Chapter 1
Introduction

Preamble

Coastlines of the world constitute the most dynamic geomorphological domain that can exhibit rapid changes in its local forms, not only over centuries or decades, but in a matter of hours or minutes. This happens as the coastal landforms try to achieve equilibrium with their environment. Sea level is the dominant element of the coastal environment which is independent at all landform scale and consequently can be considered as the ultimate control in shaping out the coastal landforms (Pethick, 2000). The coastal evolution is a net result of a combined geological processes that have been operated in the region through time and space, and recorded (in general partially) in the form of various depositional events. A detail study of geological records both, depositional and erosional becomes *ergo* highly warranted to construct a comprehensive model of geomorphic evolution for any region

Much has been published about the Quaternary carbonate sequences of the Saurashtra peninsula linking them to the sea level changes of a magnitude as high as 220m, either due to glacioeustasy (Verma & Mathur, 1978) or due to the tectonic instability (Baskaran et al., 1989). Although, the studies have ruled out such extreme changes in the geo-environment of the region, an integrated approach to appreciate the geomorphic and geologic units of the Quaternary sequences of coastal Saurashtra has remained unattempted (Bhatt, 2003). The present study was initiated with an objective to fill up this gap The study has shown an intricate role of the global sea level changes and local tectonics over the evolution of southwestern coast of Saurashtra during the Late

Quaternary time. Various geomorphic units and carbonate sequences are therefore, described at length in its sedimentological perspective along with the stratigraphic relations and imprints of neotectonics. With a rationale that any change in sea level is not a mere shift in land-sea interface, the present study also includes details of geomorphic and geologic response of the coast as well as the coastal rivers. To achieve the said objective, the following methodology was adopted.

1. Geomorphological and geological maps were prepared on larger scale (1:50,000) with the help of SOI topographic sheets (forming parts of 41 G, K, L & P) and satellite data (Path 91 Row 57 of IRS-1D) with subsequent ground check, aided by precise positioning using GPS.
2. The coastal and fluvial sequences were characterized by studying their constituents, diagenesis, grain size, and acid insoluble residues.
3 Details of lithological composition, sedimentary structures, facies variation, bounding surfaces and cliff profiles were collected from the coastal and river bank cliffs, abandoned quarries, dug wells, etc.
4. The tectonic imprints were evaluated using satellite data and field observations, in the form of lineaments, drainage basin geometry, abrupt geomorphic and/or geologic changes and deformational structures like flexures, contorted beddings, faults and joints developed in the Quaternary sequences of the study area.
5. Quantitative and semi-quantitative geomorphological analyses were carried out to evaluate the morphometric attributes of the coastal rivers.
6. The review of current international and national status of understanding about the Late Quaternary environmental changes formed basis for the meaningful interpretation of thus acquired database.

Physical Setup of Saurashtra Peninsula

Physiography

Lying between the north latitudes 20°30'& 22°30' and east longitude 69°00' & 72°30', the Saurashtra peninsula is surrounded by the Gulf of Kachchh in north, Arabian Sea in south and Gulf of Khambhat in east (Fig. 1.1). The core portion of Saurashtra rises upto 300m amsl and is known as Jasdan plateau This forms the major drainage divide between the westerly and easterly flowing streams The southern hilly terrain of the Saurashtra is the conspicuous Gir highlands ranging in height from 100m to 480m The highest physiographic point of Saurashtra peninsula is the Girnar hill which is an igneous massif rising to an impressive height of 1117m In the west of this lies three other igneous intrusions viz , Osham (311m), Alech (298m) and Barda hills (637m). The southeastern part of the Saurashtra peninsula is characterized by a number of dyke ridges trending in NE-SW direction. The coastal tract of the Saurashtra possesses the dissected ridges of limestone that also forms impressive coastal cliffs along the southern coast

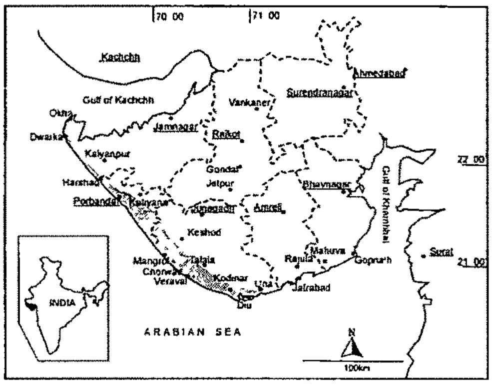

Figure 1 1 Map showing major locations and the extent of the study area (with grey shed) in Saurashtra

Broadly, Saurashtra peninsula can be divided into three distinct geomorphic units. They are rugged highlands, gentle seaward sloping coastal plains and a narrow coastal zone. The gently rising topography from coastal zone to coastal plain and then abutting against the highland can be well appreciated from the shaded relief map (Fig. 1.2). Coastal plain can be fairly marked upto the 60m contour where a sudden break in the physiography occurs.

