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Source Rock Evaluation of wells from a NELP-VI Block, KG Basin (OIL as operator)

Abstract

The study area is confined to a NELP Block, KG Basin (OIL as operator), situated in the East Godavari sub-basin. Eight (8) exploratory wells have been drilled through this block in order to probe the hydrocarbon prospects of the area. Since the presence of source rock is an important component of the petroleum system, a detailed systematic study of source rock potential was carried out by analysing known source rock intervals in few of the wells. On the basis of Source Rock evaluation of the three (3) studied wells from Krishna Godavari Basin, three different source rocks are envisaged in East Godavari sub-basin area: mature oil/gas prone Type II/III organic matter; over-matured dry gas prone Type III organic matter and barely mature Type III gas prone organic matter.

Keywords: East-Godavari Basin, source rock potential, Rock-Eval pyrolysis, geochemical analyses

Introduction

The study of source rocks is an important step towards accurate assessment of the hydrocarbon source potential of sedimentary rocks.The determination of the most favourable petroleum exploration targets depends on the geochemical knowledge of source rocks and on the knowledge of generation, migration and accumulation processes combined with the geophysical and geological features of the sedimentary basin under evaluation. Most petroleum hydrocarbons are generated from kerogen, which generally occurs finely disseminated in fine grained sedimentary rocks (Hunt, 1972). The inherent potential of a kerogen to generate crude oil or gas depends on its type, which in turn depends on the chemical nature of the materials forming the kerogen. Rock-Eval pyrolysis is one of the most widespread analytical technique used for the estimation of the organic matter content in sediments and provides the basic quantitative data for further geochemical analyses. It enables the rapid screening of sediment samples, without the tedious preliminary kerogen isolation, and the reliable estimation of the organic content. In the present study the source rocks have been characterized primarily by utilizing this technique.

Geological Setting

Krishna-Godavari is a peri-cratonic basin, located in the central part of the eastern passive continental margin of India. The structural trend of the basin is NE-SW. It includes the deltaic plains of the Krishna and Godavari rivers and the inter-deltaic regions. Geographically, the basin lies in between north of Kakinada in the NE and Ongole in the SW. Tectonically, the basin is divided into three sub-basins (Krishna, West Godavari & East Godavari Sub basins) by a series of fault-controlled ridges (Fig. 1). The block under the present study is situated in the East Godavari sub basin which is separated by Tanuku horst from west Godavari sub-basin extending up to Pithapuram cross trend towards the N-E side. Eight (8) exploratory wells have been drilled by Oil India Limited through this part of the basin in order to probe the hydrocarbon prospects of the area. The stratigraphic succession expected in the block is shown in Fig.1.

Experimental Details

Drill-cutting samples recovered from the various litho-stratigraphic horizons encountered in the three (3) studied wells were acquired for source rock analyses in the R & D geochemical laboratories of Oil India Limited. Hand-picked shale samples were subjected to Rock-Eval pyrolysis using Rock-Eval6 (Make: Vinci Technologies, France) following the procedure of Espitalie *et al*. (1985a, 1985b, 1986).These

samples were cleaned to remove mud and other contaminants, air dried and crushed.The parameters determined during the analyses are TOC (wt.%) content, S1 (mg HC/g Rock, amount of free hydrocarbons in the sample), S2 (mg HC/g Rock, hydrocarbon generated during pyrolytic degradation of organic matter during the temperature range of 300-550°C), S3 (mg CO_2/g Rock, amounts of CO_2 produced during pyrolysis and indicates amount of oxygen in organic matters), T_{max} (temperature in °C, at which the maximum release of hydrocarbons from decomposition of organic matter occurs during pyrolysis).The secondary parameters calculated from the pyrolysis data are hydrogen index (HI = S2*100/TOC) and oxygen index (OI = S3*100/TOC).

Results and Discussion:

The geochemical log of the Source Rock parameters versus depth of the studied wells are summarised in Fig. 2, Fig. 3 and Fig. 4. The statistical summary of results is given in Table 2. A plot of Hydrogen Index (HI) versus Oxygen Index (OI) of all the three (3) studied wells plotted in a modified Van-Krevelen diagram is shown in Fig. 5 and a plot of Tmax versus HI is shown in Fig. 6. This is to minimize the influence of "matrix effect" which can substantially lower HI values as compared with that of isolated kerogen for samples with low TOC values (< 1%) (Espitalie *et. al.,* 1984).

