Status Report

Petroleum Exploration in India - A perspective and Endeavours

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(Received on 15 May 2016; Accepted on 25 June 2016)

Indian oil industry has come a long way since the first oil discovery at Digboi in 1889 through concerted exploratory efforts. Production of oil from a 5 barrels per day level from a single field in Assam has grown to more than 750000 barrels per day from over 50 major oil and gas in seven sedimentary Basins and is projected to attain 1 million barrels per day mark in near future. After Independence, oil and gas exploration was accorded high priority and was taken up by National, Private and International oil companies across the 26 sedimentary Basins covering an area of about 3.14 million sq. kms. Of the 26 sedimentary Basins, 7 Basins are producing oil and gas today. Sedimentary Basins of India are categorised into four categories based on their degree of hydrocarbon prospectivity as presently known. At present India's estimated hydrocarbon resource is of the order of 28 billion tonnes of oil equivalent (BTOE) and an Initial In-place volume of about 11.18 billion tonnes of oil equivalent (BTOE). A project for re-assessment of the resource potential of Indian Sedimentary Basins has been initiated by Government of India with active participation of ONGC, OIL and DGH in view of extensive availability of new data from all the Sedimentary Basins.

Current efforts are to enhance the production from category-I Basins with a focus on upgrading the Category-II Basins to Category-I Basins. Present paper outlines the endeavours during last few years through opening up of new areas, especially frontier areas of Proterozoic Basins of Vindhyan and Satpura, Deep offshore Basins of Bay of Bengal and Arabian Sea within Indian exclusive economic zone, Andaman fore-arc and back-arc Basins, unconventional sources of hydrocarbons such as Basement exploration, CBM (Coal Bed Methane), shale oil and gas, gas hydrates and leveraging the technology advances in Petroleum exploration.

Keywords: Petroleum; Resources; Reserves; Category; Basins; NELP; Frontiers; Unconventional

Introduction

Quest for Petroleum in India spans over 162 years since the first lease given in Assam by British government during 1854. A new chapter and challenging journey of Indian upstream Petroleum industry began with discovery of oil from the historic first well Digboi No:1 in 1889 barely 30 years after the first Drake Oil well was drilled by Col. E L Drake in Northwest Pennsylvania, USA. Indian upstream industry since then has travelled a long way through various socio-political changes and surged ahead with the economic growth of the country. Growth of Indian economy and the development of the upstream industry have always moved hand in hand. Sustained efforts by the Indian upstream industry have resulted

in discovery of more than 830 oil and gas fields including 50 major fields with an increase in production from an insignificant 5 bopd from a single field in Assam to present production of 750000 bopd across the country. Independent India witnessed an enhanced exploratory activity in its sedimentary Basins by the then newly created National Oil Companies leading to opening up of new Petroliferous Basins of Cambay, Rajasthan, Assam & Assam-Arakan fold Belt, the prolific Western Offshore, Krishna-Godavri and Cauvery Basins. The spectacular achievements by these NOC's have brought India into the World Oil Map. Sustained exploratory efforts by National Oil companies coupled with the initiatives by GOI in terms of New Exploration License Policy (NELP) has opened up the industry for exploration by International

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Oil and gas companies, as well as Private oil companies. As on date the Indian E&P industry is operated by over 117 companies consisting of 11 PSU's, 58 Indian Private Companies and 48 International/Foreign Oil and Gas Companies targeted to explore the 26 sedimentary Basins covering an area of 3.14 million square kilometres, including the deep water areas beyond 400m bathymetry.

Exploratory efforts by these companies resulted in accreting about 11187 MMTOE of in place hydrocarbon volume by 2015, an increase of 32% as compared to base year of 2006.

India's demand for fossil fuel by 2040 is estimated to grow by CAAGR (Compounded Annual Average Growth Rate) of 3.6% for oil and 4.6% for natural gas to keep pace with the projected economic growth. The oil import dependency of the India is predicted to rise to 90% from the current 70%. To meet the increasing energy demand Government of India has adopted several policies such as opening up of upstream exploration through competitive bidding under NELP during 1997-98, marginal field policy during 2015 and is now moving towards Open Acreage Policy model for future acreages under Hydrocarbon Exploration Licence Policy (HELP).

An overview of the status of exploration in the petroliferous Basins of India, their future perspective and the endeavours carried out by Indian E&P companies, especially Indian NOC's leveraging the advances in the technology for establishing producible hydrocarbons has been presented in the following paragraphs.

Sedimentary Basins of India

Exploratory efforts since 1850's by foreign private oil companies (Assam Railways and Trading Company Limited (AR&T), Assam Oil Company (AOC) and Burma Oil Company (BOC) and later by NOC's from late 50's and subsequently by private/foreign companies (1980) has resulted in expanding the geological knowledge of the Indian sedimentary Basins and about 88% Basinal areas are at various stages of exploration (DGH, 2011). These efforts have also aided in working out a scheme of tectonic classification of the Basins (Biswas *et al.*, 1993, Biswas, 1998, Ravi Bastia *et al.*, 2007) that was required for the detail Basin analysis. Multifold

increase in 3D seismic data acquisition led to many discoveries in challenging environments. Drilling of the deeper exploratory wells resulted in refining the geological models of the existing Basins and better understanding of their tectonic styles, sedimentation pattern and evolution.

Biswas *et al.* (1993) for the first time published a comprehensive classification of Indian sedimentary Basins using the Dickinson (1976) scheme of Basin classification based on the structural style, geometry and size, nature of stratigraphic fill and thermal history into 38 sedimentary Basins and grouped them in three main settings: (i) intracratonic, (ii) rifted, (iii) orogenic settings (Table 1) and regrouped into 26 sedimentary Basins based on the hydrocarbon proclivity.

Most of the Indian Sedimentary Basins are pericratonic, bordering the Indian plate radially. The northern Basins are bordered by orogenic belts of Himalaya and Assam–Arakan and are the peripheral foreland Basins subducting under the orogenic belt. The coastal pericratonic Basins, especially in the south are extending from onshore to offshore and are rifted Basins, separated by horsts. The Intracratonic Basins are rift Basins such as Gondwana Basins/grabens or structural depressions such as Vindhyan, Cuddapah, Kaladgi and Bhima Basins.

Petroleum occurs mainly in the marginal and pericratonic rift Basins. Occurrence of commercial petroleum from the northern foreland Basin is yet to be established excepting in the Upper Assam inter-orogenic foreland Basin – Assam Shelf situated on cratonic wedge between Himalayan and Assam–Arakan mountains. Tectonic setting and collision of the Indian plate created favourable habitat for generation and preservation of the hydrocarbons. Hydrocarbon discoveries from the Interior and Intracratonic rift Basins are so far elusive barring few gas indications; however, recent exploratory efforts are indicating encouraging results such as gas discovery from Proterozoic Vindhyan Basin.

