Proc Indian Natn Sci Acad **86** No. 1 March 2020 pp. 609-621

DOI: 10.16943/ptinsa/2020/49777

Review Article

Potential Petroleum Deposits & Shale Oil Exploration

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(Received on 15 September 2019; Accepted on 29 September 2019)

India is endowed with twenty six sedimentary basins covering an area of 3.36 million sq. km spread over Onland, Shallow water (down to 400m isobaths) and Deep water (400m isobaths to EEZ) sectors. The aerial extent of Onland, Shallow water and Deep water are 1.63 million sq. km, 0.41 million sq. km. and 1.32 million sq. km. respectively. A large portion of the basinal area is still to be appraised in terms of knowledge building efforts for evaluating hydrocarbon prospectivity of the basin through Geological studies, Geophysical surveys and exploratory drilling.

The National Seismic Programme (NSP) introduced by MoPNG, GoI for Geo-Scientific Data generation in Indian Sedimentary Basins is intended to assess the un-appraised onland areas in 26 sedimentary basins. The project relating to Acquisition, Processing and Interpretation (API) of 48,243 LKM of 2D Seismic Data is being implemented through National Oil Companies: ONGCL and OIL. With the increase in exploration spread and quantum jump in availability of geo-scientific data generated under the New Exploration Licensing Policy (NELP), a need was felt to revisit the Hydrocarbon Resource assessment of India which was last carried out during 1995-96. The Reassessment exercise has been carried out during 2015-17.

In order to intensify exploration activities and bring investments in Indian sedimentary basins Govt. of India (GOI) has taken a number of measures in recent times. The Hydrocarbon Exploration Licensing Policy (HELP) permits operators to explore and extract all types of hydrocarbon resources from a single acreage. It has also announced fiscal incentives for unconventional hydrocarbon production through this policy.

A number of Indian sedimentary basins possess huge volume of organic rich shale rocks deposited through wide geological time. The unconventional hydrocarbon reservoirs include shale oil/gas, tight oil/gas, heavy oil, Coal Bed Methane etc. which are capable of providing a cleaner source of energy than other fossil fuels albeit with appropriate safeguards.

Introduction

Energy is integral for collective progress of the society and provides the impetus for social and economic development of a nation. It has become a strategic commodity considering the implications it has on sustained growth of economy and human development. After independence India adopted a state led Planned Economy Model with 5 year Plans. Between 1947 and 1980, the Indian economy grew at an annual average rate of 3.5%. Given an annual population growth of over 2%, the country's per person income, was at a sub 2% rate of growth. The economic reforms and liberalisation initiated in the early nineties ushered in a new era which saw a growth of over 4% in annual per capita income in the last three decades. Under this backdrop, role of energy security for sustainable future has become of paramount importance. Energy security, as per International Energy Agency (IEA) is the uninterrupted availability of energy sources at an affordable price.

The predictions by various energy forecast models indicate that India would be the fastest growing energy consumer and likely to account for 25% of the rise in global energy demand by 2040 (IEA). This not only applies to the hydrocarbon sector but also to the renewable energy (RE) sector. Fast declining costs have turned solar and wind energy as the main drivers of growth in the power sector. However, fossil fuels will continue to dominate global energy scenario as they are expected to contribute

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between 75-85% of the global energy mix. Oil constitutes the critical energy source for today's industrialised economies as well as for the developing economies. However, coal is and will remain the most important fuel in the overall energy mix for some time. Currently India's primary energy mix is dominated by coal (45%) followed by oil (25%), natural gas (5%), Bioenergy (22%), hydropower (1%) and nuclear (1%) and other renewables (1%) (Fig. 1).

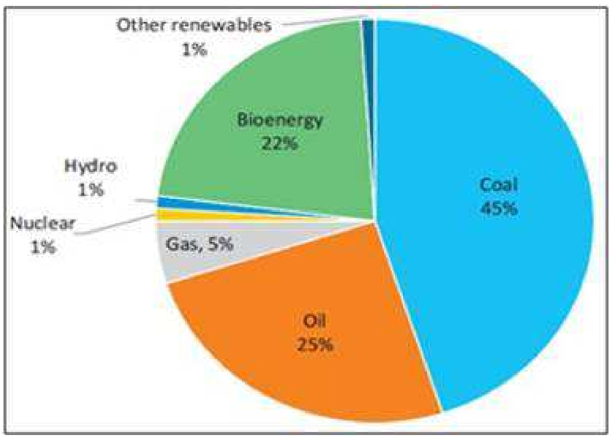

Fig.1: India's primary energy mix

It is estimated that the global oil consumption is expected to rise up to 117 MBPD (Million Bbls/day) in the next ten years. India and China together will constitute the bulk of the energy demand, a whopping 45%. Roughly 82% of India's oil consumption, 50% of natural gas consumption and 15% of thermal coal consumption depend on import (World Energy Outlook, 2018). India's crude oil import has steadily increased from 163 MMt (Million metric Tonnes) in 2010-11 to 220 MMt during 2017-18 (Fig. 2). An analysis of the total crude oil and gas production and consumption in India during the last six years (Fig.3) and during 25 years (1990-2015, Fig. 4) clearly shows the rising dependence on import causing a very heavy burden on the exchequer.

In value terms, the country's crude oil imports rose by 25% to USD 87.8 Billion in 2017-18. (Source: DGCIS, Ministry of Commerce). Thus, in order to bridge the ever increasing gap between the supply and demand, the need for augmenting production by tapping the unconventional hydrocarbon resources like Coal Bed Methane (CBM), Shale oil/gas, Tight oil/

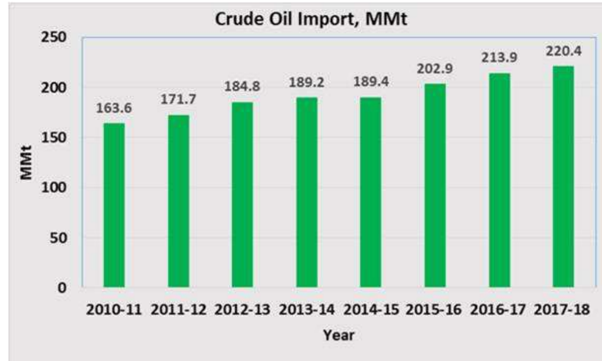

Fig. 2: India's crude oil import during last seven years

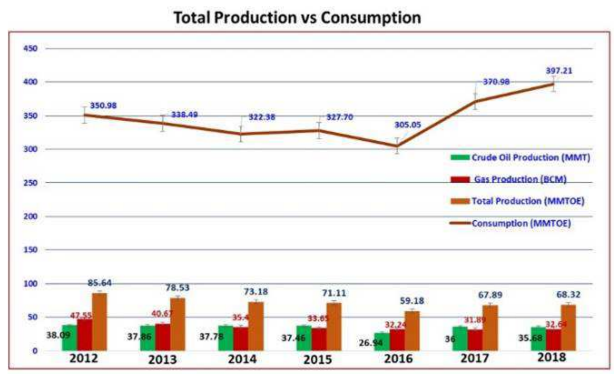

Fig. 3: India's total crude oil and gas production vs consumption during the last six years

gas, Gas Hydrates is the need of the hour. During the last two decades, exploration efforts were systematically directed towards realising the unconventional hydrocarbon resources of different sedimentary basins of India. And, ONGC has played a pivotal role in this regard.

