Study of Cambay and Krishna-Godavari Basin for Shale Oil and Gas

P. S. Saravanan
Head of the Department
Department of Petroleum Engineering
Excel College of Engineering & Technology

Ashutosh Kumar
UG Student
Department of Petroleum Engineering
Excel College of Engineering & Technology

Anand Lidwin Peter. A
UG Student
Department of Petroleum Engineering
Excel College of Engineering & Technology

Divakar. G
UG Student
Department of Petroleum Engineering
Excel College of Engineering & Technology

Amal Johny
UG Student
Department of Petroleum Engineering
Excel College of Engineering & Technology

Abstract

This paper contains a detail study about the two major basins of India in the perspective of shale oil and gas. According to estimates by EIA, India has 96 tcf of recoverable shale gas reserves. However there has been a recent downward revision in the estimates. India's shale gas reserve estimates pale in comparison to global standards, however limited exploration has been carried out so far. The Cambay, Krishna Godavari, Cauvery and the Damodar Valley are the most perspective sedimentary basins for carrying out shale gas activities in the country. The Cambay Basin in Gujarat is the largest basin in the country, spreaded across 20,000 gross square miles, with a prospective area of 1940 square miles. Around 20 tcf of gas has been classified as recoverable in this basin. It is estimated that the Krishna Godavari basin, located in eastern India, holds the largest shale gas reserves in the country. It extends over 7800 square miles in gross area with a prospective area of around 4340 sq miles. The basin encloses a series of rich organic materials, containing around 27 -30 tcf.

Keywords: Shale oil, Shale gas, Cambay Basin, Krishna-Godavari Basin, Geologic Setting

I. CAMBAY BASIN, INDIA

A. Introduction and Geologic Setting

The Cambay Basin is an elongated, intra-cratonic Late Cretaceous to Tertiary rift basin, located in the State of Gujarat in northwest India. The basin includes four assessed fault blocks: Mehsana-Ahmedabad, Tarapur, Broach and Narmada, Figure 1.

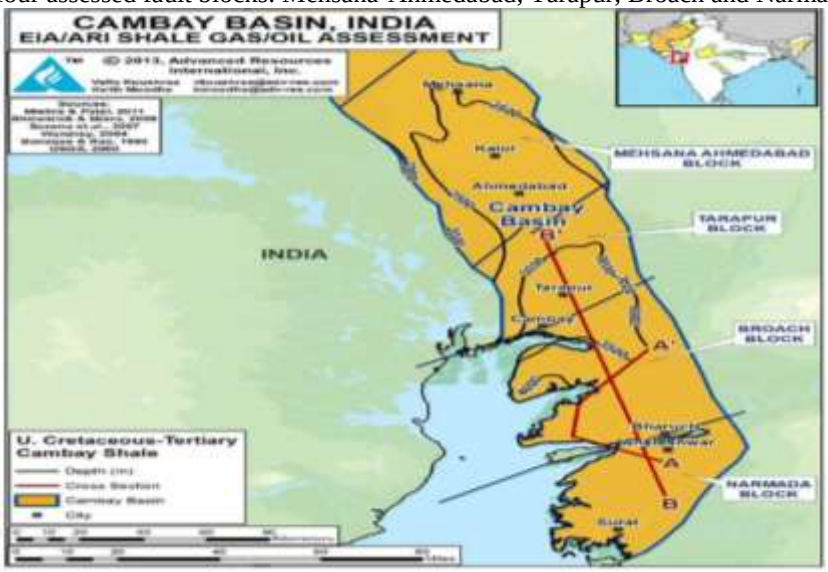

Fig. 1: Depth of Cambay Black Shale, Cambay Basin

Cambay Basin is bounded on its eastern and western sides by basin-margin faults and extends south into the offshore Gulf of Cambay, limiting its onshore area to 7,900 mi2. The Deccan Trap, composed of horizontal lava flows, forms the basement of the Cambay Basin. Above the Deccan Trap, separated by the Olpad Formation, is the Late Paleocene and Early Eocene Cambay Black Shale, Figure 2, The Cambay Black Shale represents the marine transgressive episode in the basin. With a thermal maturity ranging from about 0.7% to 2%, the shale is in the oil, wet gas and dry gas windows. For purposes of this study, we have assumed that the oil window starts at 6,000 feet of depth, that the wet gas window starts at 11,000 feet, and that the dry gas window is below 13,000 feet of depth, Figures 3 and 4.

