Extended Abstract
(For PhD open seminar)

Petro-chemistry of Permian Coal Deposits from the Sohagpur Coalfield, Son Valley, Central India: Implications for Paleoenvironments and Coal Bed Methane (CBM) potential

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Abstract

India has vast reserves of fossil fuels and ranks fifth in the world in coal resources. For many years, coal has played a key role in India's energy needs—running industries, generating electricity, and supporting economic growth. However, the use of coal is currently under scrutiny due to growing concerns about climate change and environmental damage, as well as the urgent need for cleaner energy. As a result, alternative energy sources that are cleaner than burning coal, like coal-bed methane (CBM), have become more critical. It is considered a cleaner and more environmentally friendly energy option than traditional coal use.

The Sohagpur coalfield is situated in Madhya Pradesh, a central state of India. This coalfield is not only rich in coal but also has excellent potential for producing CBM. Despite its importance, detailed scientific studies of this area are still lacking. Researchers conducted a previous study on the Sohagpur coalfield, analyzing sporadic coal samples for petrological, chemical, and trace elements. The seismic imaging of the coal block, as well as the geophysical and geomechanical characteristics of the coal deposits in Eastern Sohagpur, was also done. At the same time, the morpho-taxonomic study of the macrofloral assemblage was also conducted. However, there have been no attempts made for the detailed petrological and geochemical characterization of the Sohagpur coalfield based on pillar samples of the currently operating coal mines.

To fill this gap, this study was carried out thoroughly on the coals from the Sohagpur coalfield. This study integrates coal's petrography and geochemistry with advanced techniques to examine the pore structure and arrangement of the coal. These methods help understand the coal's formation, its environment, and its potential for utilization in the industry. Most importantly, the study also estimates how much CBM the coal could generate, supporting India's goal to move toward cleaner and more sustainable energy sources. Most importantly, the study also estimates how much CBM the coal could generate, supporting India's goal to move toward cleaner and more sustainable energy sources. Through this approach, the research aims to address primary objectives-

- Decipher the paleoclimate and paleodepositional conditions of Sohagpur coals
- Coal bed methane generation potential and potential CO_2 sequestration for the enhanced coal bed methane recovery or storage of CO_2 in abandoned coal mines.
- Potential industrial utilization of Sohagpur coal.

To ensure the robustness, accuracy, and reproducibility of analytical results, coal samples were systematically collected from all workable coal seams of the Sohagpur Coalfield using the pillar sampling method. This method was chosen to minimize contamination and maximize representativeness across the stratigraphic section. The samples that were collected were then prepared in a way that was specific to their size and the needs of each analytical technique. For instance, –72 mesh size fractions were used for proximate and ultimate analyses and FTIR; –100 mesh for XRF and XRD analyses; –60 mesh for Rock-Eval pyrolysis; –18 mesh for petrographic and reflectance studies; –230 mesh for low-pressure gas adsorption and SAXS; and 0.5–1 cc chunks for MIP. This size-specific methodology enabled precise measurements

of a range of physical, chemical, and structural parameters critical to understanding coal properties relevant to CBM potential.

The petrographic analysis reveals that Sohagpur coals are predominantly composed of vitrinite and inertinite group macerals, followed by the liptinite group. This composition is favorable for CBM generation, as vitrinite contributes significantly to methane generation in coal seams during coalification. Vitrinite reflectance values indicate that the coals fall within the high volatile bituminous rank, confirming a level of thermal maturity that is generally optimal for methane generation. Textural analysis also highlights the heterogeneous nature of the coals, with variations in maceral distribution and bonding textures that may influence pore structure and gas diffusion behavior. Geochemical analyses further support the suitability of these coals for CBM potential. Proximate analysis shows moderate volatile matter and relatively high ash content.

