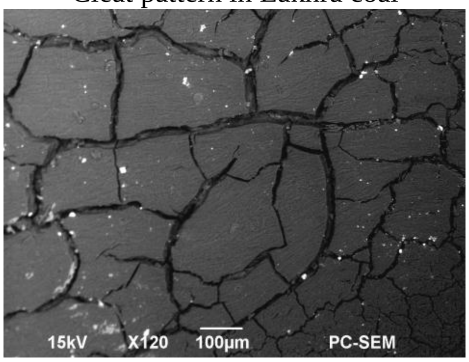
6. Conclusion

The SEM microphotographs of Lakhra and Thar coal show that Lakhra coal has the prospects of coal bed methane from macro cleats. The size of micropores or interstitial pore spaces within the coal matrix act as stores for methane gas in coal forming coal bed methane reservoir. Whereas because of minute size of micropores, these are not considered as ideal from the porosity point of view, but the internal surface area of the coal matrix may store methane gas as coal bed methane reservoir. Therefore, in Thar coal due to occurrence of micropores of <0.1μm size, there is least chance of occurrence of methane gas. However, detailed seam wise study of cleat geometry will further reveal the situation, particularly in Lakhra coalfield.

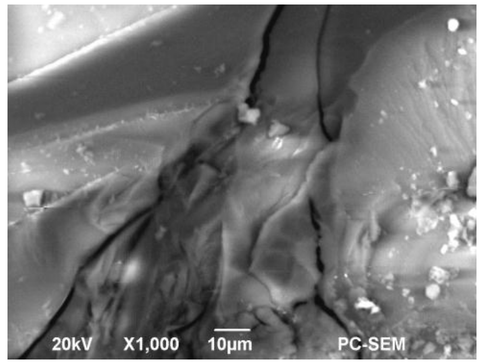
Cleat pattern in Lakhra coal



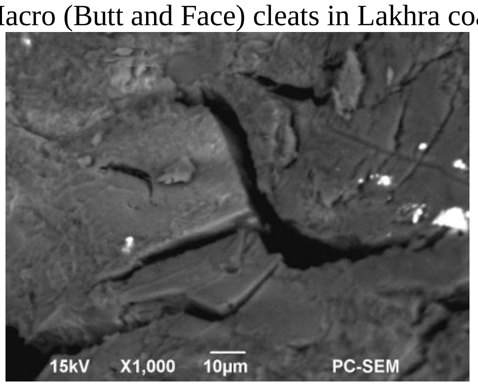
Micro cleats in Thar coal



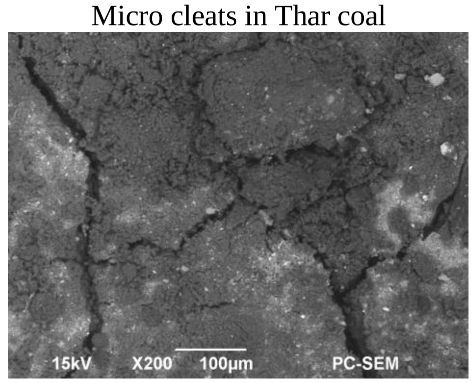
Macro (Butt and Face) cleats in Lakhra coal



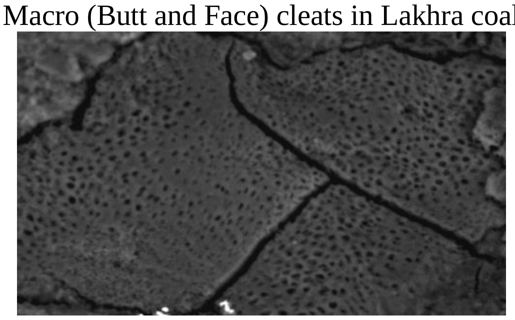
Micro cleats in Thar coal



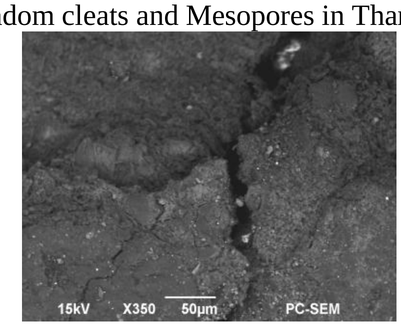
Macro (Butt and Face) cleats in Lakhra coal



Random cleats and Mesopores in Thar coal



Granular micro pores in Lakhra coal



Micropores in Thar coal

Fig. 5. Showing Micrographs of cleat pattern and matrix porosity in Lakhra coal and Thar coal.

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