Basic Introduction :.



Geographic Location of the basin

Saurashtra Basin is located in the northern part of western continental margin of India which trends NNW-SSE. The onland part of the basin is also known as Saurashtra Peninsula.





(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

INDEX MAP OF SAURASHTRA BASIN

This basin lies north of commercially proven Mumbai Offshore and south of highly prospective Kutch basin. The onland part of the basin borders with the commercially proven Cambay Basin on its eastern flanks. The deeper offshore Saurashtra borders with the Indus fan (to the abyssal plain of the Arabian Sea).

<u>Offshore Saurashtra</u> the shelf extends much less than its average extension on the western offshore (i.e. 160km). The shelf break also occurs at a water depth of 200m itself.



Saurashtra Basin

The seabed physiography is that of moderately to steeply sloping shelf followed by steep shelf break.

Category of the basin

Category III (Prospective Basin)

Area

Onland : Offshore : 2,40,000km²

Age of the Basin & Sediment-thickness

The oldest phanerozoic rocks in this basin are the Mesozoic rocks exposed in the north eastern part (Dharangdhara Formation) of this basin. To the north of this basin, i.e. in Kutch good thickness of Mesozoic rocks are exposed onland and have laterally continued presence in the offshore as well. However major part of the Saurashtra Basin (both onland & offshore) is covered by Deccan Traps which have hindered the exploration of Mesozoic Hydrocarbon targets. Rocks of Early Cretaceous are exposed in the onland part

of the Saurashtra Peninsula (north eastern part of the basin).

Late Cretaceous – Early Paleocene Deccan Volcanics cover most of the Saurashtra Peninsula and the Tertiary sediments are exposed only on the periphery of the Peninsula. The tertiary sedimentary sequences consisting dominantly of Carbonates and fine grained clastics overlying the Deccan Trap Volcanics in the shelfal region have been explored for Hydrocarbon prospectivity.

Sedimentary Thickness

6000m (approx.)

Exploration Status

Mesozoic, Tertiary exposures in Saurashtra peninsula and in offshore area of the basin have been covered by detailed to semi-detailed geological mapping by NOCs as well as by private companies which have been fruitful to an extent.

However, major part of the Saurashtra peninsula (onland) is covered by Deccan Trap volcanics of Late Cretaceous – Early Paleocene age. A major part of the estimated global reserves of hydrocarbons are present in rocks of Mesozoic age. In India the mesozoics are mostly overlain by thick basaltic sequences which makes imaging structures in the basalt covered region a key exploration challenge. Studies like Deep Resistivity Sounding (DRS), Transient Electromagnetic (TEM), Gravity data, Controlled source seismic (CSS) have been conducted by ONGC. Geoscientists have also tried to model the onland part with the help of geophysical data collected and the information available from the two wells drilled in the area (Lodika-1 & Dhanduka-1).

Tectonic History :.



Tectonic framework of the western continental margin showing Precambrian tectonic trends, rift faults and major structural trends within rift systems

<u>Tectonic</u> movements in the Tertiary were milder and cyclic, represented in the stratigraphic column as extensive unconformities. In the Tertiary sedimentary section extending upto Early – Mid Miocene age, a number of cycles of relative change of sea level can be identified

on the seismic section. After the early Middle Miocene, the western margin as a whole experienced heavy influx of clastics and manifests basinward rapid shift of the shelf over considerably long distance to its present position. Shale diapirism often noticed in the Laxmi depression marks the youngest deformation phenomenon.



MAIN TECTONIC ELEMENTS OF WEST-COAST DEEP OFFSHORE BASINS

The principal tectonic elements in the offshore region are :

Shelfal Horst-Graben Complex -

Constitutes the main part of the rifted continental margin, lying between the coast and shelf margin trough. The shelf structural assemblage consists of a number of horsts & grabens. The shelf break mostly occurs around 200m isobath itself.

Shelf Margin Trough -

Is a narrow linear trough elongated parallel to the shelf edge. It lies between shelfal horst-graben complex to the east and Laccadive ridge to the west.

