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

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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, Raniganj

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 $100 \times \frac{S2}{TOC}$. The oxygen index (OI) is defined as $100 \times \frac{S3}{TOC}$, 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 ($\frac{TOC_p}{0.64}$ =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 0.24 mg 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 CO2/g TOC with an average of 7.13 mg CO2/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](image)
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.

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