

# METHANE FORMATION

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# Course Objective

- Methane is a greenhouse gas (GHG). The millions of cubic meters of methane vented to the atmosphere increases methane load and causes climate change by global warming. The global warming potential (GWP) of methane (CH<sub>4</sub>) is 28 times more than that of carbon dioxide.
- In addition, the release of methane into the mine atmosphere raises concern about the mine safety due to the explosion hazards associated with methane gas. The coal seams before mining may contain 60-95% methane and the gas drained from fractured formations above mined seams and accumulated in gobs may contain 30-95% methane.
- Keeping the aforementioned challenges in view, the course has been designed taking into the need of methane recovery and utilization for more productivity and safety.
- The course objective is to impart theoretical and practical knowledge for formulating the mechanisms for recovery and utilization of methane. In addition, the students will be acquainted with several case studies demonstrating the intricate challenge of methane removal technology faced in Indian coal mines and development of methods for solving those problems.

# Learning Outcomes

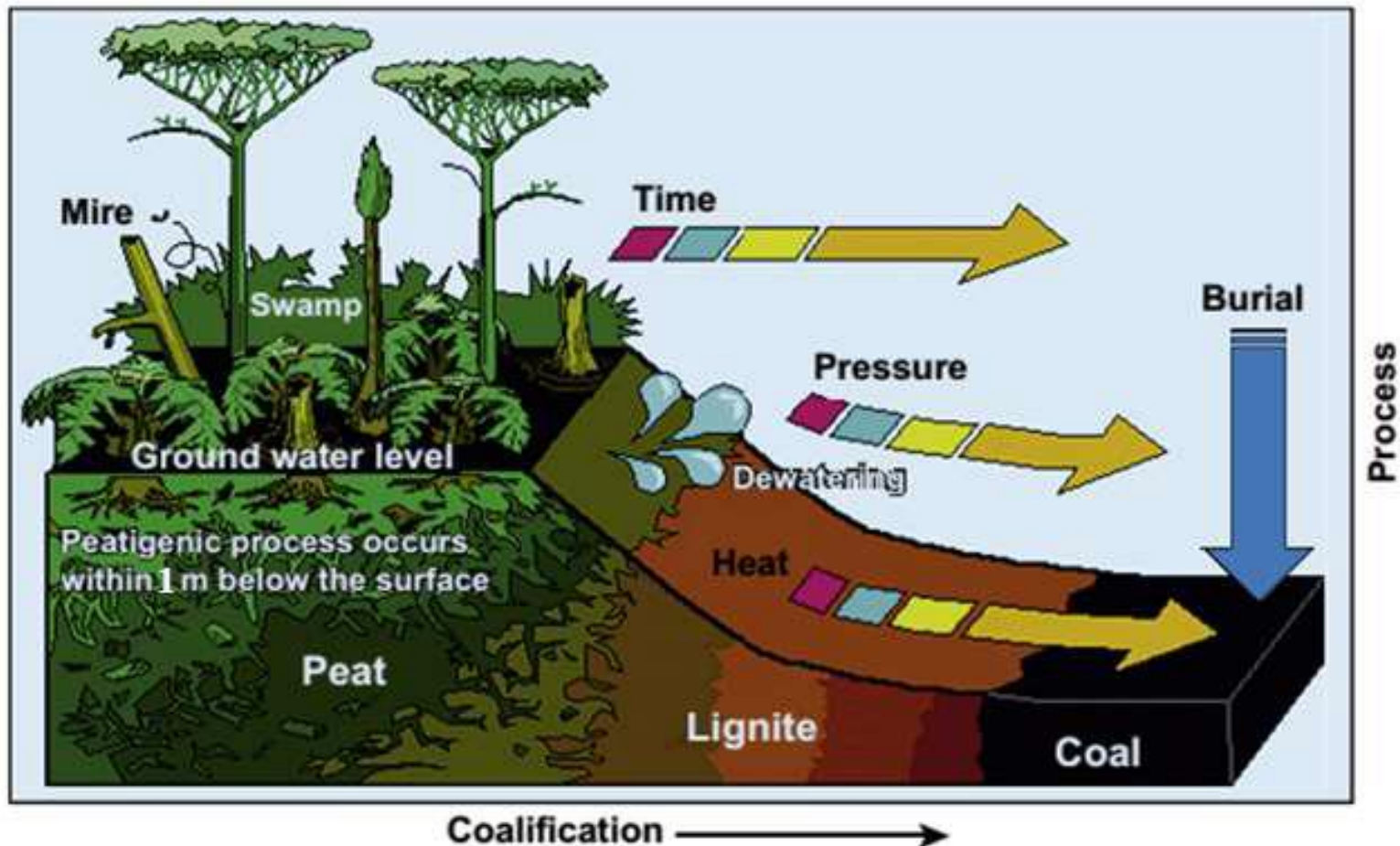
Upon successful completion of this course, students will:

