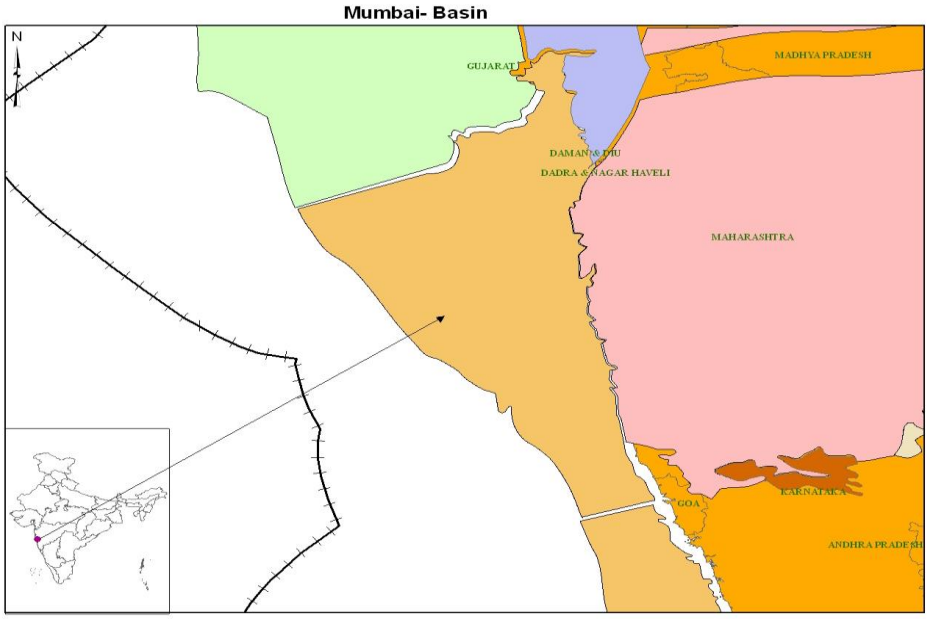
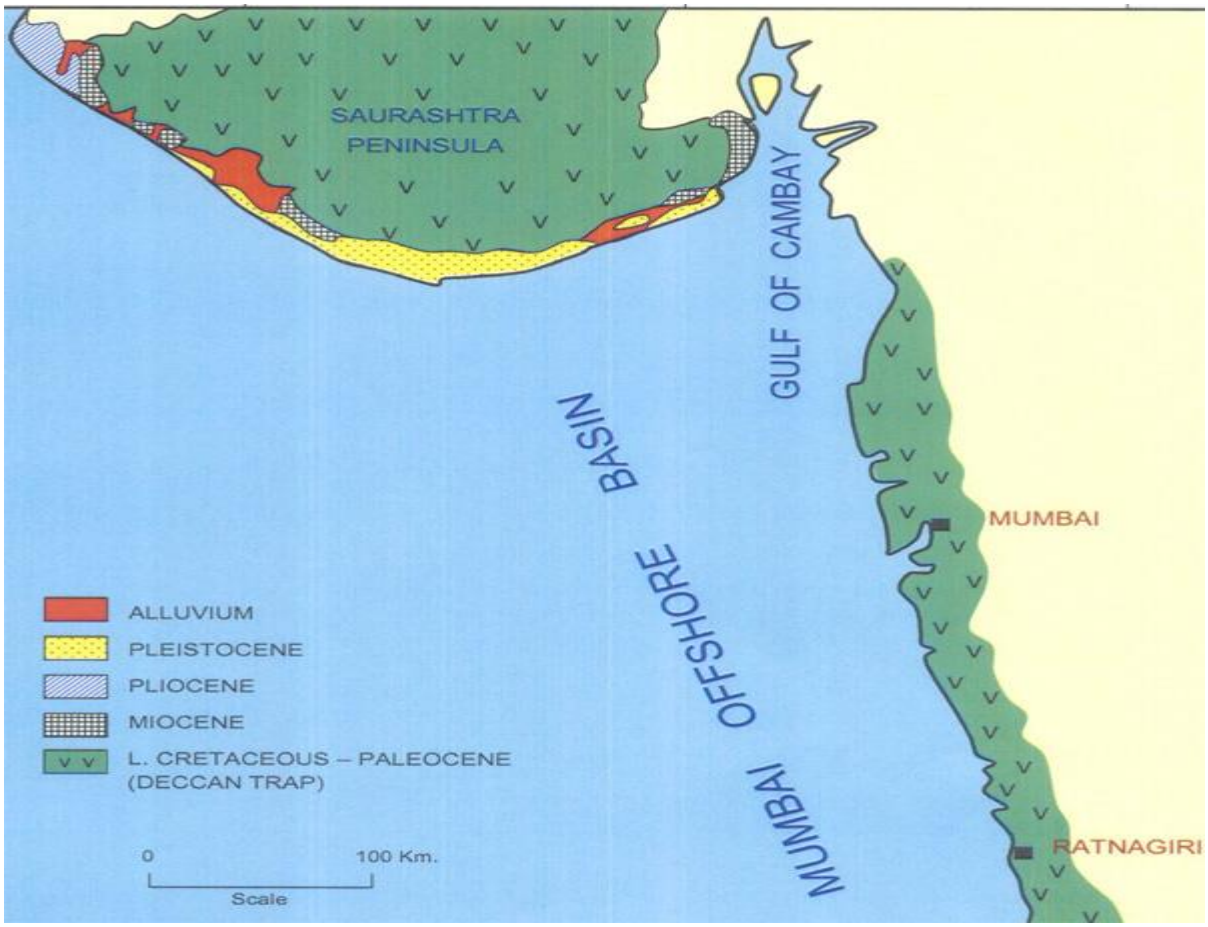
Basin Introduction :