In order to intensify exploration activities and bring investments in Indian sedimentary basins, Govt. of India (GOI) has taken several measures in recent times. As a first step, GOI has formulated and notified a new licensing policy named Hydrocarbon Exploration Licensing Policy (HELP). This is a uniform license enabling E&P operators to explore and extract all types of hydrocarbon resources from a single acreage. The exploration and production regime of NELP, Coal Bed Methane (CBM) Policy and nomination regime did not permit the contractors to exploit unconventional hydrocarbons in previously allotted licensed or leased areas. The HELP and Discovered Small Field (DSF) Policy brought about a paradigm shift in the approach of the GOI towards

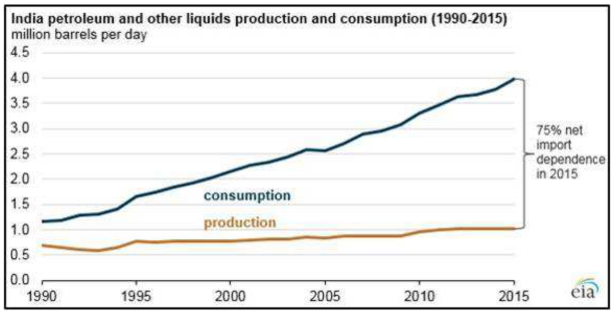

Fig. 4: India's total crude oil and gas production vs consumption during 1990-2015

upstream oil and gas sector. The Open Acreage Licensing Policy (OALP) was unveiled by the government on 06.03.2017. Further to it, the Union Cabinet on 1st August 2018 approved the policy framework for the exploration and exploitation of unconventional hydrocarbons. It has also announced fiscal incentives for unconventional hydrocarbon production through this policy.

Potential Petroleum Deposits (Conventional)

India has twenty six sedimentary basins covering an area of 3.36 million sq. km spread over Onland, Shallow Water SW, down to 400m isobaths) and Deep Water (DW, 400m isobaths to EEZ) sectors. The aerial extent of Onland, SW and DW are 1.63 million sq km, 0.41 million sq. km and 1.32 million sq. km. respectively. A large portion of the basinal area is still to be appraised in terms of knowledge building efforts for evaluating hydrocarbon prospectivity of the basin through Geological studies, Geophysical surveys and exploratory drilling.

Accordingly, National Seismic Programme (NSP) has been taken up by GOI under the broad policy framework for Geo-Scientific Data generation in 26 Indian Sedimentary Basins to assess the un-appraised onland areas. The project relating to API of 48,243 LKM of 2D Seismic Data is being implemented through National Oil Companies - ONGC and Oil India Ltd. With the increase in exploration spread and quantum jump in availability of geo-scientific data generated under NELP, a need was felt to revisit the Hydrocarbon Resource assessment of India, carried out last during 1995-96. The recent reassessment project (2015-17) adopted global industry practices under supervision of international domain experts. Rigorous methodologies of Petroleum System Modelling (PSM) for basins with adequate G&G data along with Areal Yield (AY) and Trap Density method for basins with relatively less to scanty data to even no data were adopted. A total of 177 Play Types have been identified under the resource re-assessment project (Source: DGH). Sedimentary Basins of India are classified into the following three categories (DGH-2017):

i. *Category-I Basins*: Basins which have proven hydrocarbon resources with established commercial production.

ii. *Category-II Basins*: Basins which have contingent resources which are yet to be converted to recoverable reserves and commercial production.

iii. *Category–III Basins*: Basins which have prospective resources with no hydrocarbon discovery and few exploration inputs and data.

As per the re-estimation, the prognosticated resource of conventional hydrocarbons now stands at 41.9 BToe (Billion Tons of oil and oil equivalent) including Onland, SW and DW sectors. The share of offshore and onland sectors are in the order of 23.7 BToe and 18.2 BToe respectively. The current estimates have brought out an increase of 49.1% over the last assessments of 28.1 BToe carried out in 1995-96. Basin wise distribution of hydrocarbon resource is given in Table 1 below.

As per the recent resource study, a total In-place hydrocarbon volume of around 12 BToe could be established by ONGC, OIL and Private/JV companies. (*Source: DGH)* which accounts for 28.84% Resource to In-place conversion. This indicates a huge *Yet to Find* (YTF) hydrocarbon potential of 29.8 BToe, i.e. 71.16% of assessed resources across all basins of the country.

Potential Petroleum Deposits (Unconventional)

Unconventional reservoirs have burst with considerable force in oil and gas production worldwide. Unconventional hydrocarbons are sources of oil and gas which require methods for extraction which are not normally necessary in the conventional extraction of hydrocarbons. The unconventional hydrocarbon reservoirs include shale oil/gas, tight oil/gas, heavy oil, Coal Bed Methane etc. which are capable of

Table 1: Basin wise Prognosticated Conventional Hydrocarbon Resources of Ind*ia (*Source:India's Hydrocarbon Outlook, 2017-18,DGH)