The estimated prognosticated resource base of the Indian Basins is 28 BMTOE including the 7 BMTOE from deep water sector. As on 2015, exploratory efforts have resulted in estimation of Initial Hydrocarbon In-Place (IHIP) of about 11.18 BMTOE which is about 40% of the present prognosticated resources. Reassessment of the hydrocarbon

Table 1: Classification of Indian Sedimentary Basins (After Biswas *et al.*, 1993)

Category	Type	Basins	Status
I. Interior Basins	Intra-Cratonic Sags	1. Vindhyan Basin 2. Chattisgarh-Bastar Basin 3. Cuddapah Basin 4. Kaladgi Basin	Gas Indications
II. Rifted Setting	II _A Marginal Aulacogen	1. Cambay Basin	Oil and Gas producing Basin
		1. Kutch Basin	Oil and Gas – Emerging Basin
	II _B Pericratonic Rift	2. Saurashtra Shelf	Oil and Gas Indications
		3. Surat Basin	
		4. Bombay-Ratnagiri Basin	Oil and Gas producing Basin
		5. Konkan Basin	
		6. Kerala Basin	
		7. Western Bengal Basin	
		8. Mahanadi Basin	Gas discoveries – Emerging Basin
		9. Krishna-Godavari Basin	Oil and Gas producing Basin
		10. Palar Basin	
		11. Cauvery Basin	Oil and Gas producing Basin
		12. Mannar Basin	
	II _C Intra-Cratonic RM	1. Pranhita-Godavari Basin	
		2. Mahanadi Graben	
		3. Purnea Graben	
	II _D Intra cratonic Transtensional Basins	1. Satpura Basin	
		2. Son Basin	
		3. South Rewa Basin	
		4. Damodar Basin	
		5. Narmada Basin	
	II _E Miogeoclinal Prism	1. Deep Water Basins of West coast 2. Deep water Basins of East coast	Oil and Gas Producing Basins
III. Orogenic Settings	III _A Superposed Basins	1. Karewa Basin	
		1. Rajasthan Basin	Oil and Gas Producing Basin
	III _B Peripheral Foreland Basin	2. Punjab Basin	
		3. Ganga Basin	
		4. Lower Assam Basin	Oil and Gas Producing Basin
		1. Upper Assam Basin	Oil and gas Producing Basin
	III _C Inter-orogenic foreland Basin	1. Kohima forearc Basin	
		2. Tripura-Mizoram Forearc Basin	Gas producing Basin
		3. Andaman Basin	Gas Indications
	III _D Forearc Basins		
	III _E Remnant Ocean Basin	1. East Bengal Basin	

resources of all the Indian sedimentary Basins including the deep water areas has been taken up and is in progress.

Exploratory activities for hydrocarbons in the 26 sedimentary Basins were initiated as early as mid-50's and are continuing with varying degree of success.

These Basins were grouped under four major categories of I to IV (Rai *et al.*, 1998) (Table 2, Fig. 1) based on the exploration success and commerciality.

Depending upon the exploration results, Basins are upgraded. The number of category-I Basins rose from a single Basin in 1956 (Upper Assam Shelf) to the current 7 producing Basins due to sustained

LEGEND

- CATEGORY-I BASIN
(Proven commercial productivity)
- CATEGORY-II BASIN
(Identified prospectivity)
- CATEGORY-III BASIN
(Prospective Basins)

- CATEGORY-IV BASIN
(Potentially Prospective)
- PRE-CAMBRIAN BASEMENT/
TECTONISED SEDIMENTS
- DEEP WATER AREAS
WITHIN EEZ

Fig. 1: Map of Petroliferous Basins of India showing the categories (after DGH)

Table 2 : Category of Petroliferous Basins of India

Category	Basis for categorization of Sedimentary Basins in India
I	Proven Petroliferous Basins with commercial production Assam Shelf, Cambay, Rajasthan, Assam-Arakan fold belt, Mumbai Offshore, Krishna-Godavari and Cauvery Basins.
II	Proven Petroliferous Basins awaiting commercial production Kutch, Mahanadi-NEC (North East Coast), Basin, Andaman-Nicobar Basins.
III	Basins geologically considered prospective with hydrocarbon shows Himalayan Foreland Basin, Ganga Basin, Vindhyan Basin, Saurashtra Basin, Kerala Konkan Basin, Bengal Basin.
IV	Frontier Basins which are either poorly explored or having inadequate geological information or are rated poor based on present concepts and knowledge of petroleum geology but considered prospective by analogy with similar Basins in the world Karewa Basin, Spiti-Zaskar Basin, Satpura-South Rewa- Damodar Basin, Chhattisgarh Basin, Narmada Basin, Deccan Syncline, Bhima-Kaladgi, Bastar Basin, Pranhita-Godavari Basin, Cuddapah Basin

exploratory efforts aided with the right technology implementation.

The present paper deals with brief geological set-up, plays established and recent endeavours to enhance success ratio.

Assam Shelf, Assam-Arakan Basin (Category-I Basin)

The onshore Assam & Assam-Arakan Basin located in the north-eastern part of India is a poly history Basin which evolved in response to the movement of the Indian plate in relation to the Eurasian and Burmese plates. The Assam, Assam –Arakan Basins cover an area of about 116000 sq.kms. Tectonically, the Assam & Assam Arakan Basin has been subdivided in to two major Basins viz., Assam Shelf & Assam-Arakan Fold Belt. Part of the Assam Shelf lying to the north and south of the E-W trending Jorhat Wrench Zone has been designated as North Assam Shelf and the Dhansiri Valley (South Assam Shelf) respectively (Fig. 2).

The North Assam Shelf constitutes platform part of the Basin and represents the shelfal front. The Fold Belt of northeast India is a part of the outer wedge of the Indo-Burmese Arch. It runs through states of Arunachal Pradesh (North Eastern part of Naga-Patkai hills), Nagaland (Naga-Patkai hills), Assam (North Cachar hills and Cachar), Manipur (Laimatol Range), and Mizoram (Mizo hills) and to the west open folds of Chittagong-Tripura Hill tracts. Structural complexities and difficult terrain are an integral part of Fold Belt, which have influenced the exploration inputs and exploration strategy for this area.

The North Assam Shelf is extensively explored block of Assam Shelf. Exploration efforts of Fold Belt progressed from anticlinal crest to target subtle structural and geomorphic anomalies viz. Agartala Dome and Banskandi structure based on aerial photos, remote sensing studies and limited 2D seismic data, yielding fair amount of success.