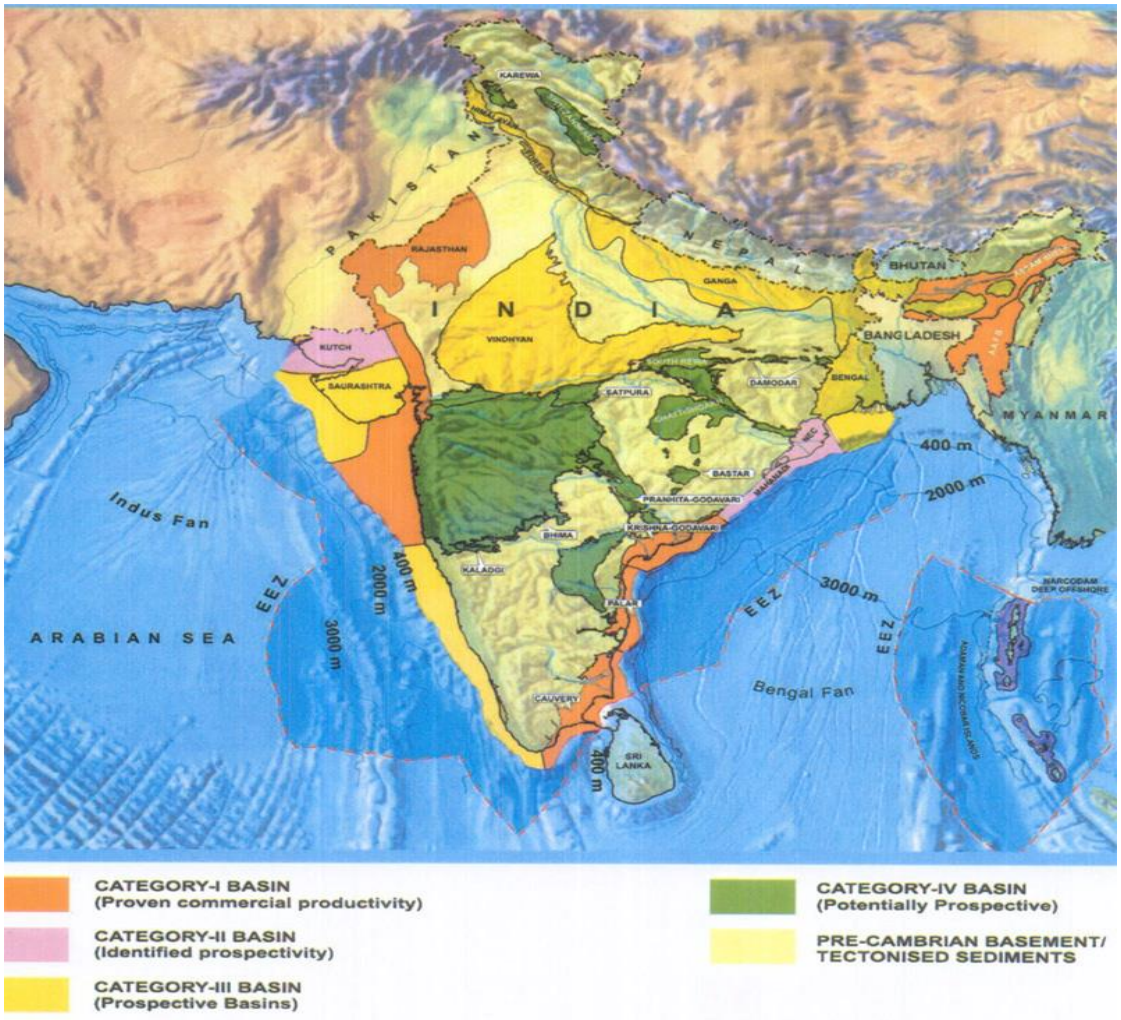
Geographic Location of the basin

Mumbai Offshore basin is located on the western continental shelf of India between Saurashtra basin in NNW and Kerela Konkan in the south.



Category of the basin

The basin falls under the category I, which implies that the basin has proven commercial productivity.



Area

It covers an area of about 116,000 km2 from coast to 200 m isobath.

Age of the Basin & Sediment-thickness

The age of the basin ranges from late Cretaceous to Holocene with thick sedimentary fill ranging from 1100-5000 m. Though possibility of occurrence of Mesozoic synrift sequences in the deep-water basin have been indicated by the recently acquired seismic data by GXT, it needs to be further ascertained by future studies.

Exploration history

Exploration in the Mumbai Offshore Basin started in the early sixties when regional geophysical surveys were conducted by the Russian seismic ship. The first oil discovery in this basin was made in the Miocene limestone reservoir of Mumbai High field in February 1974. Subsequent intensification in exploration and development activities in this basin have resulted in several significant discoveries

including oil and gas fields like Heera,Panna, Bassein, Neelam,Mukta, Ratna,Soth tapti, Mid Tapti etc.In addition number of marginal fields like B-55, B-173A, B-119/121, D-1 and D-18 have been put on production in the last decade.

Recent Discoveries (2007-08)

Block/Prospect	Discovery	Formation	Operator
B-55-5	Gas	Mukta	ONGCL
B-12-11	Gas	Daman	ONGCL
D-1-14	Oil	Ratnagiri	ONGCL
B-172-9	Gas	Panna	ONGCL
BNP-2	Gas	S1 Pay	ONGCL

Top

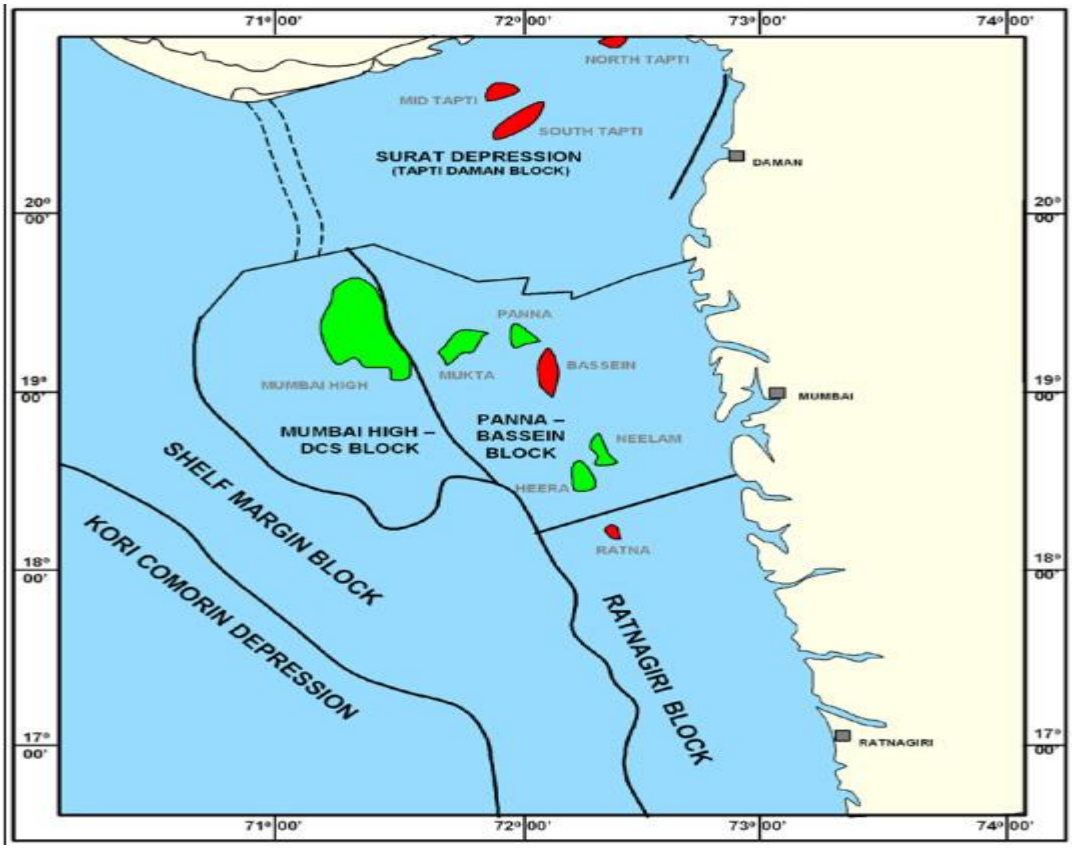
Tectonic History :.

Type of Basin

Mumbai offshore is a pericratonic rift basin situated on western continental margin of India. Towards NNE it continues into the onland Cambay basin. It is bounded in the northwest by Saurashtra peninsula, north by Diu Arch. Its southern limit is marked by east west trending Vengurla Arch to the South of Ratnagiri and to the east by Indian craton.

Different Tectonic Zones with in the Basin

Five distinct structural provinces with different tectonic and stratigraphic events can be identified within the basin viz. Surat Depression (Tapti-Daman Block) in the north, Panna-Bassein-Heera Block in the east central part, Ratnagiri in the southern part, Mumbai High-/Platform-Deep Continental Shelf (DCS) in the mid western side and Shelf Margin adjoing DCS and the Ratnagiri Shelf.