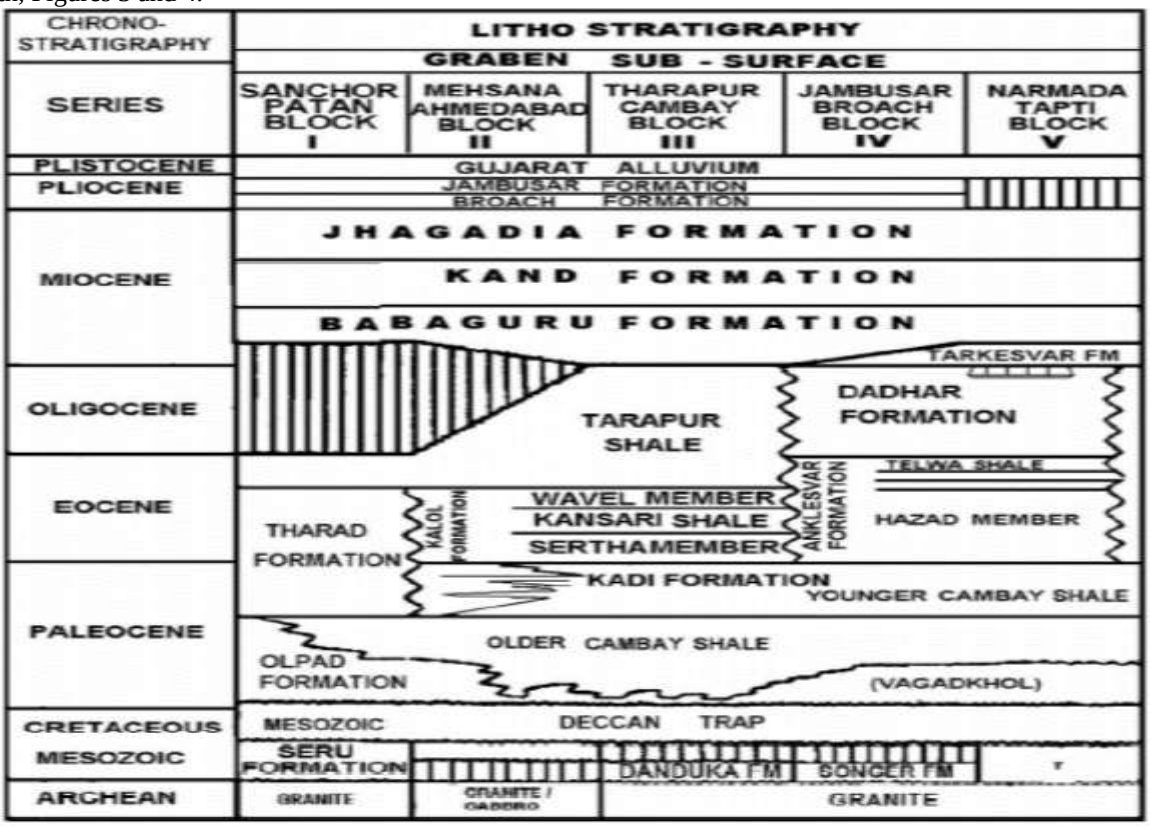

Fig. 2: Generalized Stratigraphic Column of the Cambay Basin

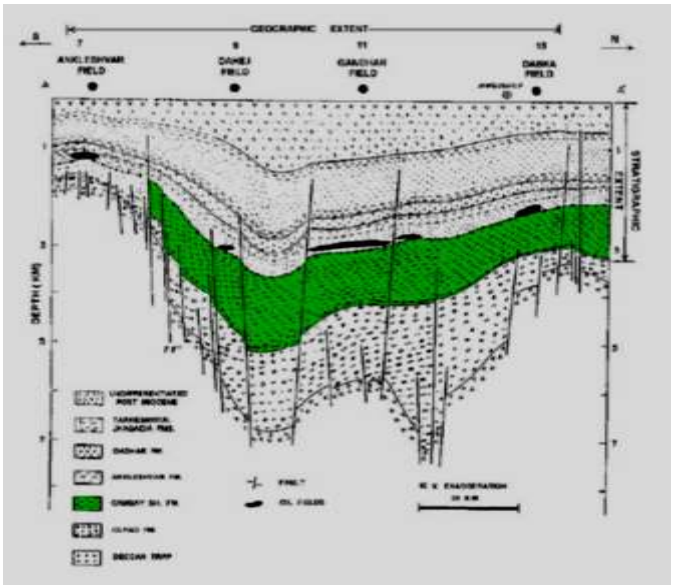

Fig. 3: Cross Section of Cambay Black Shale System

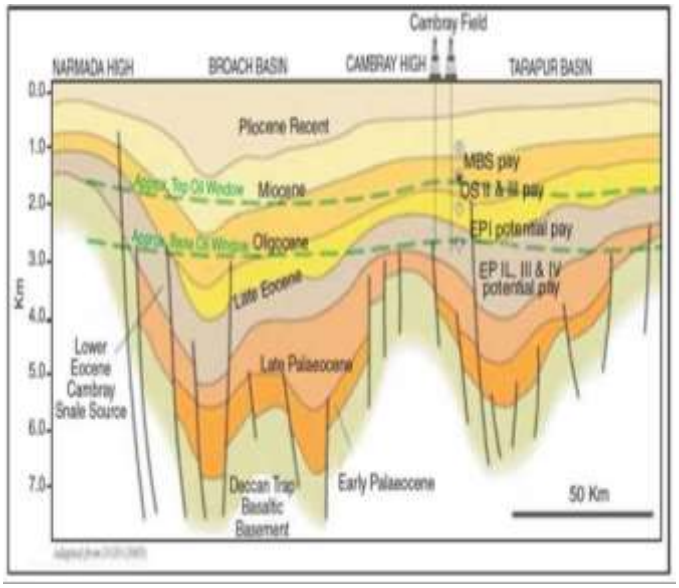

Fig. 4: N-S Geological Cross-Section Across Cambay Basin

The Cambay Basin contains four primary fault blocks, from north to south: (1) Mehsana- Ahmedabad; (2) Tarapur; (3) Broach; and (4) Narmada. Three of these blocks appear to have sufficient thermal maturity to be prospective for shale gas and oil, Table 1.

Table – 1
Major Fault Blocks and Shale Prospectivity of Cambay Basin

Fault Blocks		*Comments*
1.	*Mehsana-Ahmedabad*	*Prospective for Shale Oil*
2.	*Tarapur*	*Prospective for Shale Oil and Wet Gas*
3.	*Broach*	*Prospective for Shale Oil and Wet/Dry Gas*
4.	*Narmada*	*Insufficient Data, Likely Immature*

B. Mehsana-Ahmedabad Block

Three major deep gas areas (depressions) exist in the Mehsana-Ahmedabad Block - the Patan, Worosan and Wamaj. A deep well, Well-A, was drilled in the eastern flank of the Wamaj Low to a depth of nearly 15,000 ft, terminating below the Cambay Black Shale. In addition, a few wells were recently drilled to the Cambay Black Shale in the axial part of the graben low. A high-pressure gas zone was encountered in the Upper Olpad section next to the Cambay Shale, with methane shows increasing with depth. Geochemical modeling for this fault block indicates an oil window at 6,600 ft, a wet gas window at 11,400 ft, and a dry gas window at 13,400 ft.

C. Broach and Tarapur Blocks

The deeper Tankari Low in the Broach Block and the depocenter of the Tarapur Block appear to have similar thermal histories as the Mehsana- Ahmedabad Block. As such, we assumed these two areas have generally similar shale gas and oil properties as the Cambay Black Shale in the Mehsana-Ahmedabad Block.

D. Reservoir Properties (Prospective Area)

The depth of the prospective area of the Cambay Black Shale ranges from about 6,000 ft in the north to 16,400 ft in the lows of the southern fault blocks, averaging 8,000 ft in the oil prospective area, 11,500 ft in the wet gas and condensate prospective area, and 14,500 ft in the dry gas prospective area. Thermal gradients are high, estimated at 3°F per 100 feet, contributing to accelerated thermal maturity of the organics. The Cambay Black Shale interval ranges from 1,500 to more than 5,000 ft thick in the various fault blocks. In the northern Mehsana-Ahmedabad Block, the Kadi Formation forms an intervening 1,000-ft thick non-marine clastic wedge within the Cambay Black Shale interval. In this block, the shale thickness varies from 300 to 3,000 ft, with the organic-rich shale thickness, located in the lower portion of the Cambay Black Shale interval, averaging 500 net ft, Figure 5. The organic matter in the shale is primarily Type II and Type III (terrestrial) with a TOC that ranges from 2% to 4%, averaging 2.6%, Figure 6. The shale formation is moderately over-pressured and has low to medium clay content. Within the overall 1,940-mi^2 Cambay Black Shale prospective area in the Cambay Basin, we estimate: a 580mi^2 area prospective for dry gas; a 300mi^2 area prospective for wet gas and condensate; and a 1,060mi^2 area prospective for oil, Figure 7.