- have a broad understanding of different types of methane formation and transport of methane in coal.
- have a detailed understanding of CO<sub>2</sub>-ECBM recovery mechanism, CBM production phases and practices.
- learn the methods for estimation of methane content of coal seams and methane emission factors for different categories of mines.
- detailed understanding of VAM utilization technologies.
- be able to formulate the mechanisms for recovery and utilization of methane in coal mines.

# Coalbed gas generation during the coalification process

- Coalbed methane is an unconventional source of energy that is formed during the process of coalification, remains in coal in the form of adsorbed gas
- The plant materials are carried away by the stream and deposited in the river, lake, ponds, and with a passage of time, the overburden covers it forming many sedimentary layers
- The transformation, from peat to anthracite over millions of year after burial through different stages of maturation, is designated as the coalification process
- Coal can store on the order of six to seven times more gas than the equivalent volume of rock in a conventional gas reservoir

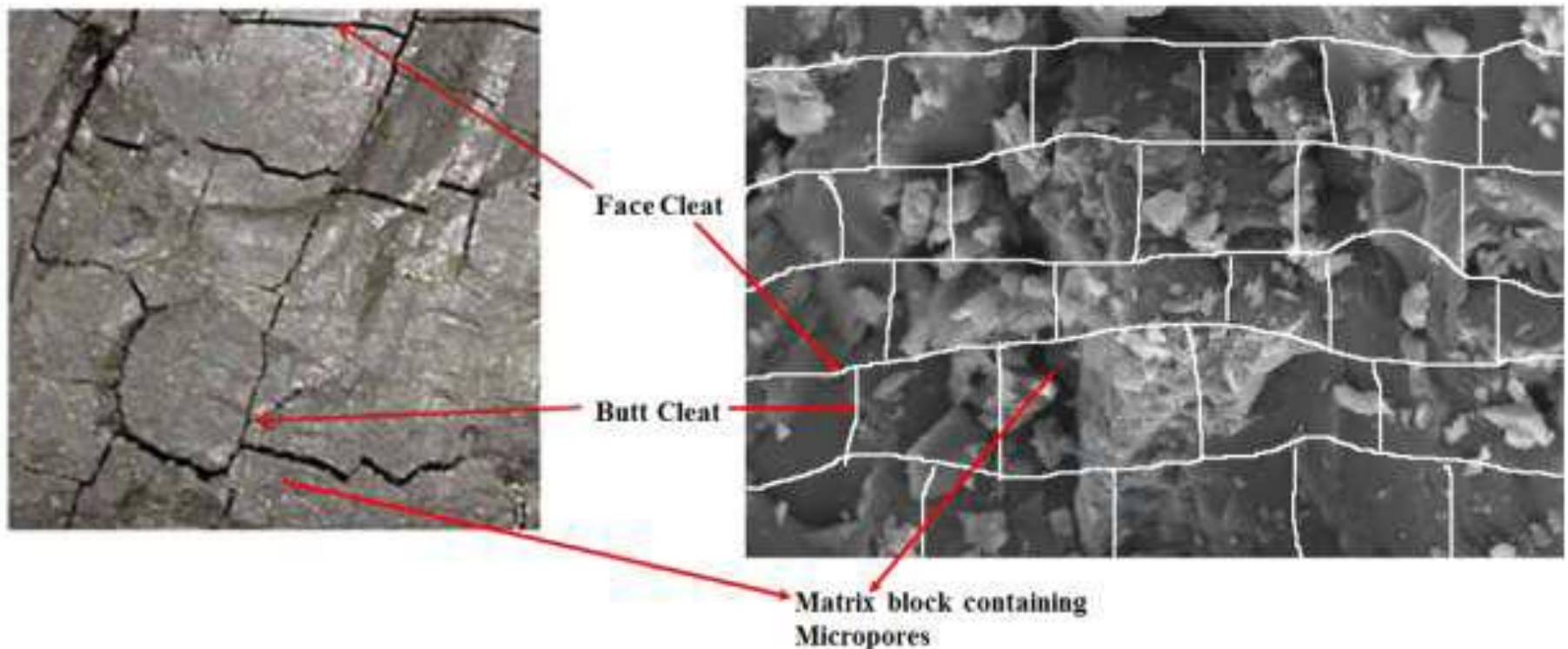
- The different stages of formation from the peat is lignite, sub-bituminous, bituminous, semi anthracite and anthracite.
- Moreover, the coalification process is accompanied by various changes in the chemical, physical or structural changes of coal. The changes bring the increment in maturation, carbon content and decrease in the oxygen content.



