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Shale Gas: A Non-conventional Hydrocarbon as Future Energy Resource of India

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Abstract: Shale gas, despite being trapped in low permeability horizons, has gained a big boom in recent years that can be utilized to partially meet the ever increasing demands of the conventional natural gas. The major assets of hydrocarbon potential are widely distributed over India. The Brahmaputra valley of NE India, the Cambay region of Gujarat coast, the west coast offshore and the east coast offshore regions are the potential areas from where the maximum hydrocarbon is tapped. In India approximately two-third production is shared by the offshore regions while the rest is contributed by the onshore regions. The average annual production of oil and gas does not meet the demands hence, dependency lies more on imports. The projected demand may increase many fold by the end of this decade. The continuous increase in demand leaves no option except to enhance R&D activities in order to explore extensively for the unconventional resources namely Coal Bed Methane, Tight reservoirs, Shale Gas, Underground Coal Gasification, Gas Hydrates etc. Except the Coal Bed Methane and the Shale Gas, the knowledge and efforts towards other alternate resources are still in preliminary stage. The present study aims to highlight the importance of Shale Gas in filling the gap between demand and supply in the Cambay basin.

Keywords: Resource potential, Non-conventional hydrocarbons, Shale gas, Cambay basin.

INTRODUCTION

The geological system of India comprises of rocks that cover almost the entire spectrum of the Geological Time Scale (Fig.1). The country has vast sedimentary cover wherein; a total of 26 sedimentary basins have been identified. Based on the exploration carried out so far and the status of knowledge in terms of occurrence of hydrocarbons, these sedimentary basins have been divided into four categories, the proven commercial productivity; the identified prospectivity; the prospective; and the potentially prospective basins (Bhardwaj and Saini, 2010 and DGH, 2011) (Fig.2).

The paper is aimed to find out the hydrocarbon resources and the role of unconventional hydrocarbons energy for the self reliance of the country. In order to fulfill the gap between the rapidly increasing the demand and supply and to cope with the fast depletion of conventional energy resources, the unconventional hydrocarbon resources are supposed to create a balance towards sustainability. The shale gas along with the coalbed methane (CBM) could play a major role (Singh, 2011).

The current energy demands of India are mostly met from coal and hydrocarbons while nuclear and hydroelectric

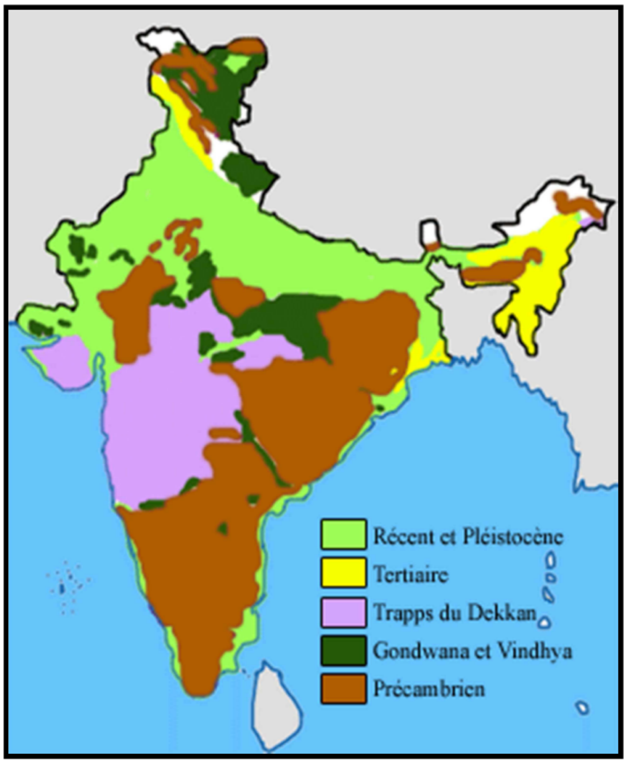


Fig.1. Geological map of India (source: Wikipedia)