Laxmi Basin -

Is located between Laxmi ridge and Laccadive ridge. Consists of a series of pronounced linear magnetic anomalies which are interpreted to represent two-limbed sea floor spreading sequence and indicates that oceanic crust is the basin floor. Total sedimentary cover in the Laxmi basin varies from 1250m on basement highs to 3000m in the depressions. Water depth ranges from 2000-3500m and has maximum width of about 300km.

Laccadive Ridge -

Is a narrow elongated ridge almost parallel to the coast, which separates shelf margin trough in the east from Laxmi Basin in the west. It is considered as a continental remnant rifted away from the continental margin and reworked by hotspot volcanism. The ridge has a complex system of grabens, half grabens & normal faults.

Laxmi Ridge -

Is a narrow elongate ridge in the deep offshore part west of Laxmi Basin.

Arabian Abyssal Plain -

Is a typical oceanic depression in Cenozoic times through the sea-floor spreading along the Carlsberg ridge. It is consistent with a set of well-pronounced magnetic anomalies characteristic of seafloor spreading.

Basin Evolution :.

Western continental margin basins of India is related to the breakup of eastern Gondwanaland from the western Gondwanaland in the Late Triassic / Early Jurassic and subsequent spreading history of the eastern Indian ocean. Western margin evolved through early rift and post rift phases of divergent margin development. A series of regional and local horsts and grabens results in response to rifting along the dominant basement tectonic trends (NNW-SSE, NE-SW & ENE-WSW).

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 formed along the Dharwar, Aravalli and Satpura trends.

The first occurrence of marine sediments in the Kutch Basin lying north of Saurashtra is in the Bathonian Age which indicates the basin became a fully marine one during the middle Jurassic (which indicated marine incursion during this time). The basin formed the site for westerly deepening epi-continental sea, probably an extension of the Tethys, in which thick pile of sediments, ranging in age from Middle Jurassic to Early Cretaceous, were deposited in shallow marine to deltaic environments.

The sediments were deposited in two major cycles 1. Major Jurassic transgressive cycle (deposition of carbonates & shales)
2. Late Jurassic - Early Cretaceous regressive cycle (deposition of deltaic clastics).

In Early Cretaceous time the sea began to recede in response to thermotectonic uparching of the western continental margin of India as a whole that preceded the Late Cretaceous – Paleocene rifting of the Mumbai Offshore and Kerala Konkan Basin. This Late Cretaceous – Paleocene rifting, dominantly along the NNW-SSE trend represents the main phase of rifting that preceded the initiation of sea-floor spreading in the western margin of India. During and after this rifting phase, the entire western margin of India behaved alike.

Sedimentation during the Mesozoic in Saurashtra Basin accumulated over 1500m of fluviodeltaic sequences resting over the Pre-Cambrian granitic basement. The Mesozoic sediments were then intruded and covered by Deccan Trap flows in Late Cretaceous – Paleocene time. There was also uparching of the Moho during this time.

Early Eocene transgression extended over the entire western margin of India, marking the beginning of post-rift history of development of the western continental margin of India. Sedimentary sequences of the subsequent time represent deposition contemporaneous with passive subsidence of the continental margin during drift of the Indian plate away from the spreading centre.

ENE – WSW Satpura trend influences the structural grain of Saurashtra offshore basin. The environmental framework of the Saurashtra Basin and basins south of it got differentiated into shelf, slope and basin floor. The shelfal horst-graben complex formed the site for development of shelf depositional systems, whereas the Laxmi Depression, Laccadive Ridge, Laccadive depression lay in the slope and basinal part.

Saurashtra onland part remained a stable horst block throughout the Tertiary with deposition of Tertiary sediments on the peripheral lows. On the other hand the shelf had good development of deltas (and other related clastic depositional environments like strand-plains), carbonate tidal flats and extensive carbonate ramps. The slope-basin regions

formed the site for development of submarine fans, hemipelagic & pelagic deposits. Sites like the Laccadive Ridge became locations for good Carbonate build-ups (pinnacle reefs).

Generalized Statrigraphy :.