Hydrocarbon Plays - Established and New Plays

Oil and gas are established from clastics reservoirs of Mio-Pliocene- Girujan, Miocene -Tipam, Oligocene –Eocene –Barails, Mid-Upper Eocene –Kopilli, Lower Eocene –Lakadong and Therria and from the fractured Archean Basement. The Miocene – Oiligocene –Tipam and Barail Formations contain most of the discovered oil.

Exploration of deeper plays (Tura and Basement) has been a major challenge in the Assam Shelf. Tura play (Palaeocene) is an exciting horizon in terms of deeper prospect exploration in entire North Assam Shelf and has potential to emerge as a significant play. Recent exploratory efforts by NOC's has resulted in risk-reward perception of Tura play and identification of prospects in Lakwa and Geleki fields in the northern part of Assam Shelf. There has been significant achievement in establishing fractured Basement and Kopili plays (Eocene) in southern part of the Assam Shelf in Khoraghat area which has opened up new area for exploration of deeper plays in the Assam Shelf.

New age data sets continued to consolidate the Miocene - Tippam Sands and the Barail Play (Oligocene) with identification of new exploration

Fig. 2: Tectonic Map of North-eastern India (after ONGC)

prospects. In the southern part of Assam Shelf Sylhet and Kopili plays are well established in Borholla-Champang fields and remain elusive in the rest of Dhansiri Valley. Taking these leads into consideration the focus of exploration is for establishing for Sylhet and Barail plays in the Assam-Arakan Basin. Bokabil play continue to be an attractive stratigraphic exploration play in southern part of Assam Shelf. In Fold Belt, elusive “Badarpur Oil Play” remains to be elusive for oil though few gas discoveries are reported. Naga up thrust Tipam Section has emerged as one of the attractive play in the north Assam shelf. Similarly the basement exploration in Khoraghat area has been rejuvenated with use of new technology DFN modelling (Discreet Fracture Network) and drilling of horizontal wells.

Cambay Basin (Category: I Basin)

The Cambay rift Basin covering an area of about 53,500 sq. km. is a Category-I Basin and encompasses

a narrow, elongated rift graben, extending from Surat in the south to Sanchor in the north. In the north, the Basin narrows, but tectonically continues beyond Sanchor to pass into the Barmer Basin of Rajasthan. On the southern side, the Basin merges with the Bombay Offshore Basin in the Arabian Sea (Fig. 3). Since the discovery of first exploratory well on Lunej structure near Cambay in 1958, more than 2300 wells have been drilled in the Basin by various companies.

Hydrocarbon Plays - Established and New Plays

The evolution of Cambay Basin from the petroleum point of view is fairly well understood and hydrocarbon accumulations are known in all sequences ranging from Paleocene to Miocene. Major accumulations are known in Middle Eocene structural traps over block uplifts and block edge folds. A few combination traps along block boundaries and over structural noses also occur. Early to Middle Cambay Shale has been established as major source rock, middle Eocene

Fig. 3: Tectonic map of Cambay Basin (after ONGC)

deltaic sands are major reservoirs and Late Eocene-Oligocene and Miocene Shales are regional cap rock in this Basin. The Broach depression in Broach block is the largest kitchen area for maturation of source rocks and the generation of hydrocarbons. Transverse highs played an important role in controlling the palaeo-drainage and distribution of sands. Most of the troughs are local generation centres for accumulation in the adjacent highs. There are several petroleum systems in the Basin and the most important one is the Cambay-Hazad Petroleum System(!) which is related to several large oil and gas fields.

The Cambay-Hazad(!) petroleum system in South Cambay Basin, has original in-place oil and gas reserves of 395 million tonnes. The system covers 9320 km² encompassing 20 different oil and gas accumulations. Carbon isotopic and biological marker data indicate that the low sulphur, high API gravity oil originated from the lower-middle Eocene Cambay Shale source rock. Burial and thermal history reconstructions indicate that oil generation and migration occurred from Miocene (21 Ma) to Recent. The overburden rocks are over 3 km thick and range in age from middle Eocene to Recent. The principal reservoir rocks are sandstone units of the Hazad and Ardol Members of the Ankleshvar Formation.

The essential elements of the petroleum system, consisting of the source, reservoir, seal and overburden rocks were deposited from early Eocene to Recent time and the critical processes of generation, migration, trap formation, and accumulation occurred from Miocene to Recent.

Although it is usually the new discoveries that capture the attention of the oil industry, 70% of the hydrocarbon liquids produced in the world today actually come from fields that have been in operation for more than twenty years: the majority of petroleum assets consist of "old" fields. With most of the world's potential oil provinces having already been explored and major new discoveries becoming increasingly rare, mature fields are slated to play an ever more prominent role in energy supply.

Currently exploration of the Cambay rift Basin is in matured stage and bears a good chance of maximizing the probabilities of discovering small fields in subtle traps. As most of the large accumulations have been located, the Basin is now being rated as

low risk/moderate reward category. Growth in oil and gas production expected from a combination of new field discoveries and effective management of existing acreage.

Rajasthan Basin (Category: I Basin)

The 1,26,000 sq. km of Recent sediment covered area to the west of Aravalli up to Pakistan border which is a part of the Thar desert, is designated as the Rajasthan peripheral foreland Basin (Biswas *et al.*, 1993). It is a part of the Indus Foreland. It is divided into four sub-basins/sectors (Fig. 4) viz., (i) Jaisalmer sub-basin (JB) on the north western slope of the Jaisalmer-Mari basement arch (JMA), (ii) Bikaner-Nagaur (BN) sub-basin on the northeast flank of the arch, (iii) Shahgarh-Miajlar (SM) sub-basin southwest of the arch and (iv) Barmer-Sanchor (BS) sub-basin south of the arch (extension of Cambay Basin). Recent discoveries of oil and gas from this Basin have enhanced the prospectivity perception.

Barmer-Sanchor sub-basin is a lacustrine failed rift comprising the sedimentary sequence of more than 6 km ranging in age from Mesozoic to Cenozoic with prolific Eocene source rocks. High quality reservoirs are encountered in the Upper Cretaceous-Paleocene syn rift deposits. Number of oil and gas discoveries like Saraswathi, Rageshwari, Kameshwari, Mangala, Aishwarya, Shakti, Bhagyam

Fig. 4: Sub-basins of Rajasthan Basin (after ONGC)

are some of the significant fields in Barmer-Sanchor sub-basin.

Hydrocarbon Plays - Established and New Plays

The Jaisalmer sub-basin is a Late Palaeozoic-Mesozoic Basin with Permian rocks resting unconformably over the Proterozoic Basement with gas discoveries of Manhera Tibba, Ghotaru Extn-I, South Kharatar, Chinnewala Tibba and Bakhri Tibba fields. The Bikaner-Nagaur sub-basin to the north has widely differing geological histories during Palaeozoic and Mesozoic times. This Basin has well developed Infra-Cambrian sequence. The Shahgarh-Miajar sub-basin is mainly Mesozoic Basin with thin cap of Palaeocene-Eocene rocks (300m) and a thin (200m) base of Permian rocks resting over the basement.