Surat Depression

It forms the southward extension of the Cambay Basin and to the west it is separated from Saurashtra Basin by Diu Arch. An arm of this Depression extends far south into Panna-Bassein-Heera block (Central Graben) and further south into Ratnagiri block (Vijayadurg Graben). A 'high' feature interrupts the north-south continuity of these grabens. A few small-scale grabens radiating from these diastamise and circumscribe horsts in Ratnagiri block. The Surat Depression has numerous structural features of different origins like basement-controlled anticlines, differential compaction over sand bodies encompassed by shale, inversions and growth fault related roll over features.

Panna-Bassein-Heera Block

This block located east of Mumbai High/Platform and south of Surat Depression has three distinct N-S to NW-SE trending tectonic units which lose their identity in Miocene. The western block is a composite high block dissected by a number of small grabens. The Central graben is a syn sedimentary sink during Paleogene and Early Neogene. The eastern block is a gentle eastward rising homocline.

Ratnagiri Block

It is the southward continuation of the Panna-Bassein-Heera block. This block is differentiated into four distinct tectonic units by three sets of NNW-SSE trending enechelon fault systems. The western block is termed 'Shrivardhan Horst' and to its east is 'Vijayadurg Graben' which is also a syn sedimentary sink during Paleogene and Early Neogene. There is a general southward shallowing of this graben. Adjoining this is 'Ratnagiri Composite Block' with a number of 'highs' and lows' and further east, like in the northern block, there is a gradual easterly rising homocline called 'Jaygad Homocline'.

Mumbai Platform

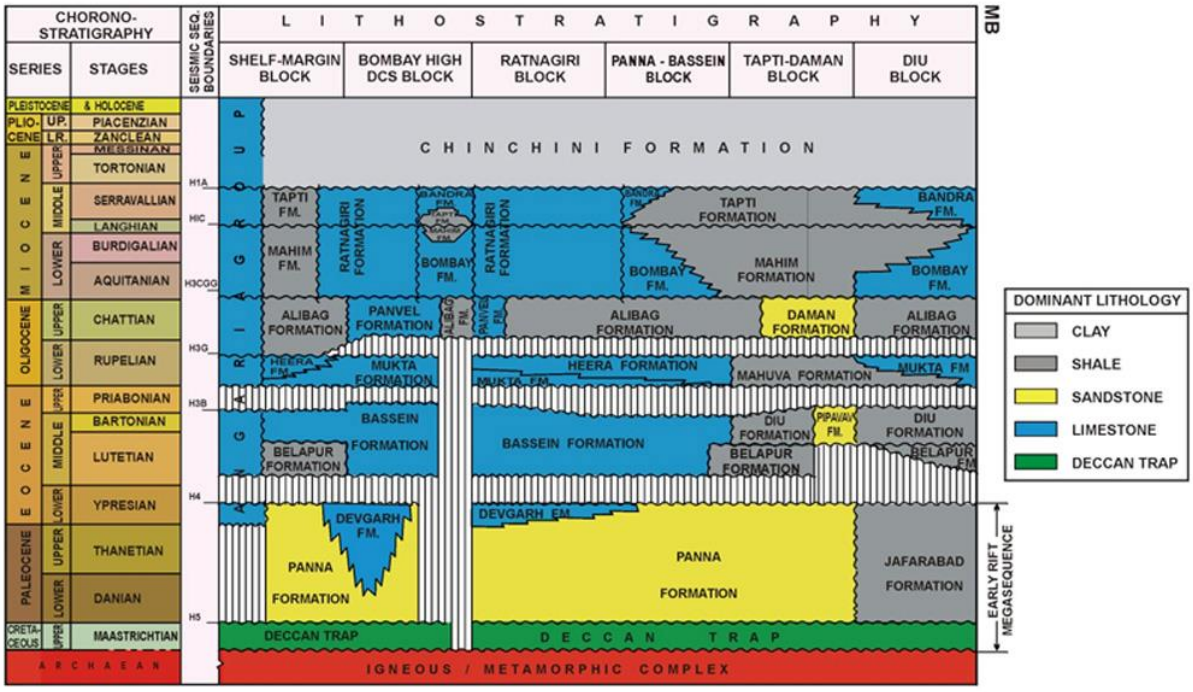
It is bounded by Shelf Margin to its west and south and by Saurashtra Basin and Surat Depression to its north. Mumbai Platform includes Mumbai high and DCS area. The intervening area between these two is gentle homoclinal rise with a few structural 'highs' of different origins. Major part of the Mumbai High area remained positive almost up to Late Oligocene missing much of the sedimentation activity. In comparison to other blocks in the basin, Mumbai block remained relatively stable which probably helped in the deposition of uniform carbonate-shale alternations over Mumbai High during Early Miocene and early part of Middle Miocene, which later accommodated huge accumulations of hydrocarbons making Mumbai High, a Giant Field.

Shelf Margin

Its northern boundary with Saurashtra Basin is indistinct and to its west lies Deep Sea Basin with the western boundary marked by part of a regional ridge 'Kori High'. Except for the deposition of thin carbonates during Eocene, possibly due to paucity of clastic supply into the basin during this period, the block essentially remained a clastic depocenter throughout Oligocene and Neogene times. During post Eocene times the block experienced continuous sinking with varied intensity to accommodate the enormous clastic material that was being brought into Surat Depression by proto Narmada and Tapti river systems and getting dispersed westward into this block.

Generalized Statrigraphy :.

- Standard stratigraphic table.



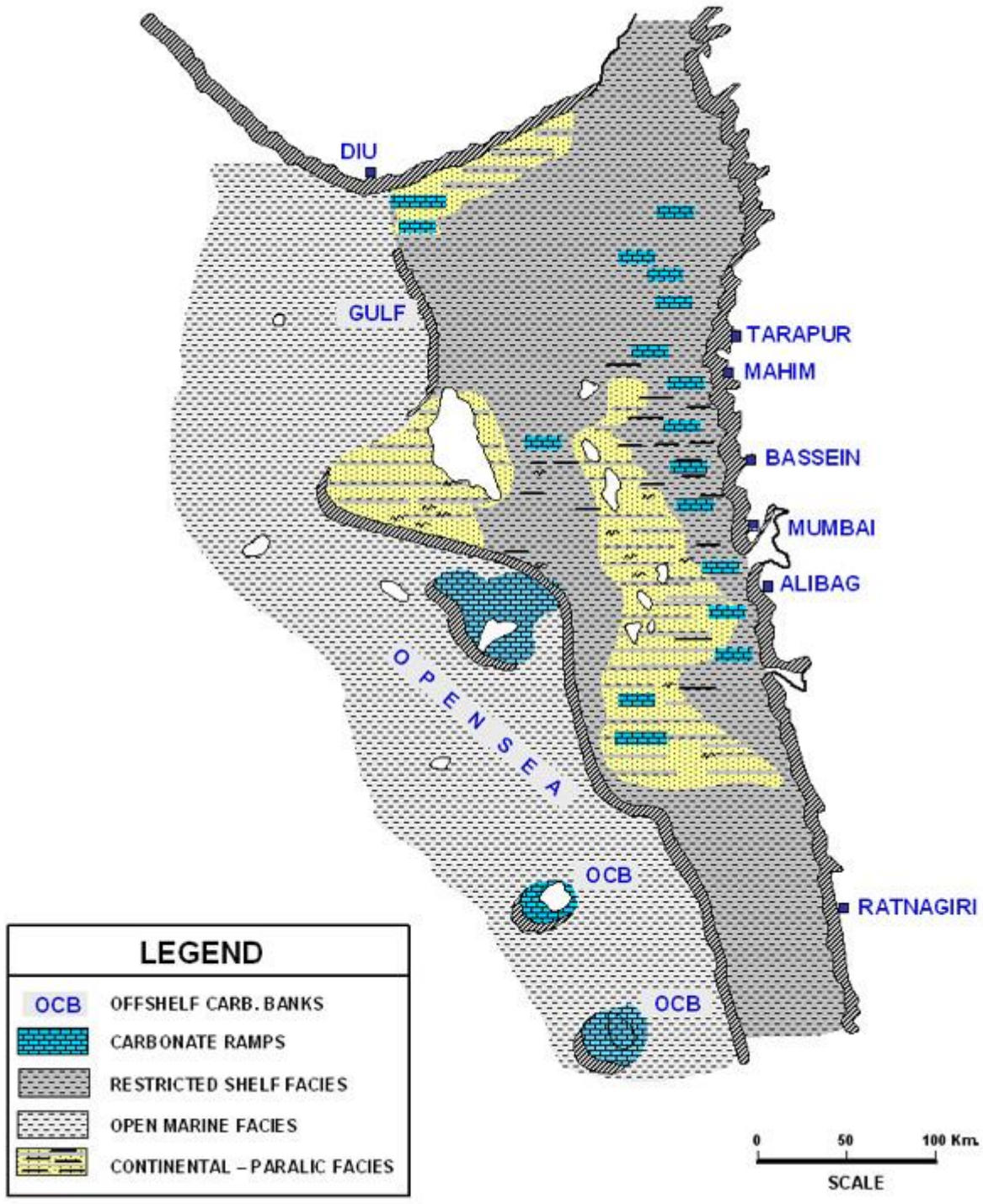
Sedimentation History and Depositional Environment

