



Mesozoic prospectivity of KG, Cauvery, WCMI, Cambay and Rajasthan basins and challenges

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Summary

Mesozoic exploration is being carried out in Indian Sedimentary basins for exploration of oil & gas reservoirs. It has gained lot of importance world-wide in terms of huge reserves of oil& gas. Much of Tertiary resources are being exhausted and to meet demands of oil & gas requirements of India, much focus is required for exploration of Mesozoic sediments. The KG, Cauvery, Kutch, Kerala-Konkan, Cambay and Rajasthan basins are having good potential of hydrocarbons in Mesozoic section. The challenges are mainly (1) deeper target depths offshore (2) mask of continental flood basalts of Deccan Traps and older traps even particularly in Kutch, KK and Cambay basin (3) Imaging sub-basalt Mesozoic sequence as most of reflected energy dissipates on onset of traps (4) techno-economics.

The basin wise stratigraphy, petroleum systems and perspective for Mesozoic exploration is discussed and challenges in exploration. The future of Indian exploration lies on accelerated efforts to tap huge potential of H/C reserves in Mesozoic sequences.

Introduction

38 sedimentary basins were recognized in on-shore and off-shore areas of Indian plate including western and eastern deep ocean basins(>1000m isobaths)(SKBiswas,2012). The current estimate for total reserves is 28 BMT(O+OEG) includes 7 BMT of deep offshore resource, out of which as on 1.4.2014, In-place hydrocarbon volume of 11,543 million tonnes of oil and oil equivalent gas could be established through exploration. So, about 59% of resources are under “yet to find category”. Out of 11,543 MMT of oil and oil equivalent gas of In-place volumes, the ultimate reserves which can be produced are about 4199 MMT of oil and oil equivalent gas since inception. The balance recoverable reserves are of the order of 2182 MMT of oil and oil equivalent gas. The basin wise estimates are shown in Table.1 below. These resources are currently under revision by DGH, due to generation of substantial geo-scientific data through NELP rounds, new oil and gas fields discovery by

utilizing improved geological understanding and new technology .

Table-1: Estimated Hydrocarbon Resources in India (Source-DGH)

S / N	BASIN	OFFSHORE (MMT)	ONSHORE (MMT)	TOTAL (MMT)
1	MUMBAI	9190		9190
2	CAMBAY		2050	2050
3	KRISHNA-GODAVARI	555	575	1130
4	CAUVERY	270	430	700
5	RAJASTHAN		380	380
6	KUTCH	550	210	760
7	KERALA-KONKAN	660		660
8	SAURASHTRA O/SHORE	280		280
9	DEEP WATER	7000		7000
	TOTAL	18505	3645	22150

As evident the major contributors of reserves are from WOB, KG, Cambay and thrust is on Cauvery, Kutch, Kerala-Konkan, Rajasthan basins and Deep water for YTF reserves. Exploration of Mesozoic and older pays play a significant role to tap significant YTF reserves of these basins.

Definition of Mesozoic era: The Mesozoic Era is divided into three time periods: the Triassic (251-199.6 million years ago), the Jurassic (199.6-145.5 million years ago), and the Cretaceous (145.5-65.5 million years ago).

1. Krishna-Godavari basin:

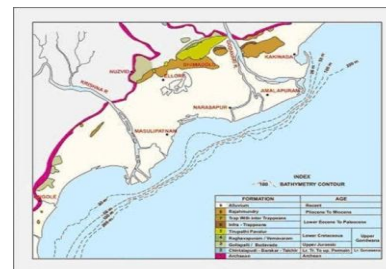


Fig.1a.Krishna Godavari basin

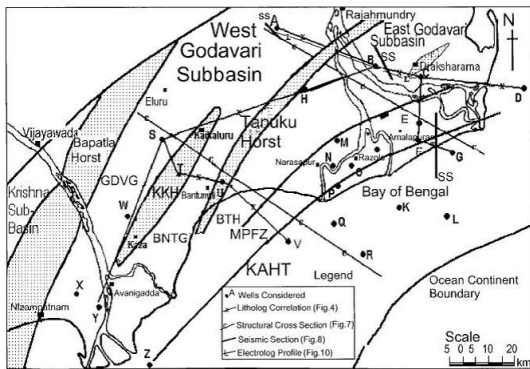


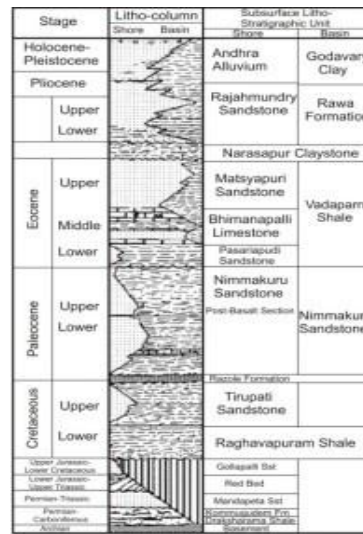
Fig.1b. Tectonic map of KG basin with deep wells considered. BNTG=Bantumalli graben, GVDG=Gudivada graben, MPFZ=Mastypuri-Palakollu fault zone, KAHT=Krishna Amalapuram High trend, BTH = Bantumalli High, KKH = Kaza-Kaikalur High. Single letters are well (Courtesy DGH and GN Rao)

The basin is located in the central part of eastern passive margin of India (Fig.1a). This marginal rift basin is styled by a series of NE-SW trending horst-graben structures sub-parallel to the coast. NE-SW trending Pranahita-Godavari (Gondwana) graben abuts against the KG basin orthogonally along the Bapatla Ridge in the northwest (Fig.1b). The Late Gondwana rocks are encountered below the Cretaceous-Tertiary sediment filled coastal rift basin (Venkatrengan and Ray, 1993). The major delta sequence that prograded seaward since Late Cretaceous, is the favourable habitat for hydrocarbon. Presently the recent sediments of Godavari and Krishna deltas cover the onshore basin. Offshore the Cretaceous deltaic sediments pass into deep water sediments beyond the shelf-slope boundary. Thick Tertiary sediments with well-developed low-stand/high-stand sequences transgress over the older sediments in the deep offshore. The Lithostratigraphy of KG basin is shown in Fig.2a.

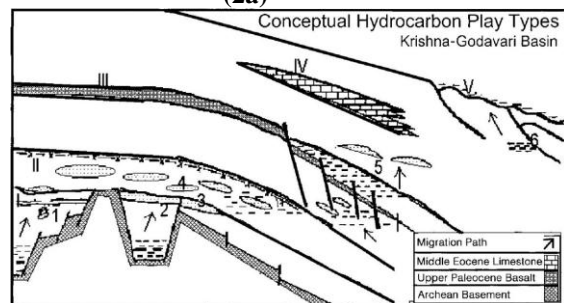
This Class I basin has the potential reservoirs ranging from Permian to Pliocene. Exploratory drilling of more than 350 wells in more than 160 prospects and 42 oil & gas fields were established. Four petroleum systems within Permian to Miocene sequence (Rao, 2001) are evident. Main H/C plays are basement involved structural closures, stratigraphic traps in growth related structures, fault closures, build up features and stratigraphic plays. In shallow water delta-slope transition complex and in deep waters

channel/levee debris flow complex, bottom floor fan and turbidites are prospective hydrocarbon flows (Bastia, 2007) (Fig.2b). The structural cross-section along East Godavari sub basin is shown at Fig.3.

The prognostic resource of on-land and offshore (Up to 200m isobaths) is 1130 MMT (DGH, 2010) of which 185 MMT of O+OEG in-place reserve has been established. The estimation of reserve of deep offshore basin is yet to be finalized. However, the gas reserve in this part of basin is expected to be more than 15 TCM as indicated by the size of reservoirs.



(2a)



(2b)

Fig.2a. Lithostratigraphy of sedimentary sequences penetrated in KG basin, (2b) Conceptual hydrocarbon play types in the Krishna-Godavari basin. Play concepts include (1) permeability barriers; (2) fault closures in Upper Permian reservoirs; (3) clastic wedges and associated unconformity traps in Upper Jurassic (Gollapalli Sandstone) fluviomarine

sediments;(4) sand lenses within Cretaceous and Paleocene argillaceous facies; (5) anticlinal closures in lower Eocene near shore clastic reservoirs;(6) growth faults, erosional cut, and rollover anticlinal accumulations in Miocene–Pliocene clastics in the shallow marine area of the basin. Regional seals: I _ red beds, II _ Raghavapuram shales, III _ Deccan basalts, IV _ middle Eocene carbonates, V _ Pliocene(Courtesy G.N.Rao,2001)

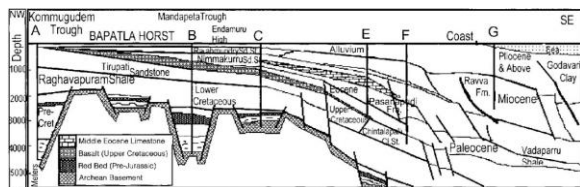


Fig.3. Structural cross section across the East Godavari sub-basin showing thick Tertiary sediments toward the southeast of the MPFZ as seen in well G in the offshore part of the basin; toward the north-western basin margin area at well A, thick pre-Cretaceous sediments were encountered.