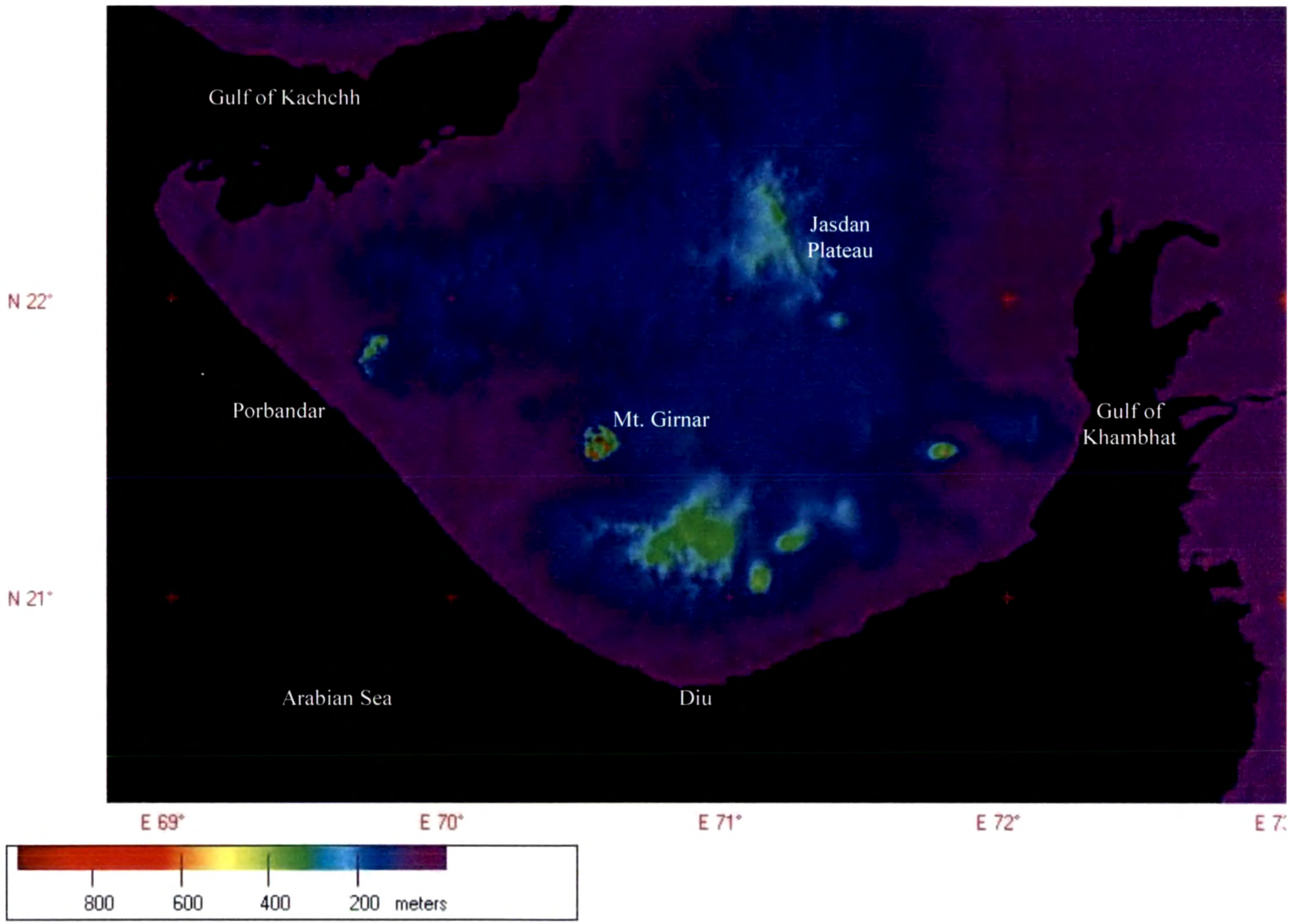

Figure 1.2 A shaded relief map of the Saurashtra peninsula. (Source USGS, GTOPO 30)

Climate

The Tropic of Cancer passes through the state of Gujarat putting it in to the sub-tropical climatic zone. The Saurashtra peninsula is experiencing arid to semi-arid type of climatic condition. The year may be divided into three seasons. January is the coolest month of the winter in which mean daily maximum temperature in coastal areas remain 28 °C and minimum 15 °C. Winter is followed by the summer that starts from the March; May-June are the hottest months with an average minimum and maximum temperature range of 27-°C and 45 °C respectively. The relative humidity is generally about 80% during the SW monsoon period, other wise air remains drier during rest of the year. The rainfall in Saurashtra varies between 300mm and 800mm; the highest being received by the Gir highlands (Fig. 1.3).

Drainage

The Saurashtra peninsula in general shows radial drainage pattern with the streams flowing from the Jasdan plateau and the Gir highlands. The Bhadar and Shetrunji are two longest rivers flowing westerly and easterly respectively. The rivers of Saurashtra are of ephemeral type and carry maximum amount of water and sediments during the monsoon season The major rivers of Saurashtra are Shetrunji, Bhadar, Ojat, Machchhu, Hiran, Saraswati, Singwado, Machchhundri, Malan, Bhogavo, etc (Fig. 1.4). The Bhadar river is longest river of the Saurashtra peninsula It meets to the Arabian Sea near Navibandar after running for about 180km. Ojat is the other large river basin having length of about 164km, which shares its drainage divide with the Bhadar basin. Other river basins of the study area are Noli, Devka, Sangwadi, Rupen, Dhantravadi and Malan.