S.No.	Basin	Basin Cat.	Area (sq km)	HC resource (MMTOE)	Discovered inplace (MMTOE)
1	Mumbai Offshore	I (Proved)	2,12,000	9,646	4,794
2	KG		2,30,000	9,555	1,977
3	Cambay		53,500	2,586	1,800
4	Assam Shelf		56,000	6,001	1,868
5	AAFB		80,825	1,633	178
6	Cauvery		2,40,000	1,964	292
7	Rajasthan		1,26,000	4126	938
8	Kutch	II (Emerging)	58,554	898	71
9	Saurashtra		1,94,114	1,325	79
10	Mahanadi		99,500	651	77
11	Andaman		2,25,918	371	2
12	Vindhyan		2,02,888	632	1
13	Kerala-Konkan	III (Yet to emerge)	5,80,000	1245	0
14	Bengal-Purnea		1,21,914	828	0
15	Himalayan Foreland		30,110	44	0
16	Ganga-Punjab		3,04,000	128	0
17	Narmada		95,215	18	0
18	Deccan Syneclise		2,37,500	11	0
19	Baster		5,360	1	0
20	Bhima-Kaladgi		14,100	3	0
21	Chattisgarh		32,000	25	0
22	Cuddapah		40,100	5	0
23	Karewa		6,671	4	0
24	Pranhita-Godavari		30,000	95	0
25	Satpura-South Rewa-Damodar		57,180	63	0
26	Spiti-Zanskar		32,000	11	0
	Total		33,65,449	41,872	12,076

providing a cleaner source of energy than other fossil fuels with appropriate safeguards.

Shale Oil/Gas

Shale oil/gas constitute one of the most important unconventional sources of natural gas generated and stored in organic rich, matured fine grained sedimentary rocks. Apart from the natural gas, part of the oil generated in the shale also is retained which can be exploited by application of appropriate drilling and production technology in favourable geological situations. Globally shale hydrocarbons have been well established mainly in USA, Canada and to a lesser extent in other places.

Shale is a fine-grained, fissile, detrital sedimentary rock formed by consolidation of clay (less than 4 micron size). It is composed of fine-grained detrital matrices of silt, clay-sized bits of organic matter, quartz, feldspar, clay minerals, calcite, dolomite and other minerals. Various clay types and their volume influence the quality of the shale reservoir from petrophysical and geomechanical perspective (Atkins *et al*., 2011). Shale acts as both source and reservoir rock for shale oil/gas.

Shale plays have abundant reserves around the world which may be sufficient to meet the demand of clean energy for many years to come. Shale gas is found in unconventional reservoirs typically trapped in shale rock, having low permeability, originally deposited as clay and silt. Unlike conventional reservoirs like high permeability sandstones capable of producing huge quantity of hydrocarbons through traditional vertical drilling, shale reservoirs require vertical drilling upto the target horizon followed by a horizontal section exposing the well to more of producing shale. These horizontal sections are then subjected to multistage fracking which involves pumping of great volume of sand with water at a pressure exceeding the fracture pressure of the particular reservoir.

"When I started out in this industry 25 years ago, if someone had told me that shale could be a reservoir, I would have laughed," says Dr. Basim Faraj, a noted unconventional reservoir specialist. "Yet now we realise that we have a substantial new resource – and it is spread throughout the globe! Indeed, the technological innovation in the production technology of shale gas has brought out a path breaking change in the hydrocarbon industry as he further points out, "The influence of shale gas has been huge in North America and I believe that its global impact is on the horizon, with Australia, Asia and Europe all set to benefit greatly from this new resource." Gas has been steadily increasing its proportion in the energy mix, but the huge increase in gas resources in the US has been driven largely due to the discovery of giant 'fields': the Eagleford, Haynesville, Horn River and Marcellus shales. Although these were all discovered since 2007, deep shale gas production had actually become a commercial reality in the 1980s and 90s, with the discovery of the Barnett Shale in North Central Texas.

Statistically speaking, shale gas provided only 1% of US natural gas production in 2000, however, by the end of 2010, it took a driving seat and contributed more than 20% of the total US gas production. As predicted by the Energy Information Administration (EIA) of US Government, 46% of the United States' natural gas supply will come from shale gas by 2035. Some analysts expect that shale gas will greatly expand worldwide energy supply. As reported by Reuters, Canada is the first country outside the United States to see large-scale development of shale resources, which already account for 8 percent of total Canadian oil output. China is estimated to have the world's largest shale gas reserves. In 2013, the EIA updated it estimation of China's shale gas reserves, reporting that China had 1115 trillion cubic feet (31 trillion cubic meters) of recoverable shale gas.

The majority of Chinese shale reserves are in 3 basins – Sichuan, Tarim and Yangtze Platform, accounting for 89% of the estimated national reserves.

Looking at the reserves of shale gas, the EIA has listed eleven countries where technically recoverable shale gas reserves are available namely Argentina, Algeria, Australia, Brazil, Canada, China, India, Mexico, Russia, South Africa and US. Out of these, as per EIA's International Energy Outlook 2016, only four countries —the United States, Canada, China, and Argentina—are currently having commercial shale gas production. However, technological improvements over the forecast period are expected to encourage development of shale resources in other countries, primarily in Mexico and Algeria. Together, these six countries are projected to account for 70% of global shale production by 2040.

Global Scenario

The EIA study (2013) suggests that major unconventional shale gas and oil plays in the world are concentrated in six stratigraphic intervals namely Silurian, Late Devonian, Pennsylvanian-Late Permian, Late Jurassic, Middle Cretaceous and Paleogene. All