The Rajasthan Basin is mostly covered by desert sands excepting on the Jaisalmer-Mari basement arch (JMA) which is the only outcropping region besides a few scattered ones. Sequence from Middle Jurassic to Early Eocene is exposed in Jaisalmer sub-basin.

Apart from Barmer sub-basin, there is no Tertiary prospect in other sub-basins of Rajasthan. Excepting small satellite pools in the Paleocene section, the chance of another large discovery appears to be low. However, the Barmer discoveries indicate that the prospect of sizeable accumulation in Sanchor sub-basin cannot be ruled out. In Shahgarh-Miajar sub-basin, the Mesozoic are the main prospective targets, particularly the Cretaceous Pariwar, Goru, and Parh Formations. Deeper Cretaceous and Jurassic targets should be the primary focus in Shahgarh-Miajar sub-basin. In Jaisalmer sub-basin focus should be on combination and subtle traps in Jurassic and Lower Cretaceous plays, while more extensive exploration for heavy oil should be planned for the Bikaner-Nagaur sub-basins.

In Jaisalmer sub-basin, deeper Mesozoic plays like Baishakhi Badesir, Jaisalmer and Lathi of Jurassic age will form frontier plays. The finer clastics along with thin irregular sand bodies within Basisakhi Badesir Formation deposited in sub tidal to inner shelf environment may form stratigraphic/strati-structural prospects which are targets for future exploration. Similarly, the thick Jaisalmer limestone with occasional oolitic development may be another suitable promising exploration objective.

Western Pericratonic Rift Basins

The Basins of western continental margin of India (WCMI) situated on the western passive margin of the Indian plate evolved during the separation of Madagascar-Seychelles in Late Cretaceous between 90 Ma and 65 Ma. The rifting started in Late Cretaceous with syntectonic Deccan volcanic activity that continued till Early Paleocene. Early Paleocene to Early Eocene hiatus was the period of the rift-drift transition marked by a widespread unconformity in all the Basins. The post-rift thermal cooling resulted in sagging and the Basins evolved into a marginal sag initiating marine transgression.

Coast parallel Ridge-Depression couplets, Kori-Comorin Ridge-Depression and Laxmi-Laccadive Ridge/Depression, crossed by first order transverse basement arches are the major features of the WCMI structure (Biswas, 1989) (Fig. 5). The transverse

Fig. 5: Tectonic map of Western Continental Margin of India (modified after Biswas, 2008b) 1: Saurashtra Arch; 2: Bombay Arch; 3: Vengurla Arch; 4: Tellicherry Arch. Basin positions: - N of 1- Kutch Basin, Between 1 & 2: Surat Depression, 2 & 3: Ratnagiri Basin, 3 & 4: Kankan Basin, S of 4: Kerala Basin. SHG-Complex: Shelfal horst graben complex (after ONGC)

arches, from north to south are, Saurashtra, Bombay, Vengurla and Tellicheri arches which divide the shelf into five offshore sub-basins - Kutch, Surat, Ratnagiri (Bombay offshore Basin), Konkan and Kerala Basins (Biswas and Singh, 1988). Kori-Comorin couplet marks the edge of the present continental shelf, which is rifted developing a "shelfal horst-graben" complex. Each sub-basin extends offshore across the shelf, depressions and ridges. Thus, a shallow shelfal horst-graben complex, a shelf margin depression and ridge, a deep slope-parallel depression and an outer ridge (Laxmi) separating the Basin and abyssal plain are the characteristic structural domains of each sub-basin. Kerala, Konkan and Ratnagiri Basins are confined to offshore. The West Coast Fault terminates these Basins along the coastline.

Of the five sub-basins, Surat and Ratnagiri (Bombay) offshore Basins qualify as a Category-I Basins with its vast reserve of hydrocarbon contributing almost 70% of India's total oil/gas production. Kutch Basin is Category-II Basin waiting to be upgraded in view of commercial discovery.

The Kerala-Konkan Basin though well explored no commercial accumulation could be located till date. Awaiting discovery, this Basin is listed in Category-III Basins.

Mumbai Offshore Basin (Category-IBasin)

The Mumbai Offshore Basin is the most prolific of all the hydrocarbon bearing provinces in India.

Bounded by Diu and Narmada Faults and Deccan Trap outcrops to its north and east, the pericratonic Mumbai Offshore Basin extends towards west parallel to the western continental margin of India up to the Western Margin Basement Arch. NE-SW trending Vengurla Arch separates the Basin from the Kerala-Konkan Basin to its south.

On the basis of structural elements and the nature of sediment fill which influenced characteristic hydrocarbon generation and entrapment patterns in different sectors, the Basin is subdivided in to a number of blocks, viz. Tapti-Daman block, Diu block, Heera-Panna-Bassein block, Mumbai High-Deep Continental Shelf block, Shelf Margin block and the Ratnagiri block.

Based on tectonic-sedimentary history and

alignment of structural elements, the Basin is subdivided in to six major units, three of which are characterised by paleo-platform set up, viz. the Mumbai High-DCS platform, the Heera-Panna-Bassein Platform and the Ratnagiri platform which were dominantly filled up by carbonate sediments. Three of the other units, viz. Murud low, Saurashtra rise- Diu depression and Surat depression are mostly characterised by clastic sedimentation acting as the dominant hydrocarbon generation centers for the Basin. The Tapti-Daman block is a clastic Basin developed in the northern part of Bombay Offshore Basin in front of a narrow Cambay Gulf having sedimentation history from Paleocene time onwards. Middle Eocene-Oligocene deltaic sediments of proto-Narmada in Cambay Basin and Late Oligocene-Miocene sediments in Tapti-Daman sector deposited as a result of progradation of the delta through the narrow Cambay Gulf.

Continued and sustained exploratory and development efforts in Mumbai Offshore Basin since last four decades have shown remarkable results and led to conversion of nearly 50% of the prognosticated resource of 9190 MMToE in to In-place volume of hydrocarbons.

Hydrocarbon Plays - Established and New Plays

The major hydrocarbon fields of the Basin include Bombay High, Bassein, Panna, Mukta, Neelam, Heera, South Heera, Ratna, D-1 fields, Tapti (north, mid and south), C22/24 structures.

Hydrocarbon accumulations in BH-DCS-HPB (Bombay High-Deep Continental Shelf-Heera-Panna-Bassein) sector are structurally controlled, in general occur, in carbonate reservoirs ranging in age from Middle Eocene to Middle Miocene with a few exceptions of stratigraphic/composition plays in clastic reservoirs. While major pay zones occur in Middle Eocene and Early Miocene plays, hydrocarbon zones have also been identified in Paleocene to Oligocene plays where as in Tapti-Daman sector Daman (Late Oligocene) and Mahuva (Early Oligocene) plays are well established.