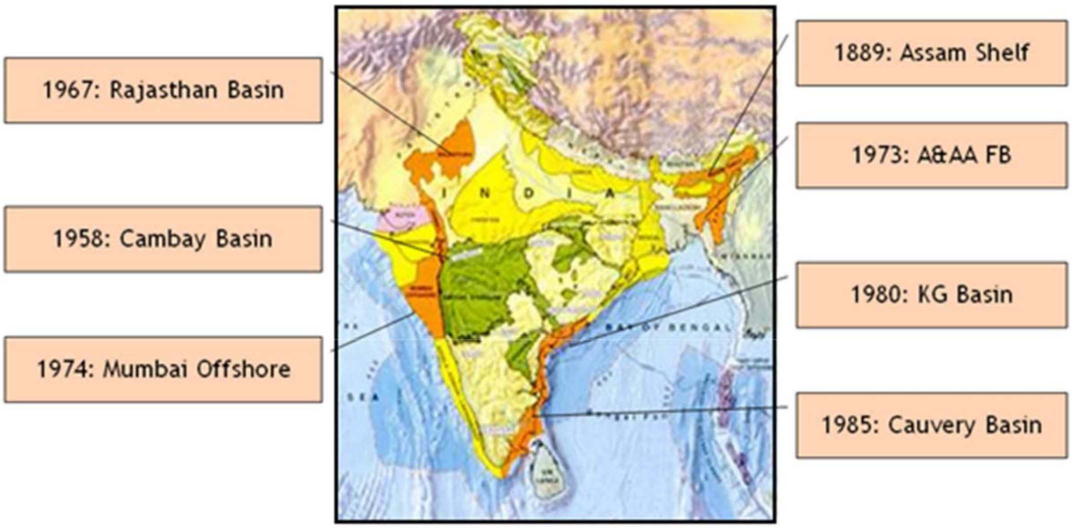


Fig.2. Petroliferous basins of India (source: Petroleum Federation of India, 2012, www.petrofed.org)

power resources contribute only a little (Fig.3). It becomes inevitable to assess the unconventional sources of energy especially the hydrocarbons, since India is an oil importer for decades that supports around 60% of its demands (Hasan et al 2013). The demands for natural gas may also require huge imports as the conventional sources are unable to meet such demands (Chandra, 1997). In India 18 areas have been identified for shale gas exploration that are associated with active or potentially prospective petroleum basins (Thusu et al 2011). Despite being trapped in low permeability horizons the integrated field and laboratory approach for shale gas assessment and development will help evolve the best sustainable targets (Hasan and Farooqui, 2011).

In India overall petroliferous basins are found throughout the Phanerozoic but the commercial hydrocarbon discoveries are reported from Cenozoic succession (Bhowmick and Misra, 2010). The categories of proven petroliferous basins with commercial production include Mumbai Offshore, Cambay, Assam-Arakan, Cauvery, Krishna-Godavari and Tripura-Cachar basins. Another category of basins with known occurrence of hydrocarbons, but without commercial production includes Andaman-Nicobar, Bengal, Mahanadi, and Himalayan foothills.

The current production and development can be seen from the trend (Figs. 4 and 5) that gives an idea regarding the future production and more search for prospects of unconventional reserves (IHV-2025). The document (IHV-2025) encourages the use of natural gas as eco-friendly fuel and to tap its unconventional sources and to develop hydrocarbon sector as a globally competitive industry that could be benchmarked against the best in the world through technological upgradation and capacity building.

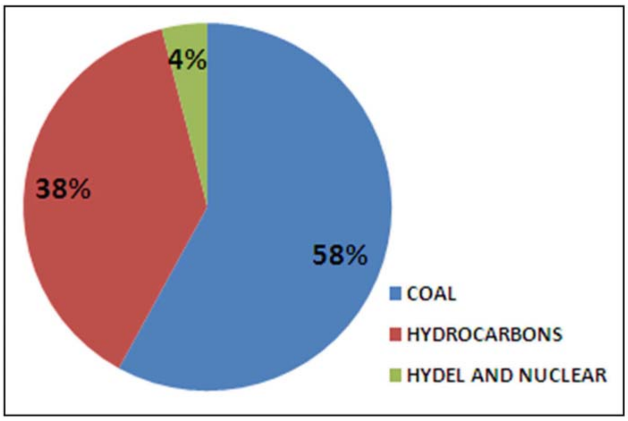
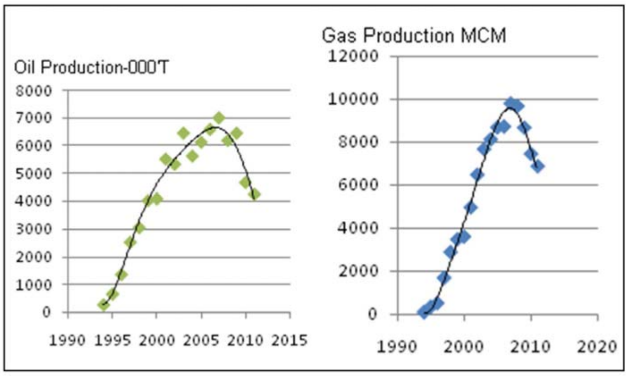


Fig.3. Energy scenario of India (modified from Chandra, 1997).