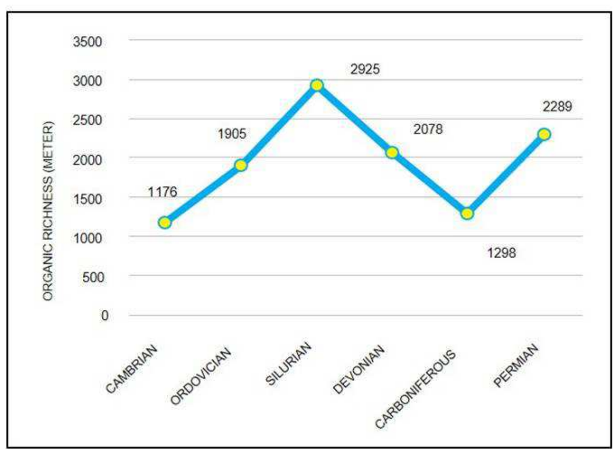

Fig. 5: Organic Richness of Global Shale during Paleozoic

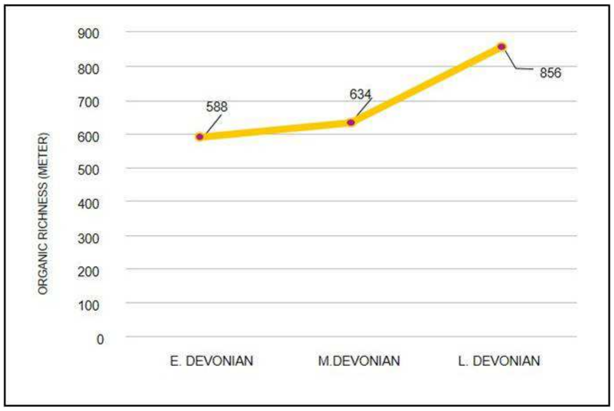

Fig. 6: Organic Richness of Global Shale during Devonian

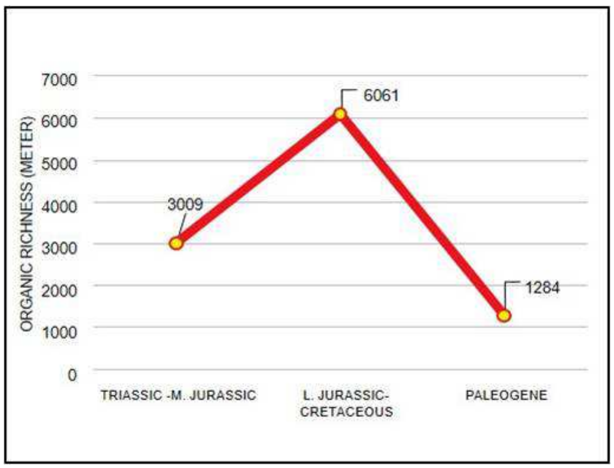

Fig. 7: Organic Richness of Global Shale

the above mentioned stratigraphic intervals are prolific for prospective shale gas exploration except for Paleogene period based on their maximum organic richness (Figs. 5, 6 and 7), thermal maturity in terms of Vitrinite reflectance (VRo) (Fig. 8), prospective area (Fig. 9) and shallow depth of occurrence (due to basin inversion, Fig. 10).

During Late Jurassic-Cretaceous

Maximum unconventional shale gas and oil are found to be concentrated in marine sediments of Paleozoic (Fig. 11) and Mesozoic period (Fig. 12) respectively.

In the same way, the total recoverable shale gas and oil are expected from Paleozoic (Fig. 13) and Mesozoic period (Fig. 14) respectively.

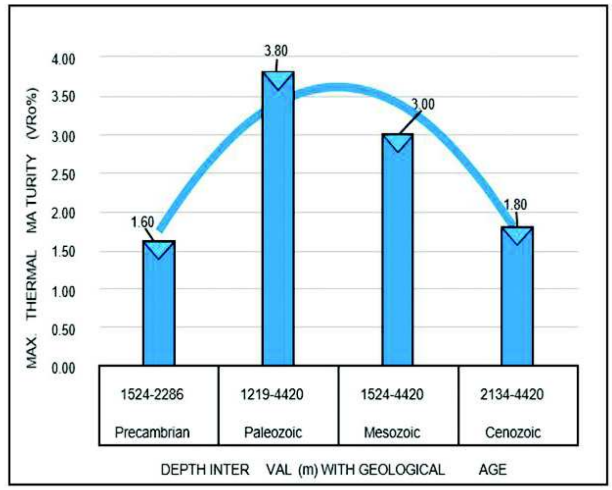

Fig. 8: Age-wise Max. Thermal Maturity *vis-a-vis* Depth Interval of World Shale

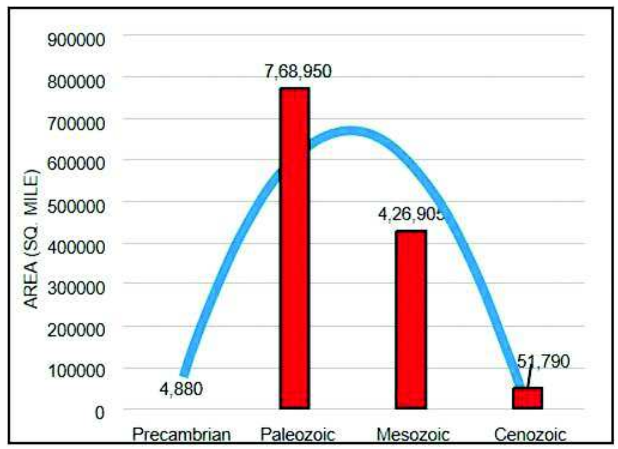

Fig. 9: Age-wise Total Prospective Area of World Basins for Shale Gas Exploration (in Sq. miles)

