Organic Geochemistry of Permian Black Shales of Raniganj Coal Field, India

Annapurna Boruah[1]*, M. Abdul Rasheed[2] and S. Ganapathi[3]

[1] University of Petroleum and Energy Studies, Dehradun
[2]Gujarat Energy Research and Management Institute, Gandhinagar
[3]ITM Universe, Vadodara

**Corresponding author:*
Dr Annapurna Boruah
Assistant Professor (SS)
Department of Petroleum engineering and earth sciences, UPES-248007Email: aboruah@ddn.upes.ac.in

Abstract

In this study, core samples of Permian shales of Raniganj field were analysed to evaluate their gas generation potential using Rock Eval pyrolysis techniques. The Total Organic Content (TOC) of the shale units of Barakar, Barren Measures and Raniganj Formations ranges from 3.75 wt% to 20.9 wt% whereas hydrogen index (HI) ranges from 58.45 to 125.34 mg HC/g TOC. Present study suggests early to late maturated (0.6 to 1%) organic matters in Barren Measures with gas prone type III kerogen. The study investigates the effect of burial history on the preservation and maturation of organic matters. The organic richness, kerogen type and thermal maturity the Permian shales are signifying fair to excellent gas generation potential.

Keywords: Shale gas, Rock-Eval pyrolysis, Kerogen, Ranigunj

Introduction

The current boom in the exploration and development of shale gas resources in The United States of America (Curtis 2002; Montgomery *et al* 2005; Jarvie 2007; Ross and Bustin 2007) has created interest in the assessment of shale gas resource potential of India. The Indian sedimentary basins have vast potential of shale gas resources. The Permian shales of

Raniganj field are considered as the most prospective shale gas plays of India (Misra 2009; Varma *et al* 2014).

Geological Setting

Raniganj field is the easternmost depository within the Damodar Basin, a typical half-grabben type E-W trending and westerly plunging synform. Depositional environment of the field is mainly terrestrial (fluvial and lacustrine) with local marine transgressions during the Sakmarian –Artinskian period (Ghosh 2002; Chakraborty et al 2003). The stratigraphy is signified by Talchir Formation (glaciogenic) of early Permian age at the base, overlying the Pre- Cambrian metamorphic rocks unconformably. The Barakar and Raniganj Formations are overlaying the Talchir deposits. The Barakar Formation is characterized by conglomerate, light grey to light yellowish/ brownish, gritty to pebbly, arkosic to sub-arkosic, cross-bedded sandstone and siltstone, interbedded with grey/black shale and thick coal seams (Casshyap and Tewari 1988). The Barren Measures Formation is sandwiched between Barakar and Raniganj Formation, fluvial–lacustrine origin and devoid of coal (Dasgupta 2005; Murthy *et al* 2010). The alluvial deposit of the Panchet Formation is also barren of coal and it overlies the Raniganj Formation. The Barren Measures of Permian age is recognized as the shale gas prospective horizon based on thickness (>1000m), areal extent and higher content (>2%) of organic matter (Varma *et al* 2014; Varma *et al* 2015). Thickness of Barren Measures Formation ranges from 91m to 330m in the study area. However, thickness is more (750-850m) towards the southern margin as compared to the northern margin and best developed (>1000m) in the depressions (Durgapur and Raniganj Depressions) of Raniganj field (ONGC 2010).

This paper presents the gas generation potential of Permian shales including Barakar, Barren Measures and Raniganj shales of Raniganj field, and also discusses the key geological factors and processes in order to identify prospective shale gas fairway over Raniganj field.

Methodology

The Total Organic Content (TOC) was determined by using LECO EC-12 carbon analyser. Rock-Eval pyrolysis technique has been used to determine the petroleum potential and the thermal maturity of the kerogen occurring in a rock. The hydrocarbon generation potential of Barren Measures shale samples was assessed using the Rock Eval 6 pyrolyser (Turbo version-Vinci Technologies). The calculated parameters of Rock Eval i.e. the hydrocarbon potential or hydrogen index (HI) is defined by 100 × S2/TOC. The oxygen index (OI) is defined as 100 × S3/TOC, where S3 is the CO_2 released during the pyrolysis. Both the measured and calculated parameters from Rock Eval pyrolysis, helps in determination of kerogen type, hydrocarbon generation efficiency and maturation. The hydrocarbon generation and maturation processes are highly controlled by time, temperature, pressure, depth of burial etc. Therefore, the experimental temperatures were set comparatively higher than normal subsurface conditions, so that appreciable reaction for the generation of hydrocarbons can occur in a reasonably short time and amount of generated hydrocarbons relative to the total potential of the source rock can be estimated.