Late Paleocene-Early Eocene	This phase signifies the early syn-rift stage & is represented by trap-derived clastics contributed by the then existing paleo-highs essentially in continental to fluvial environment in its lower part (Panna Formation). It is overlain by grey to dark grey shales with subordinate sands possibly representing the first marine

	transgression into the basin. Presence of carbonaceous shale and coal at a few places suggest localized restricted conditions. Main clastic depocenters like **Surat Depression** and the contiguous southward lows like Central Graben **(Panna Bassien block)** and Vijayadurg Graben **(Ratnagiri Block)** received these sediments in considerable thickness aided by syn-sedimentary activity of the bounding faults. A few localized depressions in **Mumbai Platform** and over some other horst blocks also received these sediments. Panna Formation is wide spread in the basin except over the crestal parts of prominent paleo-highs like Mumbai High, Heera etc. Its thickness varies from almost nil to hundreds of meters in deep sinks. **Shelf Margin block,** though under deep marine realm seem to have received lesser quantities of sediments which were either derived from the Diu Arch (?) or from localized provenances. The facies developed in this block are mainly claystone, argillaceous and carbonates with some amount of pelagic fauna. Carbonate facies (Devgarh Formation) development is observed towards the southern edge of **Mumbai High** in the form of muddy foraminiferal- algal banks; Deep Continental Shelf area and isolated off-shelf carbonate build-ups at a few places in **Shelf Margin** and **Ratnagiri.** The syn-rift stage of Late Paleocene-Early Eocene period got terminated with a basin wide regression and development of an unconformity
Middle –Late Eocene Early Oligocene	After a period of peneplanation, the basin witnessed a major transgression. Extensive carbonate sedimentation occurred in the shallow shelf area of **Mumbai Platform, Panna-Bassein-Heera block** and **Ratnagiri block** (Bassein Formation). However the period witnessed essentially clastic sedimentation in **Surat Depression** (Belapur and Diu formations) with occasional carbonate bands and a few sand stringers and argillaceous carbonates and shales in Central and Vijayadurg Grabens (**Panna-Bassein-Heera block** and **Ratnagiri block**). Shelf margin was generally starved of clastics with deposition of minor claystone and carbonates of mixed middle shelf to bathyal origin (Belapur Formation) Bassein Formation also indicates a wide range of environments – restricted platform, shelf lagoon with isolated shoals in Bassein area to open carbonate shelf in **DCS** and **Ratnagiri** and finally deep water carbonates in **Shelf Margin** area. It also formed wedge outs against the rising flanks of Mumbai High and Heera, which can be considered as potential exploration targets. During this period, **Surat Depression** experienced the maximum subsidence-accumulating thick under compacted claystone relating to the prograding delta from northeast (Mahuva Formation). The **Mumbai platform** experienced generally shallower water depths and shale interbeds within limestone becoming more frequent. In **Shelf Margin** area thinner carbonates are deposited under relatively deeper conditions. End of Early Oligocene also witnessed initiation of the westerly tilt of the basin.

	Close of Early Oligocene is marked by a minor period of non-deposition except in **Shelf Margin** area. A few brief spells of transgression followed by continuous eustatic rise in sea level up to Early Miocene marked this period. Crestal part of **Mumbai High** that hitherto remained a positive area also got submerged during this period. **Surat Depression** witnessed reduced subsidence resulting in a regressive coastline. A package consisting of sand bodies deposited in distributary channels, coastal bars, tidal deltas and other transitional environments encased in marginal marine normally pressured silty and carbonaceous shale overlying over pressured prodelta clay stone of Early Oligocene. (Daman Formation) The reservoir facies within this Formation have assumed great importance as they have been found to host significant amounts of hydrocarbons.
Late Oligocene	There was faster subsidence in **Shelf Margin** to accommodate the increased sediment load supplied by the westward prograding delta system. The finer clastics reaching the **Shelf Margin** block were mainly deposited in the depression between Kori High and the carbonate platform. (Alibag Formation) Southward Close of Early Oligocene is marked by a minor period of non-deposition except in **Shelf Margin** area. A few brief spells of transgression followed by continuous eustatic rise in sea level up to Early Miocene marked this period. Crestal part of **Mumbai High** that hitherto remained a positive area also got submerged during this period. Southward from Surat Depression, clays got dispersed over Panna-Bassein-Heera block, including the crestal areas and the northern part of Ratnagiri block as well as Bombay Platform. While in Mumbai High-DCS area and southern part of Ratnagiri, the unit is termed as Panvel Formation, in Panna-Bassein-Heera and northern part of Ratnagiri, the unit is named as Alibag Formation.)
	It was a period of eustatic rise in sea level punctuated by a brief spell. The finer clastics entering into **Surat Depression** got mostly dispersed westward into Saurashtra basin and **Shelf Margin area**. Limited quantity of clastics got dispersed southward and entered **Mumbai platform** at its southeast and also up to Heera area. In response to the rising sea level, the delta being formed in **Surat Depression** in Late Oligocene shifted eastward.
Early Miocene	Bassein and the area to its south that experienced shoaling conditions during Eocene was the site for fine clastic deposition during Early Miocene. **Mumbai High** and its western part **(DCS)** underwent fairly thick carbonate sedimentation. In fact the major reservoir of **Mumbai High** that hosts major part of the Country's hydrocarbon reserves belongs to this unit. While over the **Mumbai High** area the facies are low energy, very fine grained to clayey carbonate reservoirs, the **DCS** area represents high-energy bio-clastic grainstone facies along with minor mudstone and wackestone.
Middle Miocene	The sea level continued to rise during this period. Clastic supply also continued into the basin. However much of the clastic material got dispersed westward into Saurashtra and **Shelf Margin** areas. Considerable quantity of clastics got dispersed