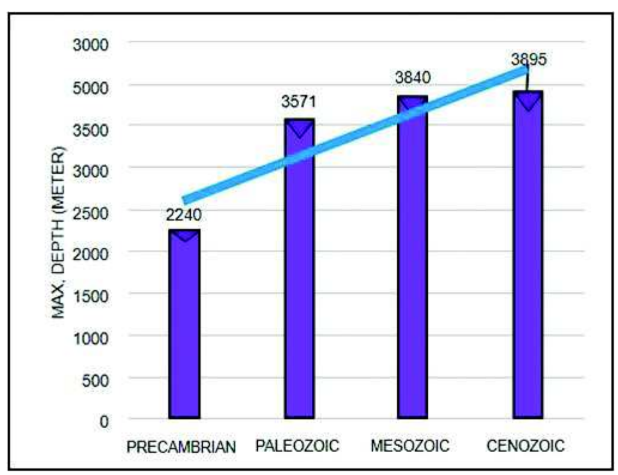

Fig. 10: Age-wise Maximum Depth of Occurrence of Shaly Horizons

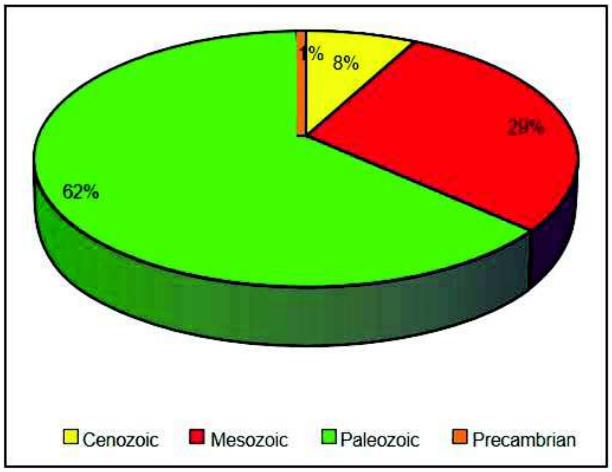

Fig. 11: Age-wise Total Gas In Place Different Shale Sequences of the World

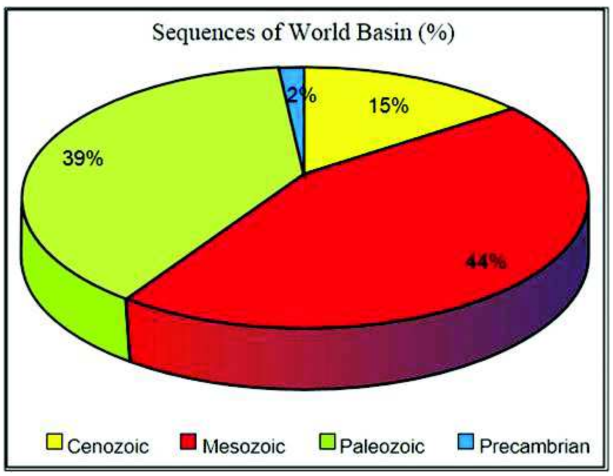

Fig. 12: Age-wise Total Oil In Place in different Shale Sequences of World Basins (%)

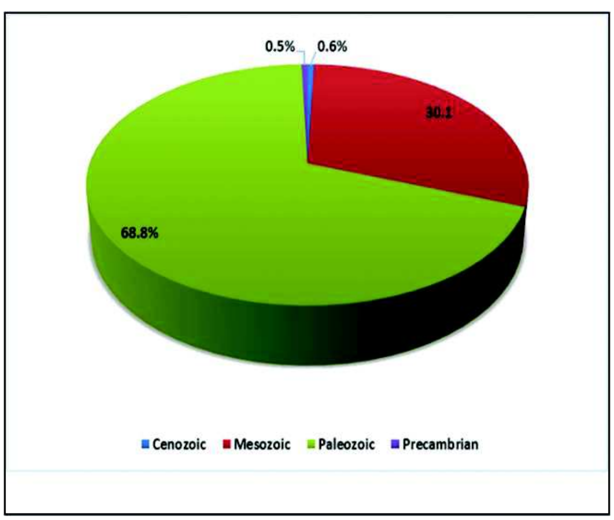

Fig. 13: Age-wise Total recoverable Shale Gas of World Basins

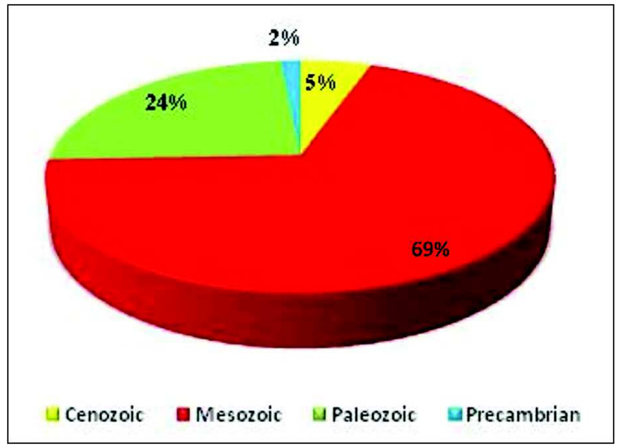

Fig. 14: Age-wise Total recoverable Shale Oil of World Basins

It is postulated that different types of organic facies are deposited under different depositional environment (Fig. 15).

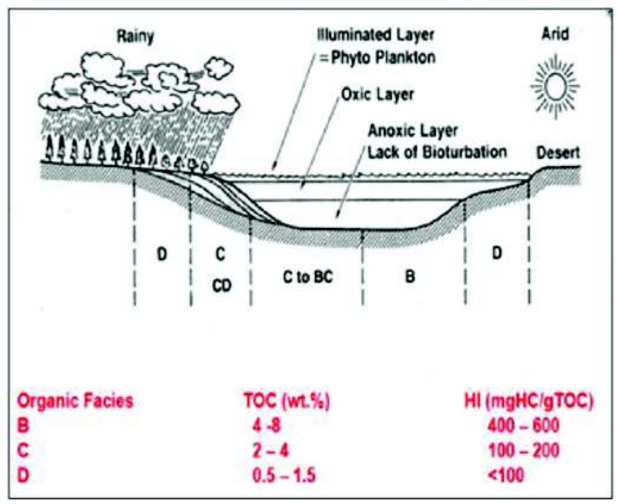

Fig. 15: Age-wise Total recoverable Shale Oil of World Basins

Marine organic facies (BC) of dominantly Type II/I kerogen are deposited under deeper part of basin while terrestrial organic facies (CD) with dominantly Type III/ II are deposited in basin margins. Paleozoic and Mesozoic basins are mainly marine basins (Fig. 16) which contain maximum concentration of unconventional shale oil and gas deposits. Global distribution of total shale formation shows low to high clay content (Fig. 17) and majority of Cenozoic shale formations (>50%) are characterized by high clay content due to their non-marine to shallow marine depositional settings.

