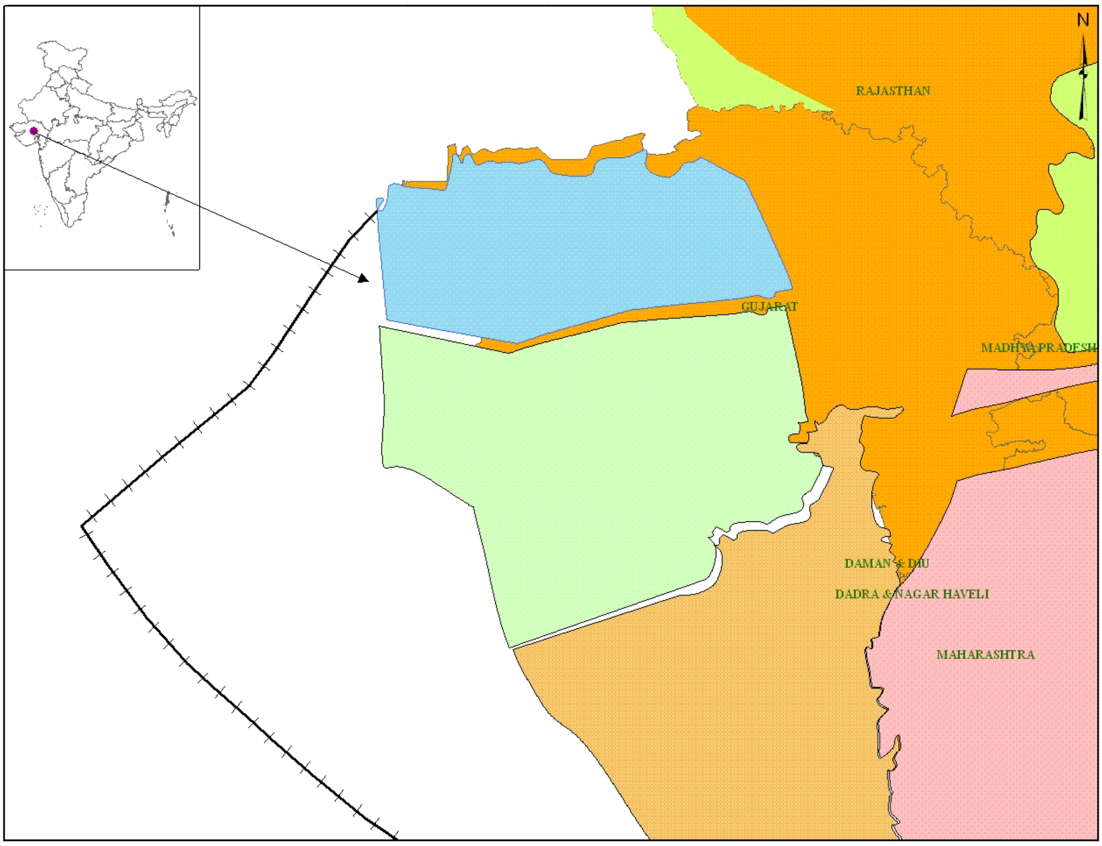
Basin Introduction :.

Kutch-Saurashtra Basin



Kutch basin forms the north-western part of the western continental margin of India and is situated at the southern edge of the Indus shelf at right angles to the southern Indus fossil rift (Zaigham and Mallick, 2000). It is bounded by the Nagar- Parkar fault in the North, Radhanpur-Barmer arch in the east and North Kathiawar fault towards the south. The basin extents between Latitude 22° 30' and 24° 30' N and Longitudes 68° and 72° E covering entire Kutch district and western part of Banaskantha (Santalpur Taluka) districts of Gujarat state. It is an east-west oriented pericratonic embayment opening and deepening towards the sea in the west towards the Arabian Sea. The total area of the basin is about 71,000 sq. km of which onland area is 43,000 sq.km and offshore area is 28,000 sq.km. upto 200 bathymetry. The basin is filled up with 1550 to 2500m of Mesozoic sediments and 550m of Tertiary sediments in onland region and upto 4500m of Tertiary sediments in offshore region (Well GKH-1). The sediment fill thickens from less than 500m in the north to over 4500m in the south and from 200m in the east to over 14,000m in the deep sea region towards western part of the basin indicating a palaeo-slope in the south-west. The western continental shelf of India, with average shelf break at about 200 m depth, is about 300 km wide off Mumbai coast and gradually narrows down to 160 km off Kutch in the north. Two coastline indentations, the Gulf of Kutch and the Kori Creek in the southern and the northern parts of the basin, respectively are the prominent features.

The basin is contiguous to the South Indus Basin of Pakistan, where a number of oil and gas fields have already been discovered. Exploratory efforts have led to the discovery of oil and gas in the offshore part of the Kutch Basin. Oil has been struck in well KD-1 in Eocene limestone / siltstone reservoirs whereas, gas has been discovered in wells GK-29A-1 and GK-22C-1 in Paleocene and Cretaceous sandstone reservoirs, respectively.

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Geological History :.

The evolution of the western continental-margin basins of India is related to the breakup of eastern Gondwanaland from western Gondwanaland in the Late Triassic / Early Jurassic (Norton and Scalter, 1979) and the subsequent spreading history of the Eastern Indian Ocean (Biswas, 1987). The western margin evolved through early rift and postrift 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 (NNW-SSE, NE-SW and ENE-WSW). The region of the shelfal horst-graben complex, the Kori-Comorin depression and the Kori-Comorin ridge thus formed a unified interior graben system, with less pronounced structural differentiation amongst them (Biswas and Singh, 1988). The northernmost part of the western continental margin was the first to be subjected to continental rifting and crustal subsidence in the Late Triassic (Biswas, 1982). The process of rifting gradually advanced towards south and by Cretaceous time and almost all the rift-related horsts and grabens came into existence.

The opening of the Kutch basin to the north of Saurashtra peninsula coincided with the transgressive phase of the sea onto the coastal areas of other parts of Gondwanaland including the western margin of Indian plate during Jurassic-Cretaceous time (Krishnan, 1960). Rifting along the Delhi trend and consequent subsidence of the block between the Nagar Parkar hills and the Saurashtra Peninsula in the Late Triassic initiated development of the Kutch Basin. Much of the Mesozoic sedimentation took place during the early rift phase of the evolution of India's western continental margin. First, the region between basin margin Nagar Parkar fault and Island Belt fault (Kaladongar-Khadir-Bela fault system) was filled up by granite-cobble fanglomerates and arkoses in the rift valley stage and then the region between the Island Belt and the Mainland was filled by continental to paralic valley fill clastics dated as Rhaetic by Koshal (1983) and evidenced in well Banni-0 and Nirona-1. The first marine transgression started with extension of graben upto Kathiawar uplift by activation of North Kathiawar fault during rift-rift transition of Indian plate movement. The graben was inundated forming a gulf. The carbonates of the basin were deposited during this period. The first occurrence of marine sediments of Bathonian age indicates that this east-west oriented ridges and depressions became a fully marine basin during the Middle Jurassic. In Early Oxfordian time, proto-oceanic stage was reached with complete inundation of the embayed basin.

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 - a Middle Jurrasic transgressive cycle and a Late Jurassic - Early Cretaceous regressive cycle (Biswas, 1981). During the transgressive cycle mainly carbonates and shales were deposited, whereas deltaic clastics constitute the regressive deposits. The east-west oriented, fault-bounded, ridges and depressions controlled the thickness and facies variation of the units deposited, though with diminishing influence as the time progressed. The westerly plunge of the basin is reflected in the general westward thickening of the units deposited during the two Mesozoic transgressive and regressive cycles, and their relatively deeper-shelf facies prograding towards the west.