- One of the main phenomena during the coalification process is the generation of methane through the process of de-volatilization.
- Generation of methane during the coalification process has been broadly characterized as biogenic and thermogenic. The biogenic methane is generated at the early stage of coalification in less mature coal (*Vitrinite reflectance*  $Ro \sim 0.3\%$  to  $0.5\%$ ).
- On the contrary, thermogenic methane and low amount of other gases are generated in the later period and so found in high mature coal ( $Ro \sim 0.5$  to  $3\%$ ). However, the quality and quantity of this coalbed gas depend on the maturity, rank and depth of occurrence.
- Unlike the conventional gas, where the source and reservoir rock are different, coal seams serve as source and reservoir rock for the coalbed methane.

- During the coalification process, natural fractures are also developed in coal. The primary natural fractures are known as face and butt cleats.
- The face cleat is continuous while butt cleats often terminate into the face cleat. The cleats act as the central passage to the gas transportation through coalbeds.
- The spacing between the same types of cleat varies widely depending on the maturity, overburden and maceral contents. The schematic diagram of the cleats has been shown in Fig.

### Cleat networks in coal



<b>Characteristic</b>	<b>Conventional gas</b>	<b>CBM</b>
<b>Gas generation</b>	Gas is generated in source rock and migrated into the reservoir	Gas is generated and trapped within the coal
<b>Structure</b>	Randomly spaced fractures	Uniformly spaced cleats
<b>Gas storage mechanism</b>	Gas storage in macropores; real gas law.	Gas storage by adsorption on micropore surfaces.
<b>Transport mechanism</b>	Darcy flow of gas to wellbore (Pressure gradient)	Diffusion through micropores by Fick's Law (Concentration gradient )
<b>Production performance</b>	Gas to water ratio decreases with time	Gas to water ratio increases with time in later stages.
<b>Macropore size</b>	1μ to 1 mm	<5A° to 50A°
<b>Permeability</b>	Permeability not stress dependent	Permeability highly stress dependent
<b>Gas content</b>	Gas content from logs	Gas content from cores. Cannot get gas content from logs