Figs.4 and 5. (4) Oil Production in India. **(5)** Gas Production in India (Data compiled from the Directorate General of Hydrocarbons, source: www.dghindia.org)

Unconventional Hydrocarbon Resource

The natural resources are distributed log normally in nature (Figs.6 and 7) in the sense that the deeper one goes in the gas-resource triangle, the lower the reservoir grade is seen which is usually because of the decrease in the reservoir permeability. The low-permeability reservoirs are considerably larger in size than the high-quality reservoirs (Holditch, 2006). The low-quality deposits of natural gas require improved technology to develop and produce economically.

Only one third of the hydrocarbon reserves of the world are conventional while the remaining sources are non-conventional (Fig.8). Because of the faster depletion of conventional resources and rapidly increasing demands from various sectors, India along with other countries have started exploring the alternative conventional energy.

The unconventional hydrocarbon sources include the tight gas sand, coal bed methane, shale gas/oil, gas hydrates

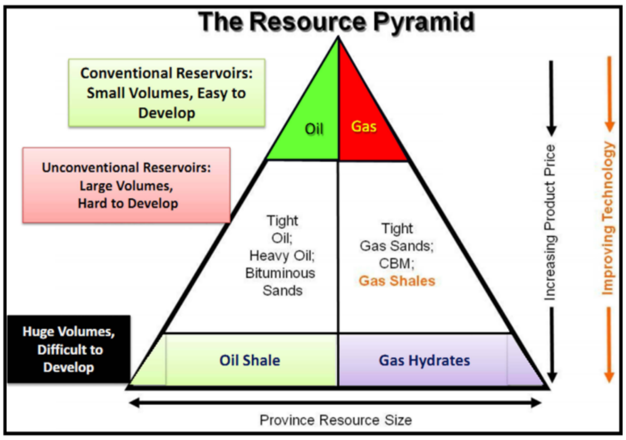


Fig.6. Resource triangle for natural gas (after Holditch, 2006).

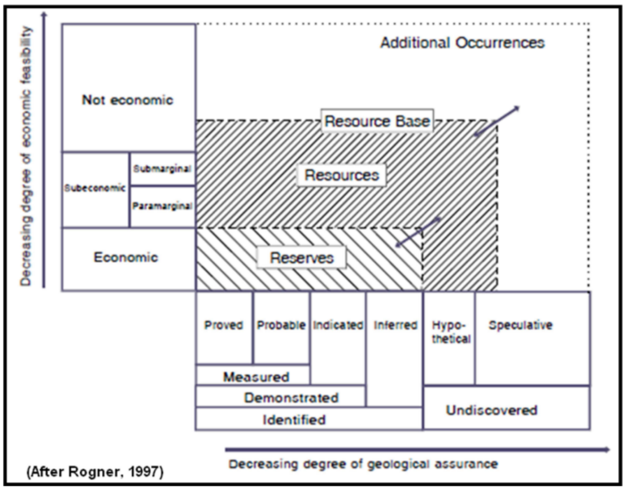


Fig.7. Classification of energy reserves and resource.

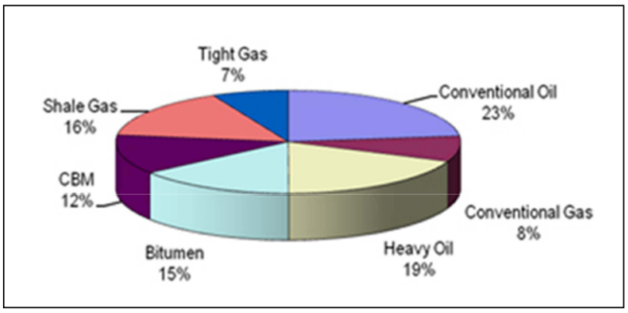


Fig.8. Worldwide hydrocarbon reserves (*after* British Petroleum, 1996).

