Marine and Petroleum Geology 66 (2015) 1056–1072

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Thermal maturity, source rock potential and kinetics of hydrocarbon generation in Permian shales from the Damodar Valley basin, Eastern India

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ARTICLE INFO

Article history:
Received 20 February 2015
Received in revised form
12 August 2015
Accepted 14 August 2015
Available online 17 August 2015

Keywords:
Permian shales
Raniganj Formation
Barren Measure Formation
Barakar Formation
Source rock
Geochemistry

ABSTRACT

This study investigates the source rock characteristics of Permian shales from the Jharia sub-basin of Damodar Valley in Eastern India. Borehole shales from the Raniganj, Barren Measure and Barakar Formations were subjected to bulk and quantitative pyrolysis, carbon isotope measurements, mineral identification and organic petrography. The results obtained were used to predict the abundance, source and maturity of kerogen, along with kinetic parameters for its thermal breakdown into simpler hydrocarbons.

The shales are characterized by a high TOC (>3.4%), mature to post-mature, heterogeneous Type II–III kerogen. Raniganj and Barren Measure shales are in mature, late oil generation stage ($Rr\%_{Raniganj}$ = 0.99–1.22; $Rr\%_{Barren\ Measure}$ = 1.1–1.41). Vitrinite is the dominant maceral in these shales. Barakar shows a post-mature kerogen in gas generation stage ($Rr\%_{Barakar}$ = 1.11–2.0) and consist mainly of inertinite and vitrinite. The $\delta^{13}C_{org}$ value of kerogen concentrate from Barren Measure shale indicates a lacustrine/marine origin (−24.6–−30.84‰ vs. VPDB) and that of Raniganj and Barakar (−22.72–−25.03‰ vs. VPDB) show the organic provenance to be continental. The $\delta^{13}C$ ratio of thermo-labile hydrocarbons (C_1–C_3) in Barren Measure suggests a thermogenic source.

Discrete bulk kinetic parameters indicate that Raniganj has lower activation energies (ΔE = 42–62 kcal/mol) compared to Barren Measure and Barakar (ΔE = 44–68 kcal/mol). Temperature for onset (10%), middle (50%) and end (90%) of kerogen transformation is least for Raniganj, followed by Barren Measure and Barakar. Mineral content is dominated by quartz (42–63%), siderite (9–15%) and clay (14–29%). Permian shales, in particular the Barren Measure, as inferred from the results of our study, demonstrate excellent properties of a potential shale gas system.

1. Introduction

Damodar Valley is an important coal repository amongst the Gondwana basins of India. Located in the northeastern part of Peninsular India, it comprises of series of east-west trending sub-basins namely, Raniganj, Jharia, Bokaro, Ramgarh, Karanpura, Auranga, Daltonganj and Hutar (Fig. 1). Sediment deposition during early Permian in the Gondwana basin was primarily fluvio-glacial and lacustrine, leading to significant development of coal beds (Gupta, 1999). Talchir, Barakar, Raniganj and Karharbari are the main coal-bearing Formations in the basin. A marine/lacustrine succession that deposited between the continental depositions resulted in a coal-devoid Formation, the 'Barren Measure' (Gupta, 1999). Shale formations occur extensively interbedded within the coal-bearing horizons in the sub-basins. The Permian–Carboniferous Gondwana facies was deposited as basal glacial sediments, overlain by coal measures across large regions of Australia, Antarctica, India, Arabia, Madagascar, Africa and South America. In addition to the traditional mineable coal, the Permian basins in several of these regions also host major coal-seam gas and oil and/or gas reserves.

The organic rich, thermally mature shales occurring in Indian Gondwana's are likely source for the gaseous hydrocarbons. Wells drilled in the Damodar Valley basin have encountered gas flows in

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http://dx.doi.org/10.1016/j.marpetgeo.2015.08.019
0264-8172/