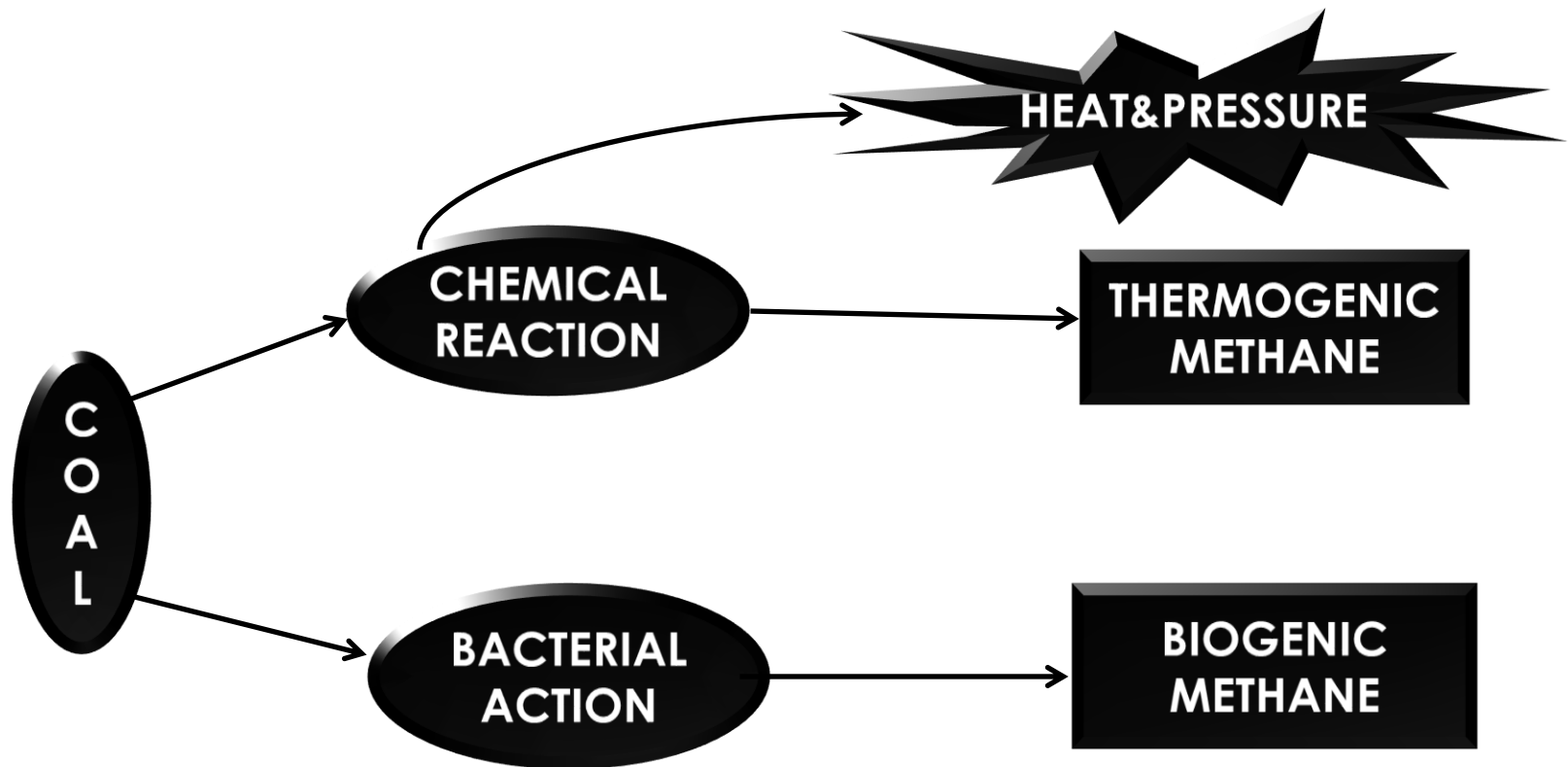
<b>Characteristic</b>	<b>Conventional gas</b>	<b>CBM</b>
<b>Hydraulic fracturing</b>	Hydraulic fracturing may be needed to enhance flow.	Hydraulic fracturing required in most of the basins except the eastern part of the Powder River basin where the permeability is very high. Permeability dependent on fractures.
<b>Reservoir</b>	<ul style="list-style-type: none"> <li>• Inorganic reservoir rock.</li> <li>• Reservoir and source rock independent.</li> </ul>	<ul style="list-style-type: none"> <li>• Organic reservoir rock.</li> <li>• Reservoir and source rock same.</li> </ul>
<b>Mechanical properties</b>	Young modules $\sim 10^6$ Pore compressibility $\sim 10^{-6}$	Young modules $\sim 10^5$ Pore compressibility $\sim 10^{-4}$