Results and discussion

The dark grey to black colour of the studied shale samples from Barakar, Barren Measures and Raniganj Formations indicate high content of organic matter. The laboratory measured TOC value ranges from 3.75 wt. % to 20.9 wt. %. In this study, the original TOC (TOC_O) is calculated and found to be deviation from the present day TOC (TOC_P) content ($TOC_P/0.64 = TOC_O$) i.e higher than present day TOC (Jarvie and Lundell 1991). However, the black

colour and high measures TOC wt % indicated the deposition of the shales in anoxic environment. The PI of studied samples shows a range of 0.06 to 0.24mg HC/ g TOC and indicates in situ petroleum generation (Peters & Moldowan 1993) of matured sediments. Generally, the commercial gas shale producing horizons show PI values ranges from 0.6 to 1.5, where shales with greater than 0.1 PI can generate excellent quantity of hydrocarbon (Ross and Bustin 2008). It is observed that the samples of Barren Measures shale have the HI ranging from 58.45 to 125.34 mg HC/g TOC with an average HI of 80.56 mg HC/ g Rock. Low HI (<125.34 mg HC/g TOC) designates a greater potential to generate gaseous hydrocarbon (Boyer *et al* 2006). The original S2 and original HI were determined using the mathematical equations (Espitalie *et al* 1986; Peter 1985; Jarvie *et al* 2004; Peters *et al* 2005; Jarvie *et al* 2007). The original generation potential (original S2 mg hydrocarbons / g rock) of studied sample is calculated numerically i.e. original S2=TOC change / 0.083 + present S2. The original S2 values ranges from 5.11 to 32.6 mgHC/g rock. Thus original HI value is calculated using the equation Original HI = Original S2 / Original TOC x 100 (Jarvie 2004; Jarvie *et al* 2007). The studied samples show original HI value of 80.78 to 138 mg HC/g TOC. OI value ranges from 1.50 to 22.66 mg CO_2/g TOC with an average of 7.13 mg CO_2/g TOC. The cross plot between HI and OI of samples (Figure1) denotes the presence of type III, gas prone kerogen (Van Krevelen 1961; Hunt 1995). HI versus Tmax cross plot was analysed for kerogen type determination (Hunt, 1995) and presence of type III kerogen was identified (Figure 2). The plot of TOC versus S2 visualizes gas prone organic matter, capable in producing mainly gas which is derived from humic and continental higher plants (Tissot *et al* 1984; Tissot and Welte 1984; Slatt and Rodriguez, 2012).

According to Espitalie *et al* (1986), for Type III organic matter, a Tmax of 434ºC is the boundary between immature and mature kerogen (oil production zone) whereas a Tmax of 465ºC as the boundary between mature and over-mature kerogen (gas-production zone).

Analysis of all the crucial Rock-Eval parameters (HI, OI and Tmax) refers early to late maturity level of the shales. Since Tmax obtained from Rock-Eval pyrolysis indicates the level of thermal maturity, it is possible to convert Tmax to Ro (Dembicki 2009). The conversion can be mathematically expressed as Ro (calculated) = (0.018) (Tmax) – 7.16 (Jarvie *et al* 2001; Jarvie 2007). The samples are showing the maturity range of 0.6-1.0%. The highly matured sediments of catagenesis stage at shallow depth, where increasing maturity trend with respect to depth, implies the geological control on both sediment deposition and thermal maturation. It also supports the presence of dry gas generation window of Barren Measures towards south- east part of the field at structurally depocentres.