Hydrocarbon Occurrence

Initial successful hydrocarbon exploration in the Krishna-Godavari basin was in thin Upper Cretaceous reservoirs in the Narasapur structure of the East Godavari sub-basin. Exploration efforts since 1978 have established oil and gas reservoirs ranging in age from Late Permian to Pliocene (Rao, 1991).

Petroleum System Analysis

By analyzing the hydrocarbon occurrence in the basin in relation to petroleum system classification, four systems can be identified. (1) Kommgudem-Mandapeta-RedBed, (2) Raghavapuram-Gollapalli-Razole,(3)Palakollu-Pasarlapudi-himanapalli and (4) Ravva-Godavari petroleum systems. Geological ages of oil & gas reservoirs in Mesozoic and older section are indicated in Table 2.The geologically oldest petroleum system is the pre-Cretaceous Kommgudem-Mandapeta–Red Bed (Rao, 1994). This system is confined to the northwest southeast–trending rift valley extending beneath the East Godavari sub-basin. The hydrocarbon potential of the system is estimated to be 330 million tons. The source rocks yield mainly gas. The system is

associated with many erosional unconformities. To date, only 20 million tons in reserves have been established. The apparent lack of high-amplitude anticlinal closures and permeability barriers currently impede new exploration efforts. The Cretaceous petroleum system is named the Raghavapuram-Gollapalli-Razole system. In the West Godavari sub-basin, thin sands and limestones within source facies are reservoirs. In the East Godavari sub-basin, lenses of sands in the Chintalapalli Claystone produce hydrocarbons. Southeast of the MPFZ, the system was under compacted during the Eocene. The petroleum potential has been estimated to be 230 million tons, of which so far only 15 million tons in reserves have been established. The Paleogene Palakollu-Pasarlapudi-Bhimanapalli petroleum system is the most prolific system in the Krishna-Godavari basin. Located southeast of the MPFZ in the East Godavari sub-basin, the system contains abnormally pressured source rocks and normally pressured reservoirs (Rao and Mani, 1993). Anticlinal closures serve to entrap hydrocarbons. The estimated hydrocarbon resources are estimated to be 300 million tons. To date, about 80 million tons in reserves have been established. The Neogene petroleum system is called the Ravva-Godavari System. The most promising area for commercial hydrocarbon production is offshore.

Geological age	Onland		Offshore		Average Depth(m) of HC bearing zone
	Oil	Gas	Oil	Gas	
Paleocene		Mummadivaram Achanta Razole Palakollu		GS-8	2000-2500
U.Cretaceous		Enugupalli Narasapur Penusadam Chintalapalli Kavitam			2400 3400 3400 4450 4380
Early Cretaceous	Kaikaluru Lingala	Kaza Vadali Mahadevapatnam Gokarnapuram Bantumalli Nandigama			1800-2000 3300 4000
Late Jurassic		Endamuru Mandapeta			1700 2700

Table-2: Age wise distribution of oil & gas fields and depth to hydrocarbon bearing zone KG Basin

Trap Styles and Play Types:

Seismic surveys and geological mapping indicate that although structural traps do exist in the Krishna-Godavari basin, most of them are only small to medium in size. In contrast, up dip pinch-outs, unconformity surfaces, and permeability barriers all

play an important role in the entrapment of hydrocarbons. The oldest gas-producing reservoir is the Permian Mandapeta Sandstone. The thickness of the reservoir is more than 2000 m. Fault-controlled structures are common, but simple amplitude reversals are uncommon. The dominant factor for entrapment is the permeability barrier, as evidenced in the presence of quartz overgrowths observed in thin-section petrography; however, the red bed overlying rift-fill sediments acts as regional seal. Upper Jurassic–Lower Cretaceous sandstones are truncated against pre-existing basement highs. The Raghavapuram Shale, which is the overlying Lower Cretaceous transgressive shale, may exist as a regional seal for these reservoirs. Thin limestone and sandstone beds deposited within the Raghavapuram Shale are reservoir rocks. Thin sandstone beds within thick Upper Cretaceous claystone beds are potential reservoirs in the East Godavari sub-basin. Stratigraphic plays include turbidite fans located southeast of the MPFZ. Basalt may form the regional seal for all the Cretaceous sediments. (Fig.2b).

Hydrocarbon Potential:

The reservoir facies of Permo-Triassic occur within the well identified source facies at the bottom and overlying Cretaceous argillaceous facies, which act as source as well as cap. In view of the fact that hydrocarbon indications are observed in well KB-4B-1, drilled in the north western part of offshore basin, and also, in well KG-1-B-1, indication of gas with higher hydrocarbon and oil stains in ditch samples collected from Late Paleozoic sediments, imparts the older sequence a fair degree of importance. These older sediments can also be expected to be present up to Krishna island area around the coastal part. The occurrence of gas fields like Mandapeta and Endamuru and indications of hydrocarbons in offshore areas point to the fair potential of this sequence.

The Cretaceous and Early Tertiary accumulations of hydrocarbons are present in several fields e.g., Kaikalur, Bantumilli, Lingala, Narsapur, Razole Chintalapalli etc. both in East as well as West Godavari Sub-Basins. The Cretaceous sequence in offshore wells, like well KB-1B, has also indicated presence of hydrocarbons during drilling. Suitable source and reservoir facies are also reported in this well. In view of this, the Cretaceous holds good

potential for accumulation of hydrocarbons where some twenty commercial accumulations have been discovered so far.

Perspective:

During last ten years majorities of discoveries are gas. Biggest discoveries are RIL'S Dhirubhai Ambani field in deep waters in 2005. ONGC had also struck second gas pool in adjacent block. This basin has shown high degree of H/C potential in deep and super-deep waters mainly in Plio-Pliocene formations and have good chances of striking more gas fields in future. In deep waters mainly slope-channel levee complex, debris flows, low stand wedge and basin floor fans are the main targets. In shallow waters, growth fault related structures, channel fills, combination traps, built up features, upper slope fans should be the attractive H/C plays particularly in delta-plain slope transition. Proven Mesozoic petroleum systems with oil & gas strikes are promising for exploration further.

Challenges:

The fields produced from Late Permian to Late Cretaceous are hydrocarbon bearing and depths encountered for pay sands range from 1700m to 4450m (Table-2). 13 fields are producers from Mesozoic sequences /older sequences on-land. The occurrence of gas fields like Mandapeta and Endamuru and indications of hydrocarbons point to the fair potential of this sequence for Permo-Triassic reservoirs in offshore areas. Development of these areas requires accelerated drilling and production of commercial quantities of hydrocarbons. High pressures may be problematic while drilling. HP-HT analysis is precisely required to tap huge potential of hidden reserves of oil & gas in deeper sediments. Detailed reservoir characterization of older sequences are required to map high amplitude structural closures and permeability barriers. So, there is much scope for further exploration for Mesozoic and deeper pays.

2. Cauvery Basin: (Cat-I)

Cauvery basin is a peri-cratonic rift basin began with the rejuvenation of rifting, i.e., creation of a new rift basin during Late Jurassic and Early Cretaceous times. The Cauvery Basin Extends along the East

Coast of India, has been under hydrocarbon exploration since late nineteen fifties. The Cauvery Basin covers an area of 1.5 lakh sq.km comprising onland (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 in the Cauvery Basin. The sediment thickness of basin is five to six kilometers ranging in age from Late Jurassic to Recent (mainly thick shale, sandstone & minor limestone).(Fig.4a)

The basin is structured by NE-SW horst and grabens in the southern part of Eastern Pericratonic Rift basins(Fig.4b). This trend is oblique to the N-S trending coast line and shelf. The N-S orientation of the coastal plain is due to the northward extension of Indrani transform fault(Katz,1978) from the Central Indian ocean Ridge(Biswas,2006). Exploration efforts in Cauvery Offshore-confined mainly to land and close to coast.Cretaceous fan model (New discovery in CY-OS-2) promising for future exploration. Discovery by RIL (Dhirubhai-35) has opened a new corridor for exploration in Cauvery deep water.