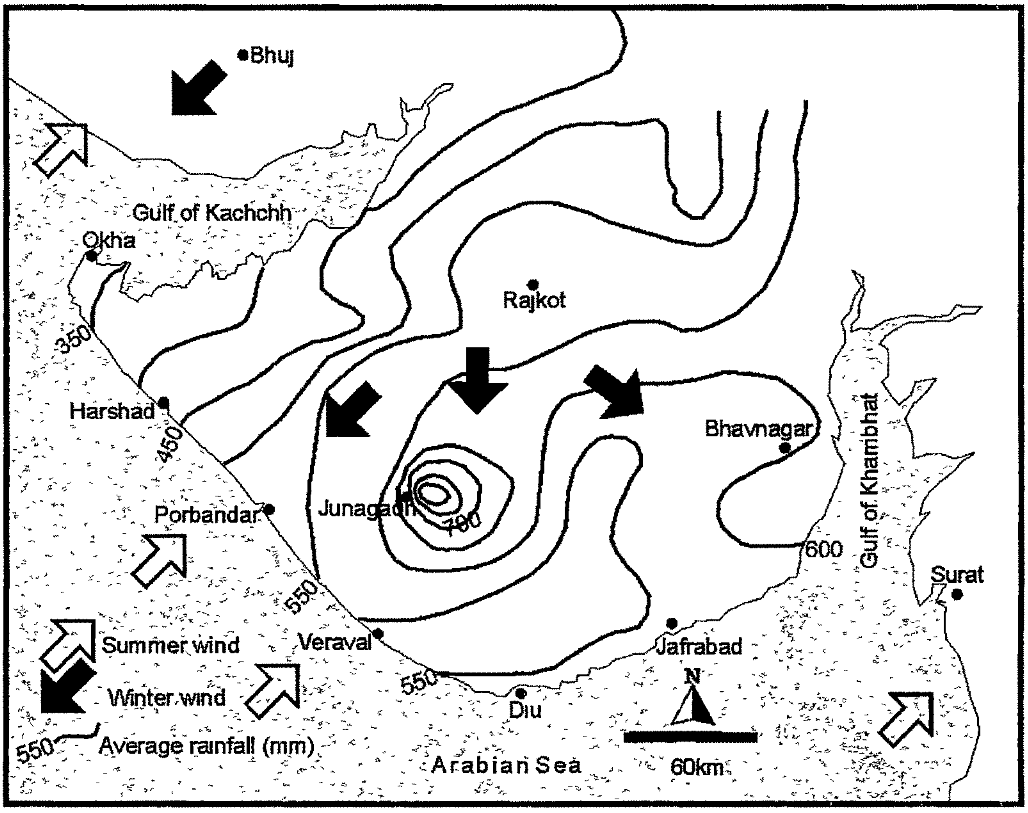

Figure 1 3 Map showing the rainfall and wind pattern on the Saurashtra peninsula.

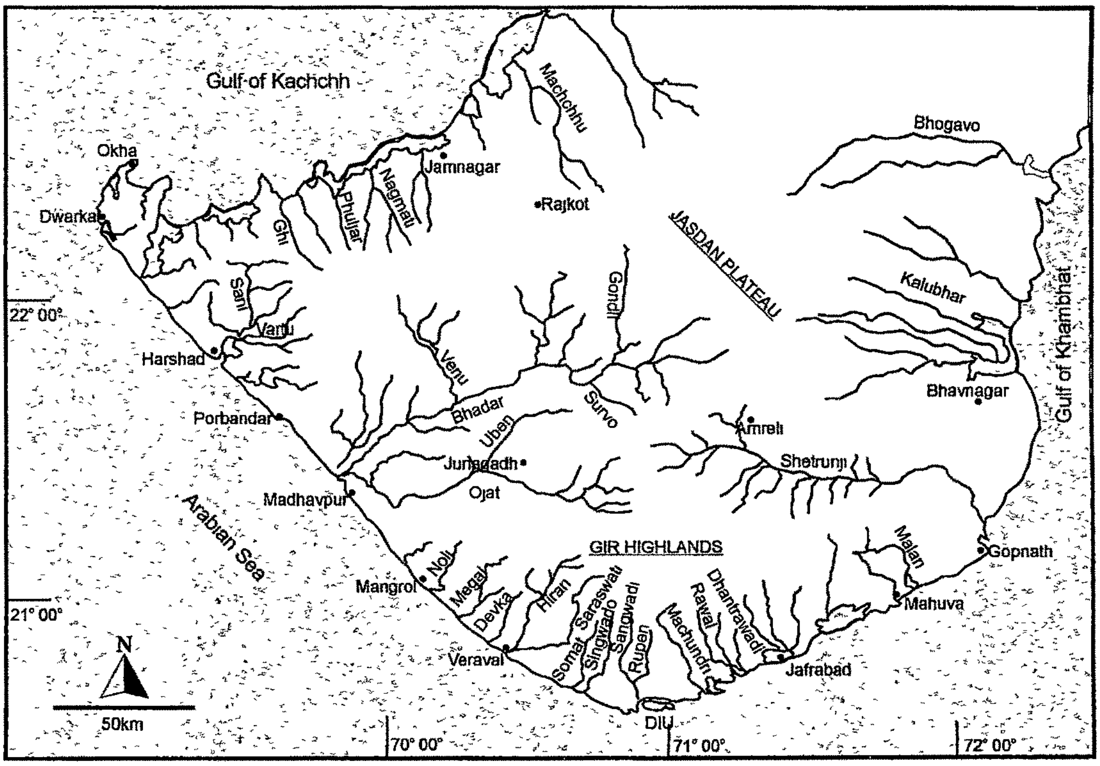

Figure 1.4 Drainage map of the Saurashtra peninsula showing radial drainage pattern.

Offshore Geomorphology

Regional offshore geomorphology (Fig. 1.5) of the Saurashtra has been described by Chauhan et al., (1993) and Purnachandra Rao et al., (1996). Accordingly, the upper slope off the Saurashtra is characterized by the prominent benches/terraces between 180m and 230m depth. Other break in the slope is recorded off Porbandar at 560m. These are well below the still stands of sea level in the region during the last glacial maximum (LGM)