and underground coal gasification (Cronquist, 2001). A tight gas reservoir is one that cannot be produced economically as flow rates are stimulated by a large hydraulic fracture treatment and/or produced using horizontal wellbores (Holditch, 2006). The coal bed methane refers to methane adsorbed into the solid matrix of the coal. Due to the increasing demand and price escalation, compelling environmental challenges due to global warming, indeed, the coal and coal bed methane have become dearer all over the globe (WCI 2005). Gas hydrates are ice like compounds in which gas molecules are engaged in interstices of hydrogen bonded water lattices at low temperature and high pressure. The variation of elastic velocities and relative permeability with respect to the concentration indicates that the dominant effect of gas hydrate in the pore space is the pore-filling characteristic (USGS, 2008). Underground coal gasification is an in-situ gasification process carried out in non-mined coal seams using injection of oxidants and bringing the product gas to surface through production wells drilled from the surface. Barring few environmental hazards, this technique could increase the coal resource available for utilization enormously by gasifying otherwise unmineable deep or thin coals under many different geological settings (Sury, 2004). Shale gas / oil are natural hydrocarbons that are formed by being trapped within shale formations that typically function as source, reservoir and seal. The evolutionary history over the globe (Fig.9) and accumulation in India (Fig.10) highlight the huge prospects of further exploration and sustainable production (Hasan et al. 2013). The shale gas in Cambay basin is dealt in detail as a part of the present study.

Shale Gas in Cambay Basin

The Cambay basin is a narrow, elongated rift graben that extends from Surat in the south to Sanchor in the north (Fig.11). The basin began evolving following the extensive outpour of Deccan basalts during late Cretaceous covering large tracts of western and central India (Bhandari and

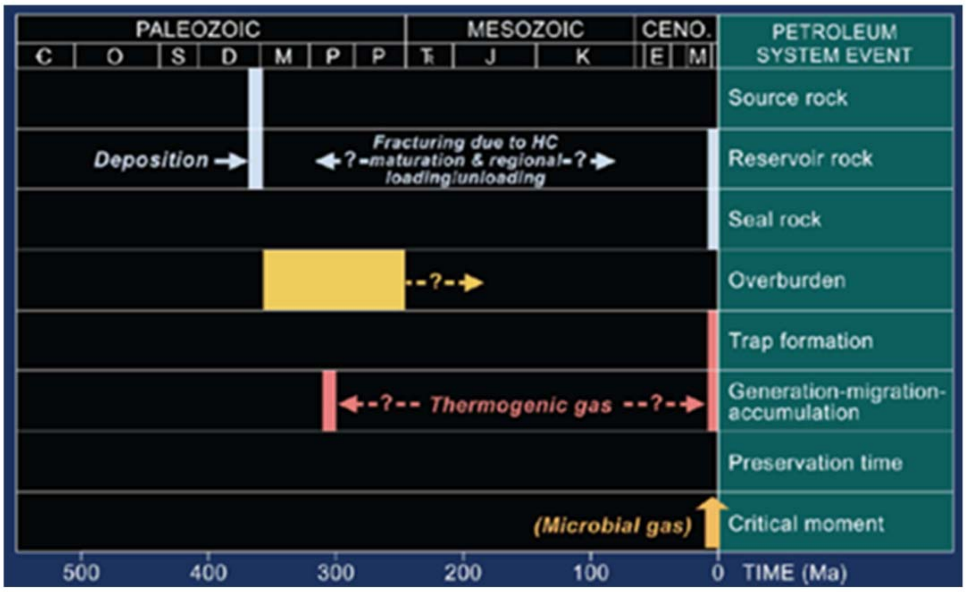


Fig.9. Evolution of shale gas (after Curtis, 2002)

Chowdhary, 1975; Biswas et al 1994, Kundu and Wani, 1992). It has been divided into five tectonic blocks from north to south as Sanchor, Ahmedabad, Tarapur, Broach and Narmada.

In the basin the sediments range in age from Paleocene to early Eocene representing syn-rift stage of deposition controlled by faults and basement highs in an expanding rift system (Balakrishnan et al. 1977). The middle Eocene witnessed a regressive phase with the deposition that developed the deltaic sequence in the entire basin (Biswas, 1977).