Prognosticated resources: 700 MMT (430 MMT: onland areas and 270 MMT: offshore)



Fig.4a. Geological map of Cauvery Basin(after Rangaraju et al.,1993)

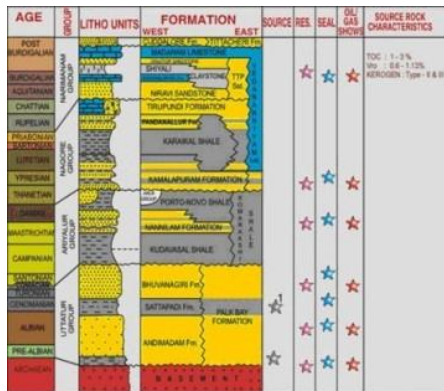


Fig.4b.Tectonic map of Cauvery Basin(after Rangaraju et al.,1993)

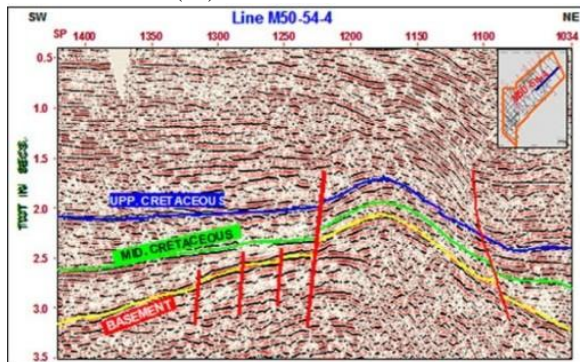
Sedimentation History and Depositional Environment:

Evolution of the Cauvery Basin is understood to have taken place through three distinct stages- (1).Initiation of Late Jurassic-Early Cretaceous Rift Stage (2).Rift stage sediments (Shivganga and Therani formations) of Upper Gondwana affinity are known from exposures.These were deposited in fluvial environments. The Kallakudi Limestone , younger to the Shivganga Formation, may represent an episode of basinal deepening and paucity of clastic supply.In the subsurface, the Andimadam Formation, overlain by the Sattapadi Shale, appears to mark the peak of this transgressive episode during Cenomanian and (3).Post Cretaceous towards the end of the Cretaceous, the basin experienced a phase of upliftment and erosion and a gradual basinward tilt of the shelf.The Tertiary sequence was deposited in a general prograding environment with gradual subsidence of the shelf. This sequence can be subdivided into two groups, the Nagore and Narimanam. The Nagore Group is well developed in the south, whereas the Narimanam Group attains its full development north of Karaikal High.

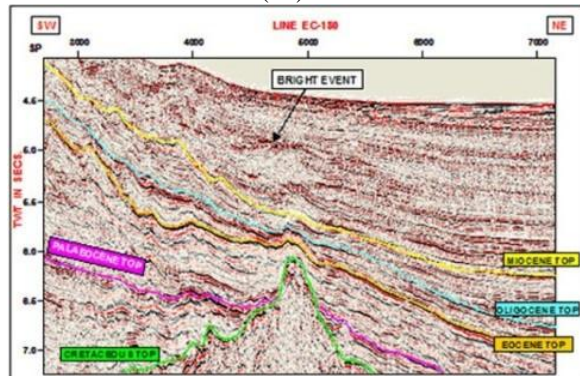
Tectonic Elements: 1.Ariyalur-Pondicherry Depression,2.Kumbhkonam-Madnam-Portonovo High,3.Tranquebar Depression,4.Karaikal High, 5.Nagapattinam Depression, 6.Vedarniyam High, 7.Thanjavur Depression, 8.Pattukuttai-Manargudi Ridge, 9.Mandapam Ridge, 10.Mannar Depression, 11.Vedarniyam – Tiruchirapally Fault Tiruchirapally Fault.Generalized stratigraphy and Mesozoic structural plays are shown at Fig.5a,5b&5c .



(5a)



(5b)



(5c)

Fig.5a.Generalized Stratigraphy of Cauvery basin and (5b) Line M50-54-4 & (5c) Line EC-180 showing Mesozoic structural plays(Courtesy DGH).

Proven / Expected Play Types

- Structural and combination traps in Early Cretaceous to Paleocene sequences.
- Stratigraphic traps such as pinch-outs / wedge-outs and lenticular sand bodies in Early to Late Cretaceous sequences.
- Source: Sattapadi shale within Cretaceous–main source, Kudavasa Shale within Cretaceous Basal part of Kamalapuram Fm (Paleocene).
- Reservoir: Andimadam, Bhuvanagiri & Nannilam Formations within Cretaceous, Kamlapuram and Niravi Formations within Paleocene Precambrian Fractured Basement.
- Cap Rock: Sattapadi shale within Cretaceous, Post unconformity shales like Kudavasa and Kamlapuram.
- Entrapment: Structural/ Stratigraphic, Combination traps.

Detailed geochemical studies established that the bulk of Tertiary sediments are inadequately matured for H/C generation. Only the syn-rift and post-rift Cretaceous shale sequences are matured source rocks. And occur within and in the vicinity of the meridian “Wrench corridor”(Rangaraju et al 1993,Biswas,2008). The occurrence of matured source rocks within the wrench corridor indicates a locally enhanced geothermal gradient that favoured maturation. Extensive sandstone deposition took place in all grabens/half-grabens during syn-rift phase of basin evolution .Besides sandstones, alloepic carbonate deposits are also form local reservoirs. In PY-1 well fractured gneissic basement is reservoir indicating basement as potential target. The common H/C traps are structural, stratigraphic, combination, fault related structures, drape and basement highs. Deep water offshore is not successful .Gulf of Mannar, a pull-apart basin between India and Sri Lanka appears to be prospective.

The estimated in place reserve is 92.99 MMT(Singh,2000) against the prognosticated resource of 700 MMT(DGH,2007). However the latest big discovery in deep waters and in Mannar sub-basin will significantly enhance the prospect and reserve base.

Perspective:

The low discovery is due to localization of mature source rocks in Nagapattinam graben and wrench corridor. This calls for more focussed exploration particularly subtle traps. The wrench corridor remains as the most favourable zone for intrinsic exploration onshore. The offshore part restricted between the slope and the 85degree ridge is an interesting area for exploration. Good structures have developed over ridges with thick sedimentary sediments. The oil & gas strike by RIL in the deep water block offshore Pondicherry confirms large reserves of gas in this part. Such large discoveries are expected in future also.

Challenges:

Having good potential for Mesozoic pays both on land and offshore, deeper prospects in offshore may have drilling complications due to presence of traps. The viable techno-economics need much consideration besides efforts for improving sub-basalt imaging. Deep water offshore Pondicherry part of EOB is rated as high risk-high reward area.

3. Western Continental Margin of India(WCMI): Western Pericratonic Rift basins:

The western continental margin of Indian basins (WCMI) (Fig.6a) situated on the western passive margin of Indian plate evolved during the separation of Madagascar-Seychells in Late Cretaceous between 90 Ma and 65Ma.The rifting started in Late Cretaceous with syn-tectonic 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 basin 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.6b). The transverse arches from north to south are Saurashtra, Bombay, Vengula and Tellichery arches, which divide shelf into five offshore sub basins-Kutch, Surat, Ratnagiri(Bombay offshore basin), Konkan and Kerala basins(Biswas and Singh,1988)(Fig.6b) Kori-Comorin couplet marks the edge of the present continental shelf, which is rifted developing “shelf Horst-Graben complex”. Each sub basin extends offshore across shelf, depression 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 the sub-basins. Kerala, Konkan and Ratnagiri basins are confined to offshore. The west coast fault terminates these basins along the coastline. Onshore extension of the Surat basin is known as Narmada basin. Cambay basin is intra-cratonic oriented N-S. E-W Kutch basin extends from onshore to offshore shelf.

Of the five sub-basins, Surat and Ratnagiri(Bombay) offshore basins qualify as Cat-I basin with its vast reserve of H/C contributing almost 70% of oil/gas production. Kutch basin is Cat-II basin waiting to be upgraded by a commercial discovery.

The other two basins, Konkan and Kerala though well explored and 17 exploratory wells have been drilled, no commercial accumulation could be located till date. Awaiting discovery, these basins are listed in Cat-III basins.