Targeting new objectives in established areas and looking for extension of known plays besides exploring deeper plays has always been the essence of exploratory activities in Mumbai Offshore Basin.

Recent successes in Basement and Basal clastic section from a number of wells on west and southern periphery of Mumbai High have seen renewed focus and exploration initiatives being adopted for exploration of this play. With integrated interpretation of seismic and well data including special analysis of cores and image logs along with application of state-of-the-art technologies for fracture imaging, a significant improvement has come in identification and mapping of probable fracture zones in basement. Simultaneous exploration for extension of other known plays in L-III to L-VI limestones of Early Miocene to Late Oligocene age beyond the known confines around Mumbai High is also expected to discover more hydrocarbons.

Exploring for Eocene – Paleocene Pannaclastics in recent times in areas away from known accumulations has shown very positive results around south and south east of Mumbai and Heera-Panna-Bassein platforms.

Renewed efforts of targeting deeper as well as established plays and success achieved in new areas have helped in more resource conversion.

The established plays in Early Oligocene to Mid/Late Eocene Carbonate reservoirs of Mukta and Bassein Formation along with fluvio-marine clastic deposits of early Eocene/late Paleocene Panna Formation continue to attract exploration.

A recent discovery of gas in the very fine grained Pliocene reservoir towards west of the Neogene Shelf margin of Mumbai Offshore block from shelf edge roll over structure opened up a new play in the frontier area.

Discovery of deeper oil, below the known oil water contacts, especially in Bombay High sector opened up new vistas of exploration.

Exploring the Mahuva Play in B-12/C-24 and C-26 areas remained as challenge due to HP-HT conditions besides the establishment of the deeper plays (Belapur, Panna and Basement) though proved prospective in few wells.

Kutch Basin (Category-II Basin)

The Kutch Basin located on the western continental margin covers an area over 80,000 Sq. Km both on-

land and off-shore. The Basin is a poly-history rift and passive margin Basin which has evolved through multiple rift phases after the separation of the Indian and African plate. Exploration commenced wayback in 1972 and decade later oil was discovered in the offshore KD structure from Eocene Limestone.

The onland part of the Kutch Basin appears to be an arm of a failed rift system and is restricted by the Allabandh fault towards the north and extends up to the North Kathiawar fault towards south. The structural trend on the onland part of Kutch Basin essentially trends in an east-west direction where as in the offshore part of the Basin the dominant structural trend appears in a NW-SE direction. This indicates that probably the separation of the Indian and African plates has a more significant imprint in the offshore area. Based on the study of recent gravity magnetic data it appears that the continental oceanic boundary took an easterly swing around Kutch Basin, distinctly indicating possible presence of Mesozoic sediments below the Deccan traps even in the Deep water areas (Fig. 6).

The most important plays in the Kutch Basin are sub-trappean Mesozoic's and Early Tertiary Sediments.

Hydrocarbon Plays - Established and New Plays

The early discoveries in Kutch Basin include oil in Eocene limestone and calcareous sandstone from KD area, gas discovery in Early Cretaceous sandstone in GK-22 area, gas in late Cretaceous marl from GK-39 and from Palaeocene sands in GK-29 area. Discoveries made in Tertiary sections have ushered in a paradigm shift in the thought process for exploration in the area. Recent discoveries from Mesozoic sediments south of Kutch Basin on the northern flank of Saurashtra Arch has established the presence of active petroleum system south of the North Kathiawar fault and corroborates with the envisaged prospectivity till Saurashtra arch in the south. Discovery of gas from GK-28 structure from Deccan basalts opened up a new play.

Eastern Pericratonic Rift Basins

The Eastern Pericratonic Basins (Fig. 1) define the present coastal and offshore structural framework that evolved since Late Jurassic related to the break

Fig. 6: Tectonic map of West coast of India Showing the Kutch Basin (after ONGC)

up and drifting of Indian and Antarctic plates (Biswas, 2008b). The eastern continental margin evolved by segmentation into a rifted northern part and southern sheared (transformed) part (Shyam Chand and Subrahmanyam, 2001). Whereas the rifted northern part, Bengal-Krishna Godavari is characterized by sedimentary Basins having coast parallel horst-graben structures, the Cauvery Basin along the sheared segment shows development of pull-apart Basins and intervening ridges oblique to the N-S shore-line. The Basins formed on the eastern passive margin of the Indian plate in a divergent set up. The continental shelf is narrow here and the Basins pass into deep-water slope to abyssal Eastern Ocean Basin (EOB) of Bay Bengal (400m to 2000m) within a short distance (Fig. 1). The Basins from north to south are:

Remnant ocean Basin of Bengal (Biswas *et al.*, 1993), Mahanadi, Krishna-Godavari (KG), Palar, Cauvery, Mannar rift Basins and Andaman. Of these, KG and Cauvery (including Palar and Mannar Basins) are category-I Basins and Mahanadi and Andaman are category-II. The Bengal Basin still remains as category-III Basin.

KG Basin (Category-I Basin)

The Krishna-Godavari Basin constitutes a typical passive margin Basin and has a polycyclic (dual-rift province) evolution history (Fig. 1 and 7). Basin comprises a wide array of sedimentary facies from early Permian through Cenozoic with the analogous outcrops defining the Basin limitation, along the north

Fig. 7: Geological Map of Krishna-Godavari Basin (after ONGC)

western part of the Basin.

It is spread over an area of 28,000 sq. km. in the on land and 1, 45, 00 sq.km (24,000 sq. km. up to 200m isobath) in the Bay of Bengal offshore. The prospective area for oil & gas exploration in on land covers the three coastal districts of East Godavari, West Godavari & Krishna and in Offshore till 85° East ridge. Efforts by both NOC's and Private oil companies have unlocked huge hydrocarbon reserves.

The Basin is estimated to have a sediment thickness in excess of 7.0 Km. Broad tectonic expression of the Basin comprises linear horst-graben system, growth fault/rollover and block tilting along synthetic fault over intra shelf regime followed by toe thrusting exhibiting typical evolution from rift Basin to passive margin Basin. The habitat of hydrocarbons spreads over a wide stratigraphic spectrum from Triassic to Pliocene and geographical distribution, on land, offshore including ultra-deep water domain

(Fig. 8).

The major plays established in KG Basin are Mandapeta (Permo-Triassic), Syn-Rift Gollapalli/Nandigama/Kanukollu (Late Jurassic to Lower Cretaceous, Raghavapuram (Early-Late Cretaceous), Pasarlapudi/Vadaparru (Late Palaeocene to Eocene), Matsyapuri/Ravva (Oligocene to Miocene) and Godavari (Pliocene). Both biogenic and thermogenic petroleum system are operative in the Basin.