	southward also covering the entire **Panna-Bassein** area and also the **Mumbai High** and its immediate surroundings to the west and south. This clastic unit over **Mumbai High** includes sheet like sand, which has also been found to be hydrocarbon bearing. Carbonate sedimentation continued in **Ratnagiri** and **DCS**areas. Toward the later part of Middle Miocene, clastic deposition almost came to a halt in **Mumbai High** and other areas and consequently carbonates got deposited over many areas. Uppermost part of the Middle Miocene Limestone in Heera field has been found to be hydrocarbon bearing. Close of Middle Miocene was marked by a very pronounced unconformity.
Middle Miocene-Holocene	Post Middle Miocene witnessed a major transgression covering the entire basin coupled with spectacular increase in clastic supply. The earlier initiated westerly tilt of the basin also became more pronounced. All these events brought the carbonate sedimentation to a total halt. The increased clastic supply also resulted in a significant progradation of Miocene shelf at places up to 80 km (Chinchni Formation)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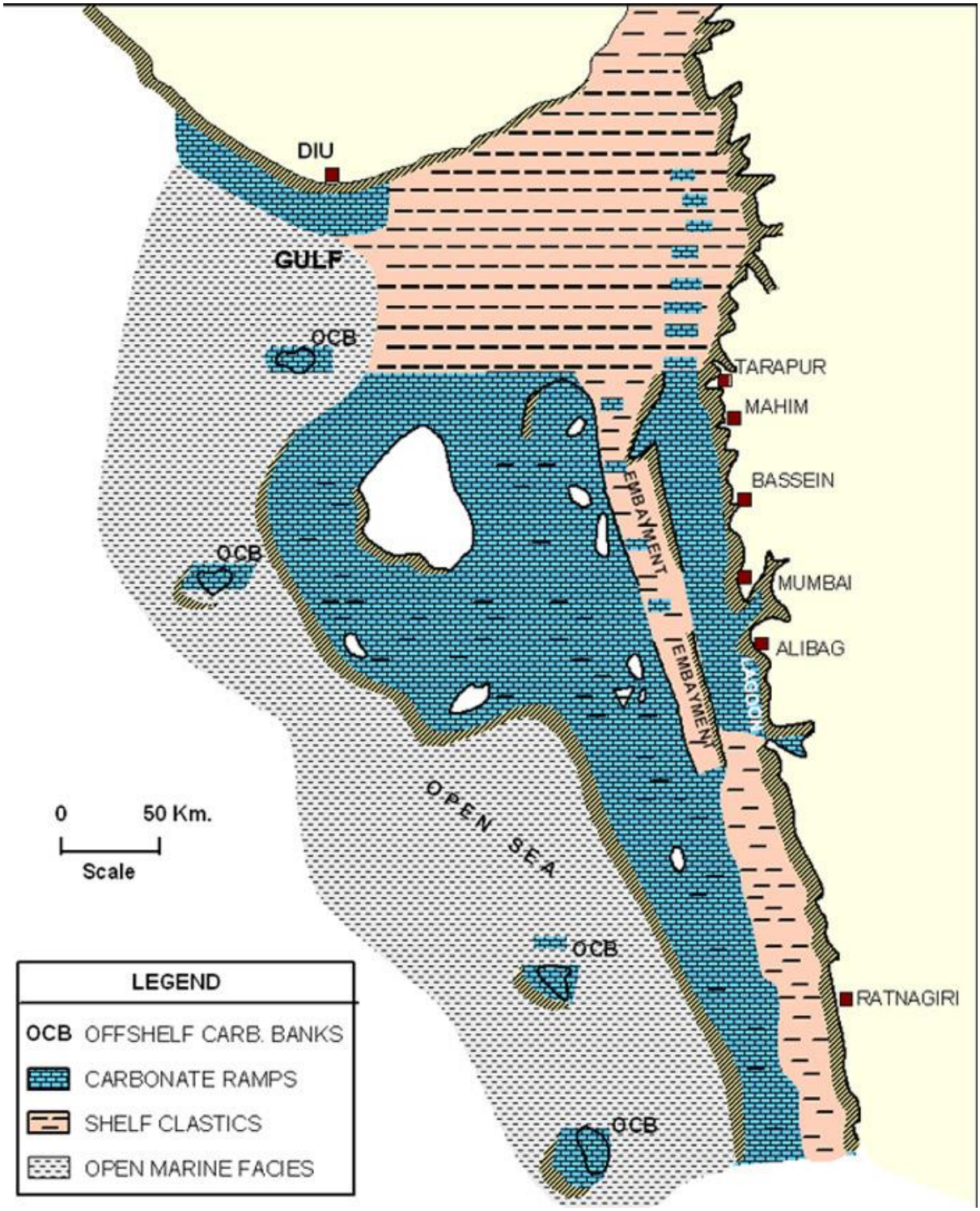
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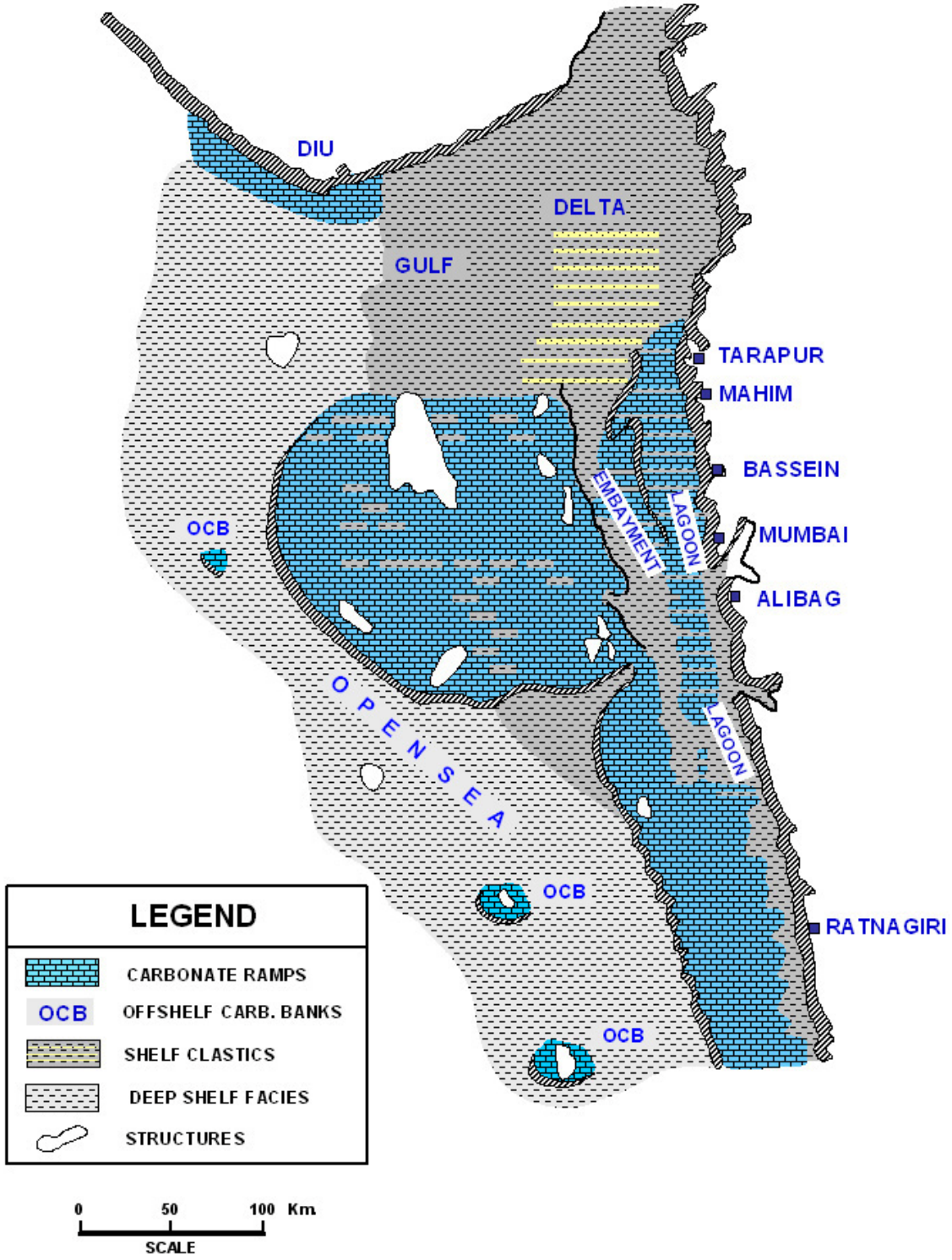
SHELF CLASTICS
OPEN MARINE FACIES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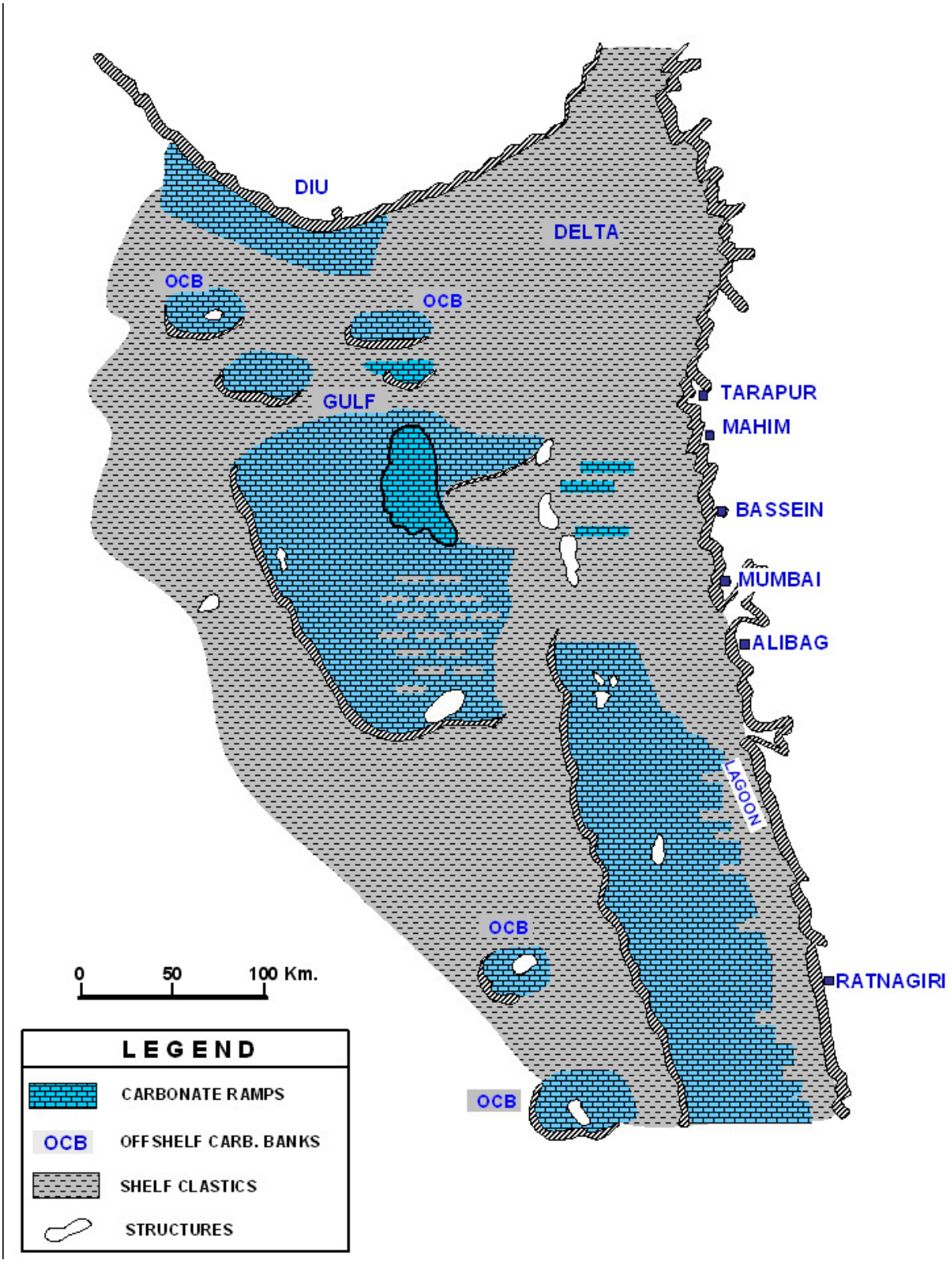
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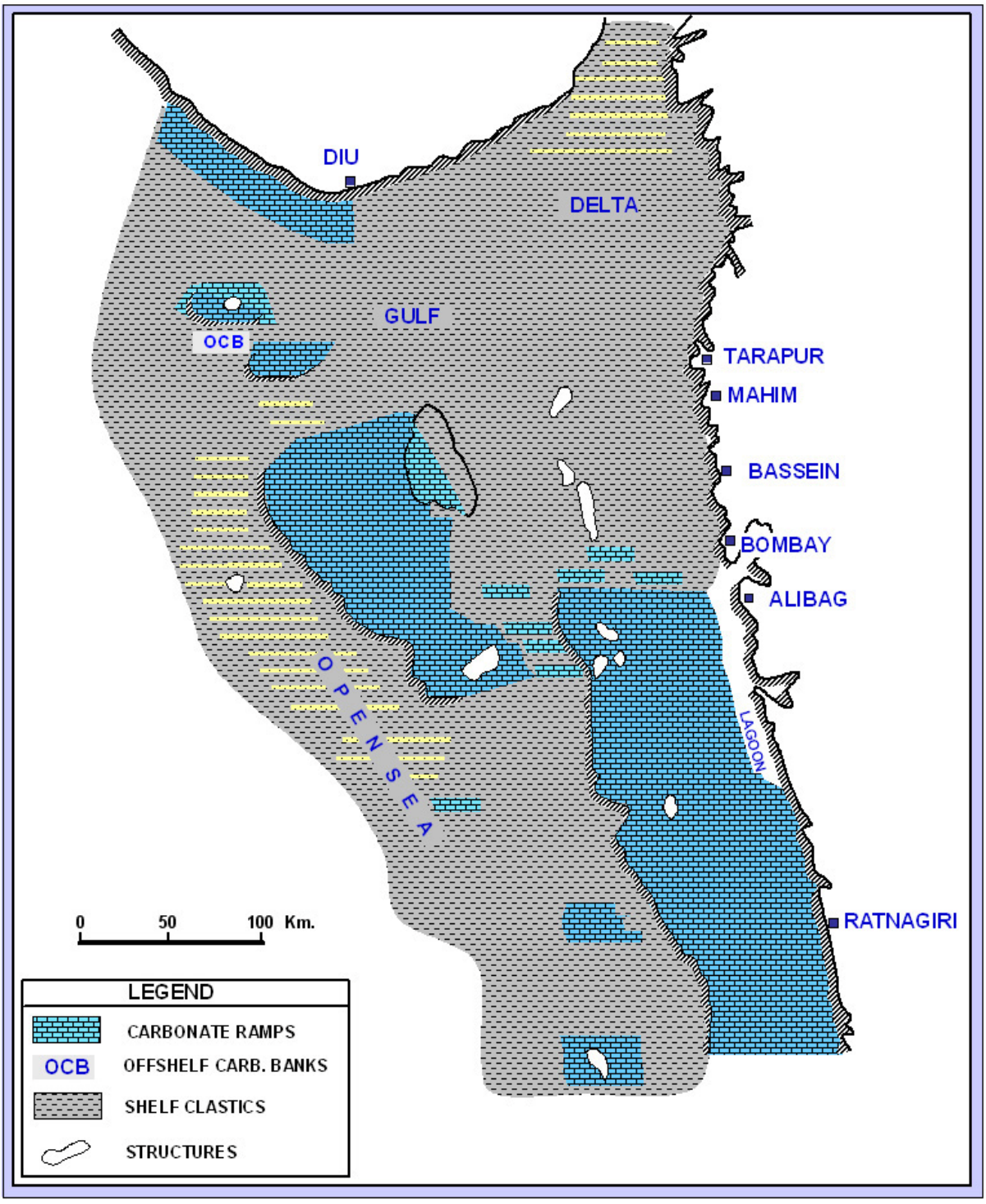
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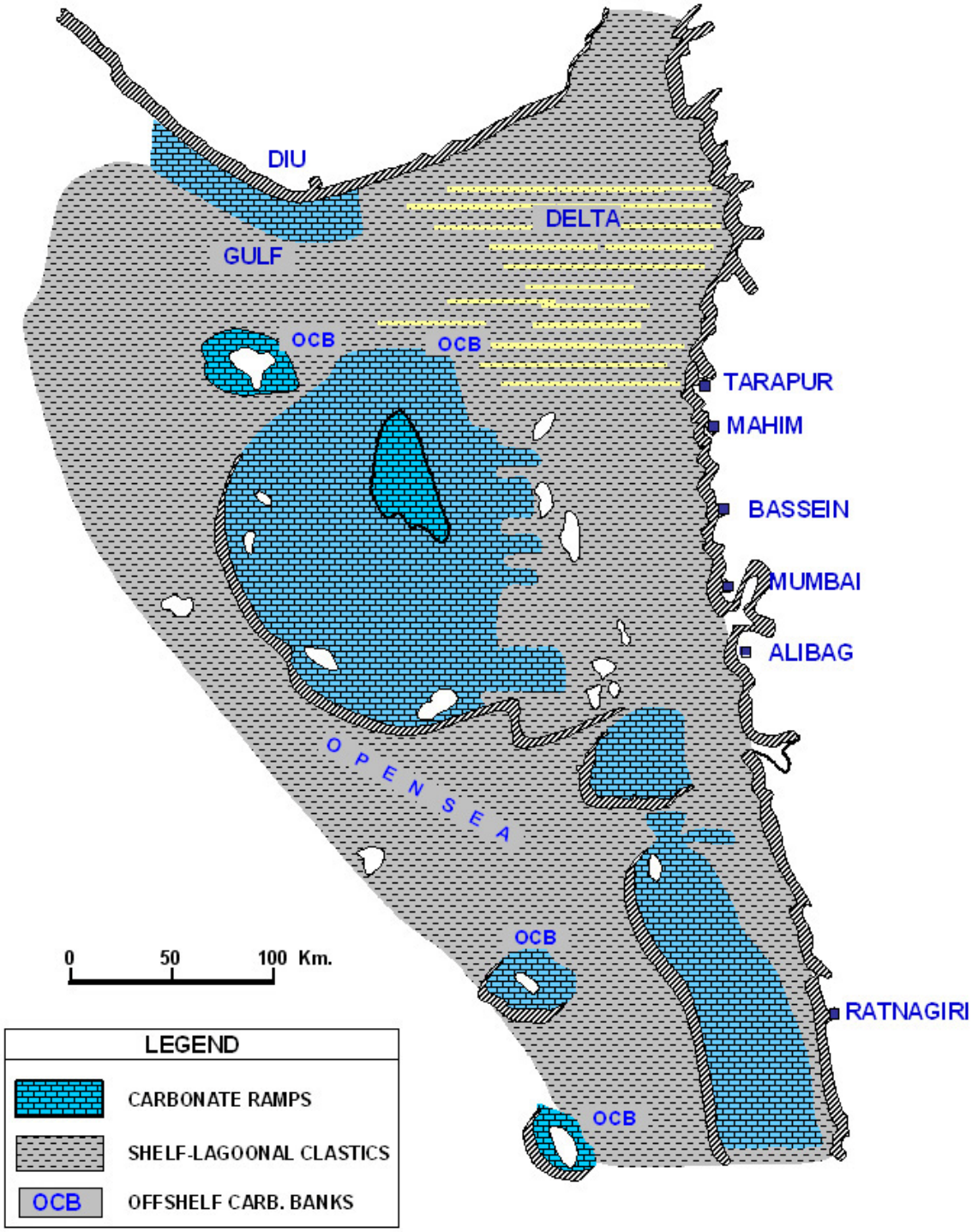