Well A

Raghavapuram Shale:

Organic Richness and Hydrocarbon Generation Potential: The Rock-Eval analyses show that the TOC of Raghavapuram shale is less than 2.12 % with an average of 1.3% (Fig. 2, Table 1). The shale throughout this formation is organically lean. The remaining hydrocarbon potential of Raghavapuram shale is less than 3.27 mg HC/g of rock with an average of 1.74 mg HC/g of rock implying that the shale can be classified as a fair source rock.

Organic Matter Type: The Hydrogen Index (HI) for Raghavapuran Shale is less than 192 mg Hc/g TOC with an average of 128.5 mg/g TOC. The Oxygen Index (OI) is high upto 350 mg CO_2/g TOC. The HI value decreases gradually from about 190 mg HC/g TOC to about 80mg HC/g of TOC with increasing depth.A plot of HI versus OI in a modified Van Krevelen diagram is composed of Type III organic matter (Fig. 5) which is gas prone. The HI-Tmax plot of Raghavapuram shale (Fig. 6) shows that it is composed dominantly of Type III organic matter of gas prone.

Thermal Maturity: The maturity parameter Tmax range between 434ºC and 446ºC (Fig. 2) which show that the Raghavapuram shale have barely entered into early mature oil window.

Kommuguden Shale:

Organic Richness and Hydrocarbon Generation Potential: The Rock-Eval analyses show that the TOC of Kommuguden shale ranges from 1.70-33.8 % with an average of 20.12% (Fig. 2, Table 1). The shale throughout this formation is organically rich. The remaining hydrocarbon potential of Kommuguden shale ranges from 1.42-73.26 mg HC/g of rock with an average of 33.78 mg HC/g of rock implying that the shale can be classified as an excellent source rock. However, this formation is dominated by presence of intermittent coaly layers.

Organic Matter Type: The HI for Kommuguden Shale is less than 227 mg Hc/g TOC with an average of 157.85 mg/g TOC. The OI is very low ranging from 4-159 mg CO_2/g TOC. A plot of HI versus OI in a modified Van Krevelen diagram is composed of mainly Type II/III oil/gas prone organic matter (Fig. 5). The HI-Tmax plot of Kommuguden shale also shows that the samples are dominantly composed of Type II/III oil/gas prone organic matter. Moreover, the values of HI decreases with depths indicating that at shallower depths the predominant kerogen is Type II and with increase in depth the predominance changes towards gas prone Type III organic matter.

Thermal Maturity: The maturity parameter Tmax range between 439ºC and 484ºC (Fig. 2). With depth the Tmax values increases in a regular trend indicating increase in thermal maturation with depth. Thus the shale within this formation has two different thermal maturity trends. The shale have entered in oil window

with Tmax in range 439-460°C at shallower depth (2869-3286m) but as the depth increases (3331-3477m) it converts into gas zone with Tmax ranging from 466-484°C.

Draksharama Shale:

Organic Richness and Hydrocarbon Generation Potential: The Rock-Eval analyses show that the TOC of Draksharama shale ranges from 3.82-33.29 % with an average of 23.20 % (Fig. 2, Table 1). The shale throughout this formation is organically rich. The remaining hydrocarbon potential of Draksharama shale ranges from 3.90-31.94 mg HC/g of rock with an average of 19.82 mg HC/g of rock implying that the shale can be classified as an excellent source rock.

Organic Matter Type: The HI for Draksharama Shale is less than 105 mg Hc/g TOC with an average of 85.03 mg/g TOC. The OI is very low ranging from 2-17 mg CO_2/g TOC. A plot of HI versus OI in a modified Van Krevelen diagram is composed of mostly gas/condensate prone Type III organic matter (Fig. 5). The HI-Tmax plot of Draksharama shale shows that it is composed dominantly of Type III gas prone organic matter (Fig. 6).

Thermal Maturity: The maturity parameter Tmax range between 469ºC and 489ºC (Fig. 2) which show that the Draksharama shale are in the post mature or dry gas zone. The hydrocarbon already generated and not yet expelled from the shale (S1) are less than approximately 2.1 mg HC/g of rock with an average of 0.77 mg HC/g which indicates that most of the generated hydrocarbon have already been expelled from the source rock.

Well B

Raghavapuram Shale:

Organic Richness and Hydrocarbon Generation Potential: The Rock-Eval analyses show that the TOC of Raghavapuram shale ranges from 1.39 % to 31.16 % with an average of 10.73% (Fig. 3, Table 1). The shale throughout this formation is organically rich. The remaining hydrocarbon potential of Raghavapuram shale is ranges from 69.97 mg HC/g of rock with an average of 20.04 mg HC/g of rock implying that the shale can be classified as an excellent source rock.