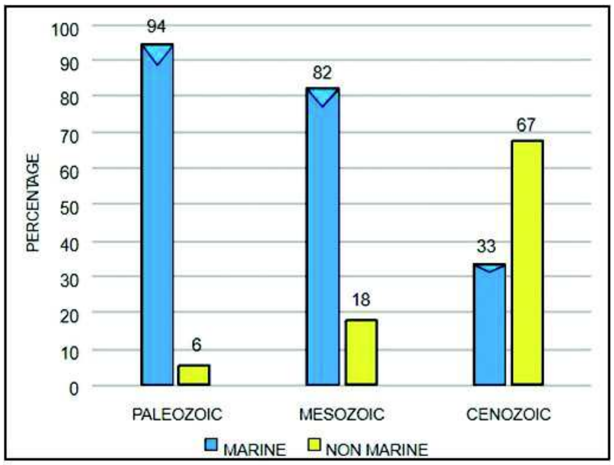

Fig. 16: Depositional Environment during different Geological Time

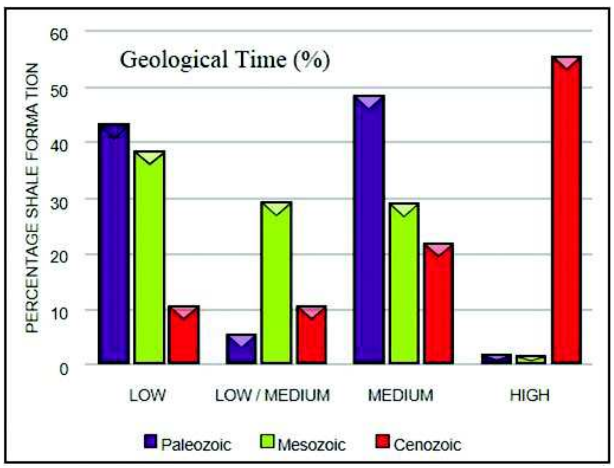

Fig. 17: Global Shale Formations vis-a vis Clay Content with Geological Age

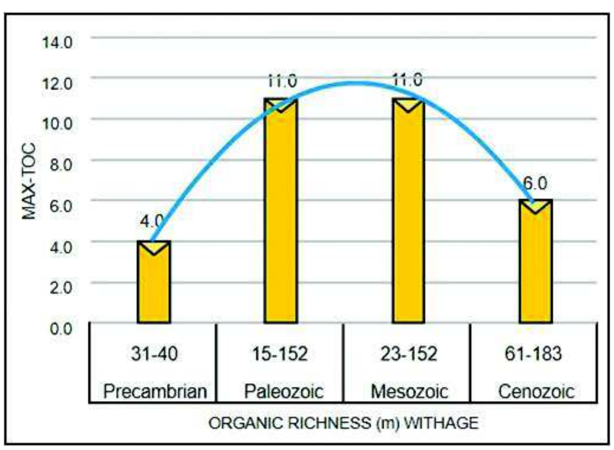

Fig. 18: Maximum TOC *vis-s-vis* Organic Richness of Shale

The studies carried out by EIA of USA in 2013 have suggested that the average Total Organic Carbon (TOC) content is around 11.0% in both Paleozoic and Mesozoic and 6.0% in Cenozoic period (Fig. 18). The thickness of shale sequences are also high both in Paleozoic and Mesozoic period. The organic rich shales are over-mature (VRo>4%) in Paleozoic, Late mature (VRo 3.0-3.6%) in Mesozoic and in Early-Peak mature stage in Cenozoic period VRo-0.85-1.8%. The average Tmax (Tmax is the temperature at which the maximum rate of hydrocarbon generation occurs in a kerogen sample during pyrolysis) is >470°C in Paleozoic, around 465°C in Mesozoic and < 450°C in Cenozoic period, which is in good correlation with VRo values. The shale plays of Paleozoic are in dry gas generation phase while associated gas is mainly confined to Cenozoic period.

Indian Scenario

A number of Indian sedimentary basins possess huge volume of organic rich shale rocks deposited through wide geological time. Beginning with the oldest, these may be summarized as Proterozoic in Vindhyan Basin, Neo-Proterozoic-Cambrian in Ganga Basin, Permian in Krishna-Godavari (KG), Pranhita-Godavari (PG), Damodar, South Rewa and Satpura basins of Gondwana, Cretaceous in KG, Cauvery basins and Paleogene in Cambay and Assam & Assam-Arakan basins. EIA study (2013) covered four Indian rift basins viz. Cambay, Krishna-Godavari, Cauvery and Damodar Valley for shale assessment.

Cambay Basin

In Cambay rift basin, there are alternating sequences of organic rich and organic poor intervals in Cambay Shale. Total Organic Carbon (TOC) content in South Cambay Basin is relatively lower (1-2%) with higher maturity (wet gas window) being observed at greater depth. In North Cambay Basin, the TOC content, in most parts, is more than 3%. Younger Cambay Shale is in immature to early oil generation stage and Older Cambay Shale is in oil window in North Cambay Basin while Younger Cambay Shale is in early oil generation window and Older Cambay Shale is in peak oil window in South Cambay Basin. Overall, the organic matter hereis mainly in early to late oil generation maturity window (VRo 0.6 to 1.2%). Cambay Shales have predominantly Kerogen Type III (D) with minor contribution of mixed Kerogen Type III/II (C/D)

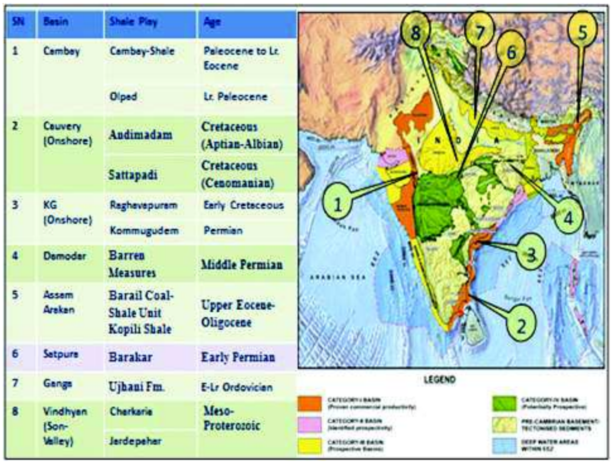

Fig. 19: Onland Shale Gas/Oil Play of different basins: (1) Cambay (2) Cauvery (3) K-G (4) Damodar (5) A&A-A (6) Satpura (7) Ganga and (8) Vindhyan (Padhy and Das, 2013)

organic facies which is suggestive of non-marine to shallow marine depositional environment. It contains a very high percentage of clay (>50% dominated by Chlorite and Kaolinite). Water saturation is very high (>80%) with very low permeability (in hundreds of nanodarcies). Porosity in Cambay Shale is rather good, averaging around 11-12%.Focus of shale gas/oil exploration is kept limited to the depth of higher TOC units. Adsorption isotherm data from recently drilled shale wells indicate fair storage capacity (2-3 scc/g) and desorption data indicate under charging of the reservoirs with most values being less than 2.0 scc/g. The thermal maturity parameters and gas composition data of the Paleocene-Early Eocene source facies (Cambay Shale) of Cambay basin indicates a predominant Shale Oil Play system. Subsequently, Shale Oil Play system has been established through one well in South Cambay basin after hydro fracturing.

Krishna-Godavari Basin

Two potential shale units have been identified in the basin. These are:

i) Lower part of Cretaceous Raghavapuram Shale (High Gamma-High Resistivity unit) and lowermost part of HG-HR unit (Basal Transgressive Unit, BTU).

ii) Permian Kommugudem Shale Formation. In NE-SW trending KG basin, TOC content varies from poor to fair in Raghavapuram Shale and is relatively higher (>2%) in upper argillaceous part of Nandigama Formation. Thermal maturity in deeper Raghavapuram is good with VRo ranging from 0.85 to 1.1%, however in deeper Nandigama it is 1.2%. TOC of Kommugudam Shale ranges from 2-8% with VRo values ranging from 0.8 to 1.2%. Organic matter is predominantly Type III.