Petroleum System :

Source Rock

There are three major depocenters in the basin viz. Surat Depression in the north, Shelf Margin

in the west and Central and Vijayadurg Grabens in the south.

Source Rock		
Blocks	**Character**	**Comments**
Surat Depression Shelf Margin	Shallow protected shelf facies consisting of organic rich shales (Panna Formation- Paleocene to early eocene & Belapur Formation- Middle Eocene) 3-11% organic carbon and the kerogene type is mixed Type II and Type III. Expected oil window is around 3000 m Several layers of shale/claystone in a few wells are reported to have requisite TOC and have reached the oil window (Panna Formation & Belapur Formation) The oil window from the available geochemical data appears to be between 2900m and 3850m.	The bounding faults of this tectonic unit have been continuously active accommodating huge pile of sediments that are being brought by the Narmada/Tapti fluvial systems The enclosure provided by the Diu Arch and Mumbai High could have prevented free open marine circulation and coupled with optimum subsidence appears to have helped in preservation of organic matter. Possible reasons for the exploration setbacks could be the speculative nature of reservoir rocks and hydrocarbon expulsion pressure did not exceed the ambient hyper pressure within the formation inhibiting primary migration .
Central and Vijaydurg grabens	The finer clastics entering into Surat Depression through Narmada /Tapti systems have been getting partially dispersed southward and entering these two prominent lows that appear to be an arm of the Depression extending to the south. Syn depositional sinking of these two lows accommodating the huge clastic influx from north is evident from the seismic data.	It is widely perceived that the Central Graben in **Panna-Bassein Heera block** and Vijayadurg Graben in **Ratnagiri block** had contributed to huge hydrocarbon accumulations in many major structural features like Panna, Bassein, Heera, South Heera, etc. lying on the western horst block suggesting a major westward hydrocarbon migration. However discovery of Neelam field within Central Graben indicated hydrocarbon opportunities within the graben itself provided better reservoir facies coupled with proper entrapment condition is available.

Reservoir Rock

Mumbai offshore basin has been blessed with both clastic and carbonate reservoir facies in almost total Tertiary Section ranging from Paleocene to Middle Miocene.