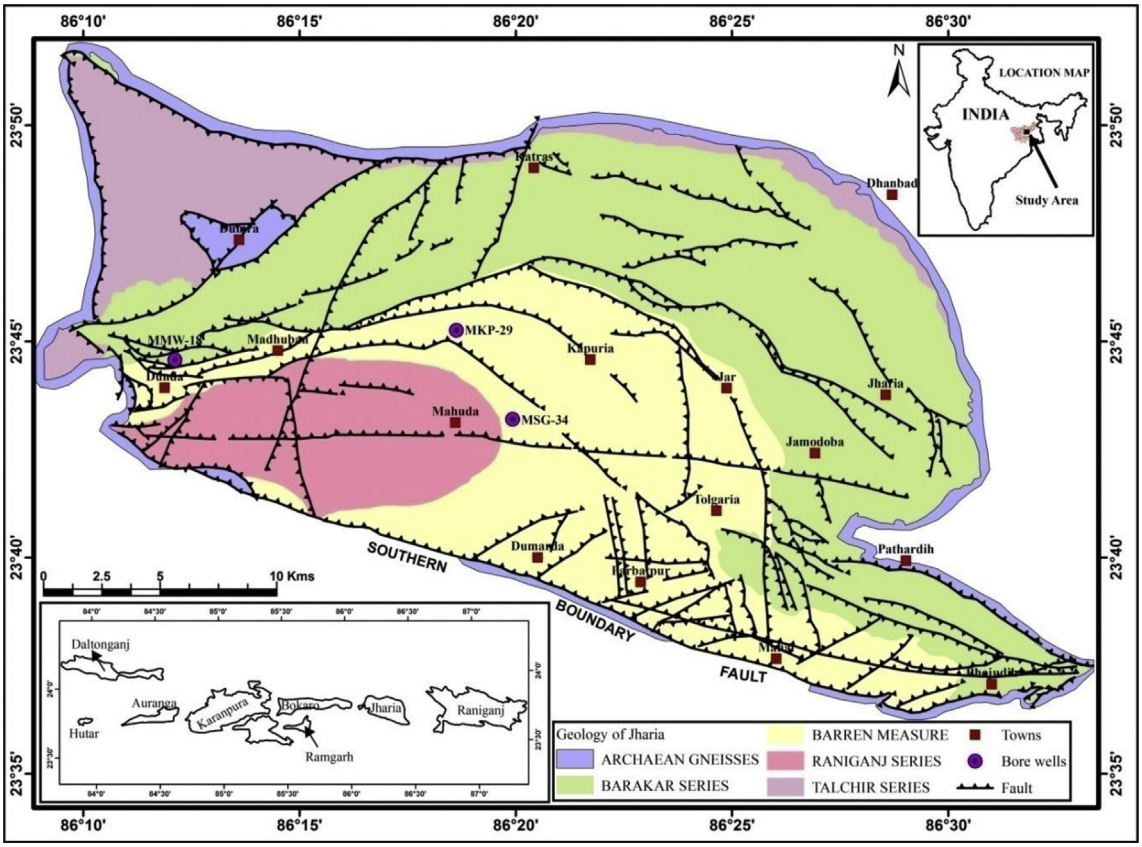

Fig. 1. Geological map of the Jharia sub-basin showing the locations of boreholes for shale sample collection (modified after; Chandra, 1992).

the Raniganj region (Padhy and Das, 2013). Thermal maturity data on coals surrounding the Barren Measure shale suggest it to be within gas window (Padhy and Das, 2013), making it a potential shale gas target. The qualitative and quantitative aspects of thermal transformation of shale organic matter can provide the much needed information towards determining the presence and properties of hydrocarbons in potential source rocks (Tissot and Welte, 1984; Hunt, 1996; Peters et al., 2005). Geochemical attributes such as organic richness, kerogen type and thermal maturity of sedimentary organic matter are directly related to the hydrocarbon generation potential of a source rock (Peters and Cassa, 1994; Rodriguez and Philp, 2010).

The kinetic parameters for the kerogen decomposition in source rocks provide quantitative estimates on the hydrocarbon generation (Tissot and Welte, 1984; Ungerer et al., 1986; Braun and Burnham, 1987; Tissot et al., 1987; Ungerer and Pelet, 1987; Sweeney et al., 1990; Jarvie, 1991).

In this paper, the abundance, source and maturity of organic matter has been investigated on the drill cores of shale from one of the sub-basins, Jharia, located in the eastern part of Damodar Valley basin to evaluate the hydrocarbon potential. Subsurface Permian shales (320–1050 m) from the Raniganj, Barren Measure and Barakar Formations were subjected to open system pyrolysis using Rock Eval 6. The pyrolysis results were further used to obtain the kinetic parameters associated with the thermal maturation of shale organic matter at varying heating rates (Tissot and Espitalie, 1975; Ungerer and Pelet, 1987). Bulk and compound-specific carbon isotope measurements were performed on selected samples to identify the source of organic matter using closed system pyrolysis. The nature and proportion of organic constituents along with its rank were investigated using organic petrology, and the mineral composition was ascertained by X-ray diffraction. The variation in geochemical parameters in the sedimentary sequences enabled the reconstruction of paleoenvironment and thermal conditions in which the organic rich sediments got preserved and matured, thus providing useful insights onto its generative potential.

2. Geologic setting and stratigraphy

The Gondwana basins occur within the suture zones of the Precambrian cratonic blocks of the Peninsular India along some linear belts. These basins preserve a thick sedimentary pile deposited over nearly 200 million years from the Carboniferous to the Lower Cretaceous (Mukhopadhyay et al., 2010). Occurring along the major river valleys, the basins have been named after the respective rivers flowing through the region. The E–W to WNW–ESE trending Damodar–Koel basin lies along the Damodar river in the Trans-Indian basin belt (Mukhopadhyay et al., 2010). The Jharia sub-basin forms part of the eastern end of the Damodar Valley. The Jharia coalfield is roughly sickle shaped, extending for about 38 km in an east-west direction and a maximum of 18 km in north-south direction with an area of about 456 sq. km (Fig. 1; Chandra, 1992). It is marked by two prominent synforms and three high zones (Chandra, 1992).

The basin is typically bounded by faults that developed along the Precambrian lineaments during deposition, as well as affected by intrabasinal faults indicating fault-controlled synsedimentary subsidence (Chakraborty et al., 2003). The Southern Boundary Fault is the most prominent and runs through the entire southern edge in WSW–ESE direction (Fig. 1). It is marked by a zone of parallel fractures with a stratigraphic throw of about 1800 m towards the north. A number of interbasinal faults having inter- and intra-