Basal Transgressive Unit, in and around Gajulapadu-Lellapudi-Lingala areas in West Godavari PML block is characterized by higher values of TOC (6% to 9%), higher S2 (6-9 mg HC/g rock), high gamma, high resistivity (80 to 150 ohm) as observed in few wells in these areas. Its characters are similar to any successful shale gas reservoir of North American basins. Good thermal maturity is indicated by VRo value of about 1.1% at 3225m in well Lellapudi-A. This unit may show better potential for shale gas and oil.

Desorption results in three shale wells show poor to moderate gas content, average being around 1.5 scc/g and maximum around 2scc/g. Raghavapuram shale have uniformly high clay percentage. Based on the thermal maturity and gas composition, the Early Cretaceous source facies (lower part of Raghavapuram) is considered to be predominantly a Shale Oil system. The envisaged Permian play (Kommugudem Shale) in KG basin could be a Shale gas play system.

Cauvery Basin

In NE-SW trending Cauvery basin, TOC data collected from three shale wells is fair to good in most parts of Andimadam Formation and consists of alternations of shale and sand/silts. It is expected that generated hydrocarbons might have migrated to thick sandstone/siltstone units and acting as conventional reservoirs. Kerogen is dominantly Type-III with some input of Type-II. Upper Andimadam is in early to peak oil window (VRo 0.8%). Deeper section has attained higher maturity with a VRo value of 1.1% at 4600m.

Desorption results show poor to moderate gas content, maximum being around 1.5 scc/g. Many of the sand layers have high water saturation. Moreover, shales have high percentage of clay content.

Assam & Assam-Arakan Basin

The important source rock sequences in Assam and Assam-Arakan basin occur within the argillaceous Kopili Formation (Upper Eocene) and in the Coal-Shale Unit of the Barail Group. TOC in Kopili shale is poor to fair in most parts with average value of 1-1.2% only. The average TOC of the Barail Coal-Shale Unit is about 3.8%. The organic matter is of terrestrial Type-III with varying contributions of Type-II. Thermal maturity even at depths 4200m is low (VRo around 0.4- 0.5%). It is envisaged that the source sequences within the Kopili and Barail formations in the subthrust would be at the peak oil generating state. In the Schuppen Belt, the Disang shale is characterised by presence of excellent source rock characteristics with TOC around 4% and VRo varying from 0.69% to 1.94%.

Gondwana Basins

In Gondawanic rifted Satpura basin, TOC of Barakar Formation is found to be moderate to very good. Vitrinite reflectance studies suggest the Barakar Formations to be still within the oil/gas window (Padhy and Das, 2013). The nature of the organic matter varies from entirely gas-prone Type-III to upto 80% of algal and plant wax Type-II material in a few samples.

Ganga Basin

In Proterozoic to recent sediments of Ganga Basin, no commercial hydrocarbons have been discovered so far. Exploratory data generated in drilled wells indicates the presence of thin but organic-rich beds with good to fair hydrocarbon generation potential within the Ujhani Formation. The sediments were deposited in a marginal marine to shallow marine environment.

Vindhyan Basin

The source rock potential of Meso-Neoproterozoic shallow marine Vindhyan sediments viz., Kajrahat Limestone, Jardepahar Porcellanite, Charkaria Olive Shale, Rohtas Limestone and Bijaigarh Shale are likely to have generated hydrocarbons and are in the wet to dry gas phase of thermal maturity, especially in the southern part.

Shale Gas/Oil Potential of Indian Shales

The studies carried out by various agencies suggested that globally total Risked Gas-inplace (GIP) is approximately 21048 Tcf and the total Risked recoverable shale gas is approximately 4450 Tcf. The contribution of India in total Risked GIP is approximately 584 Tcf (2.8% of total Risked GIP of global shale gas, Fig. 20).

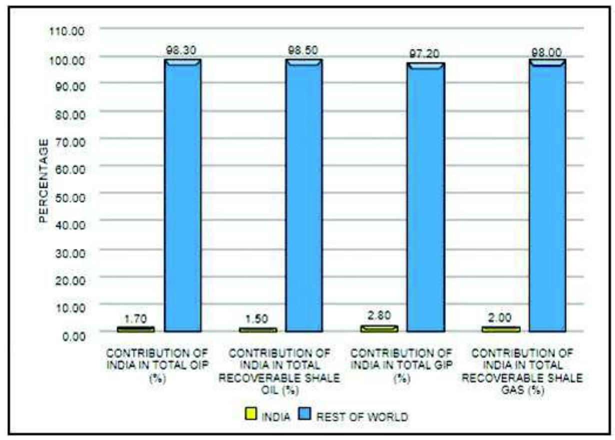

Fig. 20: Contribution of India *vis-a-vis* World in Shale Gas and Oil (%)

The contribution of India in total Risked recoverable shale gas is approximately 96.3 Tcf (2% of total technically recoverable global shale gas). Globally the total Risked Oil-in-place (OIP) is approximately 5059 Bbbl and the total Risked recoverable shale oil is approximately 251 Bbbl. The contribution of India in total Risked OIP is approximately 87.3 Bbbl that is 1.7% of total Risked OIP of world shale oil. The contribution of India in total Risked recoverable shale oil is approximately 3.75 Bbbl that is 1.5% of total technically recoverable Shale oil (Fig. 20).

As discussed earlier, the potential shale formations of Indian sedimentary basins are Cambay Shale in Cambay, Kommugudem and Raghavapuram in KG, Sattapadi-Andimadam in Cauvery and Barren Measures in Damodar basins. The contribution of these shales have been summarized in Fig. 21.

Govt. of India Initiatives

Following the success of shale gas/oil as an unconventional source of energy in North America

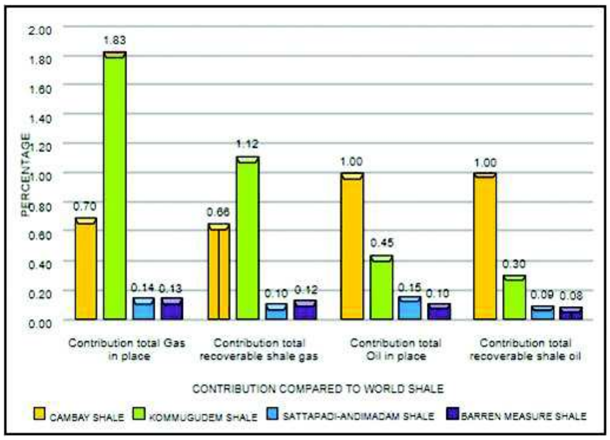

Fig. 21: Contribution of Indian Shales *vis-a-vis* World Shales in Shale Gas and Oil (%)

and in its effort to boost the domestic oil and gas production, GOI announced policy guidelines for exploration and exploitation of shale gas/oil in October 2013.