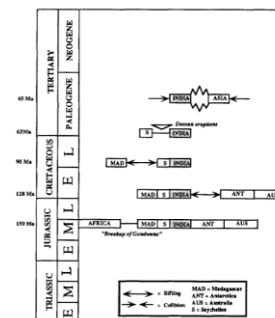
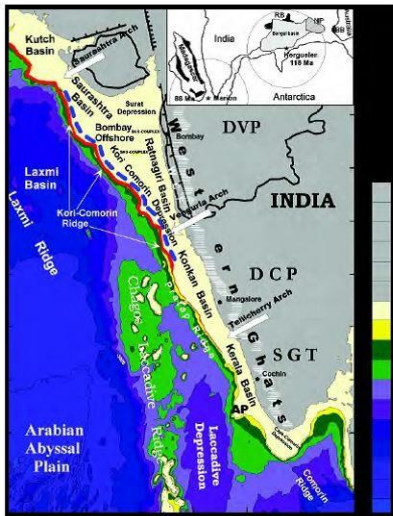


Fig.6a. Summary of tectonic history of India. Rectangles represent plates and microplates which originally comprised Gondwana (Gombos et al)



(6b). Tectonic map of Western Continental Margin of India(modified after Biswas,2008b). 1: Saurashtra Arch: 2: Bombay Arch: 3: Vengula Arch: 4: Tellicherry arch. Basin positions: -N of 1-Kutch basin, between 1 & 2 : Surat Depression, 2 &3: Ratnagiri basin, 3 &4: Konkan basin , South of 4: Kerala basin. SHG-Complex: Shelfal horst-graben complex.

3.1 Kutch Basin : (Cat-II)

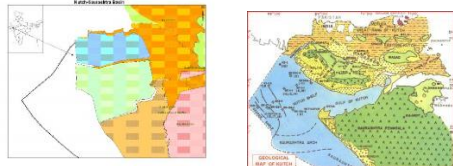


Fig.7:Kutch basin and Tectonic elements (Courtesy DGH and Unpublished report of ONGC)

A western most part of Pericratonic basin situated at the northern end of Western Sea board of India(Fig.7). It is a rifted basin with early rift during break up of Africa and India(Biswas,1982). This mid-Mesozoic E-W rift occurs between Nagar Parkar-Tharad basement ridge on the north Saurashtra Plateau on south(Biswas,2002). On the east the rift is constrained by the NNW-SSE trending Radhanpur-Barmer basement arch, which is also the western rift shoulder of Cambay basin(Fig.8a). To the west the basin extends into the western offshore shelf. E-W oriented horsts, grabens and half grabens feature the structural style of the offshore basins(Biswas,2005).

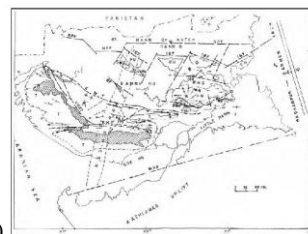
The Mid-Jurassic – Early Cretaceous rift-fill sediments are covered by Lt.Cretaceous Deccan trap flows and overlapped by Tertiary sediments deposited in the western peripheral region during post-rift marine transgression. In the offshore the thick sequence of Paleocene-Quaternary marine sediments occurs above the Early Cretaceous post-rift deltaic sediments.

The Mesozoic rocks are folded over the faulted edges of the tilted horsts crating a narrow deformed zone over the foot walls of the bounding faults. Mesozoic sediments are affected by intensive post-rift basic igneous intrusions. The rift was aborted in Late Early Cretaceous following the break-up of Seychells continental fragment during the final stages of India-Africa separation. The continental rifting took place along NW-SE faults which set up the main structural trend in the offshore. The rift is undergoing tectonic inversion since Lt.Cretaceous till date causing neo-tectonic uplifts, complicating folding thrusting and earthquakes.

Petroleum geology:

The rift basins particularly the marginal ones are favourable habitat of petroleum. The syn-rift Jurassic marine sequence with sandstone-shale carbonate association appears quite promising. However, the organic rich shales occurring on-land are immature. It is an enigma that in-spite of rift and hot-spot related magmatic activities, the shales are immature. The Early Cretaceous post-rift deltaic sequence is highly promising exploration target and yielded gas at a few shallow offshore locations. Recent discovery of oil from Early Cretaceous sandstones confirmed the expected high potential of this deltaic prospect particularly in the mid-shelf region where delta-pro delta transition is expected. Both structural and stratigraphic plays are present.

A resource base of 210 MMT on-shore and 550 MMT offshore has been prognosticated for this basin by DGH,2005.



(8a)

Fig.8a.Tectonic map of Kutch basin(after Biswas,2002).Index: Heavy dashed lines: Master faults.Lines with transverse bars: anticline, Lines with cross: synclines, arrow heads indicate plunge direction.Large+:domes.T:Tertiary;Hatch: Deccan Trap;Blank:Mesozoic within uplift limits;outside Quaternary:Small +:Precambrian.KMU:Kutch mainland uplift;WU:Wagad uplift;PU:Pacham uplift;KU:Khadir uplift;BU:Bela uplift;CU:Chorar uplift;NPU:Nagar parkar uplift;NPF:Nagar Parkar fault;IBF:Island Belt fault;GDF:Goradogar Fault;GF:Gedi fault;SWF:South Wagad fault;KMF:Kutch Mainland fault;KHF:Katrol Hill fault;NKF:North Kathaiwar fault;HG:Half graben;G:Graben;RHG:Rav half-graben,GOK HG:Gulf of Kutch half-graben

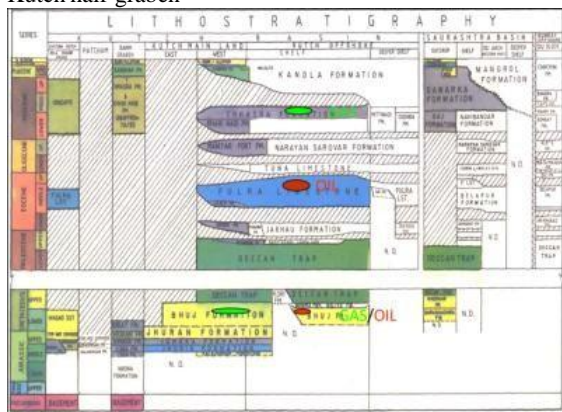


Fig.8(b).Lithostatigraphy of Kutch-Saurashtra basin

Generalized Stratigraphy:

The stratigraphic succession, ranging in age from Middle Jurassic to Holocene, is exposed in the highlands of the Kutch Basin. Sediments were laid down on a Precambrian granitic basement exposed only in the eastern part of the Nagar Parker – Tharad ridge, which forms the northern limit of the basin. Although, extension of the Early Jurassic to Holocene sequence in the offshore part of the basin has been confirmed by drilling data, none of the offshore wells has been drilled deep enough to penetrate the older units and the Precambrian basement. Presence of stratigraphic units older than Middle Jurassic has been indicated by two wells drilled in the onland part of the basin viz., Banni-2 and Nirona-1 where a continental sequence, composed of conglomerate, greywacke and sandstone has been dated as Late Triassic-Early Jurassic based on palynological evidences (Fig.8b).

Habitat of Oil & Gas

The Kutch Basin is a petroliferous basin where one oil and two gas strikes have already been made. The gas pools were struck in GK-29A and GK-22C structures in sandstone reservoirs of Paleocene and Late Cretaceous age respectively, whereas oil was struck in KD structure in Middle Eocene limestone and siltstone reservoirs. Oil and gas shows have been observed in a number of wells. Kutch Basin is contiguous to the hydrocarbon-producing Cambay Basin in the east and southeast, Mumbai Offshore Basin in the south, and the South Indus Basin of Pakistan in the North, where several discoveries of oil and gas have already been made.

Source Rocks

The geochemical data of outcrop samples and onland wells indicate that Upper Jurassic to Lower Cretaceous stratigraphic units, in the western onland part of the basin, contain good source rocks with TOC as high as 10% and T-max suggesting adequate maturity. The organic matter is of type II and III. The productivity index of the Mesozoic outcrop samples indicates migrated hydrocarbons. Geochemical data of the offshore wells reveal that fair oil-prone and mature source rocks are present in the shale units of Upper Cretaceous and Paleocene sequences in the eastern offshore part of the basin. Studies on subsidence history, temperature and thermal maturation indicate that oil generation in these sequences began relatively recently i.e. around 5-10 Ma (Late Miocene). At present, the Upper Cretaceous sequence is in peak oil generation phase and hence the major phase of oil migration is likely to have started only around 1-2 Ma (Pliocene-Pleistocene). The argillaceous Jhuran Formation of Late Jurassic age has been drilled in only one of the offshore wells i.e. GK29A-1, where shale layers with adequate TOC are buried deep enough to attain maturity. The oil pool of KD structure, the gas pools of GK-29A and GK-22C structures, and mild bubbling of combustible gas containing C1 to C6 components during testing a limestone reservoir of Middle-Late Jurassic age (Jumara Formation) in the onland well Lakhpat-1, confirm the generation of hydrocarbons in the Kutch Basin. The fact that the source and the reservoirs of the major oil and gas field in the contiguous South Indus Basin of Pakistan are located within the Early Cretaceous sequence enhances the prospectively of the Kutch Basin, as the equivalents can holds high potential for source and reservoir.

