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Pore geometrical complexity and fractal facets of Permian shales and coals from Auranga Basin, Jharkhand, India

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ABSTRACT

The pore system is a significant factor for the hydrocarbon generation, storage and production. Several studies had been carried earlier by distinguished researchers on pore system characterization, where little information regarding a thermally immature basin has been discussed so far. To understand these, total fifty-one samples including 41-shales and 10-coals are taken for study from Barakar (L.Sakmarian-Kungurian) Formation of Auranga basin to investigate the pore characteristics of a low mature substance. This work provides information regarding a low mature basin having oil generation potential. For this, authors have carried low pressure N_2 sorption, FE-SEM/EDX with rock eval pyrolysis, total organic carbon (TOC), ash yield, vitrinite reflectance and clay content. The low-pressure N_2 sorption: BET (Brunauer-Emmett-Teller) and BJH (Barrett-Joyner-Halenda) are employed to analyze the pore size, area, geometry and its distribution. Shale samples have shown variation in the specific surface areas (BET) and pore volume from 7.43 to 30.36 m^2/g and 0.019–0.069 cm^3/g respectively; whereas coal samples exhibits these properties ranging from 3.13 to 17.2 m^2/g and 0.08–0.31 cm^3/g respectively. Here, two kinds of desorption curve have been observed: (a) sub-hysteresis types H2′ where rapid desorption (lacking a plateau at high pressure) indicating pipette shaped pore (b) hysteresis type H3 having slow rate of desorption suggesting slit shaped pore. The subtype H2′ i.e. lacking the plateau at high pressure has been distinguished under H2 hysteresis. The dominance of mesopores to macropores are deduced from BJH and presence of micropores were also observed in few samples from t-plot method. The Type II isotherms are observed dominantly in shales and few coal samples (27-shales; 3-coals) whereas Type IV isotherms (13 shales; 7 coals) are mainly noticed in coals and in limited number of shales. Moreover, the total organic carbon (TOC) content of the shale and coal samples ranges from 1.35 to 29.42 wt% and 32.38–63.46 wt% respectively. T_{max} [temperature under S2 to release maximum amount of pyrolyzate from the kerogen under rock eval pyrolysis (REP)] range from 409 to 468 °C and 420–426 °C of shales and coals respectively indicating of immature to early mature stage of the sample. The TOC normalized-BET (BET*) in relation to ash yield exhibits the significance of mineral matter in the shales for pore formation. The relation of pyrolysis parameters (S1and S2) with BET* gives the indication of bitumen retention in the pore spaces of organic matter, which reduces their surface area in coals. Fractal geometry of the samples were also studied. The surface fractal dimensions viz. D_1 ($P/Po = 0.0–0.5$) and D_2 ($P/Po = 0.5–1.0$) both are calculated for the basin. The D_1 (pore surface) varies from 1.9888 to 2.5530 and 1.8190–2.4430 for shales and coals respectively pointing towards surface heterogeneity and ruggedness of the surface favorable for increasing the adsorption capability. However, D_2 (pore structure) for the shales and coals are placed in the range of 2.570–2.759 and 2.6150–2.7530 respectively indicating large heterogeneity of the pore structure causing high capillary condensation that reduces the adsorption ability. The FE-SEM with EDX study supports the analysis of pore structure, characteristics and fractal behaviour of shales and coals.