Hydrocarbon Plays - Established and New Plays

The exploration efforts by various operators have brought out that the synrift play as one of the most significant hydrocarbon bearing play in KG Basin. Improved 3D seismic imaging and better understanding of the geological evolution resulted in discovering of oil and gas from syn rift sequences, both onland and offshore, including the deep water sector. Reservoirs, invariably from the complex

Fig. 8: Geological Cross section across KG Basin showing the hydrocarbon habitat (after ONGC)

sequence of synrift or more aptly Gollapalli Formation are tight in nature and hydro-fracturing may improve the productivity. Synrift reservoirs in KG Basin exhibit low porosity and permeability with some sweet spots. The play at deeper depth exhibit high temperature ($>400^{\circ}\text{F}$) and high pressure ($>70\%+$ hydrostatic) conditions challenging the current technical limits.

Recent discovery of oil from synrift play in Krishna river mouth area (Nizampatnam bay) has opened up a new area albeit with a challenge of tight reservoirs.

The Basin has distinction of reporting maximum number of discoveries in the last decade. (DGH: 2005-15).

Subsequent to discovery of a large Dhirubai gas field (DGH, 2005) by Reliance Industries Ltd., ONGC notified a large gas field from the ultra-deep waters in 2006. As such, this Basin has shown a very high degree of hydrocarbon potential, particularly in deep waters off the Godavari river mouth, essentially from Mio-Pliocene & Pleistocene Formations. Similarly, recent discoveries of gas from Machilipatnam bay area from Eocene-Pliocene Formations from shallow water segment endorses for sustained exploration. Based on trend of discoveries, there are good chances of discovering large fields, especially from deep water segment.

In KG deep waters mainly slope-channel-levee-complex, debris flows, low stand wedge and Basin floor fan complexes remain as major targets. In shallow water growth fault related structures, channel fills combination traps, upper slope fans still remain as attractive plays particularly in the delta-slope

transition. In on land, the deeper syn rift plays remain as major attractive play. Based on the emerging exploration trend, sands within the Lower to Upper Cretaceous Raghavapuram play attain importance for further exploration.

Major hydrocarbon discoveries in KG ultra deep water sector subsequent to Ultra Deep (UD) biogenic gas discovery are elusive, exploration density in the sector is meagre and the area still remains a "frontier area" and warrants further exploration specially for biogenic petroleum system.

Cauvery Basin (Category: I Basin)

Cauvery Basin is pericratonic Basin, evolved due to rifting between India and Sri Lanka during the break-up of Eastern Gondwana land (Katz, 1978) during Late Jurassic-Early Cretaceous and subsequent drifting (Late Aptian) of Indian plate from Gondwana land along NE-SW oriented Eastern Ghat trend. The rifting has created several horsts and grabens. The present day horst and graben picture of Mesozoic-Cenozoic stratigraphic column have been related to two principal tectonic episodes namely, extension stage during Late Jurassic – Early Cretaceous and thermal subsidence stage during late Cretaceous to Cenozoic. Cauvery Basin has been divided into sub-basins, namely Ariyalur-Pondicherry, Tranquebar, Nagapattinam, Tanjore, and Ramnad-Palk Bay separated by Kumbakonam-Madanam, Pattukottai-Mannargudi & Mandapam-Delft ridges (Fig. 9).

The potential source in the Cauvery Basin is envisaged to be the Synrift Andimadam sediments along with contribution from Sattapadi and Bhuvanagiri sediments. Source rock is generally Type-II & Type-

III capable of generating both liquid & gaseous hydrocarbon. Two sets of faults, one trending NE-SW and associated with the Synrift phase and the other NW-SE fault system dissecting the older system are envisaged to have played major role in the depositional setting, hydrocarbon migration and accumulation.

Concerted efforts to explore the Basement play resulted in major success with discovery of hydrocarbons from Madanam, Pandanallur and Chidambaram areas.

Hydrocarbon Plays - Established and New Plays

Basement Play: Exploratory drilling in Madanam and Pandanallur areas established the commercial hydrocarbons from basement play in Cauvery on land area.

The other important operative plays in Cauvery onland are - Andimadam Play : (prolific producer in

Kuthalam-Kali, Pallivaramangalam-Vijayapuram, Periyakudi fields and is characterised by poor porosities and low permeabilities). Bhuvanagiri Play: (Well established in Pallivaramangalam – Vijayapuram, Pundi, Kanjirangudi and Periyapattinam fields tight reservoirs), Nannilam Play (in most of the wells drilled in Ariyaluru-Pondichery sub basin, well established in Nannilam, Tiruvarur, Kanjirangudi, Periyapattinam, Perungulam and PBS fields) Kamalapuram Play (The Paleocene play is well established in Adaiyakkamangalam, Kamalapuram, Nannilam, Kuthanallur & few fields in Ramnad sub-basin).

Recent discovery of Periyakudi field from synrift sequence gave a major impetus to synrift play and chance of discovering large fields in the Basin. However, as in the case of Krishna-Godavari, this play is also known for HP-HT conditions.

In Cauvery Offshore, there is no much

Fig. 10: Geological and Tectonic Element map of Mahanadi Basin (after ONGC)

breakthrough except in the established PY and PH fields. Recent discoveries reported by Hardy Oil in Cauvery shallow water, by Reliance Industries Ltd (RIL) in Cauvery deep waters (discovery of thick column of gas & condensate from synrift sequence from the CY-PR deep water area) and Cairn Energy India Ltd (CEIL) from Srilanka/Gulf of Mannar Basins has rekindled the exploration interest in the Cauvery Offshore.

Mahanadi Basin (Category-II Basin)

Mahanadi Basin is a category-II sedimentary Basin located in the Eastern Passive Continental Margin of Indian sub continent. Geographically, it is flanked by the Bengal Basin in the NE and Krishna-Godavari Basin in the SW. The on-land part of the Basin encompasses the deltaic plains of Mahanadi river and its distributaries lying between Jagannathpur in the northeast and Chilka Lake in the southwest which extends in to offshore Bay of Bengal covering a total area of about 2,60,000 sq.kms.

Tectonically, Mahanadi Basin is a poly-history Basin - starting as a NW-SE trending Permo-Triassic Gondwana rift characterised by a failed arm superposed by Late Jurassic-Early Cretaceous NE-SW trending east coast rifting and finally leading to passive margin Basin set-up during Late Cretaceous - Recent period. Various sub-basins/depressions with NE-SW trend are present which include Cuttack-Chandbali depression, Paradip depression, Puri depression, Northern and Southern offshore depression with sediment thickness varying from 5000m in on land to more than 10,000m in the offshore Basin(Fig:10).Exploration process started in Mahanadi Basin way back during 1960 – 70 by OIL and ONGC. Fifteen exploratory wells have been drilled with no major hydrocarbon interest reported.