The rifting failed by Early Cretaceous time when the clastics of prograding delta filled up the basin as the sea began to recede (Biswas, 1982) in response to thermotectonic uparching of the western continental margin of India that preceded the Late Cretaceous-Paleocene second cycle of rifting in the Kutch Basin and contemporaneous early rift phase of the Mumbai Offshore Basin and the Konkan-Kerala Basin. This Late Cretaceous-Paleocene rifting, dominantly along the NNW-SSE Dharwar 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 similarly.

In the region of the Kutch Basin, the thermotectonic uparching and the process of rifting of the second cycle differentiated the basin, particularly the onland part, into highlands and lowlands. The Mesozoic sediments were intruded and covered by Deccan Trap basaltic flows in Late Cretaceous-Early Paleocene time. The onland part of the basin experienced a period of non-deposition during Late Cretaceous time. Occurrence of over 2,000 m thick limestone unit of Late Cretaceous age in the offshore wells KD-1 and K1-1A indicates that shallow marine conditions continued to prevail in the offshore part of the basin during this time and withdrawal of the sea from the offshore part of the basin was for a very short duration represented probably by the period of Deccan Trap activity and the development of the Early Paleocene continental clastics. The Paleocene is represented by terrestrial volcano-clastic sediments of the Madh Series in the onland part of the basin. The imprints of the second rift cycle are represented by NW-SE trending faults, Kori-Comorin depression and Kori-Comorin ridge.

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. The environmental framework of the Kutch Basin and those of the other southern basins got differentiated into shelf, slope and basin floor. The shelfal horst-graben complex, including the lowlands of the onland part of the Kutch Basin, formed the site for development of shelf depositional systems, whereas the Kori-Comorin depression, the Kori-Comorin ridge, the Laxmi-Laccadive depression and the Laxmi-Laccadive ridge lay in slope and basinal region. The Mesozoic highlands, in the onland part of the Kutch Basin, behaved as stable horst blocks throughout the Tertiary time restricting Tertiary deposition in peripheral lows bordering them. The shelf depositional systems comprised deltas, clastic and carbonate tidal flats, strandplains and extensive carbonate ramps. The slope-basin regions, viz., the Kori-Comorin depression, the Kori-Comorin ridge and the area west of it, formed the site for development of submarine fans and hemipelagic and pelagic deposits. Regions of favourable paleobathymetry over the Kori-Comorin ridge formed the sites for development of carbonate buildups (pinnacle reefs) as observed in the well GKH-1 drilled in the northwestern part of the basin.

Tectonic movements in the Tertiary were milder and cyclic and are represented in the stratigraphic column as extensive unconformities. In the Tertiary sedimentary section extending upto early Middle Miocene age, a number of cycles of relative change of sea level can be identified on the seismic sections. The depositional systems tract described in the preceding paragraph, that existed during one cycle of relative change of sea level, repeated several times, with minor deviations in the post-rift sedimentary section extending upto early Middle Miocene. After the early Middle Miocene, the western margin as a whole experienced heavy influx of terrigenous clastic sediments resulting in development of monotonous shale / clay sequence over major part of the margin. The heavy influx of clastics during this time is manifested in basin-ward rapid shift of the shelf edge over considerably long distance to its present position. In the region of Kutch basin, the structural differentiation between the shelfal horst-graben complex, the Kori-Comorin depression and the Kori-Comorin ridge got lost as the Kori-Comorin depresion was covered up with rapidly prograding slope facies of the Neogene time.

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Tectonic History :.

The major portion of the Indian Peninsula is the Shield area with intracratonic and pericratonic fault bounded basins. More than half the area of Peninsula exposes Archaean gneisses and schists, Precambrian sediments and igneous rocks, which have been metamorphosed to various degrees. The rest of the Peninsula is covered by volcanic flows (Deccan and Rajmahal Trap flows), Late Precambrian-Early Palaeozoic sediments and Gondwana rocks.

Krishnan (1953) brought out that there are certain persistent regional trends noticeable in the Precambrian rocks of different parts of India. These trends are regional foliation, strikes, fold axes of ancient mobile belts and strike faults which are manifest as regional tectonic lineaments. Basement controlled tectonics have been discussed by many authors (Prucha et. al, 1965; Beloussov, 1962; Eremenko, 1968; Milanovsky, 1972; Katz, 1978; Biswas, 1980, 1982). Naini and Kolla (1982) also brought out that horst and grabens in the western continental margin of India were formed by reactivation of Precambrian basement trends. Katz (1973. 1979) demonstrated in the context of the India-Madagascar and India-Sri Lanka separation, that Precambrian lineaments were rejuvenated in the Mesozoic-Tertiary to form oceanic transform faults and rifts which determined phases of Indian Ocean floor spreading. Thus, reactivation of major basement faults and block faulting along them gave rise to intracratonic and marginal basins of Indian Shield. Repeated movements along them at different times controlled the evolution of these basins.

The tectonic history of Mesozoic Era began with the fragmentation of Pangea into two parts i.e., Gondwanaland and Laurasia. The southern part of the Pangea (Gondwanaland) broke apart during Mesozoic itself whereas the northern part (Laurasia) broke during Tertiary.

The breakup of eastern Gondwanaland from western Gondwanaland during Late Triassic/Early Jurassic (Norton and Sclater, 1979) marked the beginning of evolution of western margin basins of India and the subsequent spreading history of the eastern Indian Ocean. During Middle and Late Jurassic, North America rifted from Africa westward that resulted in the opening of North Atlantic. Also during the same period of time, India together with Antarctica and Australia began to drift away from Africa that gave rise to the graben faulting on the western margin of India by reactivation of ancient faults sequentially from north to south (Biswas, 1982).

The western continental margin of India can be classed as an Atlantic-type passive margin (Biswas, 1982). During the course of evolution of Indian plate, three prominent pericratonic rift basins (Kutch-Saurashtra, Cambay and Narmada) developed on the periphery of Indian Peninsula. Rifting along Precambrian tectonic trends formed these basins. Interplay of three major Precambrian tectonic trends of western India, Dharwar (NNW-SSE), Aravalli-Delhi (NE-SW) and Satpura (ENE-WSW), controlled the tectonic style of basins. These trends are seen as metamorphic belts representing three major orogenic cycles. Of these, Aravalli and Dharwar represent the oldest orogenic cycles followed by Satpura (Biswas, 1987).

The Narmada-Son lineament along the Satpura trend is a major tectonic boundary (West, 1962; Choubey, 1971) dividing the Indian Shield into a southern peninsular block and a northern foreland block. The Dharwar trend is parallel to the faulted west coast of India and a series of extension faults responsible for widening the western continental shelf (Mitra et, al, 1983). Its northvrrard extension into the western part of the Indian Shield across the Narmada rift gave rise to the Cambay basin. The third important tectonic trend is the NE-SW Aravalli trend, which splays out into three components at its southwestern extremity. The main NE-SW trend continues across the Cambay graben into Saurashtra as a southwesterly plunging arc. The arc extends across the continental shelf dividing it into a northern Kutch-Saurashtra shelf and a southern Bombay-Kerala shelf (Biswas. 1987). The northern component of the Aravalli orogen, which is the trend of the Delhi fold belt, swings to E-W and continues into the Kutch region across the Cambay graben. The Saurashtra horst remains as a foundered block between these three intersecting rifts along the major Precambrian trends. It is more or less square shaped block tilted to the southwest. Its straight western margin is also faulted margin, which follows the Dharwar trend. The western margin fault cuts across the Saurashtra arch uplifting this block.