The thick shale has been the main hydrocarbon source

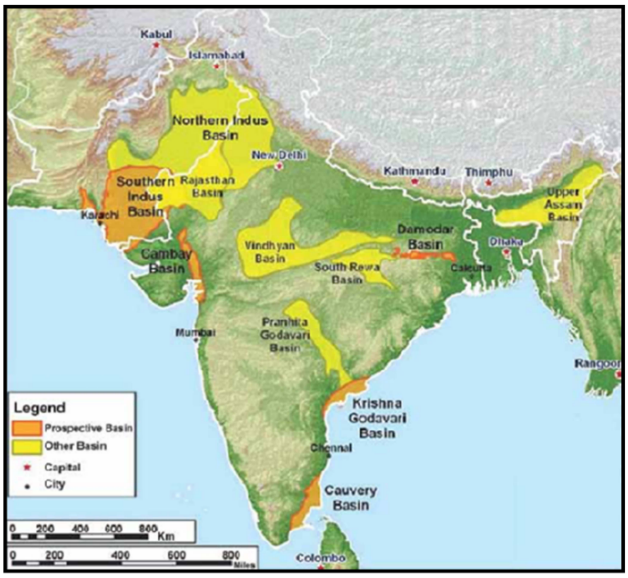


Fig.10. Potential shale gas basins of India (source: IUGF-2011)

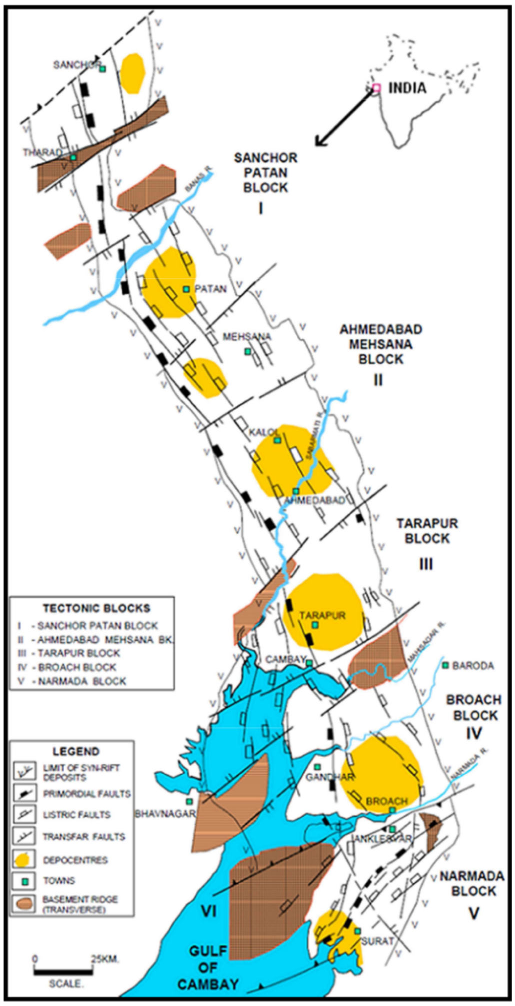


Fig.11. Tectonic map of Cambay basin (after Mishra and Patel, 2011)

rock in the basin wherein the lithological heterogeneity gave rise to permeability barriers, which facilitated entrapment of hydrocarbons (Fig.12). The proven reservoirs are dominated by sandstones, siltstones, conglomerates, fractured shales and basalts wherein the shales dominate the proven seals.

The oil and gas production trends, (Figs.13 and 14) highlights a decline during the recent years. To overcome the deficiency the shale gas reserves are the best alternative because of their larger extent. The production can be continued at a steady rate for decades (Frantz and Schlumberger, 2005). This can be incremented and made sustainable with the application and advent of newer technologies.

The Cambay shale has undergone different phases of maturation at different stratigraphic levels and depressions. After the expulsion of oil and gas from the shale in different depocenters, the remaining hydrocarbon generated has been trapped in pores, fractures and in kerogen surfaces either in free state or adsorbed state (Padhy and Das, 2013). Thus,