With the advent of New Exploration Licensing Policy (NELP), the exploration efforts were rejuvenated and additional inputs in terms of seismic API and drilling was carried out by NOC and Private E&P companies and number of gas discoveries were made in the offshore part of the Basin.

Hydrocarbon Plays - Established and New Plays

Most of the gas discoveries in Mahanadi offshore Basin are Non-Associated Natural Gas (NANG) and

biogenic in origin from Mio-Pliocene channel plays. In Oligocene-Eocene level only two wells encountered gaseous hydrocarbon of mixed origin. In all the cases the hydrocarbon bearing clastics reservoir facies are of limited areal extent. New plays- deeper fan prospects of Cretaceous and Paleocene age could not be probed due to severe down-hole complications related to high-pressure. The delta- prodelta sequence at the shelf edge is prospective for potential petroleum system in this Basin. In the offshore area Mio-Pliocene shales and channel sands in channel-levee complex on paleo-continental slope suggest prospective source-reservoir combination which is proved by the discoveries.

Exploratory efforts till date are restricted up to the Neogene level. Hence, the Low stand deep-water canyon fill deposits and the associated relict structures of Eocene age and the slope fans of Palaeocene and Eocene age remain as prospective candidates for future exploration targets in this area.

Andaman Basin: (Category-II Basin)

The area of Andaman Nicobar Island is approximately 6000 Sq. Km. The offshore extension forms a sedimentary Basin which occupies an area of more than 75,000 sq.km including the deep water segment. The Basin formed in intra-oceanic setting as an island arc in a convergent set up where the Indian plate is subducting under the Burma-Malayan plate since Cretaceous time. It is a typical island arc with an outer trench, fore-arc Basin, an inner volcanic arc and a back arc Basin (Fig. 11 and 12).

The Andaman fore-arc Basin is sitting on the subduction prism represented by outer sedimentary arc (Roy and Das Sharma, 1993). Thick Palaeogene flysch overlain by shallow marine Neogene sediments are exposed in the islands of Andaman and Nicobar.

Hydrocarbon Plays - Established and New Plays

The first gas discovery from Miocene Limestone (AN-1-1), the see pages in the islands and oil/gas shows in the mud volcanoes indicate presence of hydrocarbon in the Tertiary sediments. Two petroleum system are envisaged to be operative in the area, the biogenic shallow gas and the deep thermogenic system. These petroleum systems are envisaged to be operative in fore-arc Basin where exploration wells have been

Fig. 11: Tectonic and Basin set-up of Andaman Basin (after ONGC)

drilled; the petroleum systems in the back-arc Basin are conceptual in the absence of well data and are analogue from the adjoining well established North Sumatra Basin with large fields like Arun and Perlak

in Indonesia and Yadana, Yetagun fields of Myanmar. The main source rocks in this Basin are the Cretaceous and Palaeocene shales of Baratang Formation. The reservoir rock established so far is the Mio-Pliocene Long Formation. Presence of a completely unexplored rift set-up in the southern part of eastern extension of Andaman Island is the future exploration target.

Category III Basins

Besides the above described major Category-I and Category-II Basins, extensive exploration activities are being carried out in Basins which are geologically considered prospective but so far indicated only presence of hydrocarbons and such Basins are categorised as Category-III. Current exploratory endeavours are to upgrade these Basins to either Category-II or Category-I Basins. Brief summary of the geological setting and status of exploration of some of the Basins is discussed below:

Himalayan Foreland and Ganga Basin: (Category-III Basin)

Himalayan Foreland and Ganga Basin are on the northern passive margin of the Indian plate which is undergoing sub-duction. Major portion of passive margin had been sub-ducted and in the foreland part only palaeo-Basin margin sediments (Late Proterozoic and Early Palaeozoic Vindhyan Group) covered by huge thickness of post-collision molassic sediments (Siwalik Group) are present. These Basins are being explored since long but excepting a few gas shows,

Fig. 12: Geological Cross section across Andaman sub-duction zone (after ONGC)

no other encouraging result was found. The main target here is the palaeo-passive margin Eocene wedge-out which are expected to be matured in the deeper part of the sub-duction zone. Eocene wedges were encountered in drilled wells in Arunachal and Punjab respectively on the eastern and western extremities of this peripheral foreland area with local shows.

The Himalaya in northwest India is divided into different litho-tectonic blocks by a number of E-W regional boundary thrusts. Exploration in the Himalayan Foreland Basin commenced in the 50's and ONGC drilled about 31 wells. The various structural plays envisaged in a fold thrust belt have been targeted and explored within the hanging wall blocks of Jawalamukhi Thrust and the triangle zone structures with limited success which proved existence of thermogenic gas in the area, albeit in non-commercial quantities.

Hydrocarbon Plays : Established and New Plays

Majority of the wells drilled in the Himalayan Foreland explored the triangle zone structures and the Jawalamukhi play, where live gas seepages are well known. Gas analysis of Jawalamukhi pool indicates to be secondary with deep gas migrating upward. Based on the exploration efforts so far, inner part of the inner tectonic belt and sub thrust prospects of Palampur thrust in Lesser Himalayas are envisaged as future exploration targets.

Vindhyan Basin (Category-III Basin)

The Vindhyan Basin is situated between the Delhi - Aravalli orogenic belt to the north-west and Son-Narmada Geofracture to the south. The Bundelkhand Massif, located in the north-central part of the Basin, divides it into two sectors: Chambal Valley to the west and Son Valley to the east (Fig. 13). Proterozoic Vindhyan Basin is one of the frontier areas of exploration in the central part of the country where presence of dry non-sour thermogenic gas has been established from very tight carbonate and clastic reservoirs.

Hydrocarbon Plays : Established and New Plays

Although the Basin has been under exploration for more than six decades, significant discovery of thermogenic gas from Lower Vindhyan Rohtas

Limestone was made from well Nohtain the year 2012 in the Son Valley sector. Exploratory efforts further led to another gas discovery from Lower Vindhyan Mohana Fawn Limestone in Damoh area in addition to establishing flow/presence of gas from multiple reservoirs within Upper, Middle, Lower Rohtas carbonate units. Lower Vindhyan and Basal Kaimur sandstone reservoirs of Upper Vindhyan sequence are the future targets of exploration.

The other category –III Basins are Kerala-Konkan Basin in the West coast and Bengal Basin in the east coast. Presences of non-commercial hydrocarbons are known from these Basins but are yet to open up.

In Kerala-Konkan Basin gas shows were reported from the Tertiary sequence mostly from Miocene and Eocene formations. Though various data sets indicate presence of subtrappean Mesozoic Basin but its hydrocarbon potential is yet to be confirmed.