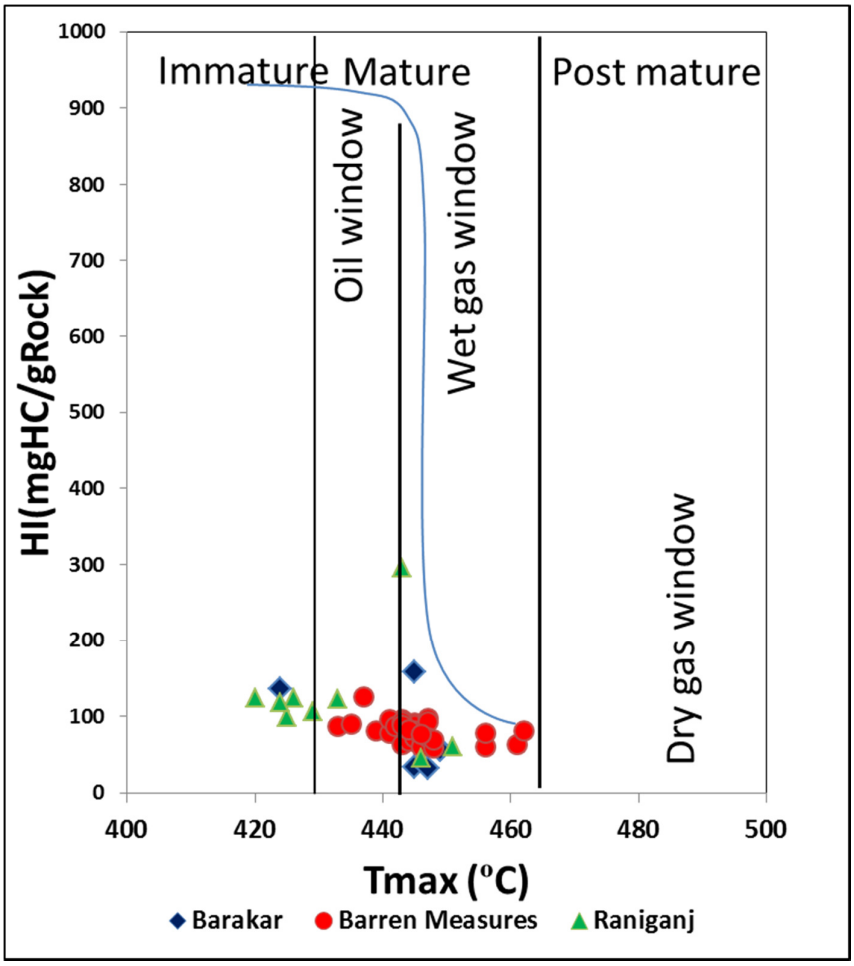

Fig.1: plot of HI vs Tmax

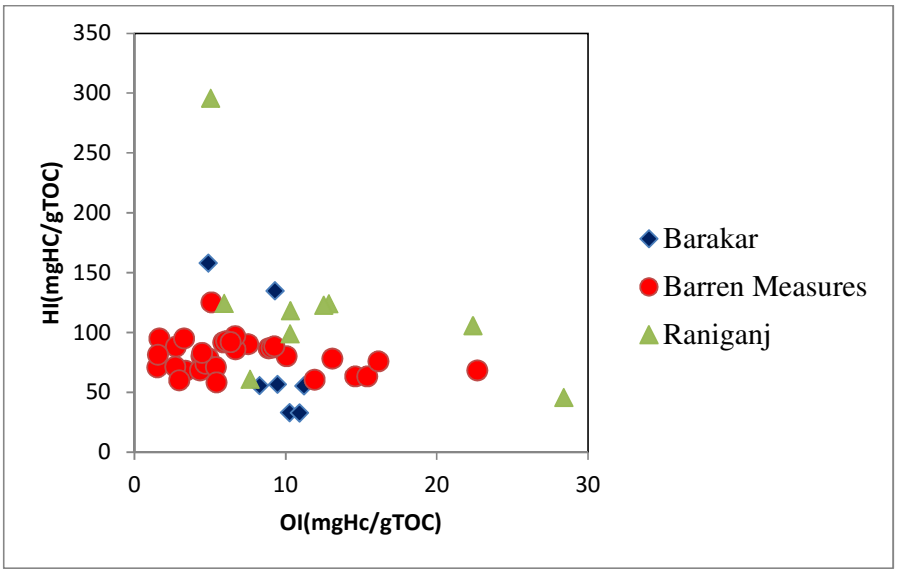

Fig.2: plot of OI vs HI

5. Conclusion

Organic geochemistry analyses suggest the organic richness of Permian black shales in Raniganj Field and consist of mainly Kerogen type III, deposited in anoxic condition and matured comparatively at shallower depth. The thermal maturity of the shales is controlled by the burial history of the sediments. Comparatively, the Barren Measures may have excellent prospects for shale gas exploration if the exploration strategies are focused considering the depth factor. In general, based on the thermal maturity trend i.e. increasing with respect to depth, the deepest and thickest shale sections of the sediments, will have the most favorable conditions for hydrocarbon generation prospectivity.