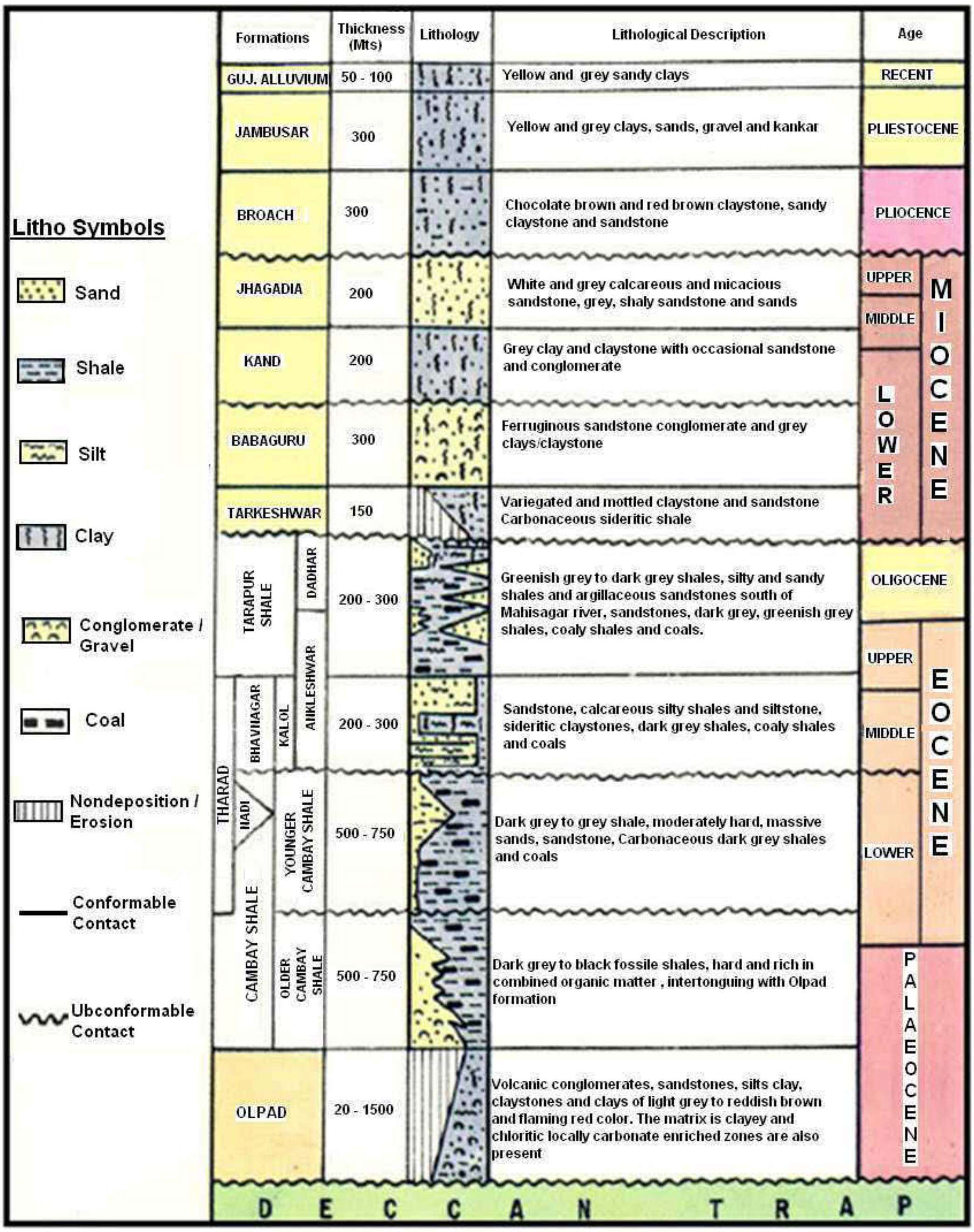
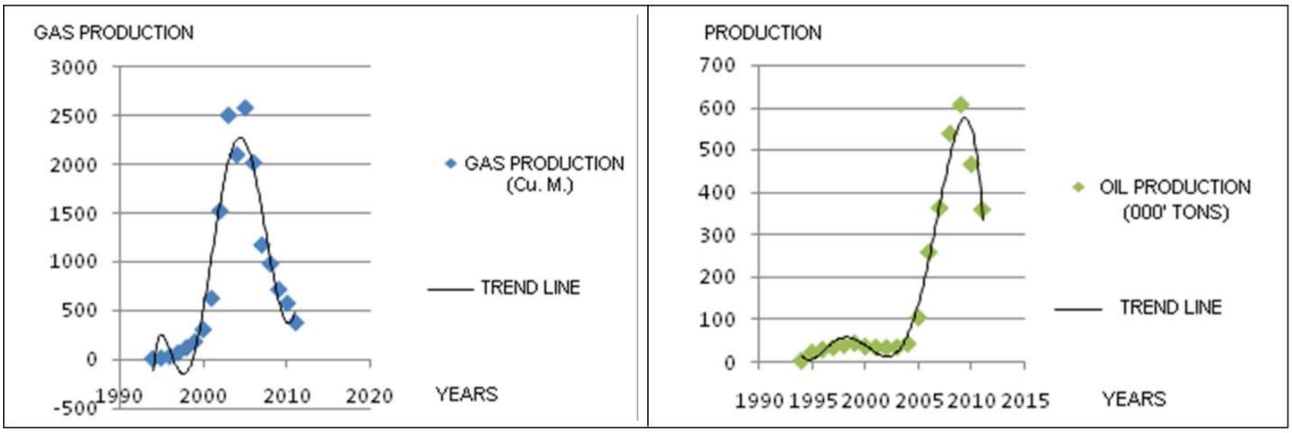