The poly history Bengal Basin was initiated as intracratonic rifted Basin during late – Paleozoic and Mid-Mesozoic time and received the continental sediments and ended with wide spread Rajmahal continental volcanic activity. The second phase along with drifting of the Indian plate and the pericratonic part on the eastern margin continuously subsided and received colossal volume of sediments from Late Mesozoic through Tertiary to Recent times.

Commercial success is still eluding however, indications of oil has been observed from Oligocene sands. Recent gas shows from the Gondwana sediments in the Basin marginal part indicate the presence of deep Basin gas from Gondwana rocks buried under thick Cretaceous and Tertiary sediments.

Fig. 13: Geological map of Vindhyan Basin (after ONGC)

Category–IV Basins

Most of these Basins are less explored in comparison to the category I and II Basins and are located in logistically difficult terrains/environments with inherent geological complexities. Exploration ventures in these Basins are capital intensive with uncertain return. However, considering the huge potential of hydrocarbon resources, more aggressive exploration is required, which can make a significant impact on the national hydrocarbon portfolio in the long run.

Exploration was carried out since 1956 in diverse geographical and geological regions of Frontier Basins like Spiti-Zaskar and Karewa Basin, Deccan Syneclise, Pranhita–Godavari, Narmada, and Satpura-S. Rewa-Damodar Basins; however, the success so far has been elusive.

Unconventional Hydrocarbons

Apart from conventional hydrocarbon occurrences discussed above, there are other types of hydrocarbon resources. These are, Coal Bed Methane (CBM), Shale Gas, and Gas Hydrates (GH). India, keeping the increasing demand for hydrocarbons is formulating the policies for exploration and exploitation of these unconventional resources. Of these, CBM exploration initiated towards the end of the last century is in advanced stage and exploitation has started in some areas. Special focus is on gas hydrates (GH) since preliminary investigation indicated good resource potential. India has already established the physical presence of GH in offshore deep water part of Krishna-Godavari, Mahanadi and Andaman areas. Exploration for shale oil shale & gas are in initial stages.

Coal Bed Methane

The adsorbed methane in coal bed which was known to be the potential hazard in coal mining is now economically exploited through bore holes at depths of 500m to 1000m. India has the fifth largest proven coal reserves in the world and thus holds significant prospects for exploration and exploitation of CBM. The prognosticated CBM resources in the country are about 92 TCF (2600 BCM) in 12 states of India, especially the eastern coal fields of Damodar-Koel valley and Son valley.

As an initiative to harness the CBM potential, GOI has awarded 33 CBM blocks and commercial

production commenced from July, 2007.

Gas Hydrates

Methane gas hydrate in the seabed shallow sediments is a prolific source of gas containing both biogenic and thermogenic gas. In India, presence of gas hydrate has been established in deep offshore of KG, Mahanadi and Andaman areas (DGH, 2010). National Gas Hydrate Program of Government of India conducted the first expedition in 2006 and the second expedition of Gas Hydrates commenced in 2015. Intensive R&D studies are being carried out to evolve technologies to produce gas from frozen sea-bed sediments and India is ranked third in this endeavour after USA and Japan.

Shale Gas

Shale gas and oil constitute an important unconventional source of hydrocarbons stored in organic rich, matured fine grained sedimentary rocks. Hydro fracturing is an essential operational activity to explore the unconventional hydrocarbons from the shale which is impervious in nature with permeability in nano scale. Meso-Neo Proterozoic source facies of Vindhyan Basin and Permian source facies of Gondwana Basins besides the conventional deeper source shales are the potential shale gas/oil resources. Six Indian sedimentary Basins viz., Cambay, KG, Cauvery, Assam-Arakan, Ganga Valley and Damodar Basin were identified for shale oil/gas exploration.

India embarked on an ambitious Shale oil and gas programme and exploration programme in 55 blocks has been initiated by NOC's.

Technology Induction to Enhance Exploration Efforts

Technology induction being an integral part of hydrocarbon exploration, following new technologies are implemented in Indian Sedimentary Basins

- Long Offset 2D seismic surveys for deeper imaging
- 3D-3C/4D Seismic Surveys
- Wide Azimuth surveys
- Onshore carpet 3D surveys
- Node based Wide angle refraction cum reflection profiling.

- Broadband Surveys
- CSEM surveys and Microgravity data for delineation
- Bean PSDM processing
- Common Reflection Angle Migration processing
- Discreet Fracture Net work Analysis
- Permeability structure analysis and fluid replacement studies

Summary

Exploratory efforts by E&P companies have discovered 7 producing Basins and converted about 11.18 BTOE out of the prognosticated resource of 28

BTOE. A growth of about 32% compared to base year of 2006 in Initial In-Place volume.

Exploratory efforts have brought down the unexplored sedimentary Basinal area to a mere 12% compared 50% as in 1995.

Continued exploratory efforts leveraging the new technologies are resulting in new discoveries from Category –I Basins and more commercial discoveries from Category–II Basins like Mahanadi and Kutch.

Challenges in term of exploring and exploiting the HP-HT and Ultra HP-HT reservoirs exists and India is gearing up to meet the challenges through induction of new technologies.

Abbreviations Used

2D/3D/4D : Two-dimensional/three dimensional/four dimensional (time-lapsed)

3D-3C : Three dimension – Three component

BCM : Billion Cubic meters

BOPD : Barrels of oil per day

BTOE: Billion Tonnes Oil equivalent

CAAGR: Compounded Average Annual growth rate

CBM : Coalbed Methane

CRAM: Common Reflection Angle Migration

CSEM: Controlled Source Electro Magnetic

DFN : Discreet Fracture Net work.

DGH : Directorate General of Hydrocarbons

E&P : Exploration and Production

EOB: Eastern OceanBasin

FRM : Fluid Replacement Model

GH : Gas Hydrates

GOI: Government of India

GSI: Geological Survey of India

HELP: Hydrocarbon Exploration Licensing Policy

HOEC: Hindustan Oil Exploration Company

HPB: Heera-Panna-Bassein

HPHT: High Pressure-High Temperature

KG : Krishna-Godavari

LWD: Logging While drilling

MBPD: Million Barrels per day

MPD : Managed Pressure Drilling

MMSCD/MMSCMD: Million Metric Standard Cubic Meters Per Day

NANG: Non associated Natural Gas

NEC: Northern East Coast

NELP : New Exploration Licensing Policy

NOC : National oil Companies

OIL : Oil India Ltd.

ONGC : Oil and Natural Gas corporation Ltd

PSU : Public Sector Undertaking

PST: Passive Seismic tomography

RIL: Reliance Industries Limited

RSS: Rotary Steerable System

SBL : Sea bed logging

WAZ: Wide Angle Azimuth

WARRP: Wide angle Refraction cum Reflection profiling.

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