Organic Matter Type: The HI for Raghavapuran Shale is less than 268 mg Hc/g TOC with an average of 153 mg/g TOC. The OI is very low upto 41 mg CO_2/g TOC. A plot of HI versus OI in a modified Van Krevelen diagram (Fig. 5) is composed of mostly Type II/III oil/gas prone organic matter. The HI-Tmax plot of Raghavapuram shale shows that it is composed dominantly of oil/gas prone Type II/III organic matter (Fig. 6).

Thermal Maturity: The maturity parameter Tmax range between 440ºC and 459ºC (Fig. 3) which show that the Raghavapuram shale has entered into mature oil window. With depth the Tmax values increases in a regular trend indicating increase in thermal maturation with depth. Thus the shale have entered in early oil window at shallower depth (2350-3270m) but as the depth increases it falls under mature oil window (3310-3470m).

Kommuguden shale:

Organic Richness and Hydrocarbon Generation Potential: The Rock-Eval analyses show that the TOC of Kommuguden shale ranges from 4.82 % to 28.90 % with an average of 16.95 % (Fig. 3, Table 1). The shale throughout this formation are organically rich. The remaining hydrocarbon potential ranges from 5.17-41.31mg HC/g of rock with an average of 25.13 mg HC/g of rock implying that the shale can be classified as an excellent source rock.

Organic Matter Type: The HI for Kommuguden Shale is less than 159 mg Hc/g TOC with an average of 137.75 mg/g TOC. The OI is very low upto 18 mg CO_2/g TOC. A plot of HI versus OI in a modified Van Krevelen diagram is composed of mostly Type II/III oil/gas prone organic matter (Fig. 5). HI-Tmax plot of Kommuguden shale shows that it is composed dominantly of Type III gas prone organic matter (Fig. 6).

Thermal Maturity: The maturity parameter Tmax range between 456ºC and 462ºC which show that the Kommuguden shale falls in mature oil window with transition from oil to gas zone.

Well C

Vadaparru Shales:

Organic Richness and Hydrocarbon Generation Potential: The Rock-Eval analyses show that the TOC of Vadaparru shale ranges from 1.17 % to 4.34 % with an average of 2.56% (Fig. 4, Table 1). Organically rich shale are present in shallower section (1650 to 2060m) with mean 3.50% TOC while shale in deeper section (2240 to 2330m) are relatively leaner with mean 1.62% TOC. The remaining hydrocarbon potential of Vadaparru shale is less than 0.57 to 5.26 mg HC/g of rock with an average of 2.73mg HC/g of rock implying that the shale can be classified as a fair source rock.

Organic Matter Type: The HI for Vadaparru Shale is less than 151 mg Hc/g TOC with an average of 96.8 mg/g TOC. The OI is very low up to 67 mg CO_2/g TOC. A plot of HI versus OI in a modified Van Krevelen diagram is composed of mostly Type III organic matter (Fig. 5) which is gas prone. The HI-Tmax plot (Fig. 6) of Vadaparru shale shows that it is composed dominantly of Type III organic matter of gas prone. The HI for Vadaparru shale has decreased from about 151 mg HC/g TOC to about 38 mg HC/g of TOC with increasing depth.

Thermal Maturity: The maturity parameter Tmax range between 430ºC and 437ºC (Fig. 4) which show that the Vadaparru shale have barely entered into early oil window.

Palakollu Shales:

Organic Richness and Hydrocarbon Generation Potential: The Rock-Eval analyses show that the TOC of Palakollu shale ranges from 1.02 % to 4.42 % with an average of 1.62% (Fig. 4, Table 1). The remaining hydrocarbon potential of Palakollu shale is less than 0.50 to 1.72 mg HC/g of rock with an average of 1.03 mg HC/g of rock implying that the shale can be classified as a poor source rock.

Organic Matter Type: The Hydrogen Index (HI) for Palakollu Shale is less than 88 mg Hc/g TOC with an average of 64.5 mg/g TOC. The Oxygen Index (OI) is very low upto 81 mg CO_2/g TOC. Since none of the samples had TOC >1% no further study was done on samples from this formation.

Thermal Maturity: The maturity parameter Tmax range between 434ºC and 438ºC (Fig. 4) which show that the Palakollu shale have barely entered into early oil window.

Chintalapalli Shale:

Organic Richness and Hydrocarbon Generation Potential: The Rock-Eval analyses show that the TOC of Chintalapalli shale ranges from 0.68% to 2.29 % with an average of 1.21% (Fig. 4, Table 1). The remaining hydrocarbon potential of Chintalapalli shale is less than 1.77 mg HC/g of rock with an average of 0.80 mg HC/g of rock implying that the shale can be classified as a poor source rock.