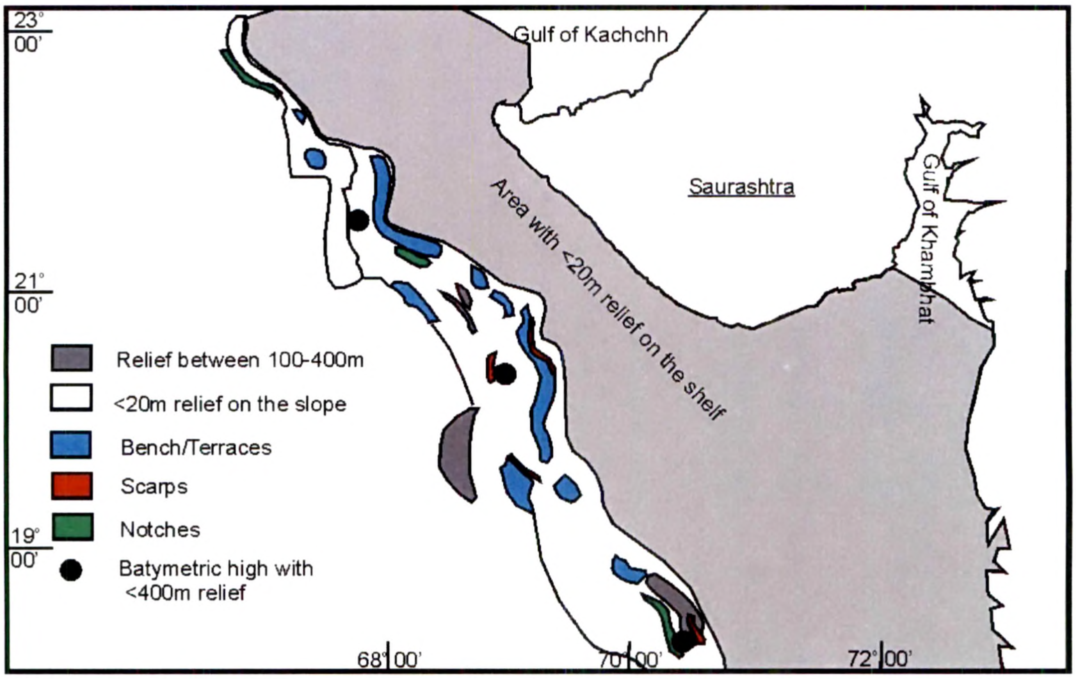

Figure 1.5 Offshore relief map of the Saurashtra showing major geomorphic features. (After Chauhan et.al 1993)

when the sea level dropped to -110m (Hashmi et al., 1995). The rivers of this region are ephemeral and contribute very less amount of sediments in the sea; therefore changes in the shelf edge off Saurashtra have been correlated with tectonic features of the region. Shelf break in the study area occurs at variable depths. In the vicinity of the Gulf of Kachchh it is at shallow depth (120-140m) and has an orientation of NW-SE, it abruptly changes off Dwarka and runs initially E-W, and then NNE-SSW before returning to original trend of NW-SE. Another regional change in the shelf edge is found at N 21°

and E 69° where it becomes almost N-S turning into NW-SE. The Saurashtra Arch which trends in NE-SW is an anticlinal uplifted block complementary to Narmada graben (Biswas, 1982). This is also known to exist in offshore Saurashtra. Seismic section from this area has revealed folded strata at the upper slope (Ghosh & Zutshi, 1989). These observations lead to propose that shelf-edge orientation of Saurashtra peninsula reflects tectonic movements associated with the formation of this anticline

Geological Setup of Saurashtra Peninsula

Tectonic Framework

Regional physiographic setting of the Saurashtra peninsula is a reflection of its tectonic framework. Bounded by Kachchh rift and Cambay rift on its northern and eastern side respectively, the Saurashtra massif is designated as a horst (Biswas, 1982). The straight nature of western and southern coastlines of the region is accounted to the tectonic control of the extension of the West Coast Fault and the Narmada rift in the offshore (Fig 1.6). Deep seated tectonic structures off Saurashtra coast are presented by Ghosh & Zutshi (1989) and Chauhan et al., (1993). Most of the structures established are associated with intricate movement of the Indian plate after its breakup from Gondwana-land in Cretaceous time (Biswas, 1982). Crustal structure of the region has been derived from the DSS data and drilling projects taken up by the ONGC and it is found that although the Tertiary sequences does not appear to be seriously affected by faults, a significant displacement in the Mesozoic record occurs (Zutshi et al., 1989). The Okha Rann which separates Okhamandal peninsula from the rest of Saurashtra is a manifestation of neotectonism in this part

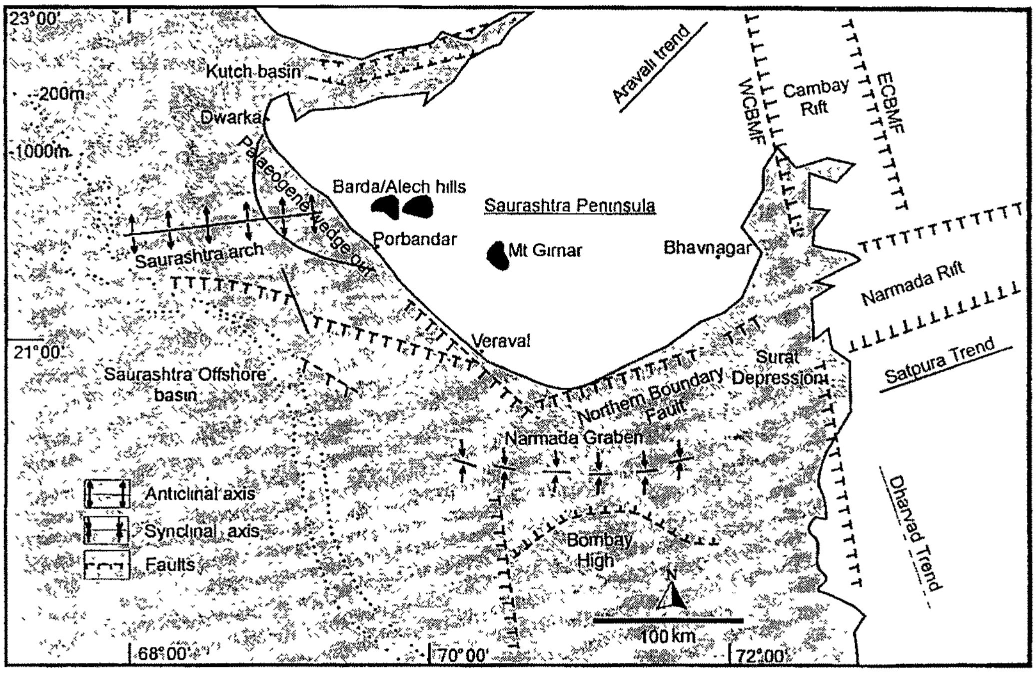

Figure 1 6 Tectonic attributes surrounding the Saurashtra peninsula (After Chauhan et al , 1993, Biswas, 1982)