References

- Barker C 1974 Pyrolysis techniques for source-rock evaluation; *Am. Assoc. Petrol. Geol. Bull.* 58(11) 2349-2361.

- Boyer C, Rivera R S *et al* 2006 Producing Gas from its Source; Oil Field Review, Autumn 36- 49.

- Bowker K A 2003 Recent developments of the Barnett Shale play, Fort Worth Basin; *West Texas Geological Society Bulletin* 42 4– 11
- Casshyap S M, Tewari R C 1988 Depositional models and tectonic evolution of Gondwana basins of Peninsular India; *The Palaeobotanist* 36 59–66.
- Chakraborty C, Ghosh S K, Chakraborty T 2003 Depositional record of tidal-flat sedimentation in the Permian Coal Measures of Central India, Barakar Formation, Mohpani Coalfield, Satpura Gondwana Basin; *Gondwana Research* 6 (4) 817–827.
- Curtis J B 2002 Fractured Shale-Gas Systems; *Am. Assoc. Petrol. Geol. Bull.* 85 (11) 1921–1938.
- Dasgupta P 2005 Facies pattern of the middle Permian Barren Measures Formation, Jharia basin, India: The sedimentary response to basin tectonics; *J. Earth Syst. Sci*. 114 (3) 287- 302.
- Espitalie J 1986 Use of Tmax as a maturation index for different types of organic matter, Comparison with vitrinite reflectance. In: Thermal modelling in sedimentary basins; *Burrus, J. Editions Technip*, Paris 475-496.
- Ghosh S C 2002 The Raniganj Coal Basin: an example of an Indian Gondwana rift; *Sedimentary Geology* 147 155– 176.
- Gupta A 1999 Early Permian palaeoenvironmental in Damodar Valley Coalfields, India: an overview; *Gondwana Research* 2 149–165.
- Hunt John M 1995 Petroleum Geochemistry and Geology (Second Edition); *W. H. Freeman and Company*, New York.
- Jarvie D M, Lundell L L 1991 Hydrocarbon Generation Modelling of Naturally and Artificially Matured Barnett Shale, Fort Worth Basin, Texas; *Southwest Regional Geochemistry Meeting*, Texas, Sept. 8–9.
- Jarvie D M, Brenda L C, Floyd H, and John T B 2001 Oil and Shale Gas from the Barnett Shale, Ft. Worth Basin, Texas; AAPG National Convention, June 3-6, 2001, Denver, CO, *Am. Assoc. Petrol. Geol. Bull.* 85 (13)
- Jarvie D M, R J Hill, T E Ruble and R M Pollastro 2007 Unconventional Shale-Gas Systems: The Mississippian Barnett Shale of North-Central Texas as one Model for Thermogenic Shale-Gas Assessment; *Am. Assoc. Petrol. Geol. Bull*. 91(4) 475-499.
- Mishra R 2009 Cambay Shale: the Potential Barnett of India; *ONGC bulletin* 61-68.
- Tissot B P and Welte D H 1984 Petroleum Formation and occurrence: A new approach to oil and gas exploration; 2nd ed*.: Springer Verlag*, Berlin 150-169.

- Varma A K., Hazra B, Srivastava A, 2014 Estimation of total organic carbon in shales through color manifestations; *J. Nat. Gas Sci. Eng.* 18, 53-57.
- Varma A K et al 2015 Assessment of organic richness and hydrocarbon generation potential of Raniganj basin shales, West Bengal, India; *Marine and Petroleum Geology* 59 480-490.
- Veevers J J, Tewari R C 1995 Gondwana master basin of Peninsular India—between Tethys and the interior of the Gondwanaland-Province of Pangea; *Memoirs of Geological Society of America* 187, 1–73.