Fig.12. Shales in stratigraphy in Cambay basin (source: IUGF-2011).



Figs.13 and 14. (13) Oil production and trend in Cambay basin. **(14)** Gas production and trend in Cambay basin (Data compiled from the Directorate General of Hydrocarbons, source: www.dghindia.org)

these shales hold tremendous potential for generation and storage of gas. The total hydrocarbon generation is calculated on the basis of the widely accepted Schmoker (1994) approach. The range of total organic carbon (TOC) from 1.0 to 4.0 in Cambay shale and 0.2 to 3.6 in Olpad shale; the range of vitrinite reflectance in Cambay shale from 0.6 to 1.2 and in olpad shale from 0.4 to 1.8 and the kerogen type II and III (Table 1) together constitute the area as highly gas prospective to be exploited initially and subsequently evaluated with the appropriate technologies.

Other Proven Prospective Indian Sedimentary Basins

India has a number of organic–rich shale formations that include Krishna-Godavari, Cauvery and Assam-Arakan basins. In case of other basins, either the shales are thermally too immature for gas formation, or the data with which to conduct a resource assessment is not available. Figure 10 and Table 1 respectively highlights the location and extent and zones of shale characterization for further exploration, development and production.

The Krishna-Godavari basin is a proven petroliferous basin of continental margin located on the east coast of India (Gupta et al. 2000). The onland part covers an area of nearly 15000 sq. km and the offshore section covers around 25,000 sq. km up to 1000 m isobaths (Murty et al. 1995). Ranging in age from late Carboniferous to Pleistocene, the sediments show cyclicity reaching thickness upto 5000m and are marked by five major tectonic segments. Commercial hydrocarbon accumulations occur in the oldest Permo-Triassic sandstone (Murthy et al. 2011) onland to the youngest Pleistocene offshore channel levee complexes in deep water (Rao, 1991). The shale of Cretaceous and Permian age with thickness varying from 2000 to 1100 meters respectively have prospects for gas accumulation (Padhy and Das, 2013).

The Assam-Arakan basin is located in the northeastern part of India categorized as category-I basin covering an area of 116000 sq. km wherein, the potential fields, discovered till date, are situated mostly on the southeastern slope of the Brahmaputra arc and the other fields lie in a belt bordering the major thrust (Chandra et al.,1995). The basin comprises of coal-shale unit of late Eocene to Oligocene age with the thickness ranging from 50 to 500 meters and lying at a depth more than 2000 meters and shows prospects for gas accumulation for future development (Padhy and Das, 2013).

Table 1. Shale characteristics of prospective Indian sedimentary basins (modified after Padhy and Das, 2013)

Basin	Shale Play	Age	Thickness (m)	Depth (m)	TOC (%)	Tmax °C	VRo (%)	Kerogen Type
Cambay Basin	Cambay Shale	Paleocene-Eocene	500-2100	2000-4000	1.04-4.0	415-431	0.6-1.2	II & III
	Olpad Shale	Lower Paleocene	1500 Max	2500-4500	0.2-3.6	413-465	0.4-1.8	II & III
Krishna-Godavari Basin	Raghavapuram Shale	Cretaceous	2000 Max	1200-4500	1.0-4.7	430-514	1.0	II & III
	Kummugudem Shale	Permian	1100 Max	1700-4200	2.0-8.0	440-580	0.8-1.5	III
Cauvery Basin	Andimadam Formation	Albian	200-2400	1000-5500	0.5-3.2	430-450	0.75	II & III
	Sattapadi Formation	Cenomanian	120-570	2000-4000	1.0-3.0	435-450	0.6-1.13	II & III
Assam-Arakan Basin	Barail Coal Shale Unit	Upper Eocene-Oligocene	50-500	>2000	2.0-12.0	410-450	0.5-0.7	III

