Chapter II

THE SAURASHTRA PENINSULA

Geography and Geology of study area

General

The Saurashtra peninsula is one of the three conspicuous physiographic divisions of the Gujarat state and lies between 20° 30′ N to 22° 30′ N. latitude and 69° 00′ E to 72° 30′ E. longitude. The Saurashtra region is structurally a horst bounded by the Gulf of Kachchh fault in the north and by the extension of Narmada-Son fault in the south. Three sides of the region are marked by Gulfs of Khambhat and Kachchh in the east and north respectively, whereas on the west is the Arabian Sea (Fig. 2.1).

Physiography

The Saurashtra peninsula forms highland in the central region, known as the Jasdan plateau, which rises from 80m contour abutting against otherwise gentle coastal strip (Figure. 2.1). The southern Saurashtra has the Gir highland that range from 100 to 480 m in height and reaches its maximum near Junagadh forming the Girnar hill having an altitude of 1117m above mean sea level. The other three high physiographic expressions are the Osham hill (311m), Alech hills (298m) and Barda hills (637m).

The southern Saurashtra coast is an emergent type of coast (Ahmed 1972), and is also characterised by impressive cliffs and shore platforms (Bhatt and Bhonde, 2006). The regional geomorphology of the Saurashtra

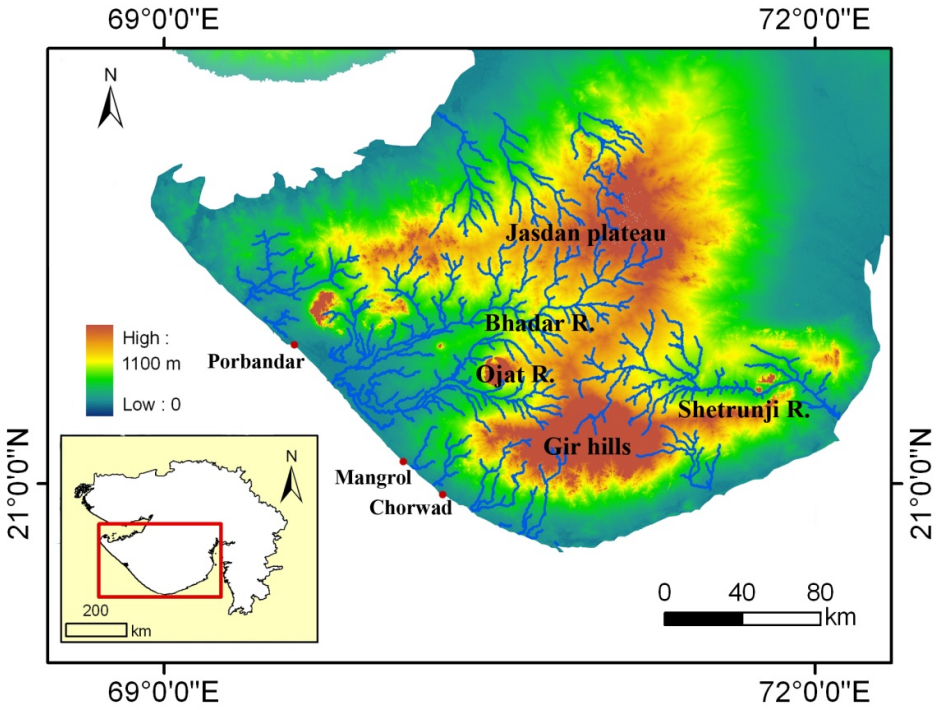

Figure 2.1 Physiography and drainage characteristics of Saurashtra peninsula.

offshore (Fig. 2.2) shows prominent benches/terraces between 180 and 230 m depth in the upper slope off Saurashtra, whereas the other slope breaks off Porbandar at 560 m (Chauhan et al., 1993 and Rao et al., 1996). These are below the still stands of sea level in the region during the last glacial maximum (LGM) 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.

Structure and tectonics

The Saurashtra horst is bounded by the Gulf of Kachchh Fault (GKF) which is a part of Kachchh Rift Zone in north, the West Coast Offshore Fault (WCOF) in west, extension of the Narmada-Son Fault (NSF) in south and the Western

Margin Cambay Basin Fault (WMCBF). Apart from this, several lineaments traverse through the region (Fig. 2.2). The Saurashtra Arch which trends in NE-SW is an anticlinal uplifted block complementary to Narmada graben (Biswas, 1982) which is also known to exist in offshore Saurashtra supportive by the seismic section revealing folded strata at the upper slope (Ghosh and Zutshi, 1989). These observations lead to propose that shelf-edge orientation of Saurashtra peninsula reflects tectonic movements associated with the formation of this anticline. NNW trending strong lineaments and faults run in the South of this arch. There is a strong contrast on land and offshore basement configuration of Saurashtra. Major fault zones trending WNW-ESE off Porbandar coast defines Saurashtra platform and separate it from deeper zone due west (Fig. 2.2).