Reservoir Development

All the five wells drilled in the onland part of the Kutch Basin reveal abundant sandstones developed in the stratigraphic section ranging from Late Jurassic to Early Cretaceous (Jhuran and Bhuj Formations) which form extensive and excellent reservoirs with good permeability and porosity ranging upto 34%. The sandstone reservoirs of the Bhuj Formation extend into the offshore part of the basin also, as indicated by the well GK-29A-1 where excellent reservoirs with porosity ranging upto 25% have been encountered.

The gas pool structure in well GK-22C-1 is located in Late Cretaceous sandstone reservoirs with porosity ranging upto 18%. In the deep-sea areas west of the Kori-Comorin ridge, a number of features are observed on seismic sections which resemble deep-sea fans. These apparent deep-sea fan complexes are likely to have resulted from extension of turbidite reservoir facies locally into the Laxmi-Laccadive depression through submarine canyons formed along the saddles of the Kori-Comorin ridge, and the depositional activity of the Indus canyon.

Entrapment Conditions

The tectonic style of the basin marked conspicuously by a number of roughly east-west ridges and depressions of the Early Mesozoic rift cycle with NNW-SSE horsts and grabens of the Late Cretaceous-Paleocene late rift cycle superimposed on them, provides ideal situation for formation of structural traps. A number of structures, identified in the regions of the shelfal horst-graben complex, the Kori-Comorin depression, the Kori-Comorn ridge and the Laxmi-Laccadive depression, enhance the possibility of structural prospects. Because of the masking effect of thick Deccan Trap unit, particularly in the offshore part of the basin, seismic information of the sub-basalt Mesozoic sequences is largely lacking. Reprocessing of the existing seismic data and/or improved seismic data acquisition is likely to help define many more structural and stratigraphic play in the Mesozoic sections, in which a gas pool has already been discovered in GK-22C structure. A few fault-associated anticlinal features have already been identified in the onland part of the basin with the help of surface geological data and sparse seismic information. Apart from the structural prospects, stratigraphic pinchout against paleohighs, shelf margin carbonate buildups and reefs (pinnacle) in offshore form exploration targets.

Perspective:

Major prospects are in offshore basin. Several oil/gas shows were noted in the drilled wells from Eocene-Miocene sections but commercial accumulations is still to be found. The Cretaceous delta plays (Bhuj Formation) yielded both oil & gas in commercial quantities. Future exploration should focus on this objective in the near shore shallow water area off Lakhpat-Jakhau coast where thick delta sequence is expected besides the Jurassic Limestone prospects. The Gulf of Kutch half-graben accommodated maximum thickness of Mesozoic sediments particularly in restricted environment. Not much exploration has been done in this sub-basin which remains to be explored for Mesozoic prospects. Thick Tertiary sequence is present in the western part of the Banni basin. This is another unexplored area for the on-land Tertiary prospect. A major constraint in exploring Mesozoic rocks below the hard trap cover is poor seismic response from the sub-Trap sections. Sub-trap imaging techniques are to be developed for proper exploration of Mesozoic rocks(Fig.8c).

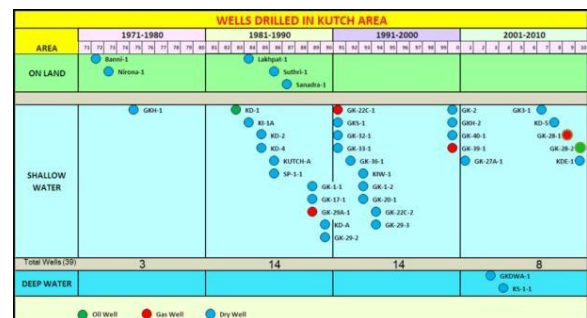


Fig.8c. Wells drilled in Kutch basin(Source-ONGC Unpublished Reports)

Challenges and Measures:

Thick basaltic section and imaging sub-basalt is a challenge. Long-offset, SBN acquisition and low frequency oriented processing are needed. As Mesozoic reserves are expected to be high, drilling more wells is required to tap the hydrocarbons entrapped in Mesozoic sequences.

3.2 Bombay Offshore basin(CAT-I):

The basin is limited to the north by the Saurashtra Arch and to the south by the Vengula arch(Fig.6b). The Bombay high arch divides this basin into two

sub-basins viz., Surat depression in the North and Ratnagiri basin in South. The western part of the Indian shield is covered by Deccan traps flows marks its eastern boundary and its west extends up to 2000m isobath. The largest Mumbai high field is located on a platform, which is a faulted part of the Bombay arch. The floor of the Tertiary sequence is Trap flows capping the Pre-Cambrian metamorphites and crystallines. The Tertiary sediments directly overlie the Precambrian rocks at places over paleo-highs where the trap is absent or eroded off, particularly in the southern part of the basin (Fig.9).

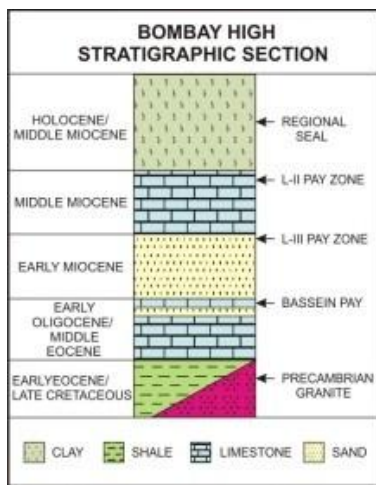


Fig.9.Generalized stratigraphic section on the Bombay High(After Rao and Talukdar,1980).

Petroleum geology

Almost all the oil/gas fields are located within the shelfal horst-graben complex where the structural and stratigraphic set up for reservoir and traps like anticlines, unconformities, carbonate build ups, wedge outs and facies change. The adjacent grabens are source rock depocenters, besides two major depressions, Surat in the North and Murud in SW of Mumbai high. The Paleocene-Early Eocene Panna Formation is the main source rock in the Ratnagiri basin and the Oligocene sequence is the source rock in Surat depression. The high geothermal gradient due to crustal stretching and shallowing of mantle in the region of Surat depression(Plume site) helped cooking of organic matters for hydrocarbon generation.

The Middle Miocene L-III and Mid Eocene Bassein Limestone are the major hydrocarbon pay zones in the basin. The basal clastics of Panna formation is also an important pay zone. In south Mumbai high where sediments directly overlie Pre-Cambrian basement, fractured granite or gneisses are also found to be good reservoir. Post Mid Miocene shales act as regional cap rock. Besides structural traps Paleocene-Eocene wedge out along periphery of Mumbai high offer good prospect.

With an estimated resource base of 9190 MMT(DGH,2010) this basin accounts for one third of the total resource of all Indian basins and over 50% of total production. The total in place geological reserve is 3390 MMT(O+OEG). Of this Bombay High field alone accounts for 2122 MMT of reserve(Singh,2000).

Perspective

The exploration of the basin is in matured stage with 3D-Seismic survey covering almost entire extent of the basin. A large number of wells have been drilled in all the structural domains of the basin. As such , there is less probability of discovering any large field in future. Only subtle traps with small reserves could be expected in the shelf part. The deep-water region of the basin west of DCS area offers future prospects. Laxmi-Laccadive depression indicates favourable habitat but there is a big question about matured source rocks and adequate sediment thickness in the latter basin. The deep WOB with less than 2000m thick Miocene/post Miocene sediments has the same problem of source rock and adequate sediment thickness. The basin could be rated as low risk-low reward area for exploration in shallow waters and high risk-low reward area in deep waters.

Challenges and measures: Mesozoic exploration limited to fractured granitic Basement and Basal clastics section only. Imaging below basalts may indicate existence of Mesozoic sediments and prospectivity.

3.5 Kerala-Konkan basin:

The KK basins form the southern part of the WCMI. The Vengula Arch, an approximate NE-SW trending basement high separates Shelfal-Horst-Graben complex of these basins from that of Bombay offshore basin. The Konkan and Kerala were divided

from each other by another basement high called the Tellicherry Arch (Singh and Lal, 1993) (Fig.10).