The three marginal basins of western India evolved in four stages: -

Stage 1: Kutch rifting along the Delhi trend was initiated in the Late Triassic as evidenced by continental Rhaetic sediments in the northern part of the basin (Koshal, 1984). During Jurassic time, in the early stages of India's northward drift away from Gondwanaland. The Kutch rift basin was formed by subsidence of a block between Nagar Parkar Hills and the southwest extension of Aravalli Range. The first occurrence of marine sediments in the Middle Jurassic indicates that this graben became fully marine basin during that time. It appears that "Great Boundary Fault" of the Aravalli Range extends beyond the continental margin along the northern coastline of Saurashtra and acted as a principal weak zone (Roday and Singh, 1982; Das and Patel, 1984). The Kutch basin was earliest of three basins that received marine sediments. The Narmada geo-fracture and the West Coast fault remained passive as important structural lineament. The southeastern extremity of the Aravalli Range was subjected to erosion and peneplanation during this stage.

Stage 2: In Early Cretaceous time, the Kutch basin was filled up and the sea began recede. The southwestern part of the Aravalli Range was peneplaned. The East Cambay fault that bounds the eastern margin (along the same NNW-SSE lineament as the West Coast fault) became active across the Aravalli Range. The entire region lying west of the East Cambay fault and north of the Narmada fault (Saurashtra arch, the extension of the Aravalli Range across the western continental shelf) subsided to form an extensive platform. The rivers flowing to the southwest from the Aravalli Hills deposited a large volume of deltaic sediments on this platform as it subsided with the East Cambay fault acting as the hinge (Biswas, 1983). The rifting along the Narmada geo-fracture was initiated during this time with the opening of a basin at its western end, where the rivers flowing along geo-fracture also deposited deltaic sediments.

Stage 3: The Late Cretaceous saw extensive regional uplift in the western part of India. The Saurashtra block separated out at this time as a result of renewed movements along the western extension of the "Great Boundary fault" (North Kathiawar fault), the western margin fault of the Cambay basin, the western extension of the Narmada fault. The Cambay graben came into existence as a rift valley by reactivation of its boundary faults. The Narmada rift opened up and received marine sediments. Intensive block movement gave rise to uplifts of Kutch. The foreland block north of the Narmada fault and the peninsular block south of it moved up as the Narmada graben subsided. The peninsular block tilted eastward, drowning the eastern intracratonic grabens (Godavari and Mahanadi) and initiated marginal deltaic sedimentation along the eastern continental margin (Biswas, 1987). Towards the end of the Cretaceous (60-65 Ma) extensive subaerial eruption took place through a number of volcanic centres in the Cambay graben, Saurashtra and Kutch (Biswas and Deshpande, 1973) when one of the spreading ridge axes was close to the western margin of India (Norton and Sclater, 1979).

Stage 4: The present shape of the continental margin of India evolved when India's drift motion along an anticlockwise path slowed down considerably after its collision with Eurasia in Late Eocene-Oligocene time (Norton and Sclater, 1979). The West Coast fault was reactivated as the present western continental shelf subsided along it. The Cambay graben extended southward along the West Coast fault into the subsiding continental shelf. The Cambay and Narmada grabens crossed and mutually displaced each other. Conjugate shearing along the bounding fault of the two grabens resulted in a right-lateral movement along the Narmada faults and right-lateral movement along the Cambay faults (Rao and Talukdar, 1980). The Cambay graben subsided, accumulating thick Tertiary sediment over a relatively thin floor of Deccan Trap flow. The Saurashtra block remained as a horst while the Kutch, Cambay and Surat basins subsided around it. The subsidence of the western continental shelf basins in Tertiary time was the result of thermal adjustment following the Mesozoic rifting event. The eastern part of the Narmada graben was uplifted, becoming a rift valley again.

In other parts of the Gondwanaland the beginning of plate separation in Jurassic and Early Cretaceous was marked by the formation of pericratonic rift basin similar to the pericratonic rift system of Kutch and Saurashtra of India (Cannon et. al, 1981; Jankard et. al, 1982).

Reactivation of ancient trends has determined the shapes, extents and subsidence histories of the horsts and grabens of the shelfal horst-graben complex, the Kori-Comorin depression and the Kori –Comorin ridge. The origin of the Laxmi-Laccadive ridge is relatively complex.

The Kori-Comorin ridge is a very prominent NW-SE trending linear fault-bounded structural high, a basement arch, which is also a prominent sub-sea topographic feature. The Kori high and the Prathap ridge (Naini and Talwani, 1982) form respectively the northern and the southern parts of this ridge. A linear belt of positive gravity anomalies, with values reaching 50 mgal extends along with entire length of the margin (Naini and Talwani, 1983) and coincides with the Kori-Comorin ridge. This ridge has undergone varying degrees of mobility as evidenced by varying thickness of sediments accumulated over it. It acted as a 'synchronous high' during the deposition of the entire sedimentary section in a relatively narrow, linear Kori-graben complex. This fault-bounded trough extends along the entire length of the margin. Thickness of sedimentary section is expected to exceed 5 km in this depression. North of Ratnagiri, the Kori-Komorin depression occurs largely within the shelf, but major part of it, along with its complementary ridge (Kori-Comorin ridge) transgresses on to the slope region in the south forming a part of the deep sea basins off Konkan-Kerala coast.

The Laxmi –Laccadive ridge is expressed as a very pronounced sub-sea feature in the southern part of the western margin of India. The crest of the ridge lies at the average depth of less than 3,000 m in the north and less than 1,000 m in the south with occasional coral atolls and volcanic islands. A vast depression, the Laxmi-Laccadive depression, separates the Laxmi-Laccadive ridge from the Kori-Comorin ridge. The Laxmi-Laccadive depression extends almost parallel to the contiguous Laxmi-Laccadive ridge. It is about 300 km wide off Mumbai and narrows down abruptly south of 160 latitude to the average width of 150 km. Gravity data indicate extension of the Laxmi-Laccadive ridge into the Kutch basin where it is buried under a thick pile of sediments brought by the Indus river. The Laxmi-Laccadive depression has 3,500 m of sediment in the north and about 2,000 m of sediment in the south. These two north westerly plunging contiguous ridge and depression behaved as a paired ridge depression complex during the evolution of western margin of India.

The Laxmi-Laccadive ridge forms the westernmost regional positive structural feature of the western continental margin of India. West of this feature lies the Arabian abyssal plain. Naini and Talwani (1982) suggested continental crust-oceanic crust boundary along the western limit of Laxmi ridge and Chagos-Laccadive ridge complex, Biswas and Singh (1988) inferred it along the western limit of the Kori-Comorin ridge.

Kutch Basin

Kutch basin is the earliest rift basin that initiated as a result of north and northeast drifting coupled with counterclockwise rotation of the Indian plate after its detachment from the Gondwanaland during Late Triassic/or Early Jurassic (Biswas, 1982; Biswas et. al, 1993). Rifting took place within the Mid-Proterozoic mobile belt that welded the northern Bundelkhand and southern Deccan proto-cratons (Biswas, 1999; Radhakrishnan and Naqvi, 1986). The rifting was controlled by the Precambrian NE-SW trend of the Delhi fold belt that swings to E-W in Kutch region. Six contiguous, NW-SE, trending major tectonics elements can be identified in the western continental margin of India (Biswas, 1998). These are shelfal horst-graben complex, Kori Comorin depression, Kori-Comorin ridge, Laxmi-Laccadive depression, Laxmi Laccadive ridge and Arabian abyssal plain.

