

Chapter 7: Resume

The fluctuating oil price, high input cost in exploration and production of hydrocarbons and the relative abundance of natural gas resources have changed the bearing towards unconventional shale gas exploration. India has the immense potential of unconventional natural gas resources i.e. coal bed methane (CBM), tight gas, shale gas, etc (Mishra, 2009; Mani et al, 2014; Varma et al, 2015; Baruah and Ganapathi, 2015). Commercial exploration of these resources can effectively make the natural gas curve more elastic. Over viewing all previous literatures of shale gas and its prospects in Indian sedimentary basins, the author has oriented the research target towards the Barren Measures Formation of Raniganj Field to know its gas potential and possibility of future exploration. This study is an effort to highlight the mineral composition, organic richness, maturity, gas generation potential, fluid flow mechanism, including pore system and fabric anisotropy study at different scales in order to assess the reservoir quality of Barren Measures shale. Integrated studies were aimed to understand mineralogical, geochemical and petrophysical factors of Barren Measures shale to validate shale gas prospects in Raniganj Field. The study area is located between latitudes 23°46'00" N & 23°43'00" N and longitudes 86° 52' 00"E & 86°55' 30" E, covered by the Survey of India toposheet no. 73I/13 & 73I/14. Field study was carried out along the exposed section of Barren Measures Formation in Chalbapur-Mahishmura areas. A total of 13 borehole lithologs were aided to the litholog correlation and to depict the subsurface geology of the study area. Cores of four boreholes (B#1, B#2, B#3, and B #4) were studied, litho units were identified, and laboratory investigations were carried out.

The Barren Measures Formation overlies the Barakar Formation with gradational contact, comprised of mainly shale, sandy shale, and thin ironstone band with sand and shale intercalation at the base. The thickness of the formation ranges from 80m to 339 m in the study area. The thickness increases towards South South East (SSE) direction. The different litho units of Barren Measures Formation are medium to fine grain sandstone; black carbonaceous shale, sandy shale, siltstone; clay/ironstone band; intercalation of sandstone and shale.

The formation is grey to black in colour, laminated to blocky, fissile to hard massive. Based on the megascopic and microscopic studies of Barren Measures shale, distinct litho- units were identified i.e. black carbonaceous shale, grey to black carbonaceous silty shale, Fe rich claystone

The Barren Measures shale is composed of quartz (49.027%), albite (6.199%), pyrite (1.00%), pyrolusite (2.09%), muscovite (1.66%), pyrrhotite (2.22%) and siderite (5.14%). The clay minerals are clinochlore Ferroan 23.47%, illite 4.74%, kaolinite 2.09%. Presence of fine grain pyrite indicates the anoxic condition of sedimentary deposition which suggests high organic content. The quartz grains are of silt size grading into fine sand, sub rounded to well-rounded and well sorted. This may reveal a slow burial of the sediments during the time of deposition in lakes with prevailing anoxic conditions which leads to preservation of carbon and carbon compounds. Presence of high quantity of silica minerals indicates the brittleness nature of the shale. The presence of sub rounded to well-rounded quartz grain in the shale units indicates a long distance of transport and/or sources of multiple cycles.

The Barren Measures shale is rich in organic content with TOC values ranges from minimum 3.75% to 20.9 %. The average organic content of Barren Measures shale samples is 9.98%. The productivity index of studied samples shows a range from 0.06 to 0.24. The average generation potential of the studied samples is 9.54 mg HC/g Rock varying from 2.9 to 20.33

mg HC/g Rock. It is observed that the samples of Barren Measures shale have the HI ranging from 58.45 to 125.34 mg HC/g Rock with an average HI of 80.56 mg HC/ g Rock. The Barren Measures studied samples are showing the maturity range of 0.6-1.0%, deposited mainly in anoxic condition. The shale has very good source rock generative potential and have obtained thermal maturity levels equivalent to the oil window. The main generation product is gas as the organic matters are derived from terrestrial plants and non-marine algal matter. The shale is having gas generation potential and may be good prospect for shale gas exploration. As the maturity is found to be increased linearly with respect to depth, the gas window can be expected at the depth of greater than 400m. So shale gas exploration strategies should focus considering the depth factor.

To evaluate the reservoir quality of the shale, the total porosity, pore system, permeability and adsorb gas analysis were carried out. The helium porosimetry results average 0.633% and 0.135 md porosity and permeability respectively. Based on SEM images the pores systems of Barren Measures shale were classified as: (a) intergranular pores; (b) intragranular pores; (c) secondary pores developed due to diagenesis, dissolution activities etc., (d) matrix pores, (e) pores associated with organic matter, and (f) fracture pores. Organic flakes (compressed wood chips, leaf fragments, etc.) are observed lying parallel to bedding. A range of 3-5% porosity was computed from Microcomputer Tomography. Micro-fractures of varied dimension were identified in the tomograms and segmented image. The different types of pores observed in the images can be classifies into three groups: (a) relatively large size poorly connected pores; (b) large pores connected by very thin conduits; (c) isolated micro pores. The images show that the samples are moderate to well sorted, grains are sub rounded to rounded which indicate the maturity of the sediments and long distance of transport. The extensive laboratory experiments result that the rock is tight, low permeable, highly heterogeneous; moderate to well sorted with poor to moderate reservoir quality. The shale has

complex pore structure and multi scale pore dimensions. The nano pores of different shaped and size (ranges from 10nm to 500nm) were identified using Transmission Electron Microscope images. The BET analysis results surface area of the shale 11.75m²/g to 15.11 m²/g, with 0.1 cc/g to 21 cc/g adsorbed gas content where pore throat diameters are of 4 to 60nm.

Moreover, the increasing maturity trend with respect to depth implies the geological control on both sediment deposition and thermal history of the basin. Post depositional tectonic upliftment and thermal maturation indicates a south eastward increasing trend of maturity level. However, the tectonic history of the Raniganj Basin indicates deeper burial of the Barren Measures shale as compared to present day depth, which was rifted during Permian–Triassic. It also supposes the presence of peak gas generation window zone of Barren Measures towards South - South- East part of the field at structurally depocentres.

The Barren Measures shale properties are identical to most of the US commercial gas shales, especially Antrim shale of Michigan Basin and also New Albany shale of Southern Indiana and Northern Kentucky. Comparing the Barren Measures Rock Eval data to some other analogue data of commercially gas producing shale plays has induced confidence in the shale gas resource prognosis of the Raniganj Field. Furthermore, the brittle nature of Barren Measures and micro scale fabric heterogeneity will help stimulate the development of variable fractures and make the shale susceptible for multistage hydro fracturing.

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