As per this policy, the national oil companies (NOC), were mandated to carry out shale exploration in their nomination blocks on obtaining necessary environmental clearances from the MoEF&CC in different sedimentary basins in the first phase of three years.

ONGC's Initiatives in Shale Exploration

ONGC began its shale gas/oil exploration in the year 2010 with a pilot shale gas/oil drilling programme in Damodar Valley under a special dispensation from GOI. Under this programme, based on detailed G&G studies of Permian Barren Measures Formation in Damodar Valley, ONGC drilled two wells each in Raniganj and North Karanpura coalfields in 2010-11. Gas flow to surface was observed in one well drilled in Raniganj area upon hydro-fracturing of an interval in the Barren Measure Formation. A joint study was carried out with M/s Conoco Phillips of USA (COP) in four basins namely Cambay, KG, Cauvery and Damodar Valley for evaluating the shale gas/oil potential and identification of prospective areas.

Based on the data available from earlier drilled wells for exploration of conventional hydrocarbons, four Category-I basins (Cambay, KG, Cauvery and A&AA), were prioritized in the Phase-I. Wells drilled for shale exploration are either exclusive shale wells or dual-objective wells to generate shale specific data to identify sweet spots for hydro-fracturing. This involves extensive coring in the target shale horizon with laboratory studies covering the fields of geochemistry, sedimentary petrology, petrophysics, rock mechanical properties, porosity and permeability and gas desorption-adsorption studies.

Phase I shale exploration activities undertaken by ONGC, so far, may be summarized below:

a. 27 wells (9 exclusive shale wells and 18 dual objective wells) have been drilled across four basins of Cambay, KG, Cauvery and A&AA Basins.

b. 113 cores measuring about 1627m have been cut in addition to recording of standard and special logs.

c. Extensive shale specific data have been generated in ONGC as well as Weatherford laboratories.

d. After analysis of all available data, 'Prospective zones' have been identified and tested after hydro-fracturing.

e. The efforts have helped in improving our knowledge base and understanding prospective Indian shales.

f. Presence of shale oil play system has been established in Cambay Basin as well as Gudivada graben in KG Basin.

Comparison of Indian Shale *vis-a-vis* Global Shale Plays

There are different geological, geochemical, petrophysical and geomechemical parameters like kerogen type, thermal maturity, depth and thickness of shale, gas content, porosity, permeability, hydrocarbon saturation, mineralogical attributes, hydrogen index, TOC, free hydrocarbon (S1) and hydrocarbon generation potential (S2) etc. which are used to provide a first order overview of the geologic characteristics of the major shale gas and shale oil reservoirs. These help in selecting shale gas and shale oil basins and potential shale sequences for more intensive assessment. On the basis of the data generated so far, it has been observed that:

1. Indian shales are rich in clay content (>50%)
2. The shale is characterized by low matrix permeability (in NanoDarcy)
3. The depositional environment is shallow marine to non-marine.
4. The reservoir pressure is mostly normal to slightly over-pressured (locally)
5. The shale sequences are generally organic rich with average TOC content ranging between 1.0 and 3.5%.
6. The organic matter is mostly in early to late oil generation maturity window (VRo:0.6-1.2%)
7. The kerogen is primarily Type-III with minor contribution of Type-II organic matter.
8. The average depth of shale sequence is high (2500-5000m).
9. Low resource concentration.
10. Low oil saturation.

Summary Status

Hydro fracturing in two wells in Cambay and one well in KG Basin have resulted in influx of little amount of oil on extended activation, thus establishing the presence of shale oil play system in Broach depression of Cambay Basin and Gudivada graben of KG Basin.

Although presence of shale oil system is established in these wells, the influx was not encouraging, apparently due to poor reservoir properties (high clay content) and multiple layers of thin silt laminations at greater depths.

After drilling of few wells in South Cambay basin, the focus has now shifted to North Cambay Basin. Although the shales in North Cambay are less mature, they are shallower and show better reservoir characteristics. A well drilled recently in Nawagam and Nandej area gave hydrocarbon shows within the Cambay Shale. One or two of the identified zones in these wells are planned for HF in the near future. A few more wells are planned to be drilled in North Cambay Basin subsequently.

In KG Basin, the Basal Transgressive Unit (BTU) of Raghavapuram Shale in Gudivada graben was targeted in one well. Although the zone looked promising, on hydro fracturing, it yielded a minor influx of oil on extended activation and does not appear to be very promising in this area. Evaluation of Kommugudem formation of Permian age is yet to be taken up for drilling in this Basin.

In Cauvery Basin, the target sequence of Andimadam is predominantly arenaceous and the intercalated shales showing only moderate thermal maturity, do not seem to be very prospective. In addition, stiff local resistance to shale exploration has hampered further work in the basin, while in A&AA Basin, the very low thermal maturity in the available nomination blocks makes it unfavourable for presence of shale hydrocarbon.

Environmental Concerns

Shale oil/gas has received a great deal of attention recently for the potential negative impacts that its development might have on the environments and communities in which it is explored/developed. Instances of ground water contamination, air pollution and earthquakes have been blamed on gas extraction activities. A thorough understanding of the techniques used to extract gas from shale formations and the safeguards that exist to prevent environmental damage is critical to assess the sources and magnitudes of risk involved in shale gas development.

The environmental hazards in shale exploration may be summarized below:

I. Excessive use of water for hydro-fracturing from few thousands to 20 thousand cubic metres per well causing depletion of aquifers in a water stressed country like India

II. Inappropriate disposal of drilling and fracking fluid leading to contamination of ground water and surface water resources

III. Requirement of vast land cover in comparison to conventional oil and gas exploration in an ever shrinking land area due to urbanization.

IV. Environmental pollution due to excessive movement of hydro-fracturing equipment and machinery.

Shale oil/gas exploration, hence, will not only have contractual, fiscal and technical challenges, but also those related to environment and capacity building. In view of stagnant oil and gas production and rising import dependency in India, it will be well worth the effort to address the above challenges to exploit our shale oil/gas resources with proper safeguards.

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