The structural style of the basin is unique. Nowhere in India is a similar style to be seen. In the onland part the basin is distinguished by highlands that are the area of uplifts and plains that are the basins between the uplifts. The uplifts are oriented east-west along five principal faults: - (1) The Nagar Parkar fault (2) the Island Belt fault (3) the South Wagad fault (4) the Kutch Mainland fault (5) the North Kathiawar fault. Linear uplifts along the first four faults have given rise to four sub-parallel ridges: Nagar Parkar- Tharad, the Island Belt, Wagad and the Kutch Mainland. The Kathiawar or Saurashtra uplift along the North Kathiawar fault is a quadrangular horst bounded by faults on all sides. In the offshore part of the basin, four major ridges with intervening depression, sub-parallel to the ridges identified in the onland part, are indicated by the geophysical and geological data. The southern-most of these offshore Ridges is popularly known as the Saurashtra arch. The Saurashtra arch, which is a prominent basement arch, forms the southern limit of the basin, whereas the Nagar Parkar – Tharad Ridge, exposed as Nagar Parkar hills and Maruda Hill of Precambrian age, forms the northern limit of the basin. These roughly east-west trending, tectonic elements are cross-cut by the Kori-Comorin depression and the Kori-Comorin Ridge, in the deeper shelfal part of the basin, and numerous margin-parallel horsts and grabens of smaller dimension in the shallower shelfal part. The Radhanpur-Barner arch forms the eastern limit of the basin. The Laxmi-Laccadive depression and the Laxmi-Laccadive ridge are indicated by the gravity data to extend from the south to the southern deep-sea region of the basin.

The most striking feature of the basin is the occurrence of meridional high in the middle of the basin. This First Order Median High controlled the facies and thickness of the sediments. It passes transversely across both positive and negative elements of the basin so that the uplifts plunge bilaterally and the sub-basins have a central high or shallow region. The Median high trends NNE-SSW. To the west of the high, the basin is deeper with thicker accumulation of sediments showing change of facies from shallow to deeper shelf. To the east of high, the basement is shallow with less thickness of sediments and the facies varies from shallow marine to littoral and fluvial. Most of the uplifts occur on the higher eastern part of the basin. Thus, this Median high occurs along the hinge line of the basin and forms a tectonized zone featured by intense faulting, folding and intrusions. This hinge is the extension of the Indus shelf hinge perpendicular to the depositional axis (Biswas, 1987), which passes close to Saurashtra uplift. The Median high started to develop during Late Jurassic sedimentation with a greater degree of subsidence on its western flank. It appears that the high was formed by the regional bending of the basin along its hinge zone, which is parallel to the regional hinge of the main Indus basin.

Top

Generalized Statrigraphy :.

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 offshosre wells has been drilled deep enough to penetrate the older units and the Precambrian basement. Presence of statigraphic 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.

The lithostratigraphy of the entire succession from Middle Jurassic to Recent and the chornostratigraphy of the Tertiary succession have been worked out in detail for the onland / offshore part of the basin on the basis of outcrop and well data. The subsurface lithostratigraphic units are described below:

Precambrian Basement:

Precambrian basement (syenite) is exposed in Meruda and Nagar Parkar Hills. In the subsurface, basement has been encountered in the wells Banni – 2 and Nirona-1. It consists of reddish brown and greyish microcrystalline to aphanitic trachyte in well Nirona -1 and 'Granitic Prophyry' 'Aplite', 'Rhyolite' in Banni-2. It is overlain by Nirona Formation.

Nirona Formation:

It consists of arkosic, coarse grained sand and igneous wash at the bottom; calcareous sandstone, minor shale, limestone and mottled clay in the middle; sandstone, laminated shale and Kaolinitic clay at the top. It is overlain by Lodai Formation in the wells Nirona-1 and Banni-2.
Depositional Environment:
Age: Upper Triassic to Middle Jurassic (Aalenian)

Lodai Formation:

New formation described in Banni-2 and Nirona-1 wells, consists of mottled claystone, shale, calcareous sandstone, minor limestone and plant impressions. It is conformably overlain by Luna Formation.
Depositional Environment:
Age: Middle Jurassic (Upper Aalenian to Bajocian).

Luna Formation:

It is overlain by Jumara Formation in Banni-2 and Nirona-1 wells. Contact is marked by sharp deflection on SP and resistivity logs. It consists of shale, limestone, calcareous sandstone, coal and carbonaceous matter.
Depositional Environment:
Age: Middle Jurassic (Bathonian).

Jhurio Formation:

This formation mainly consists of bedded limestone, golden oolite and shale which are overlain by Jumara Formation. It is present in Kutch Mainland and Banni Graben. Bottom of this formation is not exposed. In the drilled wells top contact is recognizable by resistivity and gamma ray change.
Depositional Environment: Sub-littoral.
Age: Middle Jurassic (Bathonian to Callovain).

Jumara Formation:

It consists of grey gypseous shales, thin bands of fossiliferous oolitic marl (Dhosa ooolite). Jumara Formation is overlain by Jhuran Formation and in the drilled well change in resistivity and gamma count is typical. It is present in Kutch Mainland and Banni Graben. The formation is also encountered in GK-29A-1 well drilled in offshore region of Kutch.

Depositional Environment: Sub-littoral.

Age: Middle to Upper Jurassic (Callovian to Oxfordain).

Jhuran Formation:

It is overlain by Bhuj Formation with a gradational upper contact marked by first occurrence of ironstone band and last occurrence of calcareous sandstone. It consists of greenish grey sandstone, with occasional Trigonia bands, grey shale and calcareous sandstone. Jhuran Formation is present in the offshore (GK-29A-1 well), Kutch mainland and Banni graben.

Depositional Environment:

Age: Upper Jurassic (Agrovian –Neocomian).

Kaladongar Formation:

Upper part of Kaladongar Formation has massive sandstone with calcareous bands; lower part consists of alternations of sandstone, siltstone and conglomerate. The formation is exposed in the Kaladongar range and is conformably overlain by Goradongar Formation, showing change in facies from sandstone to flaggy limestone.

Depositional Environment: Infra-littoral.

Age: Middle Jurassic (Bathonian).

Goradongar Formation:

It consists of massive sandstone and fossiliferous grey gypseous shale, flagstone and ferruginous bands. Limestone with chert nodules and golden oolitic bands in the lower part. Top of Goradongar Formation is not exposed.

Depositioanl Environment: Infra –littoral.

Age: Middle Jurassic (Callovian).

Khadir Formation:

Khadir Formation exposed south of Charyabet, consists of fossilliferous shales with calcareous sandstone. Occasional oolitic limestone, chert, coquina limestone and granite pebble conglomerate occur in basal part. Top and bottom contacts of Khadir Formation are not exposed.

Depositional Environment: Sub-littoral to littoral.

Age: Middle to Upper Jurassic (Bathonian to Oxfordian).

Washtawa Formation:

It is dominantly sand-shale sequence exposed in the central part of the Wagad Island. Top contact is marked by a zone of fossiliferous bands exposed in Kanthkot hill and lower contact is not exposed. Sandstone is reddish-brown in color with alternating gypseous shale.

Depositional Environment:

Age: Middle to Upper Jurassic (Bathonian to Oxfordian).

Wagad Formation:

Wagad Formation is covered by alluvium in Wagad Island. It's lower boundary is marked by fossilliferous calcareous sandstone bands on top of thick bed of shale. The sandstone of this

formation is dominantly feldspathic.
Depositional Environment: Sublittoral to littoral.
Age: Upper Jurassic (Oxfordian to Albian).