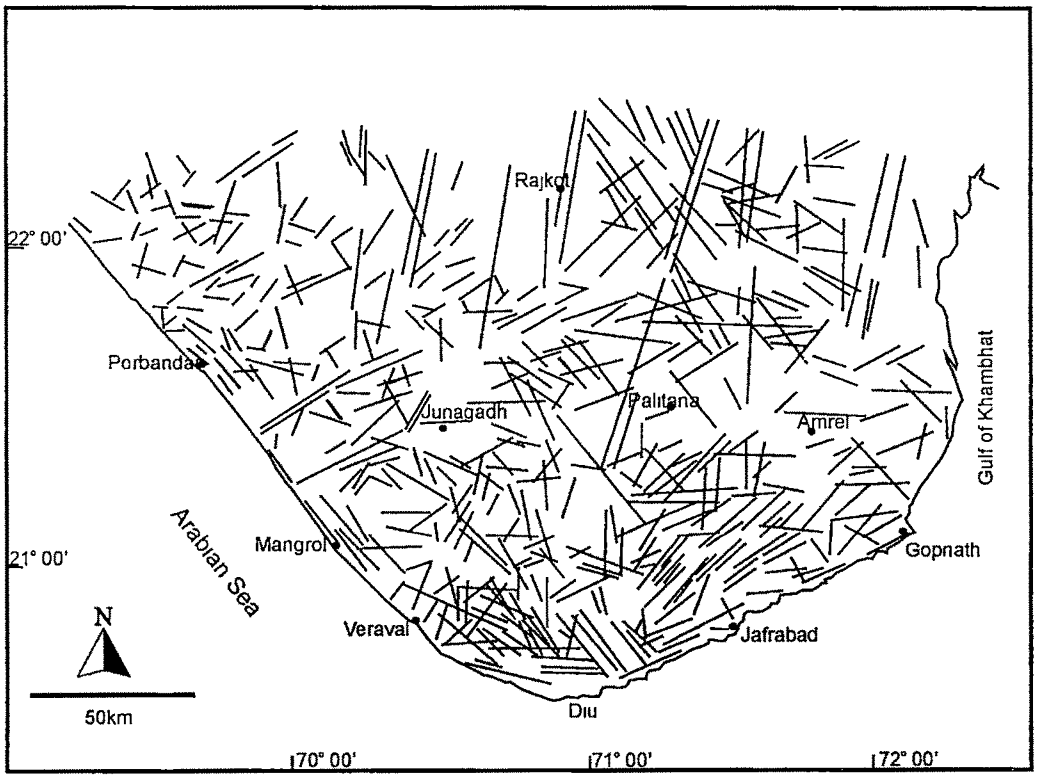

Figure 1.7 Major lineaments on the Saurashtra peninsula. (After Mishar et al , 2001)

A prominent feature observed off shore Dwarka is the occurrence of Saurashtra Arch trending in NE-SW that distinguishes the Kachchh rift from the Saurashtra basin (Fig. 1.6). South of this are strong lineaments and faults tending in NNW. There is a strong contrast between the onland and offshore basement configuration of the Saurashtra. Major fault zones trending WNW-ESE off Porbandar coast defines Saurashtra platform and separate it from deeper zone due West (Zutshi et al., 1989).

The Saurashtra coast is mainly affected by the break up of the India from Africa during mid-late Jurassic. The large scale volcanic eruption over Africa and Antarctica in the form of Karro and Ferrar volcanics respectively was mainly responsible for this breaking apart (Storey, 1995).

A lineament map (Fig. 1.7) prepared from the False Color Composite (FCC) and thematic maps from NRSA shows a dense concentration of lineaments along the coast and in the adjoining areas. (Mishra et al., 2001). Four major structural trends have been identified from this viz., NE-SW, ENE-WSW to E-W, NW-SE and NNE-SSW to N-S trend The gravity trends in the Saurashtra (Fig. 1.8) clearly shows the gravity highs of 40-60 mGal near Junagadh, Barda and Alech hills (Mishra et al., 2001) The gravity anomaly is circular at Junagadh representing the volcanic plug whereas, at Barda and Alech individually it is circular but, together it forms an E-W trend indicating fracture zone occupied by these volcanic plugs. Prominent low gravity of about -40 mGal has been observed over Jasdan plateau that is attributed to the isostatic compensation or to some deep seated source, probably the upper mantle.

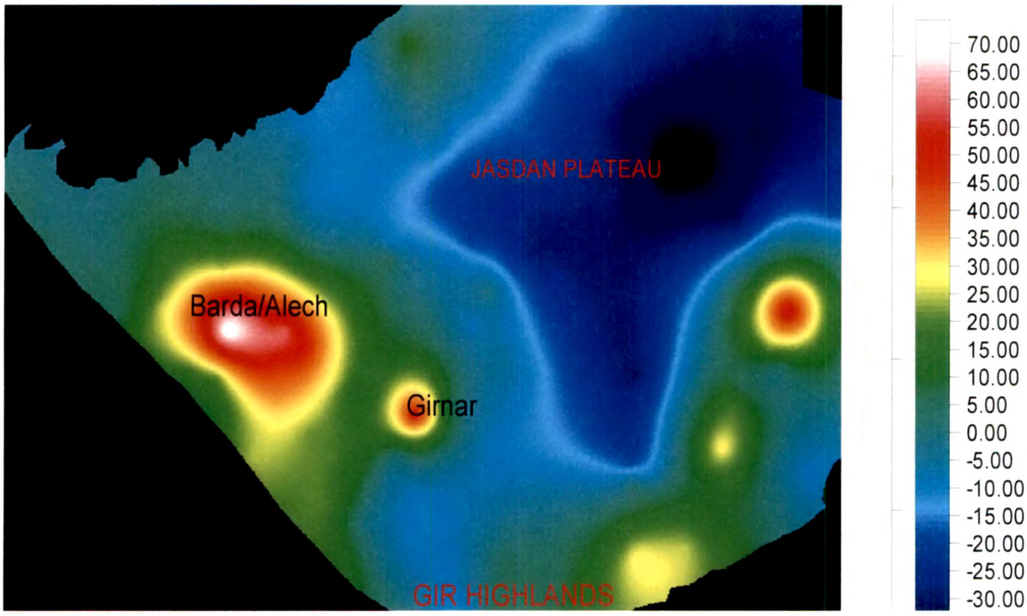

Figure 1.8. Gravity anomaly map of the Saurashtra peninsula with values in mGal. (digitised after Mishra et al., 2001).