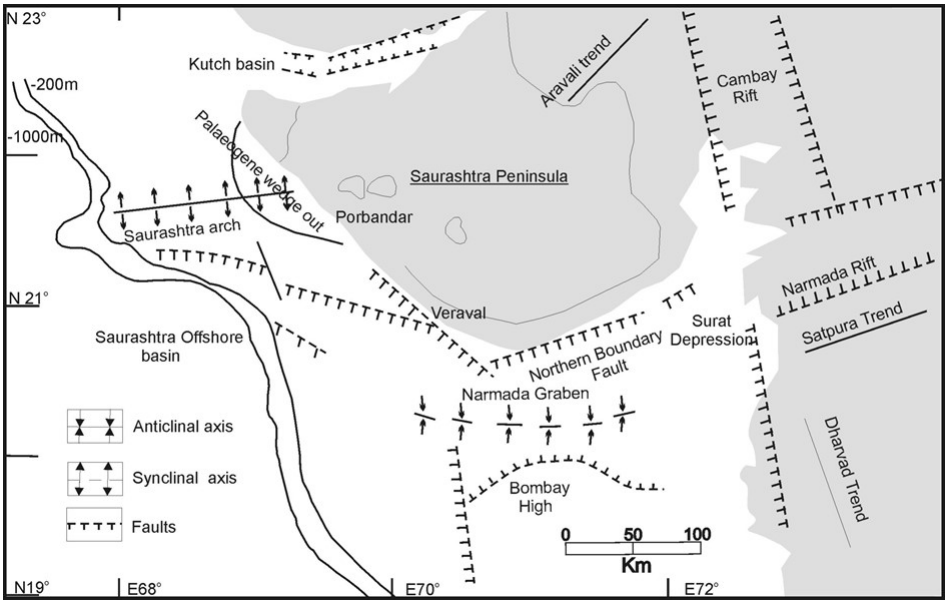

Figure 2.2. Tectonic framework of the Saurashtra peninsula (After Chauhan et al. 1993).

The tectonic configuration of Saurashtra coast is mainly featured out since the breakup of Africa from India during mid-late Jurassic; envisaged due to the large scale volcanic eruption over Africa and Antarctica that formed the Karro volcanics and Ferrar respectively (Storey, 1995). Recently, Mishra et al., (2001) identified four major structural trends by mapping several major and minor lineaments using false colour composite and thematic maps from NRSA data. These workers presented gravity and magnetic trends of the Saurashtra region showing gravity highs of 40-60 mGal at Junagadh, Barda and Alech. The gravity anomaly is of circular shape at Junagadh representing the volcanic plug but, at Barda and Alech it together forms an E-W trend indicating a fracture zone occupied by these volcanics. Prominent low gravity of about -40 mGal has been observed over Jasdan plateau that has been linked to the isostatic compensation or to some deep seated source probably the upper mantle.

Climate

The Tropic of Cancer passes through the northern part of the Gujarat state categorizing it in to the sub-tropical climatic zone. The Saurashtra peninsula experiences arid to semi-arid type of climatic condition. The year may be divided into three seasons. January is the coolest month in which mean daily maximum temperature in coastal areas remain 28^{o}C and minimum 15^{o}C. The winter is followed by the summer from March-June. May and June are the hottest months with maximum temperature reaching up to 45^{o}C. Relative humidity is generally 80% during SW monsoon; otherwise air remains drier during the rest of the year, particularly in the interior areas. The major rainfall

in the region is received in the month of July to September. The highest rainfall is received in the month of July. The Gir highlands and southwestern coastal part around Veraval receives maximum rainfall in the whole Saurashtra peninsula.

Drainage

The Saurashtra region in general shows radial drainage pattern rising from the Jasdan plateau and the Gir high lands (Fig. 2.1). The major rivers include Shetrunji, Bhadar, Ojat, Machchhu, Hiran, Saraswati, Singwado, Machchhundri, Malan, Bhogavo, etc. All these rivers are of ephemeral types, carrying water only during monsoon and part of winter seasons. The Bhadar is longest river of the Saurashtra peninsula covering almost half of the study area that forms the western coastal part of the Saurashtra. The other major river basins of the study area are Ojat, Noli, Megal, Hiran, Saraswati, Devka, Singwado, Rupen and Machundri (Fig. 2.1).

Stratigraphic Units

Geologically, the Saurashtra region contains rocks belonging to the Mesozoic and Cenozoic Era (Fig. 2.3). Stratigraphically the sequence begins with the Juro-Cretaceous sedimentary rocks which are nonconformably overlain by the Upper Cretaceous volcanic igneous rocks followed by the Mio-Pliocene and Quaternary sedimentary sequences (Fig. 2.3; Table-2.1).