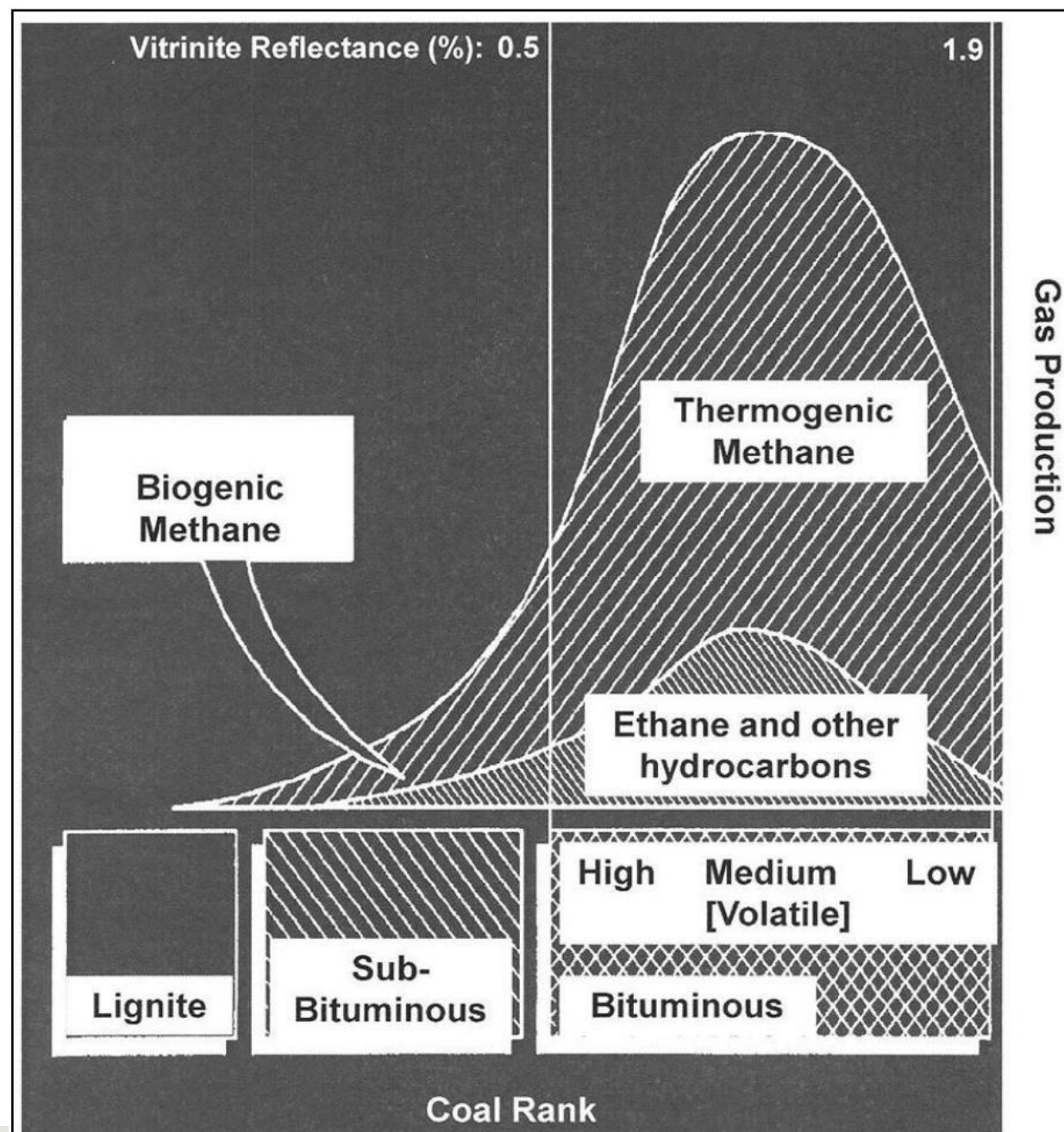
# Formation

- CBM in coal is a result of chemical and physical processes
- CBM is generated either through chemical reactions or bacterial action
- Chemical action occurs over time as heat and pressure are applied to coal in a sedimentary basin, referred to as thermogenic methane
- Bacteria obtain nutrition from coal, and produce methane as a by-product, is referred to as biogenic methane

- The biogenic methane is formed by microbial decomposition of the organic material at temperatures below 50 °C in the early stages.
- The thermogenic gas generation occurs at temperatures above 50°C. As temperature increase the depth of burial and coal rank also increases with time