Organic Matter Type: The HI for Chintalapalli Shale is less than 102 mg Hc/g TOC with an average of 65.71 mg/g TOC. The OI is very low upto 90 mg CO_2/g TOC. Since none of the samples had TOC >1% no further study was done on samples from this formation.

Thermal Maturity: The maturity parameter Tmax range between 431ºC and 439ºC (Fig. 4) which show that the Chintalapalli shale have barely entered into early oil window.

Conclusions:

On the basis of Source Rock evaluation of the three (3) studied wells from Krishna Godavari Basin, three different source rocks are envisaged in East Godavari sub-basin area:

- Mature oil/gas prone Type II/III organic matter
- Over-matured dry gas prone Type III organic matter
- Barely mature Type III gas prone organic matter.

In view of the above, further geo-mechanical studies may be carried out to evaluate the potential for exploiting shale gas in this area.

Acknowledgement:

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Table 1: Summary of statistical parameters of Rock-Eval analysis

Well	Formation Depth(m)	S2 (mg/g TOC)	TOC %	Tmax (ºC)	HI (mg/g TOC)	OI (mg/g TOC)
		Min-Max (Avg.)	Min-Max (Avg.)	Min-Max	Min-Max (Avg.)	Min-Max
Well A	Raghavapuram (1845-2867)	0.46-3.27 (1.74)	0.52-2.12 (1.3)	434-446	79-192 (129)	90-350
	Kommuguden (2867-3478)	1.42-73.26 (33.78)	1.70-33.8 (20.12)	439-484	50-227 (157.85)	4-159
	Draksharama (3478-3660)	3.90-31.94 (19.82)	3.82-33.29 (23.20)	469-489	50-185 (85.03)	2-17
Well B	Raghavapuram (2300-3470)	1.22-69.97 (20.04)	1.39-31.16 (10.73)	440-459	88-268 (153)	4-41
	Kommuguden (3480-3843)	5.17-41.31 (25.13)	4.82-28.90 (16.95)	456-462	107-159	4-18
Well C	Vadaparru (1473-2334)	0.57-5.26 (2.73)	1.17-4.34 (2.56)	430-437	38-151 (96.8)	35-67
	Palakollu (2334-2857)	0.50-1.72 (1.03)	1.02-4.42 (1.62)	434-438	28-88 (64.5)	17-81
	Chintalapalli (2857-3278)	0.37-1.77 (0.80)	0.68-2.29 (1.21)	431-439	47-102 (65.71)	30-90

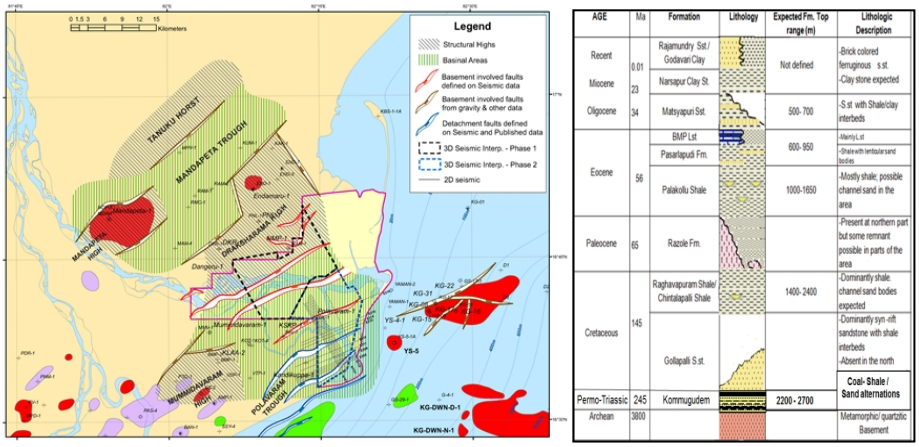

Fig.1: Map showing Structural Setting of the Block and generalised Stratigraphy of the Block.