E. Resource Assessment

The Cambay Black Shale has resource concentrations of 228 Bcf/mi^2 of shale gas in its 580mi^2 dry gas prospective area; 170 Bcf/mi^2 of wet gas and 19 million barrels/mi^2 of condensate in the 300mi^2 wet gas/condensate prospective area; and 80 million barrels/mi^2 of shale oil (plus associated gas) in the 1,060mi^2 oil prospective area. Within the overall 1,940mi^2 prospective area for the Cambay Black Shale in the Cambay Basin, we estimate a risked resource in place of 146 Tcf for shale gas and 54 billion barrels for shale oil. Based on moderate to favorable reservoir properties, we estimate that the Cambay Black Shale has 30 Tcf of risked, technically recoverable shale gas and 2.7 billion barrels of risked, technically recoverable shale oil.

1) Recent Activity

Although the shales in the Cambay Basin have been identified as a priority by India, no plans for exploring these shales have yet been publically announced. However, two shallower conventional exploration wells (targeting the oil-bearing intervals in the basin) penetrated and tested the Cambay Black Shale. Well D-A, a vertical well, had gas shows in a 90-ft section of the Cambay Basin at a depth of about 4,300 ft. After hydraulic stimulation, Well D-A produced 13 bbl/day of oil and 11 Mcfd of gas. Well D-B, an older vertical well drilled in 1989 to a depth of 6,030 ft, also encountered the Cambay Shale at about 4,300 ft. The well was subsequently hydrofractured and produced 13 bbl/day of oil and 21 Mcfd of gas.