Bibat Formation:
Bibat Formation is unconformably overlain by undifferentiated Kharinadi/Chasra Formation in Banni graben. Lower contact with Jumara Formation is unconformable. It consists of variegated claystone/shale and minor quarzitic, ferruginous sandstone.
Depositional Environment:
Age: Upper Jurassic to Lower Cretaceous (Tithonian to Neocomian).

Kori Formation:
It consists of dark greenish-grey fossiliferous limestone, bands of calcareous sandstone and disseminated pyrite. It is unconformably overlain by Nakhtarana Formation in well K1-1A. Lower contact of the formation is not observed in the well.
Depositional Environment: Middle to Outer Neritic environment.
Age: Upper Cretaceous (Maastrichtian to Coniacian).

Bhuj Formation:
Bhuj Formation consists of feldspathic, friable, brown ferruginous sandstone, kaolinitic shale, thin ironstone bands and occasional carbonaceous bands followed by olive green to dark green glauconitic sandstone which is unconformably overlain by Deccan Trap in Kutch Mainland and Kutch Offshore. Bhuj equivalent have also been penetrated in wells GK-29A-1, SP-1-1 and GK-33A. A marine tongue within Bhuj Formation comprising of glauconitic fossiliferous sandstone occurs and is called as 'Ukra' bed.
Depositional Environment: Fluviatile to Deltaic.
Age: Lower to Upper Cretaceous (Santonian to Neocomain).

Mundra Formation:
It consists of sandstone, laminated shale, streaks of carbonaceous matter and thin basalts. It is unconformably overlain by Deccan Trap. Lower contact is conformable with the Bhuj Formation in well SP-1-1. It has ill preserved small benthic forms of Watznaueria and Nano planktons in the lower part.
Depositional Environment: Fluvio-deltaic to Marginal Marine.
Age: Upper Cretaceous (Santonian?).

Naliya Formation:
It is unconformably overlain by Deccan Trap and conformably underlain by Bhuj Formation. It consists of calcareous and fossiliferous claystone, marl, limestone with minor calcareous sandstone, shale and coal.
Depositional Environment:
Age: Upper Cretaceous (Santonian – Coniacian).

Deccan Trap:
Deccan Trap outcrops in Kutch Mainland and it's presence has been established in the Kutch offshore also. It is overlain by Nakhtarana/Matanomadh Formation and consists of dark grey, greenish grey, hard massive vesicular and amygdaloidal basalt, highly weathered at places with lateritic clay. Intra-trappeans consists of poorly fissile, siltstone and clay. Deccan Trap in Kutch Offshore is described in well GK-33-A. The volcanics are subaerial and subaqueous in nature.

Age: Upper Cretaceous to Paleocene.

Matanomadh Formation:

his formation is exposed bordering Tertiary outcrops in the western part of Kutch Onland and consists of lateritic conglomerates, laterite, bauxite and ferruginous clay with volcanic ash. It is disconformably overlain by Naredi Formation and contact is marked by lignite band. It directly overlies the Deccan Trap. Plant fossils present are Dicot leaves and Polospores. In the offshore, the sequence has been penetrated in Wells GK-29A-1, GK-29-2, GK-29-3 SP-1-1, GK-1-1, GK-22C-1 and GK-22C-2.

Depositional Environment: Different Terrestrial during warming up phase of volcanicity.

Age: Paleocene.

Nakhtarana Formation:

Upper part of Nakhatrana Formation is white-buff compact limestone with alternations of silty claystone. Lower part contains dark to greenish grey, moderately hard, calcareous, pyretic claystone/shale, weathered basalts and minor sandstone which has two members. In the KD area, lower part of this formation is mainly sandstone/shale and is termed as Anjar Member consisting of M. Miscella PRZ.

Depositional Environment:

Age: Paleocene.

Naredi Formation:

It is exposed in the western part on Kutch Mainland and consists of shales, laterites, gypceous shales, glauconitic shale, fossilliferous marls, mud balls, ochre and lignite bed and is unconformably overlain by Harudi Formation.

Depositional Environment: Lagoonal to Inner Shelf environment.

Age: Lower Eocene (Ypresian).

Jakhau Formation:

It is unconformably overlain by Fulra Limestone in Kutch offshore. It consists of limestone with minor claystone, fossiliferous shale with coal bands at the top.

Depositional Environment: Inner Neritic.

Age: Lower Eocene.

Panadra Formation:

It consists of dominantly sandstone with alternations of ferruginous claystone,silty shale and siltstone in lower part. It is unconformably overlain by Fulra Limestone and underlain by Matanomadh Formation and the contact is also unconformable.

Depositional Environment: Near Shore Beach environment.

Age: Lower Eocene

Harudi Formation:

It consists of greenish grey, calcareous, fossilliferous, splintery shake with layers of gypsum and carbonaceous matter. A thin coquina marks the base. This unit is exposed throughout the tertiary belt of Kutch, which is conformably overlain by Fulra Limestones.

Depositional Environment: Shallow Marine environment.

Age: Early Middle Eocene (E. Lutetian).

Fulra Limestone:

It consists of cream, buff, crystalline massive silty, fossiliferous limestone interspersed with clay and shale at places. It is unconformably overlain by Maniyarafort Formation in the Kutch Mainland and Tuna limestone in Kutch offshore.
Depositional Environment: Inner to Outer Shelf environment.
Age: Middle-Upper Eocene.

Sir Formation:
Sir Formation has dominantly shaly facies and is present in the deeper part of shelf. Its lithofacies is similar to Belapur Formation of Mumbai Offshore Basin.
Depositional Environment:
Age: Late to Middle Eocene.

Maniyarafort Formation:
It consists of yellow to ochre coloured foraminiferal limestone with a basal greenish glauconitic siltstone exposed in western part of Kutch Mainland and unconformably overlies the Fulra limestone. It is divisible into four members. The upper contact with the overlying Khari Formation is unconformable and marked by blue clays. In all the offshore wells, except GK-29A-1 (near the coast) the unit is represented dominantly by carbonates.
Depositional Environment: Marginal Marine Littoral to Shallow Inner Shelf environment.
Age: Oligocene.

Tuna Limestone:
It consists of white, hard, crystalline, chalky, fossiliferous, pyretic limestone; light grey to dark grey shale and reddish brown, moderately calcareous siltstone. It extends beyond Saurashtra Shelf over Diu Arch and is unconformably overlain by Narayansarovar Formation over Kutch Shelf.
Depositional Environment: Shallow Marine to Inner Shelf environment
Age: Lover Oligocene.

Narayansarovar Formation:
It consists of dirty white, greyish, brownish, compact limestone with claystone/siltstone alternations towards base. It changes to marl, shale glauconitic sandstone facies of Upper Member of Maniyarafort Formation. It is unconformably overlain by Godhra and Mittinadi Formation.
Depositional Environment: Inner Shelf to Marginal Marine
Age: Upper Oligocene.

Godhra Formation:
It consists of grey, chalky limestone with minor clay, sandstone and siltstone. Godhra Formation is distributed all over Kutch shelf and is conformably overlain by Chhasra Formation.
Depositional Environment:
Age: Early Miocene.

Mittinadi Formation:
The formation is present in the deeper part of Kutch shelf and consist of grey claystone, shale, limestone bands and minor sandstone. It has two members. It is conformably overlain by Kandla Formation.
Depositional Environment:
Age: Lower Miocene.

Kharinadi Formation:

Kharinadi Formation is a distinct litho-unit of variegated siltstone, fine grained sandstone, occasional claystone, with few thin fossilliferous limestone beds. Vertical burrows are filled with red hematite. It is exposed in western part of Kutch. In the eastern Kutch, red lateritic conglomerate often with agate peebles, ferruginous sandstone and laminated claystone bands characterize the lithology of this formation.