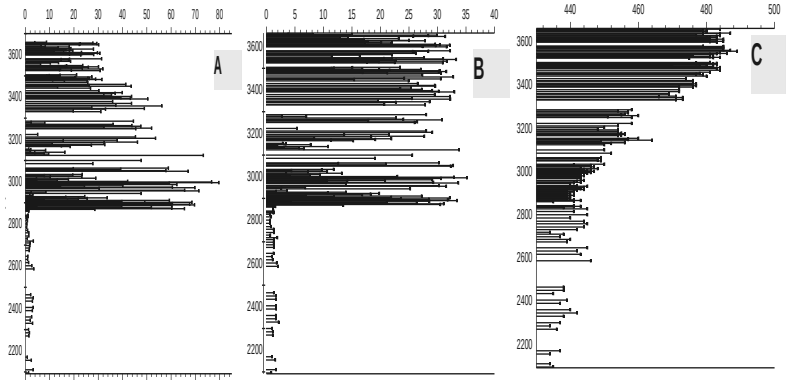

Fig. 2 Well A: Geochemical Plot of (A) Depth versus S2, (B) Depth versus TOC, (C) Depth versus Tmax

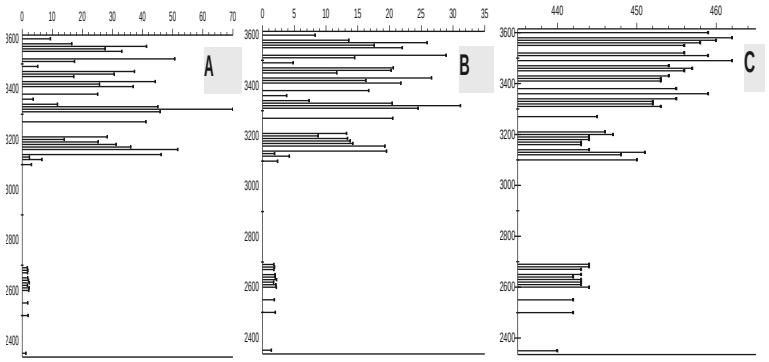

Fig. 3 Well B: Geochemical Plot of (A) Depth versus S2, (B) Depth versus TOC, (C) Depth versus Tmax

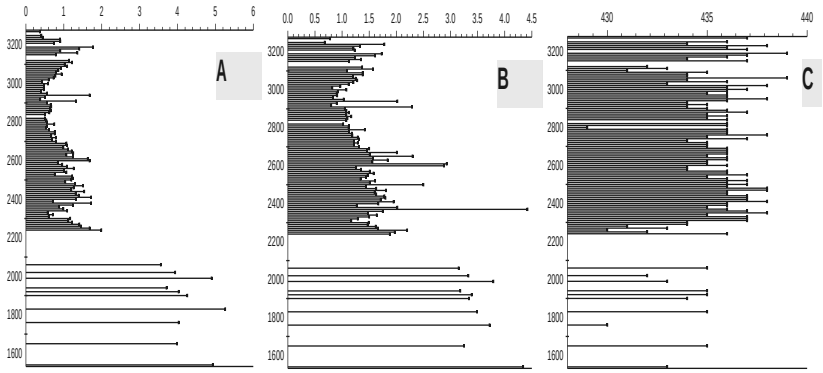

Fig. 4 Well C: Geochemical Plot of (A) Depth versus S2, (B) Depth versus TOC, (C) Depth versus Tmax

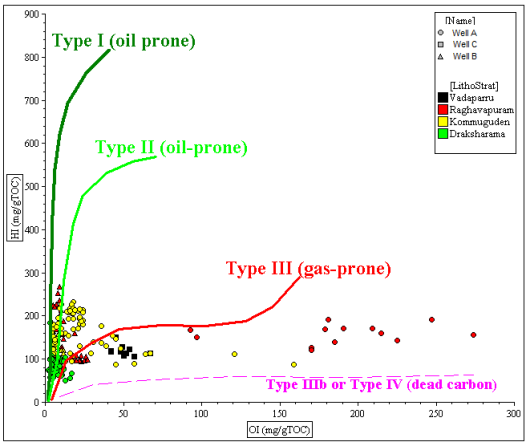

Fig. 5 Modified Van-Krevelen diagram

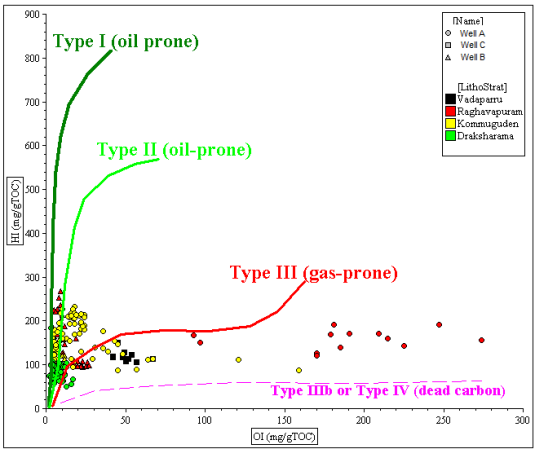

Fig. 6 Plot of HI versus Tmax