Saurashtra Basin Stratigraphy The Saurashtra Basin is mainly a clastic basin and development of limestone is noticed over Saurashtra arch and other paleohighs. Limestone sequences of Eocene to Miocene age which attain considerable thickness over Mumbai platform are found to be shaling out in the Saurashtra depression. The tertiary sedimentary section is interrupted by several unconformities, the prominent ones being :

- 1. Middle Late Paleocene
- 2. Early Eocene
- 3. Middle Eocene
- 4. Oligocene
- 5. Early Miocene
- 6. Middle Miocene

Brief description of rocks units in the Saurashtra Basin -

Mesozoics : Dharangdhara Formation -

Lithological Formation	Formation consists of feldspathic, argillaceous sandstones with subordinate shales and clays. Coarse to fine grained, cross bedded, conglomeratic, pebbly, ferruginous, fining upwards sandstones. Shales occur as lenses with carbonaceous matter.		
Sedimentary Environment	Environment of deposition appears to be fluvio-deltaic. Presence of neavy minerals suggests a metamorphic provenance. Grain size analysis nas indicated nearshore depositional conditions.		
Extent & Thickness Age	Exposed in the north-eastern part of Saurashtra Peninsula and is correlatable with Bhuj Formation of Kutch & Serau and Viramgam formations of the Cambay Basin. Estimated thickness is 488.0m from the exposed section. Different thicknesses have been estimated using various geophysical methods which indicates a general increase in the thickness towards west (from seismic data 500-1600m; gravity data suggests 1000-1500m; refraction data suggests 800m). In the well Dhanduka-1 this formation lies directly over the Precambrian Basement.		
Ayc .			
Fossil Content	Pollens, spores, Ammodiscus sp., Gastropod shells, maglomidium indicum and Ptylophyleum sp. have been reported from this formation.		

Mesozoics : Wadahawan Formation -

LithologicalThis formation is divided into 3 members. Lower member consists ofFormationbrick red ferruginous, medium-fine grained, pebbly, moderately sorted

	sandstone with lenticular shales. Middle member consists of sandy shale	
	with impure but fossiliferous limestone bands. The Upper Member	
	consists of current bedded, pebbly, gritty Quartzose Sandstone.	
Sedimentary	Fluvial overall, middle member represents a more or less littoral	
Environment	environment (marine tongue).	
	Exposed in the north-eastern part of Saurashtra Peninsula overlying	
Extent &	Dharangdhara formation and is likely to be present westwards	
Thickness	underneath the basalt cover. The contact between the two formations is	
	gradational. Exposed section thickness is 45.0m.	
Age	Upper Cretaceous (?)	
Fossil Content	Pelecypods (Pecten sp.), Echinoids, Gastropods, Ammonite fragments, Bryozoa, Corraline fragments.	

Mesozoics : Deccan Trap Volcanics -

	consists of alternating basaltic flows and intervening sedimentary
	deposition. The formation overlies Wadhwan Formation disconformably, and
	consists of effusive grey to dark grey and greenish grey to hard
Lithological	columnar basalts. At places vesicles filled with zeolite, quartz and calcite
Formation	are present. Between different flows certain clastic beds of shales/clays,
	siltstones and sandstones occur locally as inter-trappean beds which are
	poorly fissile. Volcanic plugs present are also arranged in ENE-WSW
	direction.
	Deccan volcanics are present over a large part of the Indian Peninsula
	itself. Totally covers the Saurastra Peninsula and is present throughout
Extent &	the western coast. Its thickness varies from a few hundred metres upto
Thickness	2000m in the onland part. In the offshore its thickness is highly variable
	(as seen in the seismics) as no well has penetrated the volcanics fully
	in the offshore.
Age	Upper Cretaceous to Lower Paleocene
Fossil Content	Few forms have been reported from the inter-trappeans.

Cenozoics : Jafrabad formation

Lithological	formation is alternating sequence of Limestone / Shale with few	N
Formation	quartzitic sandstone layers in the lower part.	
Sedimentary Environment	Shallow marine	

Extent & Thickness	Formation is present over the Diu Blocks and it extends over Saurashtra shelf and pinches out against Saurashtra Arch and is absent on the Saurashtra Peninsula. It lies unconformably over Deccan Traps and is 165m thick in well OS-II-G-1.	
Age	Upper Paleocene to Lower Eocene	
Fossil Content	N.burdigalensis – Lohartia hunti pustulosa A.S.Z. in the upper part while the lower part of the formation is unfossiliferous.	