1. Introduction

The adsorption capability of conventional/unconventional reservoir are controlled by the pore internal surface, size, shape, volume and their distribution. The spectacular success in the exploration of shale gas in United States had encouraged various countries e.g. Canada, Australia, Poland, Argentina, China (Cai and Yu, 2010; Chalmers et al., 2012a; Chen et al., 2017; Curtis et al., 2012a, 2012b; Jiang et al., 2017; Loucks et al., 2012, 2009; Lin et al., 2015, 2017; Yang et al., 2017) towards the analysis of its pore connectivity and network to determine

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the fluid flow and chemical transport depending upon the pore size distribution, quantitative estimation of volume and density distribution of structural pores. The pores are major pathways for the gas diffusion from the matrix to fracture system during production (Cai et al., 2013; Chalmers et al., 2012a, 2012b; Chen et al., 2015; Loucks et al., 2009; Ross and Bustin, 2009, 2008). A well-developed organic pore network have major influence on porosity, permeability and hydrocarbon storage in various shale gas system (Chalmers et al., 2012a; Curtis et al., 2012a, 2012b; Loucks et al., 2012, 2009; Löhr et al., 2015; Milliken et al., 2013; Passey et al., 2010; Slatt and O'Brien, 2011). Hydrocarbon gases derived through biogenic/thermogenic process may be present as a free gas in pores and fractures, as an adsorbed gas on the surface of organic or inorganic composition with a small dissolved amount in water, oil and bitumen (Curtis, 2002; Jarvie et al., 2007). The organically generated pores results due to expulsion of hydrocarbons from the thermal maturation of the kerogen (Curtis et al., 2012a, 2012b; Loucks et al., 2009).

The microstructure of shale or coal both exhibits a high degree of complexity and heterogeneity in them. The pores are present mainly from nanometer to micrometer scale in pore system found in organic matter and inorganic matrix, that governs the gas storage and fluid migration (Bustin et al., 2008; Chalmers and Bustin, 2013; Chalmers et al., 2012a, 2012b; Gasparik et al., 2013, 2012; Zhang et al., 2012). The sorption capacity of any organic entity are dependent on their type, content, associated mineral matter and porosity (Ross and Bustin, 2009). The type, quantity and arrangement of pores are important for assessing the reservoir quality (Loucks et al., 2012; Milliken et al., 2013). Based on physical adsorption capability and capillary condensation various researchers have been classified pores (Clarkson et al., 2012d; Gregg and Sing, 1982; Hodot, 1961; Shi and Durucan, 2005). However, this paper had followed IUPAC classification of pore on the basis of diameter viz. micropore or adsorption pore (< 2 nm), mesopore or transitional pore (2–50 nm) and macropore (> 50 nm) (Rouquerol et al., 1994; Zou et al., 2013).

However, low-pressure N_2 gas adsorption (LP-N_2GA) can only provide open pores gas adsorption and flow. LP-N_2GA can inquest pores mainly in the range of 0.35–300 nm, therefore the study of pores less than 50 nm are more reliable (Vishnyakov et al., 1999). The pore structure are characterized through the ascribed hysteresis recommended by IUPAC in 1984. These hysteresis loops are correlated with various pore shapes as H1, H2, H3 and H4. Moreover, authors have described under H2 hysteresis loop H2 for having plateau and H2′ for lacking plateau at high pressure (P/Po). Several scientists (Bernard et al., 2012b; Curtis et al., 2012a, 2012b; Gu et al., 2015; Jiang et al., 2016; Klaver et al., 2016, 2015, 2012; Li et al., 2015a, 2015b; Tang et al., 2016; Wang et al., 2016a, 2016b, 2016c, 2014,; Zhang et al., 2017; Zhou et al., 2016) had used FE-SEM to characterize the pore shape, size and its distribution for qualitative information. Although, here authors have also applied EDX analysis together with FE-SEM to characterize the mineral composition impact on the pore formation. This causes FE-SEM with EDX to impart distinguishability of the pores and their surface composition. In general organic porosity is acquired with the maturity (Bernard et al., 2012a; Curtis et al., 2012a, 2012b; Loucks et al., 2012) but chances of their restraining is also possible (Fishman et al., 2012; Milliken et al., 2013). The extent to which thermally immature organic matter host pores in them and their influences on the pore development is poorly understood so far (Löhr et al., 2015). Many authors (Hazra et al., 2015; Mendhe et al., 2016, 2015; Varma et al., 2017, 2015a, 2015b) had worked on Indian basin in search of hydrocarbon generation potential, pore connectivity and geometry which are significant factor for the reservoir characterization. This paper imparts the information regarding a low mature basin (Auranga) which has the potential of oil generation (Varma et al., 2018). As per the earlier studies by several researchers, it is observed that organic pores are rarely evident in an early oil window samples compared to late oil window (> 0.9 VRo%) and abundant in gas and over mature samples (Bernard et al., 2012b; Curtis et al., 2012a; Loucks et al., 2012; Milliken et al., 2013; Schieber, 2013). Milliken et al., 2014 had observed for thermally immature organic matter, primary organic feature depending on the type of organic matter (Hunt, 1996) can have the potential to influence the pore development.