# CBM formation

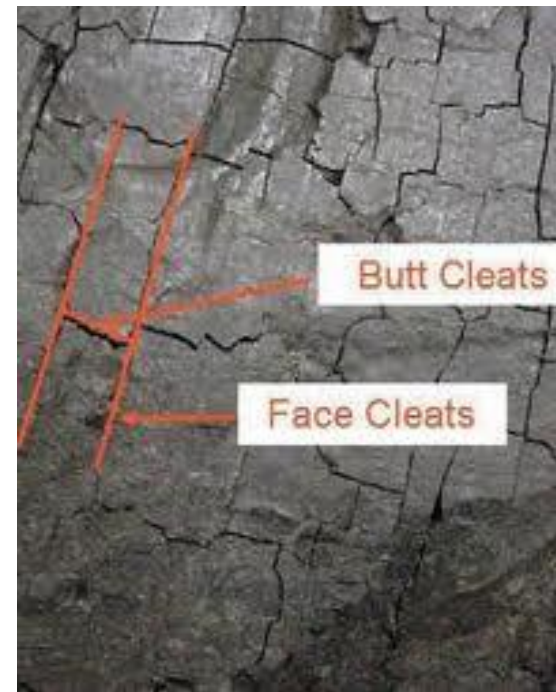
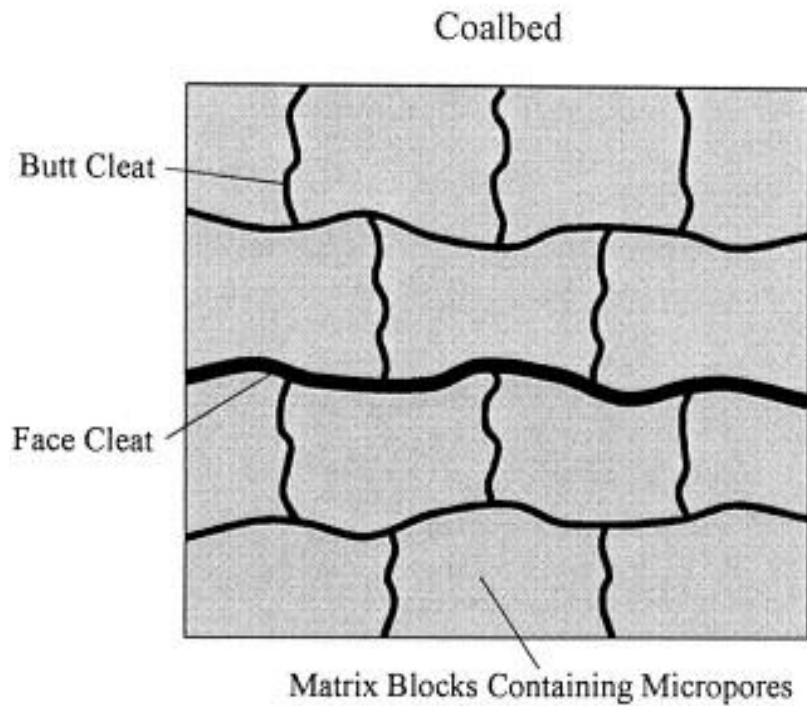




# Physical Structure of Coal

- Coal has a dual porosity structure
  - Micropores  $< 2\text{nm}$
  - Macropores  $> 50\text{nm}$
- Macropores are natural fracture that exists perpendicular bedding plane also called cleats
  - Face cleats
  - Butt cleats
- Micropores are exist between cleats which are also called coal matrix

# Cleats in Coal



# Cleats in Coal



# Movement of Methane in Coal

- Movement of methane in coal occurs at three phase:
  - phase 1: Desorption of methane from internal surface of coal
  - phase 2 : Movement of desorbed methane from coal matrix to cleats through diffusion following Fick's 2<sup>nd</sup> law of diffusion
  - phase 3 : Transportation of methane from cleats to production well following Darcy's law of fluid through porous media