Cenozoics : Nakhtarana Formation

Lithological Formation	Formation is white-buff compact limestone with alternations of silty claystone. Lower part contains dark to greenish gray, moderately hard, calcareous, pyritic claystone/shale, foraminiferal wackestone/packstone, weathered basalts and minor sandstone. The lower part of this formation is generally sandstone shale facies.
Sedimentary	
Environment	
Extent &	formation is present only the deep waters of Saurashtra offshore and is present in Kutch offshore as well. Unconformably overlying the Deccan
Thickness	volcanics in the deep offshore. Formation has an average thickness of 250m.
Age	Paleocene
Fossil Content	M. Miscella P.R.Z.

Cenozoics : Belapur Formation

Lithological Description	formation is dominantly calcareous shale / claystone with a limestone marker bed at the bottom. Calcareous shales of Belapur formation changes to silty shales of conformably overlying Diu formation in the western part of Diu Arch.	
Sedimentary		
Environment		
Extent & Thickness	formation is present over Diu block in Mumbai offshore basin and extends over Saurashtra shelf and pinches out against Saurashtra arch and is also absent over the Saurashtra Peninsula. The formation is 424m thick in well B-12-1 (Mumbai offshore) and reduces to 61m in the Saurashtra shelf.	
Age	Lower to Middle Eocene	
Fossil Content	From well OS-II-G-1 Fasciolites-Lokhartia alvelata-Nummulites	

diokartae, N. burdigalensis-Lokhartia hunti Pustulosa A.S.Z., Discaribus - Discocyclina A.S.Z.

Cenozoics : Jakhau Formation

Lithological Description	It Consists of Limestone with minor claystone, dominantly wackestone with chalk, foraminiferal wackestone/packstone and sideritic siltstone.
Sedimentary Environment	Inner neritic
Extent & Thickness	Formation is present in Kutch offshore and is reasonably thick in the Saurashtra deep offshore.
Age	Lower Eocene
Fossil Content	

Cenozoics : Diu formation

Lithological Description	Formation consists mainly of shales with few thin limestone bands. Towards Saurashtra arch lithology changes from silty shales to sandstone facies.		
Sedimentary Environment	Prodelta		
Extent Thickness	formation extends over most of the Tapti Daman block and Diu block. The formation unconformably overlies Belapur Formation and is unconformably overlain by Mahuva Formation.		
Age Fossil Content	_ate Eocene J.Jacksonensis P.R.Z. just below the top of this formation.		

Cenozoics : Fulra Limestone

Lithological Description		In the well OS-II-G-1, Limestone is white to medium gray, moderately hard to hard, very fine to fine grained with abundant carbonaceous matter.		
Sedimentary Environment		Foraminiferal assemblage and lithology are characteristic of low energy, clear water environment for the formation.		
Extent Thickness	å	formation is exposed in Kutch mainland, extends into the Kutch offshore & beyond Saurashtra arch to Saurashtra Shelf and conformably overlies the Belapur formation. Maximum thickness is about 60m in onland Kutch.		

Age	Upper Eocene
Fossil Content	N. Fabianii P.R.Z., Pelatispira P.R.Z.

Cenozoics : Tuna Limestone

Lithological Description	In the well OS-II-G-1, the formation consists of white to grey, moderately hard to hard limestone with clayey carbonaceous material. Towards the Diu arch, limestone facies of this formation changes into dominantly shaly facies.
Sedimentary Environment	Sub-littoral to littoral.
Extent & Thickness	Formation is present in Kutch offshore and extends over Saurashtra shelf. Lower part shales out towards Diu arch.
Age	Early Oligocene
Fossil Content	N. Fichteli P.R.Z. & N.fabianii P.R.Z. in well OS-II-G-1.