In contrast, ultimate analysis confirms that the samples are rich in organic carbon. Elemental ratios derived from CHNS data indicate a humic-type kerogen, which is typically associated with terrestrial plant material and favorable for hydrocarbon generation. XRF and XRD results reveal that the mineral matrix is dominated by clay minerals and quartz, consistent with deposition in a humid, clastic-influenced environment. FTIR spectroscopy detects various organic functional groups such as aliphatic and aromatic hydrocarbons, hydroxyls, and carbonyls, along with inorganic groups like silicates and carbonates, all of which provide information on depositional conditions and adsorption characteristics. Rock-Eval pyrolysis data show hydrogen index (HI) and Tmax values that are consistent with gas-prone, affirming their capability to generate methane under suitable burial and thermal conditions.

Pore structural analysis offers important clues about the methane storage and transport characteristics of the coals. Studies of low-pressure gas adsorption show that micropores (<2 nm) make up most of the surface area of the samples, which is important for methane adsorption. Mesopores (2–50 nm), while contributing less to surface area, enhance the overall gas storage capacity and facilitate diffusion pathways. Mercury intrusion porosimetry identifies the presence of macropores (>50 nm), which contribute to permeability and gas migration within the coal seams. SAXS measurements reveal a hierarchical pore network structure with multiscale connectivity, providing a more comprehensive understanding of pore morphology and its influence on CBM recoverability. The integration of these techniques highlights the complex interplay between coal composition, mineral matter, and pore development, which together influence the methane sorption capacity and production potential.

Paleoenvironmental interpretations based on petrographic and geochemical evidence suggest that the coals were deposited in a humid, swamp-dominated environment, with alternating oxic and anoxic conditions. The significant presence of inertinite macerals indicates periodic wildfire activity during peat accumulation. The mineralogical and geochemical indicators point to fluvio-deltaic and occasionally lacustrine depositional settings, influenced by episodic clastic influxes. These interpretations align with the inferred warm and humid paleoclimatic conditions characteristic of the Permian Gondwana period.

The thesis is structured into seven chapters. Chapter 1 introduces the study, including an overview of Indian coal reserves, a literature review of previous work on the Sohagpur Coalfield, and a statement of research objectives. Chapter 2 talks about the geology of the area, such as the stratigraphy, structural features, and where the coal seams are. Chapter 3 describes the sampling procedures, sample preparation methods, and analytical techniques in detail. Chapter 4 shows the results of the petrographic, geochemical, and pore structure tests. Chapter 5 focuses on evaluating the potential of hydrocarbon source rocks, with emphasis on CBM implications. Chapter 6 provides an integrated discussion of the results, interpreting them in terms of coal genesis, depositional environment, and industrial applications. Finally, Chapter 7 summarizes the key findings and highlights their scientific and practical significance.

Research Publications from this work-

1. **Kishor et al. (2023):** Geochemical study of coals from Sohagpur Coalfield, India, and its implication to CBM potential. *International Journal of Coal Preparation and Utilization* 10.1080/19392699.2023.2212611

2. **Kishor et al. (2023):** Geochemical and microstructural analysis of coals from Sohagpur coalfield with reference to adsorption behaviour: an assessment for CO_2 sequestration. *International Journal of Coal Preparation and Utilization* 10.1080/19392699.2023.2232721

3. **Kishor et al. (2024):** Pore Characteristics and Gas Adsorption Properties of Permian Coals in Sohagpur Coalfield, India: A Comprehensive Multi-Analytical Study. *Energy and Fuels* 10.1021/acs.energyfuels.4c04722

4. **Kishor et al. (2025):** Paleoenvironmental and Paleodepositional Reconstruction of the Permian coals from Burhar Seam IV of Sohagpur Coalfield, India: Using Integrated Mineralogical, Geochemical, and Petrographic Proxies. *Geological Journal* 10.1002/gj.70113

5. Geochemical and Petrological Characterization of Coals from Sohagpur Coalfield: Insights into Rank, Utilization, and Hydrocarbon Potential **(Under Review)**

6. Role of petrographic constituents in gas adsorption, pore characterization, and CO_2 sequestration potential **(Ready to submit)**

7. Permian Peat to Coal: Reconstructing Depositional Dynamics in the Sohagpur Coalfield through Petrochemical Fingerprinting **(Ready to submit)**