Depositional Environment: Tidal Flat, Lithoral to Shallow Inner Shelf environment.

Age: Lower Miocene.

Chhasra Formation:

Chhasra Formation is unconformably overlain by Sandhan Formation in Kutch Mainland and Kandla Formation in Kutch Offshore. It is exposed in southern and eastern Kutch. It consists of grey-khaki clay, fossilferous marl and micaceous siltstone. It has two members. In Banni Graben, it remains undifferentiated from the underlying Kharinadi Formation.

Depositional Environment:

Age: Upper Miocene (Halvetian to Burdigalian).

Kandla Formation:

Kandla Formation extends upto sea bottom and is youngest in offshroe. It increases in thickness from east to west. It consists of clay/claystone, shell fragments and bands of sandstone and silt are common.

Depositional Environment:

Age: Middle Miocene to Recent.

Sandhan Formation:

Sandhan Formation is exposed in the coastal plains in the cliff banks of major streams. It consists of sandstone, clay, siltstone, thin limestone in lower part; conglomerate and coarser sandstone in the middle part and calcareous grits, pink sandstone and calcareous nodules in the upper part. It is unconformably overlain by Millolite/ Alluvium/Rann. Outcrops are also reported from Wagad Island. In Banni Graben, this formation has been recognized and is overlain by the marsh sediments of the Rann. Depositional Environment: Supra-littoral to Deltaic environment.

Age: Pliocene to Pleistocene.

Milliolite:

Milliolite is unconformably overlain by the recent sediments and is exposed on the southern flank of Katrol hills. It consists of pelletoidal, sandy oomicrite, sandy pelmicrite and calcareous sandstone. The soft, cream coloured limestone comprising this unit contains plenty of white, fine sand sized round milliolids and quartz grains in minor amounts.

Depositional Environment:

Age: Pleistocene to Holocene.

Alluvium/Rann:

Alluvium (recent-sediments) overlie unconformably the Millolite/Sandhan Formation. It consists of partially consolidated conglomerates, grits, kankar and Oyster bed. The recent sediments in the northern and eastern part of Kutch Basin consisting of salt, silt and clay are known as Rann.

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Exploration Status :.

Geological Surveys

Initial geological surveys were carried out by Geological Survey of India. Subsequently, an area of

35,000 sq.km has been covered by Oil & Natural Gas Corporation Limited (ONGC) for detailed geological mapping.

The stratigraphic succession ranging from Middle Jurassic to Holocene is exposed in the highlands of the Kutch Basin. The outcrops reveal a fascinating geology of the region and have attracted the attention of many geologists to this area for study.

Geochemical Survey
300 samples were collected for geochemical analysis by DGH (outsourced to NGRI) from Kutch onland region covering an area of 43,000 sq.km in 2002-03.

Geophysical Survey
Systematic studies conducted by various national and international agencies during the last four decades have provided valuable data concerning the Kutch Basin.

Gravity and Magnetic surveys in the onland part, involving about 7,528 stations were carried out by ONGC during the period from 1956 to 1967. In the offshore part of the basin, gravity and magnetic data recording was carried out simultaneously with seismic data acquisition. About 27,395 LKM of gravity data and 14,691 LKM of magnetic data have been acquired. Aero-magnetic data of 23,730 LKM covering an area of 48,000 sq.km was acquired by DGH in year 2000.

Gravity picture of the onland part of the basin corroborates well with the features delineated utilizing outcrop geological and seismic data, whereas in the offshore part, major gravity highs coincide with the seismically indicated deep depressions. Apparently, the reason for this anomalous situation is the masking effect of basaltic flows (Deccan Trap) on the recorded gravity values. From the experience gained elsewhere in the western continental margin of India, the paleotopographic lows are known to have provided the favorable locales for accumulation of huge thickness of the Deccan Trap. Geological map of the basin and the well data, particularly of the offshore region indicate that the Deccan Trap activity had been more extensive in the offshore part of the basin.

Conventional reflection seismic surveys were conducted during the period from 1962 to 1968 covering 1,894 LKM in the onland part of the basin. Subsequently, refraction seismic survey was carried out in 1971 covering 367 LKM in Rann of Kutch. Multifold reflection seismic surveys were conducted in the onland part of the basin during the period from 1982 to 1989 covering about 1,445 LKM. The seismic data confirm the interpretation based on geological mapping regarding sub-surface stratigraphy and structure. M/s Focus Energy Ltd. acquired 520 LKM of 2D seismic data, of which 38 LKM was acquired in 2004-05, 15 LKM in 2006-07 and 467 in 2007-08.

The offshore part of the basin has been extensively covered by multifold seismic surveys. About 35,440 LKM of seismic data have been acquired in the offshore part on regional semi-detailed and detailed grid pattern. During 1996-97 in offshore, additionally 1,732 LKM of seismic data have been acquired for Mesozoic prospect. M/s Tullow acquired 188 sq.km of 3D seismic data in 1999-2000. M/s Reliance acquired 1282 LKM of 2D and 833 sq.km of 3D seismic data in 2001-02.

2D reflection seismic data of 900 LKM in onland Kutch has also been acquired by DGH (outsourced to NGRI) in Q2, 2008 which is in processing and interpretation stage.

Marine seismic data of 235 LKM and Magnetotelluric data from 32 stations (9 stations washed out due to tides) has also been acquired by DGH (outsourced to NGRI) in Q1, 2008. Processing and interpretation of the acquired data is in progress.

Seismic data acquired by GXT in western offshore region also covers part of Kutch offshore region. The seismic lines which cover the region are W-1000, W-3000 and W-9000.

Exploratory Drilling

Till 31st March 2008, 29 exploratory well have been drilled in Kutch Basin. Out of these ONGC has drilled five exploratory wells in the onland part and twenty two exploratory wells in the offshore part of the basin. M/s. Reading and Bates drilled one exploratory well GKH-I (for ONGC) in the deeper part of the continental shelf of the basin. Recently M/s RIL has drilled two exploratory wells in the shallow offshore area of the Kutch basin. M/s Okland has drilled one exploratory well in Kutch offshore.

Of the twenty two exploratory wells drilled by ONGC in offshore, three wells viz., KD-2, KD-4 and KD-A were drilled for delineation of oil pool discovered in the KD Structure. Well GK-29-2 and GK-29-3 were drilled for delineation of gas discovered in GK-29 structure. Well GK-22C-2 was drilled for delineation of gas discovered in GK-22C structure.

Well Banni - 2:

Drilled in onland part of the basin, the well penetrated 616 m of Miocene and younger clay/silt section, 109 m of shale/claystone section of Early Cretaceous age, 99 m of siltstone unit of Late Jurassic age, 403 m of Upper and Middle Jurassic interbedded shale, sandstone and limestone section, 391 m of Middle Jurassic shale and sandstone alternation, and 100 m of conglomerate, greywacke and sandstone of Late Triassic-Early Jurassic age (indicated by palynological evidences). The well was terminated at the depth of 1,764.5 m after drilling through 46.5 m of Precambrain granitic basement.

Well Nirona-1:

The well penetrated 925 m of Miocene and younger sediments consisting of mainly claystone section interbedded with coarser clastics, 125 m of alternating sequence of claystone, siltstone and sandstone of Early Cretaceous age, 202 m of Upper Jurassic claystone, siltstone and sandstone unit, 177 m of interbedded shale, claystone and sandstone section of Middle Jurassic age, 781 m of Middle Jurassic claystone and shale section and 175 m of interbedded conglomerate greywacke and arkosic sandstone of Late Triassic-Early Jurassic age (indicated by palynological evidences). The well was terminated at the depth of 2224.45 m after drilling through 14 m of Precambrian trachytic basement.