Stratigraphic Framework

The Saurashtra region consists of the rocks belonging to the Mesozoic and Cenozoic Era. Stratigraphically, the sequence begins with the Juro-Cretaceous sedimentary formations which are nonconformably overlain by the Upper Cretaceous volcanic igneous rocks followed by the Mio-Pliocene and Quaternary sedimentary sequences (Fig. 1.9; Table-I.1). Approximately, 5000 sq. km area in the NE corner of the Saurashtra peninsula is occupied by Upper Jurassic to Middle Cretaceous sedimentary rocks which are divisible into two Formations i.e. Dhrangadhra Formation and Wadhwan Formation.

Dhrangadhra Formation

The rocks belonging to this Formation were first described by Fedden (1884) and Oldham (1893) but, were assigned a formal litho-stratigraphic status of the Formation by Srivastava (1963). The rocks constituting the Dhrangadhra Formation are feldspethic

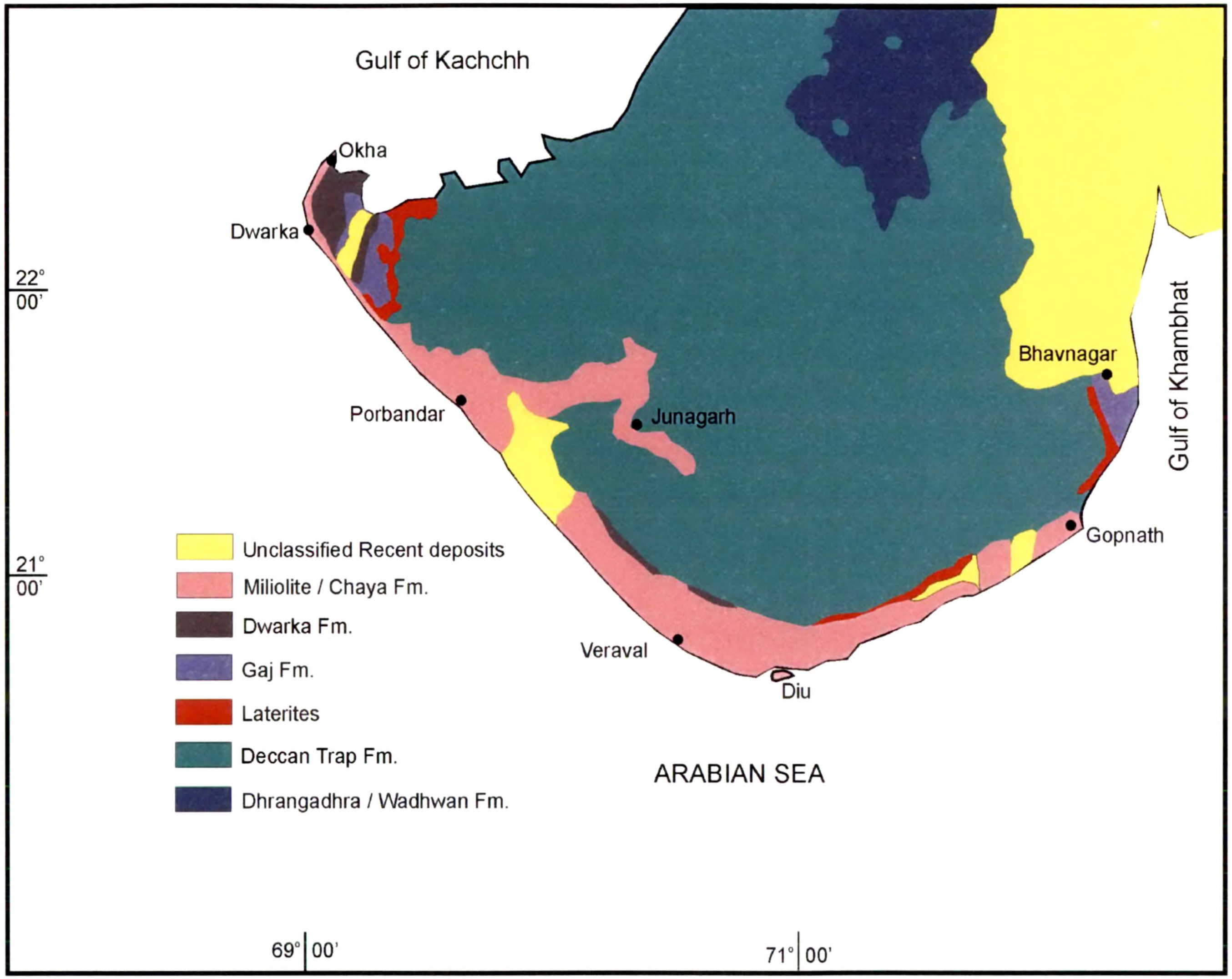

Figure 1.9 Geological set up of the Saurashtra peninsula. (Modified after Merh, 1995)