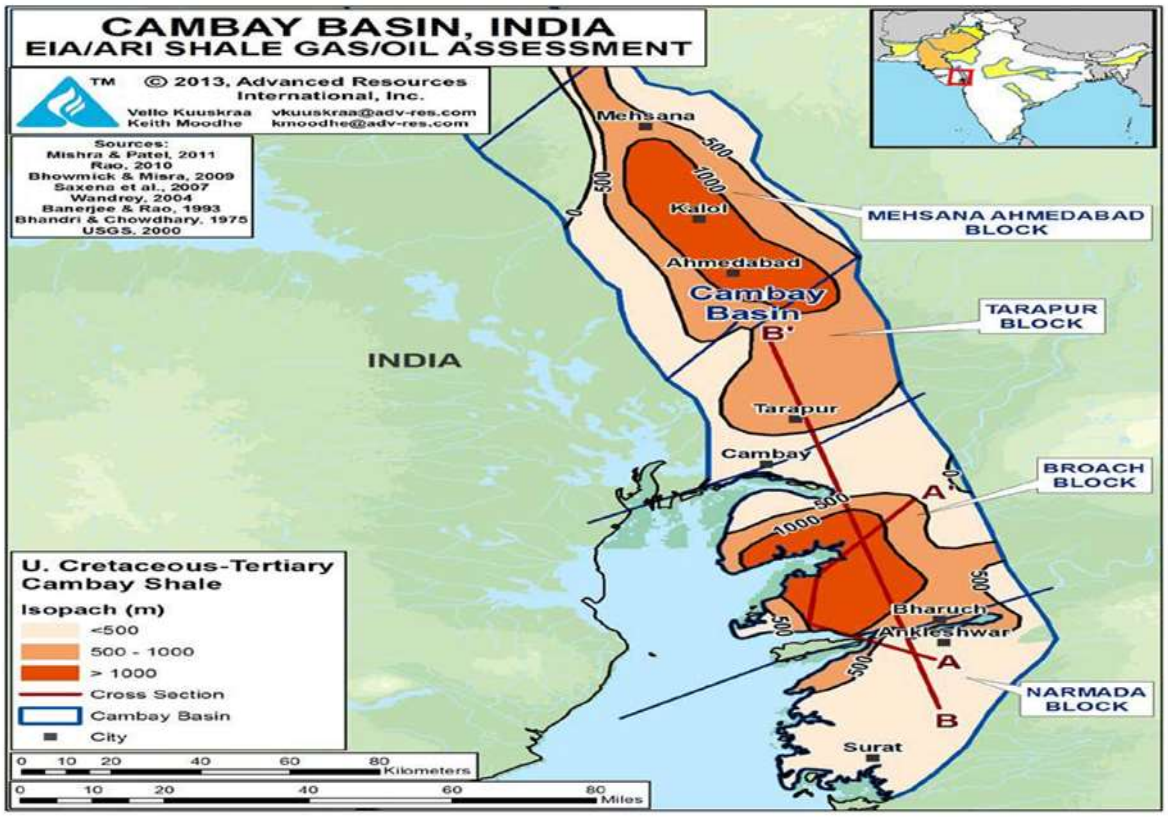

Fig. 5: Gross Thickness of Cambay Black Shale, Cambay Basin

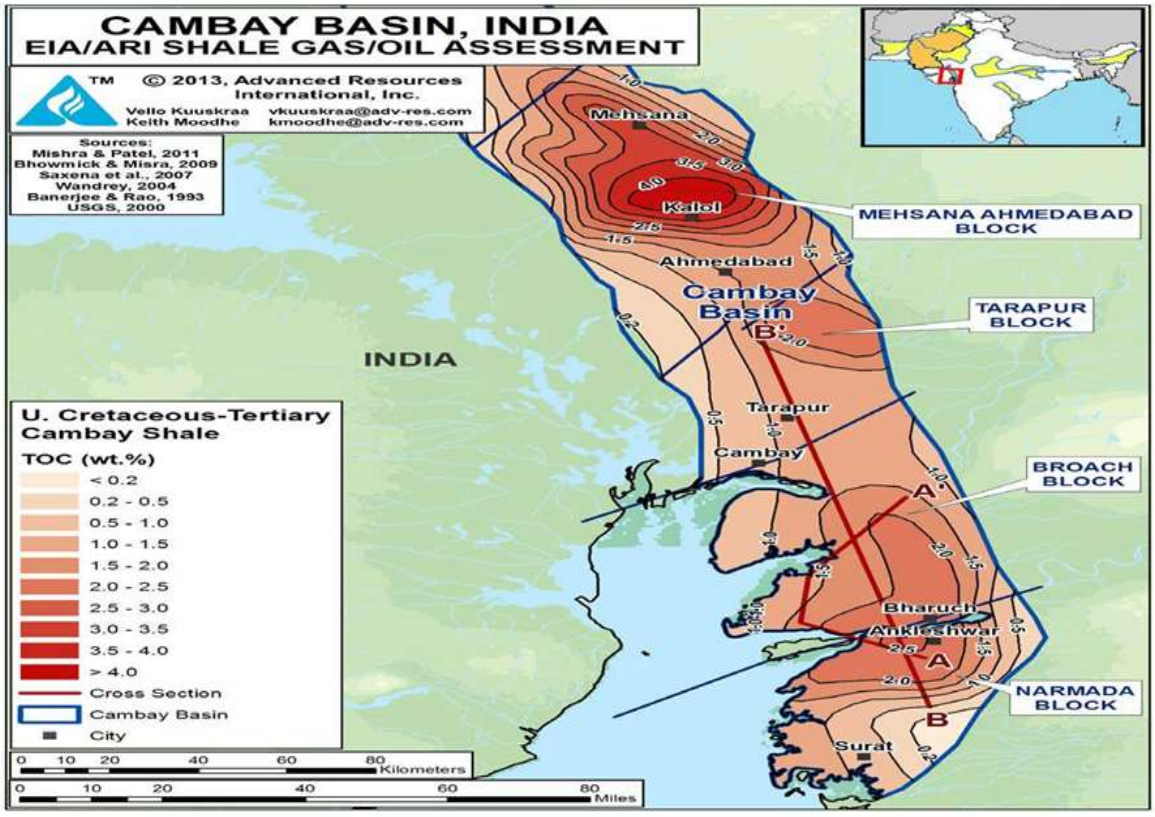

Fig. 6: Organic Content of Cambay "Black Shale", Cambay Basin

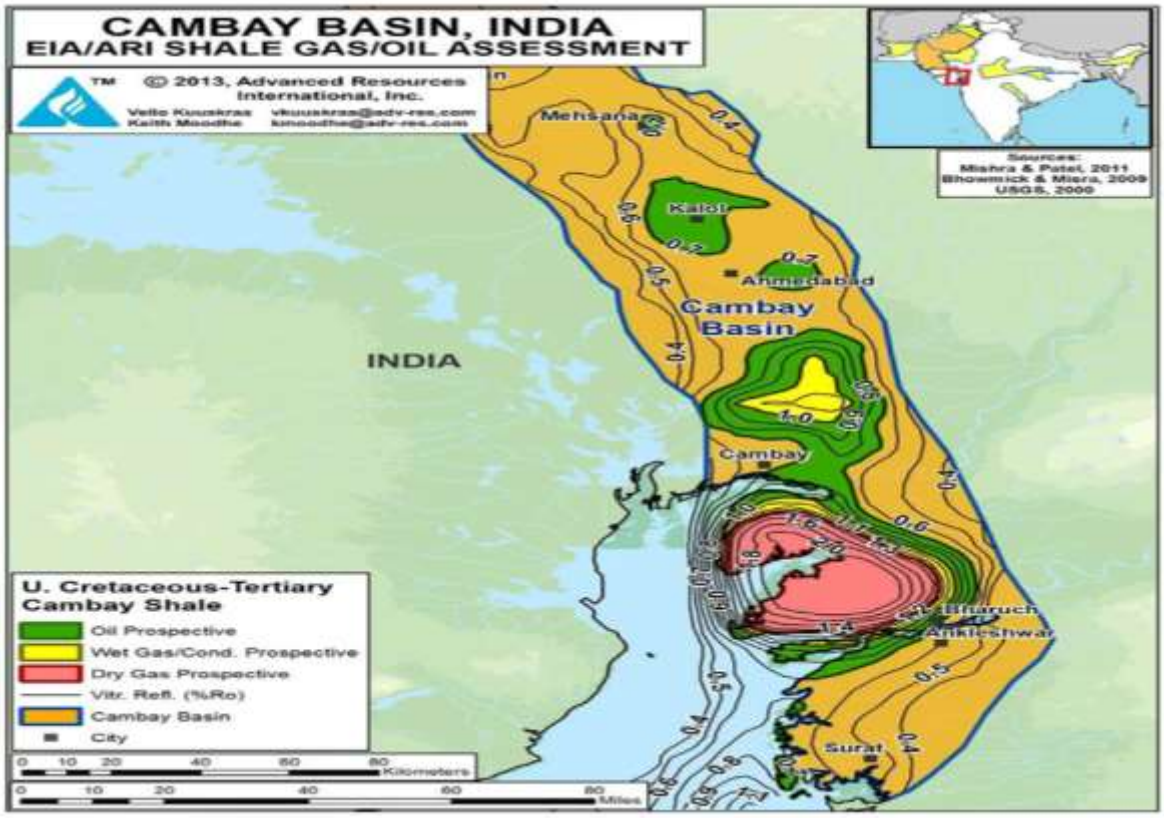

Fig. 7: Prospective Areas of the Cambay Black Shale, Cambay Shale Basin

II. KRISHNA-GODAVARI BASIN, INDIA

A. Introduction and Geologic Setting

The Krishna-Godavari Basin covers a 7,800-mi^2 onshore area of eastern India, Figure 8. The basin contains a series of organic-rich shales, including the Permian-age Kommugudem Shale and the Triassic-age Mandapeta Shale. For purposes of this assessment, these two shales have been combined into the Permian-Triassic Shale. With thermal maturities ranging from 0.7% to 2% Ro, these shales are in the oil to dry gas windows. The Upper Cretaceous Raghavapuram Shale may also have potential but was not assessed by this study.

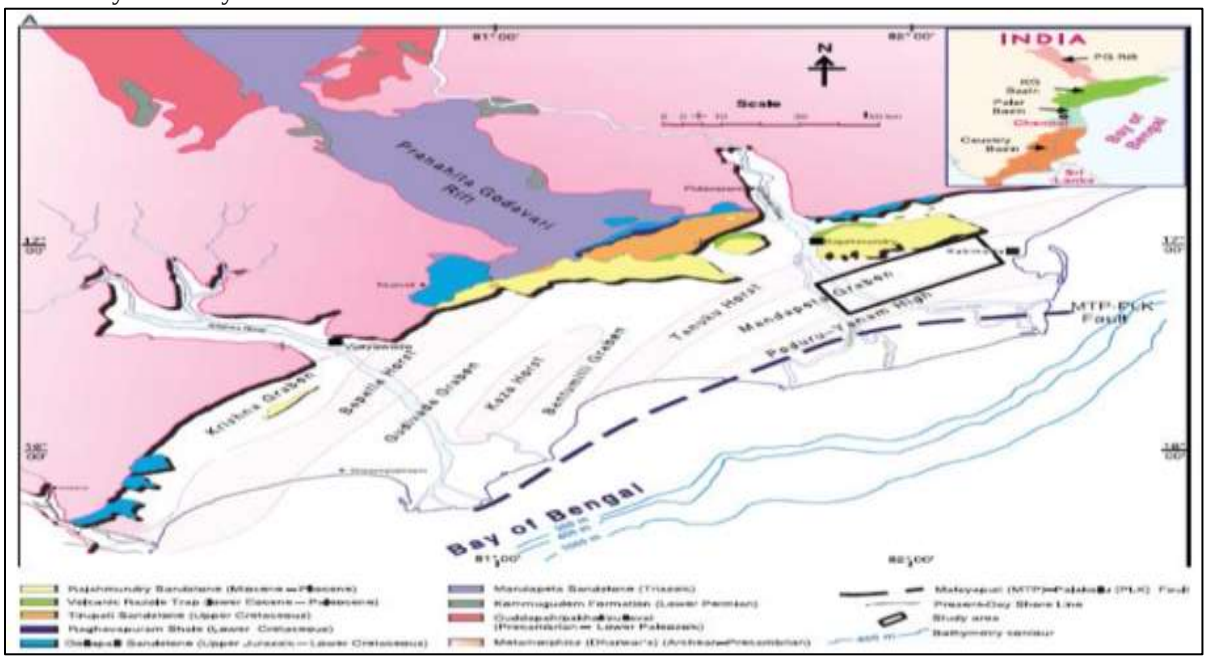

Fig. 8: Krishna-Godavari Basin's Onshore Horsts and Grabens

B. Permian-Triassic Shale

The Kommugudem Shale, the lower unit of the Permian-Triassic Shale, is a thick Permian-age rock interval containing alternating sequences of carbonaceous shale, claystone, sand and coal, Figure 9. The Mandapeta Graben, the most extensively explored portion of the Krishna-Godavari Basin, provides much of the geologic and reservoir characterization data for this basin.