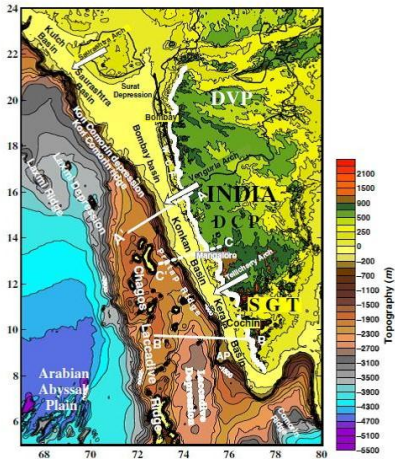


Fig.10. Tectonic and morphological features along the WCM and the adjoining Arabian sea. Structural details in the west coast and western offshore are adopted from Biswas(1982) and Biswas and Singh(1988). Thick white line along the coast represents the position of Western ghat scarp (After Subrahmanyam, 1998). AA' and BB' are the locations of seismo-geological sections. CC' is the profile off-Mangalore. WCF – West Coast Fault, DVP – Deccan Volcanic Province, DCP- Dharwar Craton province, SGT – Southern Granulite Terrain

Geologic History:

The Kerala-Konkan basin situated south of east-west trending Vengurla Arch and extends up to Cape Comorin in the south of Indian sub-continent in the western offshore basin. The sedimentary sequence is comprised of Mesozoic and Tertiary sediments. Western continental margin basin of India evolved through the break-up of eastern Gondwanaland from western Gondwanaland in the Late Triassic/Early Jurassic and the subsequent spreading history of the eastern Indian Ocean. The western margin evolved through early rift and post rift phases of divergent margin development. A series of regional and local horsts and grabens resulted in response to rifting along the dominant basement tectonic trends. The northernmost part of the western continental margin was the first to be subjected to continental rifting and crustal subsidence in the Late Triassic. The process

of rifting gradually advanced towards south and by Cretaceous time almost all the rift-related horsts and grabens came into existence.

The deposition started with continental environment, changed gradually to paralic and finally to pulsating marine conditions, punctuated by basic lava flows (Deccan Trap) in the terminal stages towards the end of Cretaceous and Early Paleocene. Towards the end of the early rift phase, most of the rift related grabens and horsts, located in the deeper parts were covered up with sediments and the continental margin became less intricately differentiated.

The Deccan Traps (Cretaceous – Early Paleocene) form the technical basement of the Tertiary Basin. For most part of early Tertiary period, Alleppey Plateau and Laccadive ridge were subjected to relative differential rise during entire Paleogene, thereby creating depressions around them. There were progressive transgressions, accompanied by syn-sedimentary positive radial movements of low to medium amplitude. Lakshadweep Depression was characterized by rejuvenation of faulting and subsidence of basement, where continental, deltaic, lagoonal and shallow marine deposition was taking place. The lithological sequence shows upward gradation from continental sand-clay section to sand-shale-coal section and finally terminating in sand-shale-coal limestone (thin) section. The depocenters kept shifting from west to east during Paleocene to Mid-Eocene period. During late Eocene-early Oligocene period finer differentiation into second order horst and graben features became more pronounced, and in some cases the direction of radial movement could have been reversed, and resulted in minor epochs of alternating transgression and regression; and consequent lateral shifting of the depocenters. Thus, the late Eocene-Early Oligocene period witnessed relative intensification of the oscillatory / pulsating movements of medium magnitude, and dominance of paralic to shallow marine depositional environment in Lakshadweep Depression.

The shelfal horst-graben complex formed the site for development of shelf depositional systems, whereas the Lakshadweep Depression and Laccadive Ridge lay in slope and basinal region. The shelf depositional systems comprised deltas, clastic and carbonate tidal flats, strandplains and carbonate ramps, platforms and banks. Lows within the shelf provided trap for the bulk of the terrigenous clastic sediments, whereas

the distal and relatively positive shoal areas favoured development of thick limestone sequences.

Extensive carbonate sequences thus developed over the northern part near Vengurla arch, Alleppy platform, distal parts of paleo-shelves and around Laccadive and Maldive group of islands Regions of favourable buildups.

Paleobathymetry over the Laccadive Ridge formed the sites for development of carbonate.

In the basin slope regions, west of the shelfal horst-graben complex, deposition of submarine fans and hemipelagic and pelagic deposits is visualised. Association of shallow and deep marine fauna in limestone bands interbedded with clastics of Early Eocene age in a few drilled wells in the Lakshadweep Depression off Mumbai suggests, that submarine canyons traversing platform limestone areas caused intermittent deposition of turbidites composed of allodapic limestone in basin slope transition zone.

In the post-Oligocene period, the basin acquired a marked westerly tilt, evidenced by numerous sigmoidal / progradational features observed in the Mio-Pliocene sections. Numerous channels, levees and turbidities observed on southwesterly slope have accommodated thick pile of post-Miocene sediments. A significant part of this pile is likely to belong to the Indus River fan in the major part of the Lakshadweep Depression.(Fig.11a)

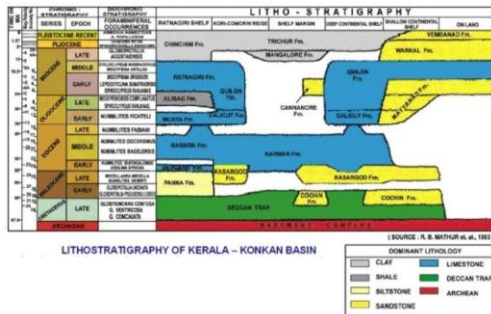


Fig.11 a.Lithostratigraphy of Kerala-Konkan basin (Courtesy DGH)

Tectonic History:

Based on available G&G data, the following first order structural elements, from east to west have been identified.1.Shelfal Horst and Graben Complex 2.Alleppy Plateau 3.Lakshadweep Depression 4.Laccadive Ridge and 5.Arabian Abyssal plain (Fig.11b).

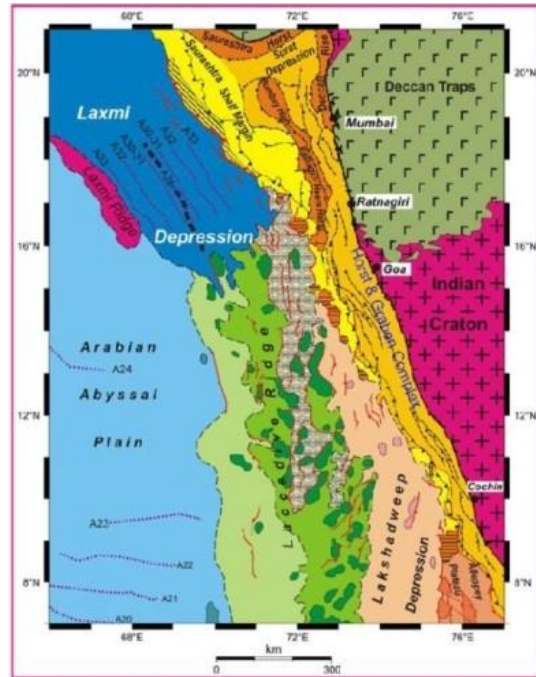


Fig.11b.First Order Structural Elements of Kerala-Konkan Basin and Lithostratigraphy of Kerala-Konkan basin(Courtesy DGH)

Basement Complex: Archaean crystalline rocks of the peninsular shield composed of granites, gneisses and charnokites are exposed along the eastern margin in the Konkan and Malbar coastal areas. The outcrops are quite close to the coast near Calicut but are upto 30 to 40 Km from the coast elsewhere. The sedimentary rocks onland rest over granitic basement as seen in a few bore holes.

Deccan Trap: The group consists of sub-aerially effusive rocks and shallow intrusives along with thin clastic rocks deposited during quiescent periods at places. Lithologically it consists of dark grey to dark greenish grey, hard fractured basalts with abundant cavities with clacite & zeolite minerals. Age of this group is Late Cretaceous to Early Paleocene.

Cochin Formation: This formation is a clastic sequence deposited in continental to outer neritic environments. Lithologically it consists of sandstones, siltstones, shales and claystones. This formation is about 919 m thick in drilled well and

the age has been assigned an age of Late Cretaceous to Early Paleocene.