Several studies being carried by various eminent scientists on pore characterization of shale gas that can be available on literature (Clarkson et al., 2012d, 2012a; Hu et al., 2017; Josh et al., 2012; Kuila and Prasad, 2013; Wang et al., 2014) gives the insights into the pore system as a complicated phenomenon consisting of various types of shape and size of pores. The study here focused towards the pore network and pore geometry, size, area and volume characterization of shales and coals which are host for hydrocarbon generation in the Auranga basin through LP-N_2GA and SEM/EDX techniques probably for the first time. This study may help in the assessment and development of hydrocarbons from the basin. Here, the investigations provide hint on the factors responsible for the pores formation and their stability in the basin with respect to organic or inorganic content/matter.

2. Geological setting

Auranga basin, lies along the western region of Damodar Valley in Palamu district of Jharkhand province in India. The basin exhibits polycyclic topography with diversity in landforms. The basin is trough-like bounded with Ranchi plateau at South and Hazaribag at North, due to earlier erosion of Permo-Triassic sedimentary rock. The basin were traversed by several number of faults, in which two sets of fault commonly reported one along E-W and other at NW-SE direction (GSI, 1971).

The bird (Kingfisher) shaped (Varma et al., 2016) basin covers an area of 250 sq.km, named after the Auranga river flowing north-westerly by Ball (1880). The basin is bounded by latitude 23° 42′ N to 23°5′ N and longitude 84°18′ E to 84°2′ E falling under the survey of India toposheet nos.73A/9 and 73A/10. The basin was initially surveyed by Ball (1880) which is mapped at a scale of 1: 63,360. In addition, it was resurveyed by Dunn (1928) and Rizvi and Sen (1972) for structural and sedimentological details respectively.

Ball (1880) and Dunn (1928) differentiated the Gondwana sedimentation into Talchir, Barakar, Raniganj and Panchet with Mahadeva Formations as unconformable deposition. The Precambrian basement surrounded the basin from all sides with the Chotanagpur gneissic complex. The Talchir Formation basically occurs as narrow strips in the north and the south of basin. The Barakar Formation has deposition of coal, shale and carbonaceous shale in the northern and the south eastern region of the basin, considered for potential interest. The gross lithology of the formation has gray to grayish white, fine to coarse grained, cross-bedded and laminated arkosic sandstone, pebble beds, conglomerate and gray to carbonaceous shale, coal seams and fire clays (Das, 1978). The Barren Measures are noticed only in the north eastern zone, where it is completely devoid of coal but having medium to coarse grained sandstone, carbonaceous shale and ironstone band. The Raniganj Formation is well exposed in the eastern part and a small area of it is recorded in the western part. The study of shale-sandstone ratio gives deepness of the basin is towards the east. The Panchet Formation having lithology of medium to coarse grained feldspathic, greenish to yellow green, purple sandstone with brown and chocolate shale similar to Barakar Formation (Das, 1978). This study emphasized on the borehole samples from Rajbar (B#1 & B#2) and Banhardi (B#3 & B#4) village belonging to Barakar Formation. The geological map, detailed locations of the boreholes are shown in Fig. 1 with generalized stratigraphic succession.