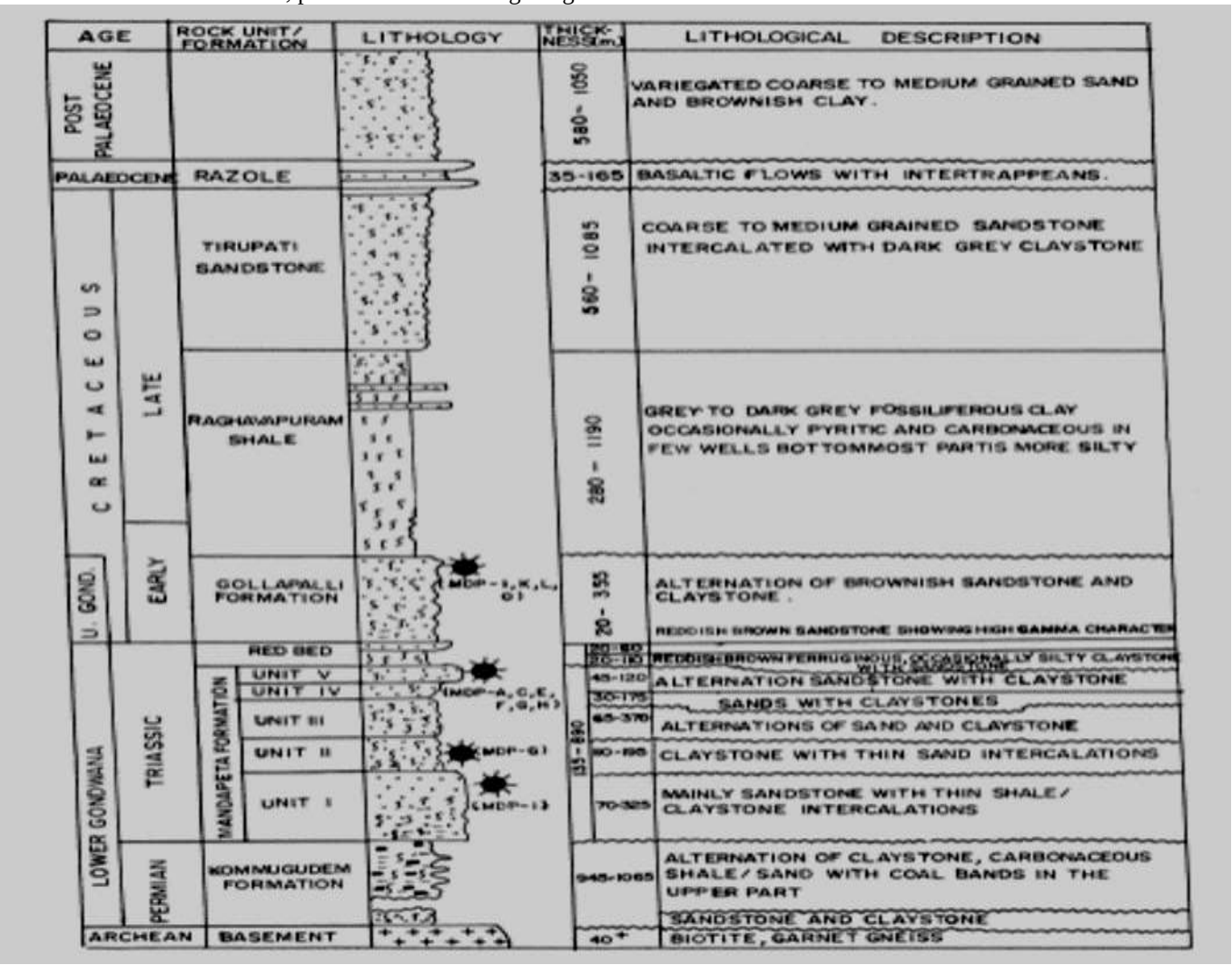

Fig. 9: Stratigraphic Column, Mandapeta Area, Krishna Godavari Basin

The Kommugudem Shale was deposited in fluvial, lower deltaic, and lacustrine environments. While an effective source rock with excellent organic richness, analysis of the shale indicates hydrogen-deficient organic matter (based on low S2 values from pyrolysis) and high levels of primary inertinite.

The basal shale in the Mandapeta Formation, the upper unit of the Permian-Triassic Shale, is a localized, thermally mature (Ro of 0.8% to 1.1%) Triassic-age shale that is considered the source rock for the oil produced from the overlying Early Cretaceous Golapalli Sandstone. The Mandapeta Formation and its basal shale are present in the Mandapeta and Bantumilli grabens but are absent in the Poduru-Yanam High (Draksharama and Endamuru areas) to the east. While the TOC of the Mandapeta Shale is generally low, 0.4% to 1.6%, we have included this Triassic shale unit into the overall Permian-Triassic sequence.

Vitrinite reflectance of the Permian-Triassic Shale in the deep graben structures ranges from 0.7% to 2% Ro, placing the shale in the oil to dry gas windows. Figure 10 illustrates the relationship of shale depth and geologic age in the Krishna-Godavari Basin to the thermal maturity (Ro) in two of the graben structures, Kommugudem (KMG) and Mandapeta (MDP).