# Movement of Methane in Coal

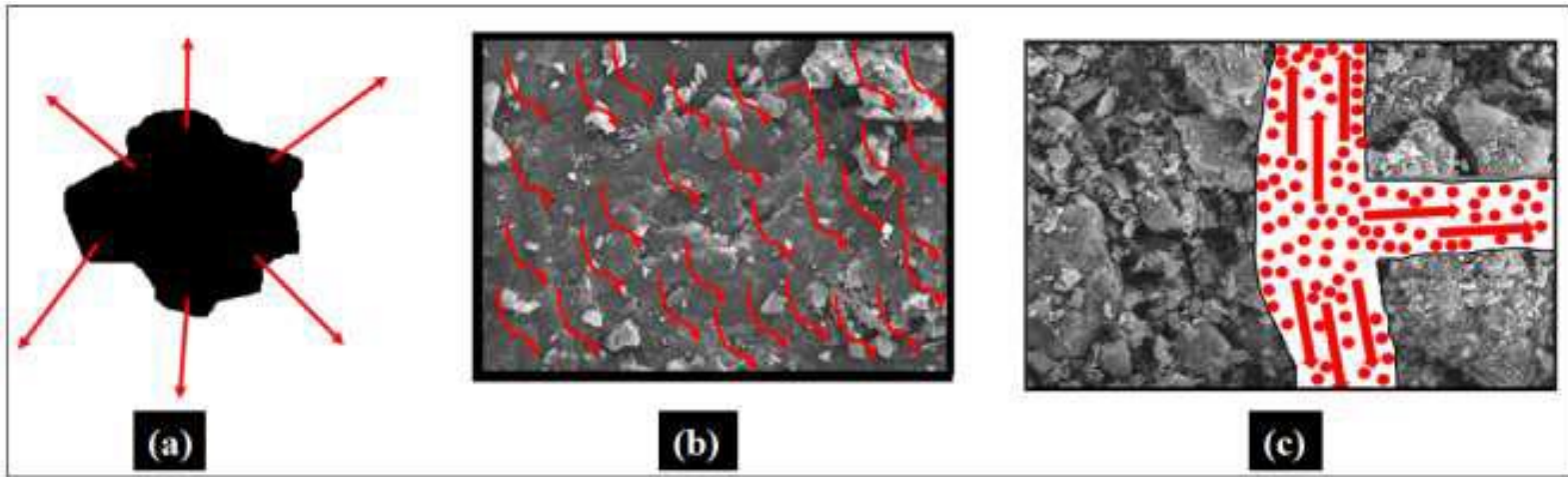
- The coal is dual-porosity (matrix porosity and fracture porosity) in nature, and a significant amount of methane remain adsorbed in the porous structure of coal.
- Coal bed methane occurs in a number of ways such as
  - 1. adsorbed molecules within micropores (<2 nm in diameter);**
  - 2. trapped gas within matrix porosity;**
  - 3. free gas (gas in excess of that which can be adsorbed) in cleat and fractures; and**
  - 4. as a solute in groundwater within coal fractures**
- However, most of the gas in coal is in adsorbed form. This gas readily desorbs from the internal surface of coal once the pressure is reduced below the critical desorption pressure.
- Most of the coalbeds are filled with water, thus dewatering leads to desorption of gases, followed by its transportation through cleats towards the low-pressure zone, i.e., mostly the producing well

- The movement of methane in the coal was shown in Fig. The three phases of methane movement in coal have been described below:

(a) The methane gets desorbed from the internal surface, i.e., the porous structure of the coal matrix

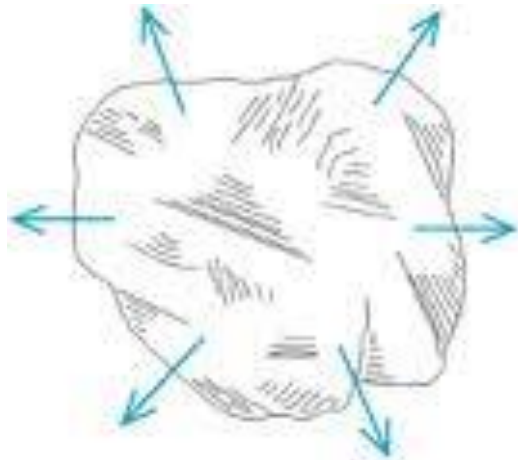
(b) Diffusion of methane from the pores to cleat network by following Fick's second law

(c) Movement of methane from cleat to production well by following Darcy's law



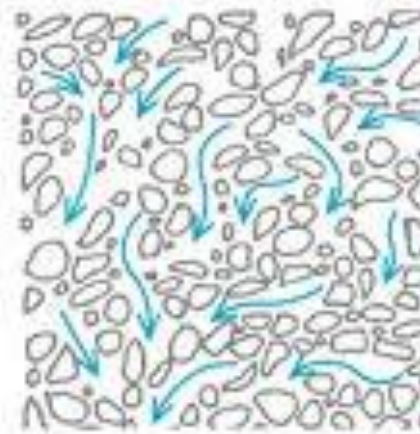
**Fig. :** Movement of methane in coal beds: (a) Desorption from coal surface (b) Diffusion of methane from pore structures to cleats (c) Movement of methane within the cleat

# Movement of Methane in Coal



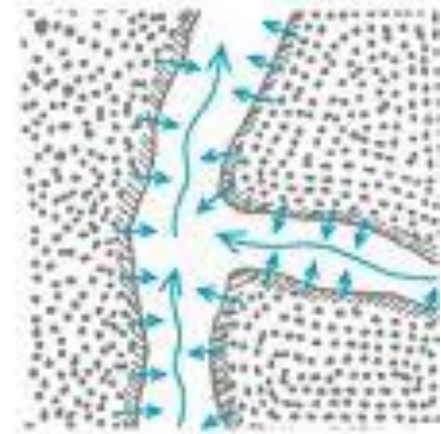
(a)

Desorption from  
coal Surface



(b)

Diffusion from  
matrix to cleats



(c)

Movement within  
the cleats