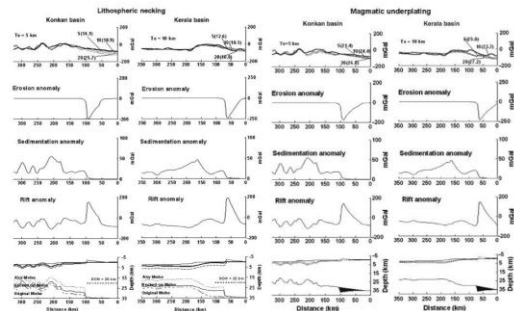


Fig.12a. Process-oriented gravity modelling with lithosphere necking at the Kerala-Konkan basins. Te of 5km for Konkan basin and 10km for the Kerala basin is based on the RMS error(shown in brackets)between the observed and computed gravity anomalies.12(b).Process oriented gravity modelling with magmatic under-plating(under plating shown in solid black) at the Konkan and Kerala basins(Courtesy Sheena V Dev,2012)

The Gravity modeling carried out with lithospheric necking and magmatic underplating results are shown at Fig.12a & 12.b.(Sheena V Dev2012)

Hydrocarbon Potential

The depositional models of the initial post-rift and late post-rift phases of basin evolution, suggest that Kerala-Konkan Basin holds promise for hydrocarbons. The prognosticated resources of Kerala-Konkan offshore basin are estimated to be 660 MMt. 17 wells are drilled by ONGC so far. Most of the wells are terminated in Deccan Traps. Two shelfal wells penetrated Lt Cretaceous Cochin Fm clastics and one deep water well drilled recently north west of Allepy platform encountered 95m limestone section as inter-trappean equivalent to shelfal part of Cochin. Recent acquisition of 2D wide angle Reflection and Refraction profiles using sea bed nodes and beam PSDM imaging has brought out complete earth model upto Moho and Mesozoic basin configuration. Thus there is a lot of scope for Mesozoic exploration in the basin.

Challenges & Scopes:

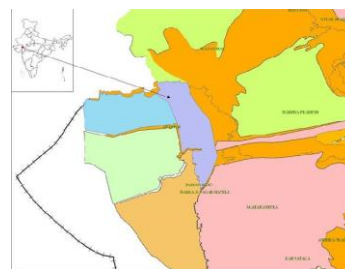
Hydrocarbon has been discovered all through coastal areas of India except Kerala-Konkan basin. In

Kerala-Konkan the Tertiary and Mesozoic sediments are separated by a thick Basaltic layer. Imaging below basalts has always been a problem in oil exploration. The thick basalt is opaque and masks deeper seismic events below the basalt. Only few wells have penetrated and drilled below the basalt. Till date the petroleum system has not been established in this basin. Moreover the establishment of the hydrocarbon kitchen area, migration path and entrapment has to be established. Wells drilled in Kerala-Konkan has shown the presence of hydrocarbons while drilling but production testing results not encouraging this fact.

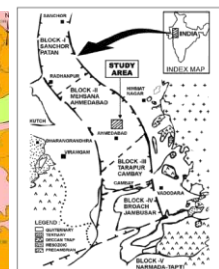
The structural style of Kerala-Konkan Basin is similar to Bombay Offshore Basin. However the horst and graben features on continental shelf are comparatively less pronounced area. Mainly we need to shift focus towards the Mesozoic exploration. Long offset data has yielded better sub-surface images below the trap which has been masked earlier; has brought out more sedimentary thickness. Heat flow studies done in few blocks have yielded better results. Multi-beam survey, done in few RIL blocks, have given the direct indication of Hydrocarbons, has to be extended to other blocks also. Sea bed logging survey has given indication of Hydrocarbons, has to extend regionally.

Reprocessing of data gives better resolution which helps in identifying interesting structures which may miss earlier. In brief Kerala-Konkan is a rare opportunity and turning it into a proven value accretion necessitates an exploration paradigm shift in terms of concepts, technology and personnel expertise.

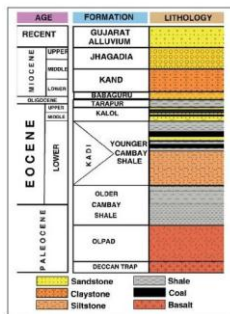
4. Cambay basin: (Cat-I)



(13a)



(13b)



(13c)

Fig.13a. Location of Cambay basin (DGH),13(b). Map of Cambay basin and 13(c).General stratigraphy The NNE-SSW trending Cambay rift basin(Fig.13a) is in the northern part of Western Peri-continental region of India. It is a long narrow rift extending northward from the Gulf of Cambay in South Gujarat to Jaisalmar-Mari ridge in central Rajasthan(500km).The basin subsurface structure is covered by Gujarat Alluvium in south and sands of Rajasthan desert in north. The rift shoulders are Aravalli mountain belt in the east, Deccan trap covered plateau of Saurashtra and Radhanpur-Barmer basement arch in the west. Transverse highs along the transfer zones divide the basin into 8 sectors with different sedimentation and structural domains(Fig.13b)(Kundu and wani,1992&1995).The Narmada and Barmer depressions are in southern and northern most sectors.The rift evolved through thermo-tectonic episodes viz., pre-rift extension, syn-rift subsidence and post-rift sagging leads to complex sedimentary pattern in the basin controlled by normal listric faulting and transverse transfer zones. Pre-dominant silici-clastic rift fill sediments range from Paleocene to Recent and include several transgressive/regressive sequences. The Deccan trap is the basement for the thick Tertiary sequence. Lower Cretaceous sediments are present below the trap overlying Pre-Cambrian gneissic basement. This rift is considered to be the failed arm of the triple junction over the Re-union hotspot plume, aborted in Early Eocene following the successful rifting of Africa and India in Late Cretaceous. The rift failure was followed by structural inversion (Fig.13c).

Petroleum geology:

Petroleum accumulations are known in all sequences ranging from Paleocene to Miocene. Major accumulations are known in the Mid 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 Mid Eocene Cambay shale is the main source rock. Mid Eocene deltaic sands are major reservoirs and Late Eocene-Oligocene and Miocene shales are regional cap rocks in this basin in various combinations in most of the discoveries. The Broach depression in Broach block is the largest kitchen area for maturation of source rocks and generation of hydrocarbons. Transverse highs played an important role in controlling paleo-drainage and distribution of sands. Most of the troughs are local generation centres for accumulations in the adjacent highs. There are several petroleum systems in the basin. The most important one is the Cambay-Hazad Petroleum system(Biswas et.al,1994) related to several large fields.

The latest estimate of resources is 2050 MMT(DGH,2010) and in-place reserve is 1140 MMT(Singh,2000)

Throughout the geological history, except during early syn- rift stage , the North Cambay Basin received major clastic inputs from north and northeast, fed by the Proto-Sabarmati and Proto-Mahi rivers. Similarly, the Proto-Narmada river system was active in the south, supplying sediments from provenance, lying to the east.

Perspective:

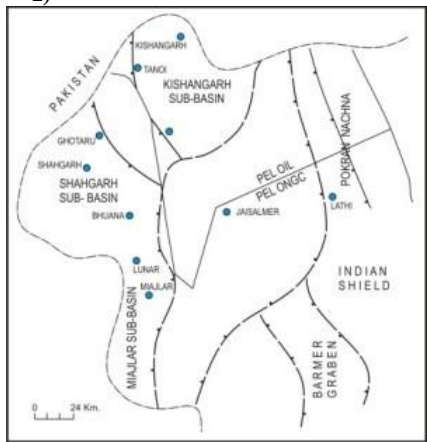
Although exploration is in matured stage good chances of discovering small subtle traps is there. The exploration is rated to Low risk-moderate reward category. Gulf of Cambay still remains to be fully explored. Recent discoveries indicate good prospect of Gulf. Barmer-Sanchor sector turned out to be highly prospective with discoveries of five oil/gas fields includes Mangala field with 116 MMT reserves. This is another discovery after Gandhar field in this basin. The future is still good with almost assured chances of discovering small fields in multiple plays with a strategy of finding new oil in old fields and deliberate search for YTF oil(Yet to find). The basin is rated as low risk-low reward.

Challenges and Measures:

The Deccan trap is the basement for the thick Tertiary sequence. Lower Cretaceous sediments are present below the trap overlying Pre-Cambrian

gneissic basement. This rift is considered to be the failed arm of the triple junction over the Re-union hotspot plume, aborted in Early Eocene following the successful rifting of Africa and India in Late Cretaceous. The rift failure was followed by structural inversion. Sub-basalt imaging and mapping sedimentary thickness is the challenge. GM modelling and latest state of art wide angle reflection cum refraction seismic acquisition, low frequency imaging and petroleum system modelling are apriori to tap potential of Mesozoic plays in addition to discovered Tertiary plays.