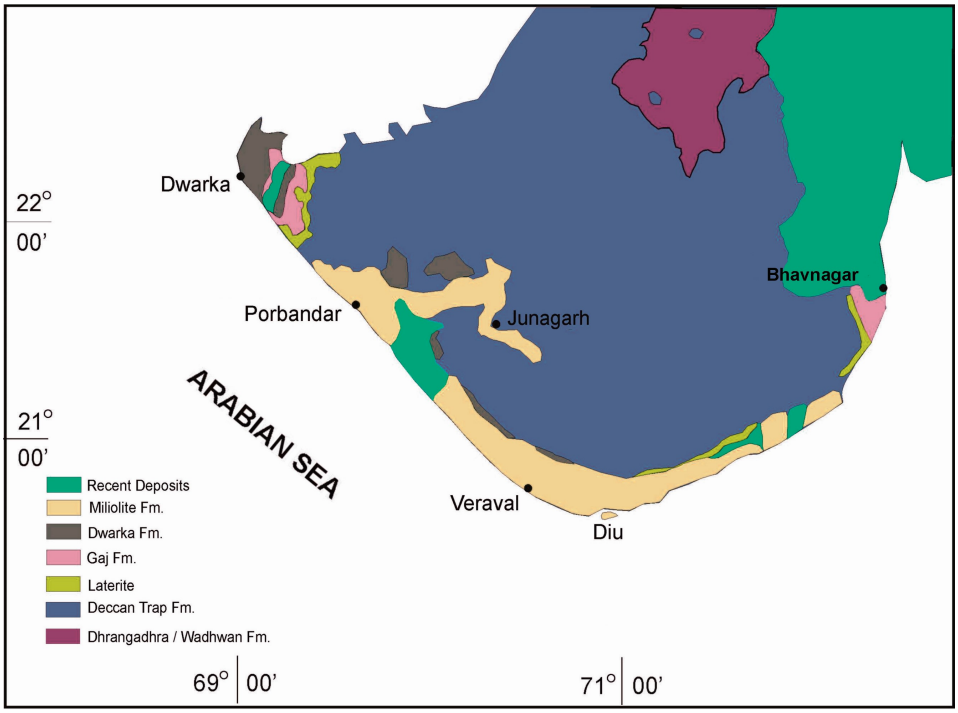

Figure 2.3 Geological map of the Saurashtra peninsula (Modified after Merh, 1993).

Approximately 5000 sq. km area in the NE 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 arkosic 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). Fedden (1884) correlated plant bearing beds of this Formation with the Umia beds of Kachchh. 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 upto the Albian).

Wadhwan Formation

This Formation is younger than the Dhrangadhra Formation. This is best exposed in Bhogavo River near Surendranagar. Fedden was first to map them and assigned this named this Formation after their best exposures near Wadhwan village.

Shrivastava (1963) identified several mega shells of gastropods and pelecepodes alongwith bryozoans and echinoderms and also microfossils to suggest their shallow marine depositional environment. According to Chiplonkar and Borkar (1973) this Formation can be divided into three members i.e. Surendranagar Limestone Member, Navania Limestone Member and Badhuka Limestone Member in ascending order. They correlated these with Nimar Sandstone, Nodular limestone and Coralline limestone

respectively of Bagh beds of lower Narmada valley. However, Biswas (1987) has explained them by correlating them with Bhuj sandstone based on his study.

Deccan Trap Formation

Most of the Saurashtra peninsula is covered with rocks of the Deccan Trap Formation. These rocks constitute elevated tableland with an uneven topography forming flat topped hills with black cotton soil cover. The bulk of the Formation is made up of succession of lava flows dominantly tholeiitic basalt. Common rock type encountered is fine to medium grained grayish black basalt with its variations. Based on DSS profiles Kaila et al. (1981) estimated thickness of the Deccan Trap Formation in west of Junagadh to be between 900-1300m and in the east to be 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. Alech hills are occupied by magmatic rocks like Rhyolite and felsite with some dolerite. Osham in NW of Junagadh shows presence of trachy-felsite with pitchstone flow at base.

Most striking feature among the Deccan Trap is Girnar hills. This massif in central core or plug consists of monzonite and diorite which occurs within ring-dyke of grnophyre. Limburgite, Nepheline Syenite, Monchiquite and Camptonite also occurs 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 in three directions viz. ENE-WSW, E-W and NW-SE are conspicuous. 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. Recently kshirsagar et al (2014) has described the tilted trachyte flows from Rajula area as Cone sheets. 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.

Gaj Formation

Rocks belonging to this Formation are best exposed in the 30-40m high cliffs on the western flank in the NE part of the Saurashtra peninsula. 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 by Bhatt (2000) i.e. Ashapura Clay and Ranjitpur Limestone Members.

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* and *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 (Jain, 1997).

Dwarka Formation

Dwarka Formation has got disconformable contact with 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. This 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 (Desai 2015). 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 with 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.

Comprehensive accounts of algae from the Neogene –Quaternary sequences of Saurashtra are made available recently by Kundal and Mude (2009; 2010), Kundal (2012) and Kundal et al (2014).

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 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 Middle 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 and 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. It consists of the buff coloured, coarse grained gently sea ward dipping rocks containing mega fossils and termed as 'calcirudite'. The rocks have been described in the literature also as the 'coast fringing rocks' (Fedden, 1884) and 'ancient beach rocks' (Patel, 1991a). The significance of these bioclastic shore deposits has been discussed by Bhatt and 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.

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 corals 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.

The Middle-late Pleistocene and the Holocene sedimentary record is the subject matter of present study and is elaborately documented in the forthcoming chapter.