Era	Period	Stratigraphic Unit	Lithology	Age
CENOZOIC ERA	QUATERNARY PERIOD	Unclassified Holocene Deposits	Beach and dune sands, tidal clays, alluvium (Unconformity)	Holocene
		Chaya Formation Aramda Reef Mbr (4 m)	Coral reef limestone	Late Pleistocene
		Okha Shell Limestone Mbr (10 m)	Off white coloured bioclastic limestones and conglomerate	
		Miliolite Formation Adityana Mbr (5-50 m)	White coloured pelletoid limestone (Calcarenite)	Middle to Late Pleistocene
		Dhobalia Talav Mbr (8-10 m)	Alternating pelletoid limestone and micrite (Unconformity)	Early Middle Pleistocene
	TERTIARY PERIOD	**Dwarka Formation** Kalyanpur Limestone Mbr (30 m)	Recrystallised fossiliferous limestone and sandy limestone	Lower Pliocene
		Shankhodhar Sand-Clay Mbr (60 m)	Sandy clays and sandstones	Upper Miocene
		Positra Limestone Mbr (25 m)	Bioclastic and coralline limestones With few dolomitic bands (Disconformity)	Middle Miocene
		Gaj Formation Ranjitpur Limestone Mbr (5 m)	Yellow and brown fossiliferous limestone	Lower to Middle Miocene
		Ashapura Clay Mbr (90 m)	Grey clay, variegated clays, marls with some gypsum bands (Unconformity)	
MESOZOIC ERA	JURO-CRETACEOUS PERIOD	Lateritic Rocks	Red Brown and Yellow Laterite	Paleocene
		Deccan Trap Formation	Basalt and other derivatives covered at places by laterite and bauxite (Nonconformity)	Upper Cretaceous to Eocene
		Wadhwan Formation Chamaraj Mbr (8-10m) Malachimata Mbr (8-10m)	Quartzo sand stone with cross-beddings, argillaceous rocks, impure limestones & thin red sandstones	Middle Cretaceous
		Surendranagar Mbr (25-30m)	Red, brown sandstone which is medium to coarse grained, sandy shale and soft clay	
		Dhrangadhra Formation	Feldspethic sandstones, argillaceous sandstones, sandy shales and clay with occasional coal bands	Upper Jurassic to Lower Cretaceous
BASE NOT EXPOSED				

Table I 1 Lithostratigraphic framework of the Saurashtra region

(After Shrivastava, 1963, Mathur & Mehra, 1975 and Bhatt, 2000) sandstone, argillaceous sandstone, sandy shale, and clay with occasional coal bands. Sandstone is the dominant rock type of this Formation. The thickness of the Formation has been estimated up to 550m based on a bore hole drilled near Dhandhuka where it lies over granite basement. Physical continuity of Wagad and Bhuj sandstone with this Formation has been envisaged by Biswas (1987). An occurrence of coal and plant fossils in the rocks belonging to the Dhrangadhra Formation suggests their formation in coastal swamp environment; the Formation being considered to be of typical deltaic type environment (Karami, 1990). This Formation is also correlated with the Himmatnagar sandstone of North Gujarat which is thought to be Lower Cretaceous in age. This Formation has been assigned an age of Upper Jurassic (Tithonian) to Lower Cretaceous (Neocomian and possibly extending up to the Albian). Fedden (1884) correlated plant bearing beds of this Formation with the Umia beds of Kachchh.

Wadhwan Formation

This Formation is younger than the Dhrangadhra Formation. This is best exposed in Bhogavo river near Surendranagar. Fedden (1884) was first to map them and has named this Formation after their best exposures near Wadhwan village. Shrivastava (1963) subdivided this Formation in to three members (Table I.1) and identified several mega shells of gastropods and pelecypods along with bryozoans and echinoderms and also microfossils to suggest their shallow marine depositional environment. Chiplonkar and Borkar (1973) separated out the limestone units occurring in this Formation and designated them as the Surendranagar Limestone Member, Navania Limestone Member and Badhuka Limestone Member in ascending order. They correlated these with the Nimar sandstone, the Nodular limestone and the Coralline limestone respectively of the

Bagh Beds of lower Narmada valley. However, Biswas (1987) has explained them by correlating with the Bhuj sandstone.

Deccan Trap Formation

A major part of the Saurashtra peninsula is occupied by the rocks of Deccan Trap Formation. These rocks constitute elevated tableland with an uneven topography. The bulk of the Formation is made up of succession of lava flows dominantly of tholeitic basalt. Common rock type encountered is fine to medium grained grayish black basalt with its variations and amygdaloidal basalt forming marker flows. Based on the Deep Seismic Survey (DSS) profiles, Kaila et al. (1981) estimated thickness of the Deccan Trap Formation in the west of Junagadh to be between 900 and 1300m, and in the east as low as 350m. Barda hills in the NE of Porbandar are made up of felsite and quartz-felsite in the eastern part of these hills. An arcuate body of granophyre and rhyolite plug of 10km diameter with sub vertical inward dipping flow structure indicating volcanic vent in the Barda hills is also conspicuous The Alech hills are occupied by magmatic derivatives like rhyolite and felsite with some dolerite whereas; the hill Osham in NW of Junagadh shows presence of trachy-felsite with pitchstone flow at the base.

Most striking feature among the Deccan Trap is the Girnar hills. This massif in central core of plug consists of monzonite and diorite which occurs within ring-dyke of granophyre, limburgite, nepheline syenite, monchiquite and camptonite also occur as veins and dykelets in the olivine gabbro. The variations in the rocks of Girnar hill have been described in detail by Sukeshwala (1981).

Numerous basalt dykes conspicuously occur in three directions viz., ENE-WSW, E-W and NW-SE. They range in width from 2-5m but, runs for several kilometers. These are structurally controlled and follow major fracture and lineament trends. NE-SW trending dykes were considered as dyke clusters earlier, but Misra (1981) based on their studies suggested that they are fault controlled tilted flow and considered them as extension of Narmada rift zone

There is also a mention of inter-trappean sedimentary beds. Near Bamanbore and Ninama as thick as 35m inter-trappean beds occur that contain massive poorly bedded chalky limestone with basal conglomerate. Based on the fossil remains the age of these inter-trappean beds has been estimated to be of Palaeocene to Lower Eocene (Merh, 1995).

Gaj Formation

Rocks belonging to this Formation are best exposed in the 30-40m high cliffs of Okha Rann on the western flank in the NE part of the study area. They are mostly argillaceous and partly calcareous, comprised of yellow and grey coloured clays, variegated clays with gypsum bands and calcareous silt and sandstones along with thin bands of yellow brown coloured limestones. The Gaj Formation has been divided into two Members, the Ashapura Clay Member and the Ranjitpur Limestone Member (Bhatt, 2000).