Well Lakhpat -1:

Drilled to the depth of 3,200 m and the sequence penetrated consists of 340 m of interbedded claystone, sandstone and lignite bands of Early Eocene age, 629 m of mainly sandstone section with subordinate shale of Paleocene age, 70 m thick dolerite layer, followed by 791 m of Lower Cretaceous interbedded sandstone and shale unit with dolerite stringers. The section in the interval 1,830-2,350 m consists mainly of shale of Late and Middle Jurassic age with limestone bands at the top and bottom, underlain by 550 m of limestone section of Middle Jurassic age, containing 152 m thick dolerite layer towards bottom.

Strong golden yellow fluorescence and solvent cut with strong odour of crude oil was observed in cuttings and side wall cores obtained from Lower Cretaceous interval of 1,198 – 1,214 m.

Well Sanadara -1:
The well was bottomed at 3,500 m. The well penetrated 125 m of basalt (Deccan Trap) of probable Late Cretaceous age, 805 m thick claystone, shale and sandstone section with dolerite stringers of Early Cretaceous age, 530 m of shale, marl and limestone intercalation of Late Jurassic age, 380 m of Upper and Middle Jurassic mainly claystone unit grading to dolomitic limestone towards bottom and 1,660 m of monotonous limestone section with occasional shale, sandstone and dolerite bands of Middle Jurassic age.

Suthri -1:
The well penetrated 305 m of Miocene and younger claystone and marl section, 65 m of clay and sandstone unit of Oligocene age, 80 m of limestone section of Early – Middle Eocene age, 75 m of shale and siltstone unit of Paleocene age, 591 m of basalt (Deccan Trap) of probable Late Cretaceous age, 848 m of Lower Cretaceous sandy section occasionally interbedded with claystone and shale, 632 m of Upper Jurassic shale and sandstone section grading to limestone towards bottom, 209 m of mainly limestone unit of Late Middle Jurassic age, 360 m of shale, sandstone and limestone intercalation of Middle Jurassic age with a thin dolerite band at the top, and 170 m thick layer of dolerite.

KD-1:
The well was drilled to the depth of 4,292 m and the sequence penetrated consists of 417 m of Middle Miocene and younger clay, shale and sandstone alternation, 295 m of Lower Miocene to Upper Oligocene clay with limestone stringers, 625 m of limestone unit ranging in age from Early Oligocene to Early Eocene, followed by 380 m of Paleocene section, the upper 180 m of which is represented by limestone and the lower 200 m by coarser clastics with shale stringers. Basalt section was encountered in the interval 1,760 – 1,930 m, underlain by 2,362 m of argillaceous limestone with shale streaks of Late Cretaceous age which continued to the bottom of the well.

The well produced oil at the rate 172 bpd through ¼" choke from Middle Eocene limestone/ siltstone reservoir in the interval 1,056 – 1,097 m.

Well GK-22C-1:
The well was drilled to the depth of 3,502 m and penetrated 838 m of Middle Miocene and younger sediments, mainly claystone section with stringers of sandstone, 260 of interbedded claystone, siltstone and limestone of Early Miocene age followed by 838 m thick limestone section with stringers of shale and coal ranging in age from Late Eocene to probable Paleocene. Basalt section was encountered in the interval 1,938 – 2,444m, underlain by 1,058 m thick Upper Cretaceous section, the upper part of which is represented by claystone/marl and the lower part by 662 m of sandstone and siltstone which continued to the bottom of the well.

The well produced gas at the rate of 2,39,930 m3/d along with 50 bbl of condensate and water through ½" choke from Upper Cretaceous sandstone reservoir in the interval 2,840 – 2,845 m.

Well GK-29A-1:
The well was bottomed at 3,828.7 m and the sequence penetrated consist of 352 m of Middle Miocene and younger sediments, mainly claystone with stringers of siltstone and sandstone, 150 m of interbedded claystone, sandstone and limestone of Oligocene to Early Miocene age, followed by 115 m limestone of Middle to Late Eocene age, underlain by 120 m of coarser clastics interbedded with claystone of Late Paleocene to Early Eocene age. Basalt section of Paleocene to Late Cretaceous age was encountered in the interval 785 – 1,590 m. The section below the basalt

interval is represented by 910 m of mainly claystone with stringers of siltstone, sandstone and volcanics of Early Cretaceous age, 150 m thick Upper Jurassic shale, 195 m of Middle of Upper Jurassic limestone, underlain by 105 m thick dolerite intrusive in the interval 2,845 – 2,950, followed by 878 m of interbedded limestone, shale siltstone and sandstone of Early to Middle Jurassic age which continued down to the bottom of the well.

The well produced gas the rate of 1,24,332 m3/day through ½" choke from a 9 m thick sandstone reservoir of Early Eocene –Paleocene age in the interval 775 – 784 m.

Well SP-1-1:
Penetrated 1,287 m of Middle Eocene and younger section represented by 1,002 m of alternations of clay, claystone and limestone in the upper part and 285 m of limestone in the lower part, followed by 447 m of Early Eocene shale with limestone stringers. Basalt with interprappean sandstone and siltstone of probable Late Cretaceous to Paleocene age was encountered in the interval 1,782 – 2,415 m, underlain by 1,437 m of Cretaceous sandy section with minor shale and 40 m of basalt at the bottom. The well was terminated the depth of 3,892 m within the basalt section.

Specky golden yellow to reddish brown fluorescence with solvent cut was observed in the cores and cuttings of Cretaceous sandy section in the interval 2,415 – 3,852 m. Gas shows (total gas content upto 15%) were observed while drilling through the Cretaceous section.

Well GK-1-1:
The well was drilled to the depth of 2,842.5 m. It penetrated 884 m of Middle Miocene and younger section mainly clay, claystone with stringers of coarser clastics and limestone, 995 m thick limestone section ranging in age from Early Miocene to Early Eocene, followed by 139 m of Paleocene (?) limestone and claystone alternation, underlain by 630 m of basalt probably of Paleocene to Late Cretaceous age with 64 m of intertrappean sandstone encountered in the interval 2,422 – 2,486 m. The section below the basalt interval comprises 99 m of sandstone, followed by 67 m of limestone of Late Cretaceous age which continued down to the bottom of the well.

GK-1-2:
Drilled to a depth of 4030 m, penetrated 626 m of clay/claystone of post Middle Miocene age, 39 m of claystone, siltstone and limestone of Middle Miocene age, underlain by 185 m of Early Miocene limestone, with thin shale bands, followed by 361 m of dominantly limestone with thin shale layers of Oligocene age and 423 m thick Eocene sequence of mainly limestone with minor shale, siltstone and coal bands. The section is underlain by 80 m of Cretaceous sandstone followed by limestone of Upper Cretaceous age. An igneous intrusion of dacite was encountered in the interval 3,523 – 3,735 m followed by 265 m thick limestone (at places marly) of Late Cretaceous (Santonian) age which continued down to the bottom of the well.

KI-1A:
The well penetrated 1,774 m of Upper Oligocene and younger section composed of mainly of interbedded clay, claystone and sandstone with limestone stringers grading to limestone towards bottom, underlain by 305 m of Upper to Middle Eocene limestone unit. Paleocene – Lower Eocene unit is developed in the interval 2,165 – 2,350 m and is represented by limestone and shale, followed by 2,161 m thick Upper Cretaceous argillaceous limestone and calcareous shale with a dolomitic limestone band towards bottom. The well was terminated at 4,511 m within Upper Cretaceous limestone section.

Gas shows were observed while drilling through the interval 1,854 – 1,864 m.