The Cauvery basin extending along the east coast of India covers an area of 1.5 lakh sq km comprising onshore (25,000 sq.km) and shallow offshore areas (30,000 sq km). In addition, there is about 95,000 sq km of deep-water offshore areas. This basin is a pericratonic rift basin and comes under category-I and marked with a number of sub-parallel horsts and grabens, trending in a general NE-SW direction. The source rocks are essentially of Albian-Cenomanian age and the reservoirs range in age from Albian to upper Cretaceous and Paleocene to Oligocene (Rangaraju et al. 1991). The formations of Albian and Cenomanian age respectively bear sufficient amount of entrapped gas at varying depth intervals (Padhy and Das, 2013).

Methodology

Time has come to infuse newer technologies that are harmonious with environmental norms and significant towards hydrocarbon value chain leading to energy security and prosperity (ASSOCHAM, 2011). The total organic carbon content, matrix porosity and water saturation are the key parameters controlling the shale gas potential of any basin. However, there are other auxillary components for shale gas development (Fig.15). Table 1 highlights the prospects of shale gas of Cambay basin and other prospective Indian sedimentary basins through physico-chemical parameters stratigraphically.

The Components of Approach

A. Field Work

1. Prioritizing the target for testing the methodology
- Collection of data
  - Geological, geophysical and geochemical data
  - Core and reservoir data
  - Testing details and production data
- Review of all available data.

B. Laboratory Work

1. Detailed core analyses with special reference to-
- Storage and transmission
- Mineral composition
- Chemical characteristics of reservoir rock
- Selection of applicable technique

2. Well data interpretation
3. Detailed structural mapping of pay zones using seismic and well data
4. Reservoir characterization using seismic and log data
5. Development of technology for incremental production in varied geological and reservoir conditions.
6. Testing the technique in a pilot prospect/well

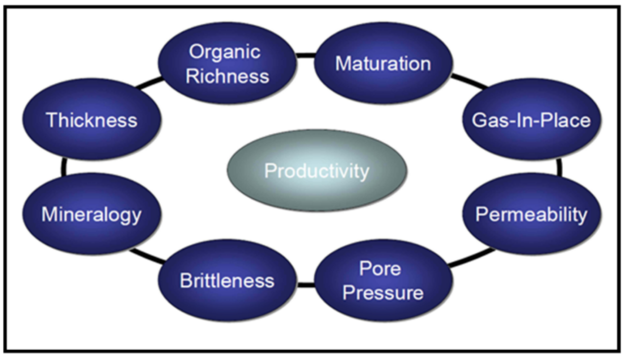


Fig.15. Elements for the development of successful shale gas play (source: PGA, 2011)

Expected Outcome

1. The result will provide the technologies to adopt for sustainable recovery
2. The findings decide the effective future predictions
3. The study will be a model for similar field conditions
4. Development, enhancement, adoption and absorption of technology

For production, the hydraulic fracturing is usually conducted with water based fluids using additives as friction reducer, scale inhibitor and proppants to keep fractures open (Kaufman et al 2008) hence, needs to address the environment concern as well (Porges and Hammer, 2001 and NRDC, 2007).

CONCLUSION

The continuous increase in demands and decline in production has the answer to move towards the resources which are unconventional but can be sustained with production with the application of advanced technologies. The shale gas appears to be an important segment of energy mix that requires thorough laboratory investigations to develop field based technologies for economically viable sustainable recovery rate.

The range of decisive parameters for the assessment of gas prospects in shales at varying depths in the Cambay, Krishna-Godavari, Cauvery and Assam-Arakan basins respectively include the total organic carbon content (0.2-4.0, 1.0-8.0, 0.5-3.0, 1.0-12.0% respectively), vitrinite reflectance (0.4-1.8, 0.8-1.5, 0.6-1.13, 0.5-0.7% respectively), thermal maturity (413-465, 430-580, 430-450, 410-450°C respectively). Since most of the blocks of the Cambay basin are under active exploration subsequent to the initial available data, the basin has a better prospect for the shale gas recovery.

The initial characterization vividly explains the prospect for future development with detailed R & D activities in the laboratory with the calibration of existing seismic and petrophysical informations. The integration of laboratory and field data will help in determining the best targets for perforation and stimulation followed by economically viable and sustainable production rate.

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