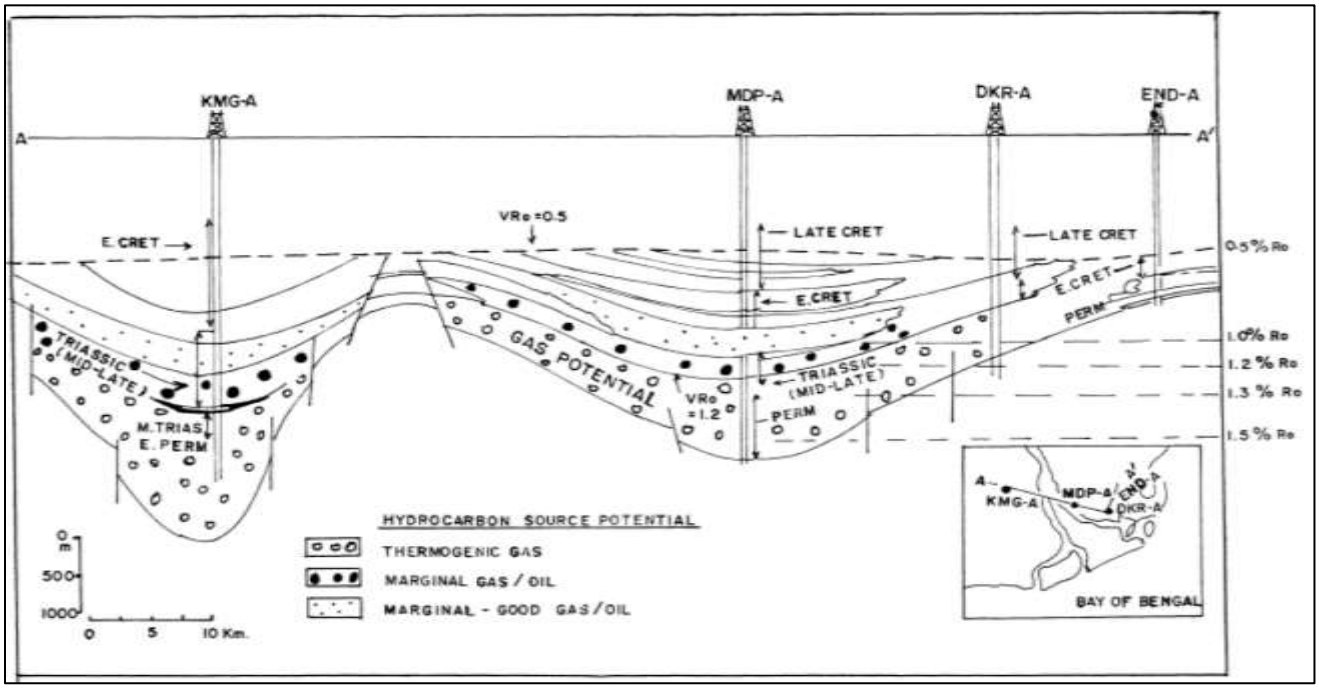

Fig. 10: Cross Section for Permian-Triassic Shale, Krishna Godavari Basin

C. *Reservoir Properties (Prospective Area)*

In the prospective area of the Krishna-Godavari Basin, the depth of the Permian-Triassic Shale ranges from 4,000 to 16,400 ft, averaging 5,000 ft in the oil prospective area, 8,000 ft in the wet gas and condensate prospective area, and 13,000 ft in the dry gas prospective area. To better understand the source rock quality of the Permian-Triassic Shale, 140 m of shale was tested in 10 wells. The data showed the TOC of the shale ranges up to 11%, averaging 6%, for ten rock samples taken at various depths, Table2. The thickness of the shale ranges from 330 to 1,300 ft, with 100 to 390 ft of net organic rich shale, depending on prospective area. The pressure gradient of the Permian-Triassic Shale is normal. The reservoir is inferred to have moderate to high clay content based on its lacustrine deposition. We mapped an 8,000mi^2 prospective area for the Permian-Triassic Shale in the Krishna-Godavari Basin which encompasses the oil, wet gas/condensate and dry gas windows.

Table – 2
Analysis of Ten Rock Samples, Kommugudem Shale

Well	*Depth (m)*	*TOC (%)*	*S2**	*Shale Interval Tested (m)*
AA-1	*3,320-3,880*	*10.4*	*7.0*	*110*
AA-2	*3,585-3,630*	*4.2*	*2.9*	*45*
AA-9	*3,330-3,360*	*7.1*	*6.4*	*30*
AA-10	*3,880-3,920*	*3.1*	*0.6*	*40*
AA-11	*2,890-3,150*	*7.0*	*7.9*	*260*
BW-1A	*3,915-4,250*	*5.6*	*0.8*	*335*
BW-2	*2,970-3,085*	*8.8*	*5.5*	*115*
BW-2	*3,100-3,175*	*7.8*	*6.0*	*75*
BW-9	*2,800-3,040*	*11.2*	*6.9*	*315*
DE-1	*1,900-2,040*	*8.9*	*13.9*	*120*

1) Raghavapuram Shale

The Cretaceous-age Raghavapuram Shale offers an additional potential shale resource in the Krishna-Godavari Basin. The TOC of this shale unit ranges from 0.8% to 6.4%, with the lower HG-HR Shale interval of the Raghavapuram Formation having the higher TOC values, Figures 11 and 12. The shale becomes thermally mature for oil (Tmax 440 to 475° C) at depth below 10,600ft. However, the great bulk of the Cretaceous Raghavapuram Shale is shallower than 10,600 ft and thus has a thermal maturity (Ro) value less the 0.7% minimum threshold used by this study. In addition, the data on the area and vertical distribution of the Raghavapuram Shale is limited. Thus, this shale has not been included in the quantitative portion of our shale resource assessment.