The Ashapura Clay Member is dominantly consisting of laminated clays with bands of grey, maroon and yellow colour. Topmost unit of this Member is marl and siltstone which is dolomitic in nature In general, the Ashapura Clay Member is characterized by thin fossiliferous bands at different levels, where most of shell material is dissolved and only their mould and cast are visible. In the eastern part of Okha Rann typical earthy yellow clays unconformably lies over laterites with bouldary conglomerate horizon at the base which becomes gravelly after a meter thickness towards top. Average thickness of about 90m has been estimated for this formation.

The Ranjitpur Limestone Member is not dominant unlike the previous one, and their sporadic exposures make it difficult to map at 1:50,000 scale. It attains a status of Member due to distinct calcareous unit associated with the otherwise argillaceous Gaj Formation. The unit comprises typical yellow to brown coloured very compact fossiliferous limestones, extensively bored and contains recrystallized shells of *Acila, Arca, Pecten & Ostrea.* Lower Miocene age has been suggested for this Member on the basis of *Pectunculus pecen, Pecten sp*, *Pecten bouei*, *Pecten favrei* and *Ostrea multicostata* and that of larger foraminifers belonging to the *Miogypsinidae* family (Kachhara et. al., 1998)

Dwarka Formation

Dwarka Formation has got a disconformable contact with the below lying Gaj Formation and is characterized by highly recrystallized limestone and sandy clay sequences. The Formation chiefly consists of two distinct fossiliferous sequences along with clastic dominated non fossiliferous sequences in between. This Formation has been divided in to three Members viz., Positra Limestone Member, Shankhodhar Sand-clay Member and Kalyanpur Limestone Member (Bhatt, 2000).

The Positra Limestone Member consists of coralline and fossiliferous limestones which have been recrystallized. At places, the brown coloured recrystallized limestone of this Member exhibits trough cross beddings and ripple marks. The Member attains maximum thickness of about 25m in subsurface.

The type section for the Shankhodhar Sand-Clay Member is at Bet Dwarka where cliffs expose grey and yellow coloured clays with occasional bands of brown coloured sandy clays and grey white coloured relatively consolidated sands The sequence also exhibits sedimentary structures like low angle cross-bedding, ripple drift laminations and ripple marks. This Member has contact with Positra Limestone Member marked by about 0 5-1m thick conglomerate horizon. The total thickness of this unit is estimated to be about 50-60m.

The Kalyanpur Limestone Member is characterized by pinkish to brown coloured highly recrystallized fossiliferous limestone that has a sharp contact with below lying non calcareous clastic dominated sequence. The rocks also show planar and trough cross-beddings. This Member characterizes topmost part of the Dwarka Formation and occurs at many places in western Saurashtra. As the Member has a distinct unconformable contact with the in general Sand-Clay sequences of the other part of the Dwarka Formation, a possibility of its being younger and different litho unit can not be ruled out.

Miliolite Formation

The Quaternary geological record of Saurashtra begins with the Miliolite Formation with a profound punctuation in the geological record from Mio-Pliocene till Middle Pleistocene. The Formation is composed of medium to fine grained well sorted rounded to subrounded allochems like foraminiferal tests, peloids, molluscan shell fragments, coral, bryozoan, echinoderm, etc. chiefly cemented by the low magnesian non-ferroan sparry calcite cement. It shows varied thickness depending upon the pre-miliolite topography. In the coastal areas the Formation attains a thickness of about 25m whereas, in the inland areas it range between 2m to 50m. The high angle tabular and wedge type planar cross stratifications and mound like body geometry have been considered indicative of its aeolian deposition. The dominantly bioclastic composition has been used to advocate its marine deposition. Recent views accept the occurrence of both, aeolian and marine Miliolites The details on this Formation have been reviewed by Merh (1980) and recently by Bhatt (2003). This Formation has been divided into two Members viz, Dhobalia Talav Member consisting of alternating pelletoid limestone and micrite, and Adityana Member consisting of white coloured pelletoid limestone 'calcarenite' Age range of this Formation based on geochronology and palaeontological criteria has been decided as early Middle Pleistocene to Late Pleistocene. It is understood based on their radiometric age data (Baskaran et al., 1989) that the Miliolites are deposited in three different episodes, M-I (50-70ka), M-II (75-115ka) and M-III (140-210ka).

Chaya Formation

Mathur & Mehra (1975) separated out the coarse grained bioclastic limestone deposits occurring associated with the Miliolite limestone in the coastal area of western Saurashtra as a formal litho-stratigraphic unit as the Chaya Formation. The formation consists of buff coloured, coarse grained gently sea ward dipping rocks containing mega fossils that can be termed as the 'Calcirudite'. The rocks have also been described in the literature as the 'coast fringing rocks' (Fedden, 1884) and 'ancient beach rocks' (Patel, 1991a). The significance of these bioclastic shore deposits in the study of Late Quaternary sea level changes in the region has been discussed by Bhatt & Patel (1998) The Chaya Formation is divisible into two Members viz., Okha Shell Limestone Member which is off white coloured shell rich limestone and conglomerates of approximately 10m thickness and Aramda Reef Member made up of coralline limestone well exposed near village Aramda, of approximately 4m thickness (Bhatt, 2000). Rocks belonging to the Chaya Formation are encountered along the coastal belt of the study area at an elevation range of 4-10 meter. The Formation has been assigned Middle to Late Pleistocene age (Bhatt, 2003).

Unclassified Holocene Deposits

The Holocene record of Saurashtra has not been investigated yet with much detail. It is characterized by stabilized coastal dunes, raised mud flats, shell beds, dead coral reefs, etc that can be prominently used to construct the Holocene history of the region. Apart from these, the present day fluvial deposits, pediment debris, beach and tidal clay deposits, etc. are considered under the Holocene deposits which are unclassified.

As the present study was oriented towards understanding of the evolution of the Saurashtra coast through the Late Quaternary time, detailed geological investigations were remained confined to the Neogene-Quaternary succession only. The forthcoming text describes in detail the geomorphic and geologic set up of the study area wherein the formal lithostratigraphic status of the individual litho-units is frequently referred to.