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Seismic imaging of coal seams and structural features: A prerequisite for CO_2 sequestration studies in the Raniganj Basin, India

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ABSTRACT

This study presents an integrated seismic and well-based characterization of the eastern Raniganj Basin, India, aimed at imaging coal seams and delineating subsurface structural features, which are essential for evaluating geological CO_2 sequestration potential. Multiple geophysical datasets, including legacy 2D seismic, high resolution 3D seismic, and 2D multicomponent (2D-3C) seismic data, were analyzed and calibrated using lithological information from drilled wells. The 3D seismic data from the northeastern part of the basin image shallow coal horizons, characterized by laterally continuous and predominantly flat lying reflectors, indicating a structurally less disturbed subsurface. In contrast, seismic interpretation in the southeastern part of the basin, based on conventional 2D and 2D-3C datasets, reveals multiple coal seams, stratigraphic boundaries, and subtle structural features, such as gentle monoclines and minor normal faults. Based on the integrated seismic analysis, the southeastern Raniganj Basin exhibits geological characteristics that are favourable for further evaluation of CO_2 sequestration potential compared to the northeastern sector. However, the presence of interpreted fault systems highlights the need for detailed investigations including high-resolution seismic imaging and fault seal analysis, to assess structural continuity and long-term containment integrity. The study establishes a preliminary understanding of the geological framework of the eastern Raniganj Basin that can be further strengthened by integrating high-resolution seismic data with other datasets to quantitatively evaluate storage capacity and long-term containment integrity.

Keywords: CO_2 sequestration, Coal seams, Seismic imaging, Subsurface structure, Raniganj Basin (India)

INTRODUCTION

Global industrialization and rapid urban expansion have led to a sustained increase in energy demand, which continues to be met predominantly by fossil fuels. While these energy resources have supported economic development, their extensive utilization has resulted in a significant rise in atmospheric CO_2 concentrations, contributing to climate change (Metz et al., 2005; Vedanti et al., 2025). This growing environmental concern, combined with the need for reliable energy, has intensified interest in cleaner and more sustainable energy solutions. In this context, geological carbon sequestration has emerged as a promising mitigation strategy (Pandey et al., 2016; Vedanti, 2026). Among various storage options, coal formations offer the additional advantage of enhanced coalbed methane recovery (ECBM), enabling simultaneous greenhouse gas mitigation and energy production (Bachu, 2008; Gale and Freund, 2001).

The Raniganj Basin (Figure 1), a sub-basin of the Damodar Valley, is of significant geological and historical importance as the birthplace of India's coal industry (Gee, 1932; Dutta, 2002). Geological investigations in the basin date back over two centuries, with formal coal mining initiated in 1774 (Varma et al., 2015). Owing to its extensive coal-bearing successions and long history of resource exploitation, the basin has attracted sustained interest in coal-bed methane and other unconventional resources. The presence of coal-based thermal power plants and ongoing coalbed methane production by commercial operators such as Great Eastern Energy Corporation Limited (GEECL) and Essar Oil and Gas Exploration and Production Limited (EOGEPL), has further motivated interest in evaluating the basin for CO_2 storage (Vedanti et al., 2020). However, safe and effective carbon sequestration in coal formations requires a detailed understanding of the subsurface geological conditions, including coal seam continuity, fault systems, and structural configuration.

Previous studies have established the regional stratigraphic and structural framework of the Raniganj Basin (Gee, 1932; Dutta, 2002; Mendhe et al., 2018; Satyanarayana et al., 2020; Satyavani et al., 2021). Multiple studies have documented the presence of several coal horizons with variable depth and thickness within the Raniganj and Barakar Formations (Ghosh, 2002; Chatterjee and Pal, 2010; Mishra et al., 2016). For instance, Mohanty et al. (2018) identified a total of nine coal horizons (R-I to R-IX) in the Raniganj Formation and seven coal horizons (I to VII) in the Barakar Formation, whereas Chattaraj et al. (2019) reported ten coal horizons (R-I to R-X) within the Raniganj Formation. These variations reflect the complex depositional and tectonic evolution of the basin.

Structurally, the basin is characterized by numerous faults, sub-basins, basement highs, and intrusive bodies (Gee, 1932; Ghosh, 2019). Intra-basinal faulting has resulted in the development of multiple structural compartments, with