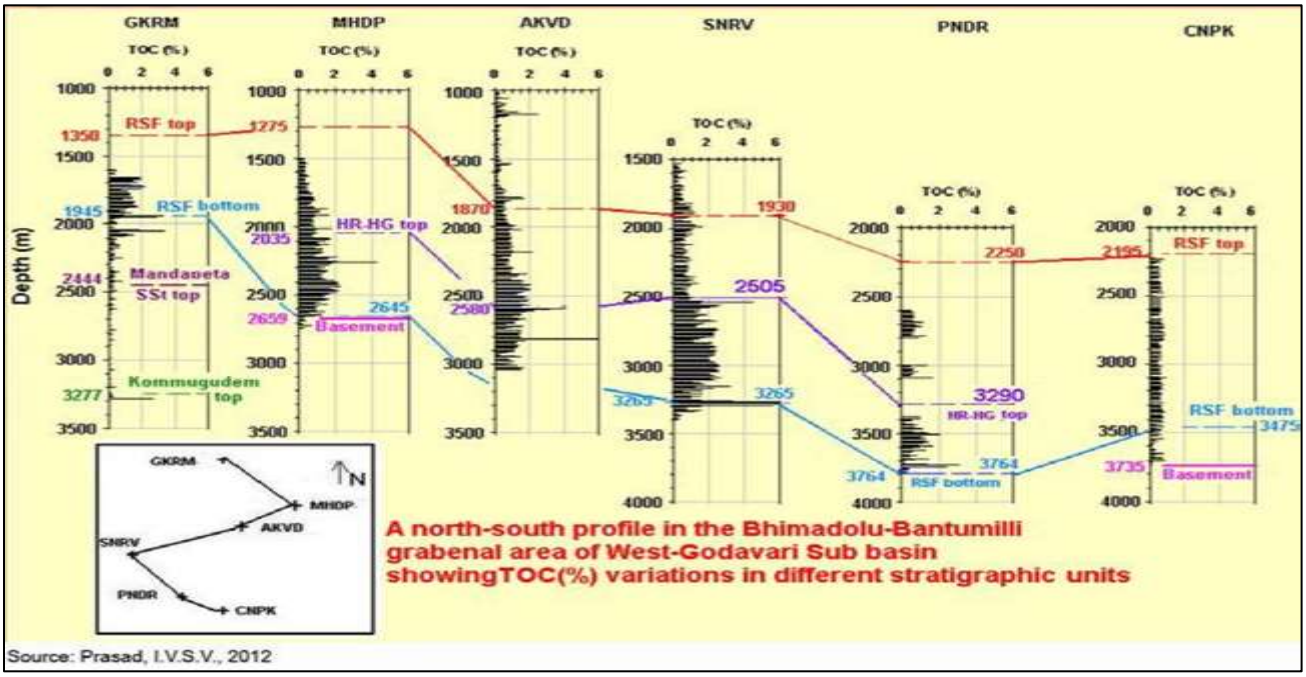

Fig. 10:TOC Cross-Section for Raghavapuram Shale, Krishna-Godavari Basin

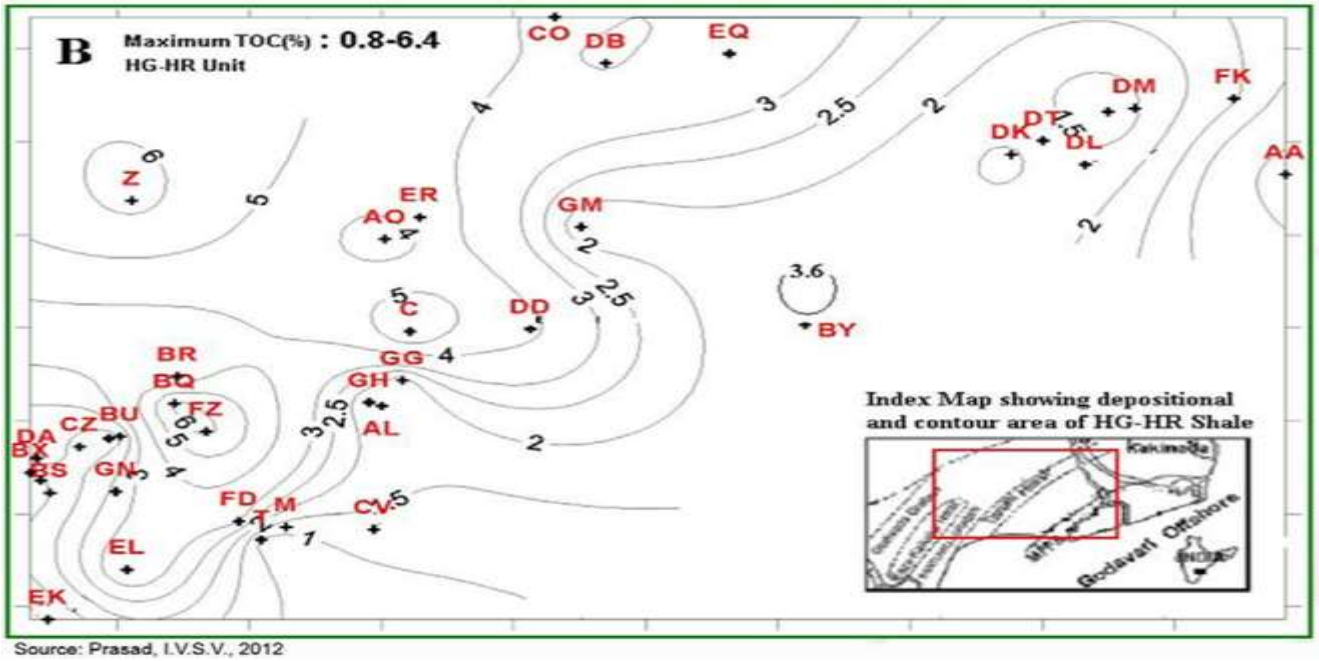

Fig. 11: TOC Isopach for Raghavapuram Shale, Krishna-Godavari Basin

2) *Resource Assessment*

The 8,000mi^2 prospective area of the Permian (Kommugudem) and Triassic (Mandapeta) Shale in the Krishna-Godavari Basin is limited to the four grabens (sub-basins) shown in Figure 12. The Permian-Triassic Shale has resource concentrations of 205 Bcf/mi^2 in the 3,000mi^2 dry gas prospective area 58 Bcf/mi^2 of wet gas and 6 million barrels/mi^2 of condensate in the 3,900mi^2 wet gas/condensate prospective area and 18 million/mi^2 barrels of oil (plus associated gas) in the 1,100mi^2 oil prospective area. Within the overall prospective area, the Permian-Triassic Shale of the Krishna-Godavari

Basin has risked shale gas in-place of 381 Tcf, with 57 Tcf as the risked, technically recoverable shale gas resource. In addition, we estimate a risked shale oil in-place for this basin of 20 billion barrels, with 0.6 billion barrels as the risked, technically recoverable shale oil resource,

3) *Recent Activity*

The technical literature discusses 16 wells that have been drilled at the Mandapeta Graben into or through the Permian-Triassic Shale in search for hydrocarbons in conventional Mandapeta and Gollapalli sandstone reservoirs. The information from these 16

wells has provided valuable data for the key cross-sections and other reservoir properties essential for the shale resource assessment study of the Krishna-Godavari Basin.