5. Rajasthan Basin: (Cat-I)



(14a)



(14b)

STRATIGRAPHIC UNIT	FORMATION	THICKNESS (M)	LITHOLOGY	SOURCE	RES.	SEAL	OIL AND GAS SHOW
QUATERNARY	SHIVAR	800					
Eocene	BANDHI/KHALA	470					1. TOC - 1.8% KEROGEN TYPE - II
PALEOCENE	SARU	200					2. TOC - 1.90% KEROGEN TYPE - I & II
CRETACEOUS	PARSI, GOND, PARSHAL	1800					
JURASSIC	BISAKHI-BEDSIR, Jaisalmer, Lathi	2000					
TRIASSIC	SHIVARWALI	700					
PERMIAN	KARAMPUR	800					
CAMBRIAN	BIRMANIA, SANDHA	800					
PRE-CAMBRIAN	BASINENT						

(14c)

Fig.14(a).Rajasthan basin(DGH) and 14(b) Sub-basins of Rajasthan peripheral foreland basin(after Mitra et.al, 1993) and 14(c) Litho-stratigraphy of Rajasthan sub basins(DGH)

The Recent sediment covered area to the west of Aravalli up to Pakistan border, part of Thar desert is the Rajasthan peripheral foreland basin (Biswas et al,1993).(Fig.14a). It is a part of the Indus Foreland and divided into four sub-basins (1).Jaisalmer basin(JB) on the north-western slope of the Jaisalmer-Mari basement arch(JMA),(2).Bikaner-Naguar(BN) basin on the north-western flank of the arch,(3).Shahgarh-Miajlar(SM) basin south west of the arch and (4.)Barmer-Sanchor basin(BS) south of the arch(extension of Cambay basin). The basin was upgraded to Cat-I due to recent commercial discoveries in BS basin.(Fig.14b)

The Jaisalmer basin is a Late Paleozoic-Mesozoic basin with Permian rocks resting unconfirmably over the Proterozoic basement. The BN basin to the north has widely differing geological histories during Paleozoic and Mesozoic times. The SM basin is mainly Mesozoic basin with thin cap of Paleocene-Eocene rocks(300m) and thin (200m) base of Permian rock resting over the basement. The Rajasthan basin is mostly covered by desert sands excepting on the JMA, which is the only outcropping region besides a few scattered ones. Sequence from Middle Jurassic to Early Eocene is exposed in JB. Litho-stratigraphy of Rajasthan basin is shown at Fig.14c.

Petroleum Geology:

Eight small lean gas fields have discovered so far by ONGC & OIL. Though the oil indications are common in Cretaceous strata drilled on a number of structures, common strike has not been materialized so far. The Early Cretaceous Bisakhi-Bedesir and Pariwar shales are considered to be regional source rock. These shales are gas prone with Type-III Kerogene matters and matured in NW part of the basin. In the Bikaner-Nagauar basin heavy viscous oil (19degree API) is present in infra-Cambrian Bilara and Jodhpur formations. The Bilara sandstones seem to be both source and reservoir rock with evaporate as cap. The Jodhpur sandstones are also the reservoir rocks. In Barmer basin oil occurs in the sandstones of Paleocene Fategar Barmer formations.

The total resource in Rajasthan basin has been prognosticated as 380 MMT(O+OEG). In Jaisalmer basin 2.57 BCM of in-place gas reserve has been estimated till date. Estimated in-place reserves in Bikaner-Nagaur and Barmer basins are 94 MMT of oil and 116 MMT of O+OEG respectively(DGH,2010: Singh 2000)

Jaisalmer sub-basin

- Paleocene extensional fault blocks with Cretaceous age reservoirs
- Early Tertiary stratigraphic subcrop closure of Sanu clastics beneath the shales of the lower Khuiala Formation
- Mesozoic subcrop of either Cretaceous age sediments below Base Tertiary or early-mid Jurassic Lathi Formation beneath Jaisalmer Limestone.
- Lowstand Fan mounds at the base-of-slope (intra Baisakhi Formation)
- Relative sea-level fall, forced regression sands at shelf break.

Mesozoic plays

- Mesozoic sediments are expected to hold good prospects on Jaisalmer – Mari platform. The rising flank of Jaisalmer Sub-basin is the target for subtle traps. Lunar and Daw are considered to be good prospects for Mesozoics. Bhuana structure has a potential of estimated 2BCM of gas. The Mukleri structure is expected to host about 1 MMt of oil. In Lunar area eight drape structure have been identified which are most favourable targets for hydrocarbon entrapment.

Cretaceous plays

Probability of striking oil in Kharotar –Sadewala area in Cretaceous sediments appear to be high

Bikaner-Nagaur sub-basin

- Early Cambrian Transpressional fault-blocks.
- Early Cambrian Transpressional reactivation combined with salt swells.

- Sands developed at the toe-set end of 'clinoform sequence'.
- Sands developing structure within prograding clinoform.
- Tertiary reactivated fault-blocks, extensional movement along existing faults.
- Late Tertiary transpression of pre-existing faults.

Cambrian plays

- Available evidence indicates that the Cambrian sediments have generated both oil and gas. Oil is discovered in Cambrian dolomites in the well Karampur-1. Heavy oil is present in multiple zones within Cambrian sediments (Bilara Limestone and Jodhpur Sandstone) in Baghewala, Tavriwali and Kalrewara structures. Presence of light oil has been reported in an exploratory well drilled in an exploration block RJ-ON-90/5.

Barmer-Sanchor Sub-basin

Mesozoic plays

Up-dip migration from Cambay basin northwards is considered to have sourced the hydrocarbons encountered in Barmer-Sanchor sub-basin. However latest data suggests that thick sediments of tharad formation having good source rock characteristics constitute a significant source sequence within kitchen areas of Barmer-Sanchor basin itself. Hydrocarbon entrapment is established in structural as well as strati-structural traps with possibility in up dip pinchout prospect towards the basin margin. Potential oil and gas bearing reservoirs range from the upper Cretaceous volcanic basalts to the Eocene - Oligocene arenaceous units. Mesozoic sediments are also possible reservoirs in the northern part of Barmer- Sanchor basin.

Perspective:

Apart from Barmer basin , there is no Tertiary prospect in other parts of Rajasthan. Barmer basin is now fully explored. Excepting small satellite pools in Paleocene section, the chance of other discovery is

low. However, the Barmer discoveries indicate that the prospect of sizeable accumulation in Sanchar sub basin is still good (S-Sector of Cambay basin (Fig.10). Production of heavy oil deposit in BN basin is pending for economic reasons. GOI has offered this for production lease since 1991. Still there are chances for discovering more economical deposit. Several structures have been mapped and drilled in the SM basin without any success so far. Facies analysis of Cretaceous Bisakhi and Bedesir formations indicates south-westerly drainage system and development of delta complex in this part of the basin (Sinha et al 1993). The Mesozoic is the main prospect target particularly the Cretaceous Pariwar, Goru and Parh formations, which are the main producers in Pakistan. The second proven prospect is Late Proterozoic and Permian. So far exploration has been focussed on the structural traps only. Most of these structures are late generation structures. Apparently, the Indus Fore-deep in Pakistan is the main kitchen area and the generation of hydrocarbon took place in post-Miocene time subsequent to the plate-collision. The migration is later than that. Within this short time only the lighter gas fraction could reach the distal foreland margin in Rajasthan while the proximal structures are flooded with gas and or oil. Therefore it is necessary to focus attention to the deeper prospects, mainly Cretaceous and Jurassic in SM sub-basin. In JB basin focus should be on combination and subtle traps in Jurassic and Lower Cretaceous while more extensive exploration for heavy oil should be planned for the BN basin.

Conclusions:

The petroleum systems in older Permian and Mesozoic sequences of East coast basins Krishna-Godavari, Cauvery is very promising for exploration in terms huge quantities of YTF reserves. The West Coast Margin of India is very much promising for sub-basalt Mesozoic exploration particularly in Kutch Saurashtra and Kerala-Konkan basins, where latest state of art wide angle reflection cum refraction seismic data acquisition, Layer tomography and Beam PSDM has brought out Mesozoic basin configuration and its structural entrapments and syn-rift prospects. Recent drilled wells in Kutch are gas bearing and in Kerala-Konkan encountered Limestone reservoir section as inter-trappeans equivalent to Lt.Cretaceous age. Thus there is a wide

potential for Mesozoic exploration in these basins in Western offshore basin. Mumbai offshore basin is producing from Tertiary Limestone and imaging below basalt may bring out Mesozoic section lying above Granitic basement. However basement exploration offshore Mumbai high is gaining importance for fractured granitic basement and overlying basal clastics. In Cambay basin tertiary petroleum systems are highly productive and sub-basalt exploration is warranted. In Rajasthan basin, there is wide scope for Mesozoic and older section exploration in lieu of proven petroleum systems.

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