KIW-1:
Penetrated 1,003 m of Pliocene and younger sediments comprising clay/claystone interbedded with sandstone and siltstone. This section is underlain by 570 m thick limestone, claystone and shale alternations of Miocene age. Towards bottom, this section comprises monotonous limestone with shale streaks. This is followed by 200m thick Oligocene limestone and 450 m of Eocene limestone, with minor shales, underlain by 220 m of mainly siltstone with minor limestone of Paleocene age and 500 m of Late Cretaceous limestone with shale alternations in the upper part.

GK-33-A:
The well was drilled to the depth of 3,860 m and the sequence penetrated 744 m of Middle Miocene and younger sediments consisting mainly of clay, claystone and sandstone section with limestone stringers towards bottom, followed by 791 m thick limestone section with stringers of sandstone, siltstone and coal towards bottom ranging in age from Early Miocene to Paleocene. Basalt section was encountered in the interval 1,610-3,175 m. The section below the basalt consists of 685 m of Upper Cretaceous shale and claystone unit grading to coarser clastics towards the lower part, which continues down to the bottom of the well.

Golden yellow fluorescence and strong solvent cut was observed in the Eocene limestone at 1,154 m (side wall core).

GK-36-1:
The well was bottomed at 2,895 m and penetrated 1,163 m of Middle Miocene and younger section consisting of interbedded clay, claystone, siltstone and limestone followed by 1,382 m of limestone with stringers of sandstone, shale and coal ranging in age from Early Miocene to Paleocene, underlain by 41 m of trap wash of Paleocene age. Basalt section was encountered at the depth of 2,678 m which continued to the bottom of the well.

Well GKS-1:
The well was bottomed at 3,606 m and the sequence penetrated consists of 1,692 m of Late Miocene and younger section comprising mainly of claystone with stringers of siltstone and limestone followed by 147 m of Middle Miocene limestone and shale alternations, underlain by 1,581 m of limestone section with occasional shale bands ranging in age from Early Miocene to probable Paleocene age.

Well GK-32-1:
The well penetrated 1,828 m of Late Miocene and younger sequence comprising mainly of claystone with few siltstone and limestone stringers, followed by 1,314 m of limestone interbedded with claystone and shale ranging in age from Middle Miocene to probable Late Eocene age. The well was bottomed at 3,241 m.

Well GK-17-1:
The well was bottomed at 4,490 m and the sequence penetrated consists of 1970 m of Late Miocene and younger sediments comprising mainly of claystone interbedded with thin bands of siltstone and sandstone, followed by 215 m of Middle Miocene limestone section with subordinate claystone and siltstone towards bottom. The Early Miocene section in the interval 2,305-3,500 m is represented by thick claystone band in the middle and limestone, shale and siltstone alternations in

lower and upper part, underlain by 990 m of Early Miocene to Late Paleocene limestone section.

While drilling gas shows were observed at 4.087 m. 4,124 m and 4,140 m. A conventional core cut in the interval 3,754 – 3,763 m exhibited strong fluorescence.

Well Kutch-A:
The well was bottomed at 3,966 m. The sequence penetrated consists of 2,186 m of Middle Miocene and younger section represented mainly by claystone in the upper part, interbedded claystone and coarser clastics in the middle part and 145 m thick limestone sequence developed towards bottom, underlain by 1400 m thick Lower Miocene section consisting mainly of claystone with siltstone and limestone stringers grading to limestone towards bottom, followed by 120 m of Oligocene limestone unit and 146 m of Upper Eocene limestone and shale section which continues down to the bottom of the well.

Well GKH-1:
Penetrated 700 m of Pliocene and younger section that mainly consist of shell debris and limestone interbedded with siltstone and sandstone, 1773 m of Late to Middle Miocene siltstone and sandstone interbedded with claystone and shale, followed by 1,992 m of limestone with stringers of claystone and shale ranging in age from Early Miocene to probable Paleocene age. The well was terminated at 4,573 m within Paleocene limestone section.

Traces of oil and stains of heavy oil and asphalt were observed in cuttings of the Lower Miocene section.

Well GK-20-1:
Drilled to 4035 m depth, the well was bottomed in Deccan Trap. The sequence encountered in this well includes 2950 m of post Early Eocene sediments mainly comprising of clay/claystone, shale, minor siltstone and sandstone with limestone development in the middle part, underlain by Early Eocene section of 125 m of limestone and shale followed by 665 m thick Late Paleocene sequence of siltstone, shale and limestone. The above sequence is followed by 270 m of basalt (Deccan Trap) of Paleocene to Late Cretaceous age, down to bottom of the well.

Well GK-22C-2:
The well was drilled down to the depth of 3446 m. The sequence penetrated, consists of 650 m clay/claystone of Middle Miocene age, 288 m siltstone and 225 m limestone with the alternations of silt, shale and sandstone of Early Miocene age. Early Miocene is followed by 77 m thick limestone of Oligocene age. Eocene section is 570 m thick and mainly consists of limestone. Trap section was encountered at 1810 m and continued to 2549 m. Trap is underlain by 897 m thick claystone, sandstone and siltstone. About 1630 m of Lower to Upper Cretaccous section was penetrated.

While drilling 8% gas show was observed at the depth of 2700-2705 m and in the interval 3200 – 3205 m (30%) of non-combustible gas was observed.

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Hydrocarbon Potential :.

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

Source rock studies have been conducted on samples from outcrops, onland wells Banni-2, Nirona-1, Lakhpat-1, Suthri-1 and most of the offshore wells except few. 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. The outcrop samples from the western onland part of the basin indicate that Eocene and Oligocene sediments contain type III and type II mixed Kerogens with TOC ranging from 0.54% to 3.45%. The adsorbed gas data indicate presence of higher gaseous hydrocarbons in these sediments suggesting possible generation of not only gas but also gas condensate. 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. Eocene shale's with adequate TOC and mature, type II and III organic matter started generating hydrocarbons around 8 Ma in the region of the Kori-Comorin depression and the Kori-Comorin ridge. This sequence is presently in peak oil generation phase. Oil-source correlation indicates a close similarity between the oil of KD structure and the extracts from Eocene sediments of well GKH-1 suggesting that the Kori-Comorin depression and the deep depression in the region between structures KI and KD form effective charge areas. 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.

The temperature data of wells indicate a geothermal gradient of 2.80C-3.80C/100 m and 2.20C – 3.00C/100 m in the eastern and western offshore parts of the Kutch Basin, respectively.

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 shallow-water areas close to the coast, abundant sandstone reservoirs are developed in the Paleocene to Early Eocene section, as indicated by the results of the wells drilled on KD and GK-29A structures. In well GK-29A-1, gas has been struck in one of these Paleocene sandstone reservoirs. Extensive carbonate platforms in association with shelf-margin reefal bodies, developed during Eocene to Early-Middle Miocene time over almost the entire western shelfal part of the Kutch Basin, provide excellent reservoirs, as encountered in wells KI-1A, GKS-1, GK-36-1, GK-32-1 and Kutch-A. The oil pool of KD structure is located in one of these Middle Eocene limestones and associated siltstone reservoirs. During Eocene to Miocene time, the Kori-Comorin depression lay in the slope-basin transition zone which providing favorable locales for development of turbidite reservoirs in deep-sea fan complexes. In the regions of favorable paleobathymetry over the Kori-Comorin ridge, development of carbonate buildups is noticed (e.g. at the location of well GKH-1 where Miocene limestones form excellent reservoirs). 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. Frequent cyclicity in sedimentation, particularly during Tertiary time, provides ample facies variations; both laterally, and vertically. Thus there are adequate reservoir and cap rock, available to form suitable entrapments.