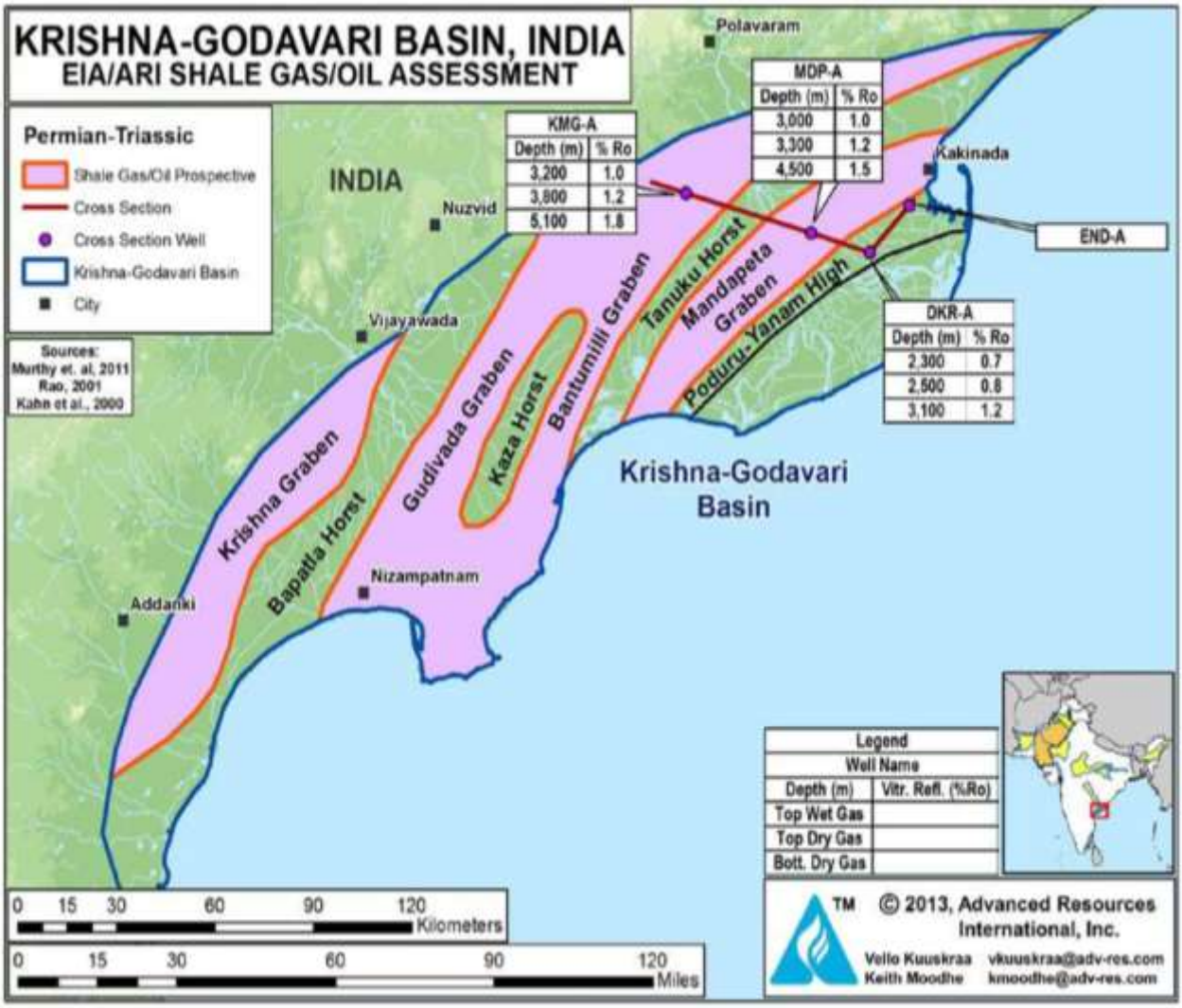

Fig. 12: Prospective Areas for Shale Gas and Shale Oil, Krishna-Godavari Basin

III. RESULT

If the excavation and production of shale oil in India is continued then we can reduce the importing of oil from the other countries. Thus the Indian economic can be waked from the downstream strategy. Thus by excavating the shale oil from the Indian basin can lead a fore step to the growth of great nation India. The modern technology would surely yield the growth of shale oil from India. By the start of the shale oil production from India we can reduce the importing of fuel from other countries of with high price. So, our modern technologies in hands with ONGC and geological men's we can hope for the production of fuel oil and it will enhance the industrial growth. shale gas has potential but it is not the silver bullet which will resolve India's energy crisis tomorrow. And although we need a policy around shale gas, it needs to be holistic and we should incorporate lessons learned from the experiences of other countries (USA and UK) that are further ahead. Understanding the challenges they faced around water, investment incentives, land, etc. will allow us to create a more robust policy for India which will sustain over the long term. Moreover, everyone following the new developments in the Shale gas industry knows about its importance in the future. Shale gas is definitely an opportunity; if harnessed effectively, can bring about a change in the energy mix of the country. The effects of shale gas can be far reaching and therefore it needs to be given adequate importance. There are some kinks and considerations that need to be worked out before the shale gas takes off economically. The industry and the government need to work together to come up with a shale gas exploration policy that not only encourages foreign investment but also encourages domestic economic growth.

REFERENCE

[1] U.S. Crude Oil and Natural Gas Proved Reserves, Year-end 2016 February 2018 U.S. Energy Information Administration (EIA)
[2] Technically Recoverable Shale Oil and Shale Gas Resources: India and Pakistan U.S. Energy Information Administration (EIA)
[3] Shale gas Key considerations for India by Petrotech 2012

[4] World Petroleum Resources Project Assessment of Potential Shale Gas Resources of the Bombay, Cauvery, and Krishna–Godavari Geologic Provinces, India, 2011.
[5] Shale Gas in India:Look Before You Leap TERI POLICY Brief 2013
[6] http://www.naturalgaseurope.com/indian-shale-gas-unique-challenges-and-solutions-4927
[7] http://www.deccanherald.com/content/44366/shale-gas-game-changer-india.html
[8] http://www.dghindia.org/NonConventionalEnergy.aspx?tab=2
[9] http://www.thehindubusinessline.com/companies/india-takes-its-first step-into-shale-gasoilexploration/article5390558.ece
[10] http://www.business-standard.com/article/economy-policy/3-phase-planfor-shale-gas-exploration-by-ongc-oil-113102200828_1.html
[11] http://articles.economictimes.indiatimes.com/2013-09 25/news/42362315_1_shale-recourses-conventional-oil-andgas-gas exploration
[12] http://www.thehindu.com/news/cities/Delhi/shale-gas-policy-a-game changer-or-spoiler/article4924493.ece
[13] http://articles.economictimes.indiatimes.com/2010-0825/news/27572778_1_shale-gas-first-basins-efficientlylarge quantities
[14] http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/Documents/shale-gas-globalperspective.pdf
[15] http://csis.org/files/publication/120824_Nakano_ProspectsShaleGas_W b.pdf
[16] http://www.deloitte.com/assets/Dcomindia/Local%20Assets/Documents/ER%20publications/Shale%20Gas%20%20Strategic%20Imperative%20for%20india.pdf
[17] http://thediplomat.com/2013/06/indias-shale-gas-boom-dream-or-reality/
[18] http://www.globalwaterforum.org/2013/04/30/shale-gas-in-india-the wrong-path/
[19] http://www.ey.com/Publication/vwLUAssets/Shale_Gas__Key_considerations_for_India/$FILE/EYIN1210-084-Shale-gas.pdf
[20] http://forbesindia.com/article/special/is-india-ready-for-shale-gas/35167/1
[21] .http://www.business-standard.com/article/companies/indian-cos-arelooking-beyond-me-cis-countries-to-meetenergy-needs-thomas-milroy-114013100331_1.html
[22] http://en.wikipedia.org/wiki/Shale_oil
[23] http://www.wow.com/wiki/Shale_oil
[24] http://en.wikipedia.org/wiki/Oil_shale_oil
[25] http://otisoil-gas.com/oilshaletech.htm
[26] http://www.academia.edu/9825466/Shale_Oil_and_Gas_is_India_Ready_scbhjsaantent/44366/s
[27] Directorate General of Hydrocarbin