Cenozoics : Narayan Sarovar Formation

Lithological Description	Consists of white to medium grey, moderately hard to hard, very fine to medium grained grainstone/packstone with abundant carbonaceous material. Argillaceous content increases towards the Diu arch.
Sedimentary Environment	Inner shelf
Extent & Thickness	Formation is present in Kutch offshore and extends over Saurashtra shelf. It lies unconformably over Tuna Limestone and is unconformably overlain by Navibandar formation. Thickness varies from the northern part of offshore basin to Diu arch where it reaches a thickness of $378m$ (in well S-2-1).
Age	Upper Oligocene
Fossil Content	M. (M) complanata R.Z. and S.Ranjanae (in well OS-II-G-1).

Cenozoics : Gaj Formation

changes into dominantly limestone facies in offshore where it is	called
as Navibandar formation. Sedimentary shallow marine (transgressive)	

Extent Thickness	Formation is exposed in the coastal part of Saurashtra Peninsula with a maximum thickness of 50m. It lies unconformably over the Deccan traps and is conformably overlain by Dwarka formation.
Age	Early Miocene
Fossil Content	

Cenozoics : Navibandar Formation

Lithological Description	Consists of white, buff to grey, moderately hard mainly mudstone and wackestone, fossiliferous & pyritiferous moderately porous limestones.
Sedimentary Environment	Inner shelf
Extent & Thickness	Subsurface or offshore equivalent of Gaj formation and is present over Saurashtra shelf. Its upper contact is conformable with overlying Dwarka formation. Its thickness is 280m in well OS-II-G-1 and it increases further south and westwards into deeper shelf
Age Fossil Content	Lower Miocene M.(L). Droggeri – A Pappillosous A.S.Z.

Cenozoics : Mitti Nadi /Chhasra Formation

Lithological Description	formation is dominantly mudstone with grey claystone with calcareous bands.
Sedimentary Environment	
Extent & Thickness	Chhasra formation is present in the Kutch mainland (south and eastern part of Kutch) and Mitti Nadi is present in deeper parts of Kutch offshore.
Age	Lower – Middle Miocene
Fossil Content	

Cenozoics : Dwarka Formation

Lithological	Consists of silty clays and argillaceous fossiliferous limestones. In the
Formation	offshore Saurashtra, it contains limestone and shale alternations.
Sedimentary Environment	Inner shelf (shallow marine transgressive)

Extent & Thickness	Formation is exposed in the northwestern coastal part of the Saurashtra Peninsula and extends into offshore. Changes into Mangrol Formation in the deeper shelf and conformably overlies Gaj formation. Thickness in the coastal part is 40m which increases to 865m in the offshore well OS-II-G-1 and continues to increase further west and southwestwards.
Age	Middle Miocene to Early Pliocene
Fossil Content	

Cenozoics : Mangrol Formation

Lithological Formation	Consists of silty clays and argillaceous fossiliferous limestones. In the offshore Saurashtra, it contains limestone and shale alternations.
Sedimentary Environment	Inner shelf (shallow marine transgressive)
Extent & Thickness	Formation is present in the deeper part of the Saurashtra shelf and western part of the Diu arch. Its thickness in the well OS-II-D-1 is 3600m which reduces towards Saurashtra arch
Age	Early Miocene - Recent (youngest stratigraphic unit in the Saurashtra offshore)
Fossil Content	Biozones present in the formation are G.cicanus – G.archeomenardii A.S.Z., G. (T) mayeri R.Z., G. praebulloides P.R.Z.

Petroleum Plays :

'Petroleum Play' is an industry term that refers to exploration & extraction of hydrocarbon reserves from a region where all the elements of a petroleum system are present and leads to provable commercial quantities of Hydrocarbons.

Normal steps in evaluating a play are given below (also referred to as Play Cycle) :

- 1. Initial observations of a possible oil reserve (presence of Hydrocarbons in initially drilled exploratory wells).
- 2. Testing and adjustments to initial estimates of extraction (geographical & stratigraphical refinements).
- 3. High success in locating & extracting Hydrocarbon as a reserve.

Expected Play types in this basin :

1. Carbonate buildups



CARBONATE BUILDUP

- 2. Transpressional rollovers
- 3. Pinchouts and wedgeouts

Directorate General Of Hydrocarbon 19 Saurashtra Basin



STRATIGRAPHIC WEDGEOUT

4. Canyon complex (in Indus fan system)



STRATIGRAPHIC WEDGEOUT