Reservoir		
Age	**Lithology/Location**	**Comments**
Middle Miocene	Carbonate sections at Ratnagiri, Mumbai high & Diu (Ratnagiri & Bandra formations)	The uppermost part has been found to be hydrocarbon bearing at a few places A sheet like sand deposited over Mumbai High (S1) is also proved to be gas bearing in commercial quantity in Mumbai High
Lower Miocene	Represented by a thick pile of carbonates hosting huge quantity of oil and gas over Mumbai High (Bombay, Ratnagiri)	Deposited under cyclic sedimentation with each cycle represented by lagoonal, algal mound, foraminiferal mound and coastal marsh facies The porosity is mainly intergranular, intragranular, moldic, vuggy and micro-fissures and the solution cavities interconnected by micro-fissures provided excellent permeability.
Oligo– Early Miocene	Sands in the central and mid-eastern part of Surat depression i.e. Tapti-Daman area, Daman formation. Carbonates adjoining Mumbai High(Panvel formation)	Deposited under prograding delta conditions Proved to be excellent reservoirs
Eocene and Early Oligocene	E.Oligocene clastics of Surat depression(Mahuva Formation) Deposition of thicker carbonate facies over the horst blocks in Panna- Basein-Heera and Ratnagiri blocks (Bassein, Mukta & Heera formations).	Proven hydrocarbon bearing reservoirs in Tapti area. Gradual increase of sea level, shielding from the clastic onslaught from the northern part of the basin. The intervening regressive phases have aided in developing good porosity in these rocks making them excellent reservoir levels in the basin.
Paleocene	Coarser clastic facies developed within the upper marine shale sequence in areas of Mumbai High, Panna and Ratnagiri (Panna Formation)	The clastics of Panna formation are proved to be excellent reservoirs in the Sw flank of Panna –Basin platform.

Cap Rocks

Shale encompassing the coarser clastic facies in the Paleocene section, widespread transgressive shale overlying the Middle Eocene Bassein Formation, alternation of shale and tight limestone over early Oligocene Mukta Formation, widespread intervening shale layers within Early Miocene Mumbai formation over Mumbai High and in DCS area, post Middle Miocene clay/claystone of Chinchini Formation over parts of Heera etc. had provided effective seal for the underlying hydrocarbon accumulations in the Mumbai offshore basin.

Entrapment

As mentioned earlier, Mumbai offshore basin has been endowed with a wide variety of entrapment situations like- structural closures with independent four way closures of very large, large, medium and small sizes, fault closures and faulted closures with effective fault sealing, strati-structural features like Paleogene wedges against rising flanks of paleohighs, mud mounds, carbonate build-ups, unconformity controlled traps, Paleogene and Neogene carbonate wedges against the rising Eastern and Jaygad Homoclines. Mumbai Offshore Basin Introduction Tectonic History Generalized Stratigraphy Petroleum System Petroleum Plays

Petroleum Plays :

Major Identified play types

1. Paleogene Synrift clastics(Paleocene-Lr. Eocene, Panna Fm)
2. Eocene Carbonate Platform (Bassein formation)
3. Lr.Oligocene Carbonate plays (Mukta and Heera formations)
4. Oligocene-Lr. Miocene deltaic Play (Mahuva &Daman formations)
5. Up. Oligocene carbonates (Panvel and Ratna formations)
6. Lr. Miocene carbonate (L-III and L-IV reservoirs, Bombay / Ratnagiri formation)
7. Lr-Mid. Miocene clastics(S1 sands),
8. Mid. Miocene carbonate (L-I and L-II reservoirs, Bandra Formation)

1. Paleogene Synrift clastics(Paleocene-Lr. Eocene, Panna Fm)

- Area : Western and southeastern flank of Mumbai High,western flank of central graben,Heera-Panna Block
- Reservoir rock: sandstone
- Depositional environment: Continental (parallic) to coastal
- Trap: structural /stratistructural(updip pinch outs)
- Source rocks: Paleocene-Eocene (Panna Formation)

Commercial production from few wells of Heera Field. Areas SW of Bassein Field containing B-80, B-23A prospects and prospect D-33 in DCS have been identified for pre-development studies along with younger pays. In addition commercial flow has been observed in prospects like B-34, B-59, B-127, Panna East wells etc.

2. Eocene Carbonate Platform(Bassein Formation)

- Area: Heera-Panna Composite Block, part of MH-DCS block (NW and SW flank of Mumbai High), Ratnagiri
- Reservoir rock: Limestone
- Depositional environment: shallow shelf /Shelf-lagoon carbonates
- Trap: structural /stratistructural(wedge outs)/diagenetic traps(?)
- Source rocks: Paleocene-Eocene (Panna Formation)

Commecial production from several medium sized and marginal Fields-

- Mukta-Panna
- Bassein
- Heera
- Neelam
- B-55
- B-173A
- South Heera

In addition several prospects in Heera-Panna Composite block and BH-DCS block has been tested hydrocarbon in commercial quantities.
Areas identified for development/pre-development studies:

- NW of Mumbai High
- SW of Mumbai High
- West and SW of Bassein
- Bassein East

3. LR. Oligocene Carbonates (MUKTA AND HEERA FORMATIONS)

- Area: Heera -Panna composite block, MH-DCS platform
- Reservoir rock: limestone
- Trap: structural
- Source rocks: Paleocene-Eocene (Panna Formation)
- Fields: Heera,panna,neelam,Basseim,B-55,D-18 etc

4. Oligocene - LR. Miocene Distal Deltaic-Coastal Play (DAMAN AND MAHUVA FORMATIONS)

- Area: Tapti-daman Block
- Reservoir rock: Sandstone
- Depositional environment: Deltaic to coastal
- Trap: Structural /stratistructural
- Source rocks: Paleocene-Eocene (Panna Formation)
- Fields: South Tapti/Mid Tapti
- Areas identified for development/pre-development studies: C-series structures, North Tapti,

5. Up. Oligocene carbonates (Panvel and Ratnagiri formations)

- Area: MH-DCS Block
- Reservoir rock: limestone
- Trap: structural

- Source rocks: Paleocene-Eocene （Panna Formation）
- Fields: B-121/119
- Tested commercial potential from wells located in the MH-DCS Blocks Area identified for Dev/pre-development studies: B-46, B-48 （NW of Mumbai High）, B-192, B-45, and WO-24 etc

6. Lr. Miocene carbonate (L-III and L-IV reservoirs)

- Area: Mumbai High
- Reservoir rock: limestone
- Trap: structural
- Depositional environment/facies: Deposited under cyclic sedimentation with each cycle represented by lagoonal, algal mound, foraminiferal mound and coastal marsh facies
- Source rocks: Paleocene-Eocene （Panna Formation）
- Fields: Mumbai High, D-1 Prospects identified for development WO-24, B-45 along with other pays

7. Lr-Mid. Miocene clastics(S1 sands)

- Area: Mumbai High and adjoining area
- Reservoir rock: sandstone/siltstone
- Trap: strati-structural
- Source rocks: Paleocene-Eocene （Panna Formation）
- Fields: Mumbai High, recent discovery on BNP prospect

8. Mid. Miocene carbonate (L-I and L-II, Bandra Formation)

- Area: Mumbai High, DCS and adjoining area （L-I and L-II）
- Reservoir rock: Limestone
- Trap: structural
- Source rocks: Paleocene-Eocene （Panna Formation）
- Fields: Mumbai High,Heera,D-1