CHAPTER 1

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INTRODUCTION

An inventory of field evidences supported by critical analysis of morphometric parameters is required to understand neotectonism and geomorphic evolution of an area. This in turn calls for multidisciplinary approach by combining structural, morphological and neotectonic data to study the setting of the area in relation to geological structures (Potter, 1978; Lanzhou and Scheidegger, 1981; Diamant et al., 1983; Centamore et al., 1996; Scheidegger, 2004). Tectonic movement, contemporaneous with the formation of the morphology of the modern river is referred to as 'active tectonic movement' (Ouchi, 1985).

Geomorphological parameters developed for the study of alluvial system have been used extensively and tested as a valuable tool to explore various aspects of the tectonic influences on the tectonically active areas. Fluvial landforms and deposits provide one of the most extensively studied continental Quaternary records. Moreover, studies related to long-term dynamics of fluvial systems and their responses to external controls provide important clues to geomorphic evolution of an area. These studies gained momentum in the last decades of the twentieth century. Sedimentary basins which are under the influence of tectonic disturbances show variable rates of sedimentation and changes in the spatial organization of alluvial facies (Mather, 1993). The geomorphic evolution of a reactivated sedimentary basin is mainly due to complex interplay between sedimentation process and tectonics (Jones et al., 1999). Tectonics is the dominant factor responsible for the development of the present day landscape of an area (Seeber and Gornitz, 1983; Sloss, 1991; Burbank, 1992) but existing climate of the area and the sea level changes also play important role in the process of sedimentation (Blum et al., 1994).

The neotectonic studies, which are based solely on the geomorphological studies are used to document the nature and type of movement along the faults (Schubert, 1982; Dumont, 1996) but they are not found to be useful in deciphering the timing and amount of movement along the fault. Therefore, an integrated approach involving geomorphic studies, geological and stratigraphic information, structural and tectonic evidences supplemented with palaeoseismic and coseismic features of the recent past, along with the geophysical data of sub-surface were assimilated to develop more precise investigation of the complexity of the process of geomorphic evolution and neotectonism in the Northern Hill Range of the Kachchh in Gujarat.

The Kachchh basin is an E-W trending rift graben located on the western Indian continental margin. The pre-Quaternary tectonic and sedimentary evolution of the Mainland Kachchh has been discussed at length by Biswas (1974, 1982, 1987). The region is one of the most seismically active regions in the subcontinent and experienced number of large magnitude earthquakes in the recent historic past. It falls within the seismotectonic zone-V in the seismic zonation map of India. Some of the large magnitude earthquakes (≥6) in Kachchh are Allah Bund (1819), Khavda (1940), Anjar (1956) and Bhuj (2001). The Kachchh region has been undergoing high compressive stress due to northward movement of the Indian plate and it's locking with the Eurasian plate in the north (Subramanya, 1996; Biswas, 1982, 1987).

Kachchh Mainland Fault (KMF), one of the major E-W trending faults in the Kachchh rift basin, has been accommodating the compressive stress resulting into moderate to high intensity seismic activity in the area. For the better understanding and evaluation of the seismic risks and to suggest mitigation measures more data on the nature of neotectonic activities along the Kachchh Mainland Fault is required. Fluvial processes and landscape evolution are normally controlled by the Quaternary sedimentation processes, tectonism and environmental changes. The role of tectonism is crucial in the development of fluvial systems in an area like Kachchh. The features developed due to the recent seismic activities provide explicit data for the approval of the derived evidences from various procedures.

Aim and Scope

The main objectives of the present work are to assess the Late Quaternary movement along the Kachchh Mainland Fault, to understand the tectonic elements involved in the seismic activities in the area and to correlate the coseismic data of the 2001 Bhuj earthquake with the conclusions drawn from the study of the morphometric processes. Therefore, in the present study emphasis has been given to the application of the detailed morphometric analysis of the river basins, study of the coseismic data of the 2001 Bhuj earthquake, study of the alluvial fans of the rivers flowing across the Kachchh Mainland Fault and assimilation of the subsurface geophysical data. Five river basins, which fall in the zone of Kachchh Mainland Fault, have been selected for detailed morphometric analysis with the help of GIS and high resolution remote sensing data to produce linear and aerial parameters of morphometric analysis precisely and to analyze these data to infer the effects of the neotectonism on the fluvial systems. The study provides insight into the nature of neotectonic movements along the Kachchh Mainland Fault and the associated transverse faults. The present study reveals more coherent evidences that KMF has been tectonically active throughout the Late Quaternary and has played important role in the geomorphic evolution of the Kachchh basin. The study also aims to explain the nature of transverse faults to the KMF, their role in the recent seismic activities in the area and how they are responsible for the geomorphic evolution of the Mainland Kachchh. During the course of study new transverse faults were discovered and bearing of these faults on the KMF has been attempted. The coseismic features developed due to 2001 Bhuj earthquake were recorded during the course of study, trenching was done at some places to see the nature of movement of faults and other coseismic features and the information was correlated with the published data. The pre- and post- 2001 Bhuj earthquake LISS-III images were studied to see the changes due to the earthquake which resulted into documentation of various changes like emergence of buried channels and liquefaction features. The significant historic earthquakes like Allah Bund (1819) and Anjar (1856) earthquake, and geomorphic features developed due to these were also studied.

The spatial and temporal distribution of the epicenters of the earthquakes and their relationship with the tectonic elements of the area throws light on the relative activeness of the segments of KMF and nature of their movement. Various transverse faults were developed in the process of northward journey of the subcontinent and reactivated while accommodating the stress exerted on the sub-plate after the locking of the Indian plate with the Eurasian plate. These transverse faults have segmented the Mainland block and strike slip component of the movement along these faults has shaped the arcuate boundary of the northern fringe of the Mainland, in contact with Rann.

Preface to the Study area

Location and Accessibility

The Kachchh Peninsula, which comprises the Kachchh district of Gujarat, is located between latitudes 22.72°-24.68° N and longitudes 68.10°-71.80° E, in the western most part of India (Fig. 1.1). The district occupies an area of 45,612 sq km, it has length and width of about 320 and 170 km respectively, and the Tropic of Cancer passes through the district. The delta land of Sindh (Pakistan), borders it in the west. Its long southern margin is shared by the Gulf of Kachchh, which separates the peninsula from Saurashtra. Its northern margin makes the International border with Pakistan and the eastern margin abuts against the Gujarat Mainland. The district has a population of 20.9 lakhs (Census, 2011) inhabiting about 949 villages in ten Talukas (Census of Housing 2001).

The study area is confined to the region of the Kachchh Mainland Fault, popularly known as KMF. KMF runs from near Vondh in the east and passes through Bhachau - Dudhai - Khirsara - Jawaharnagar - Lodai - Loriya - Nirona -Chari up to Lakhpat in the west (Fig.1.1 & 1.2). The study area falls in Survey of India toposheet nos. 41 I/7, 3, 41 E/15, 11, 6, 7, 2 and 41 A/13, A/9 from east to west respectively. The nearest town is Bhuj, the district headquarter, which is about 415 km west of Ahmedabad. Bhuj is well connected by railways, National Highway and Airport. The area of investigation is well connected with Bhuj by Bhachau-Bhuj, Bhuj-Gandhidham, Bhuj-Nakhatrana-Lakhpat and Bhuj-Bibar state highways. Besides, there are several fair-weather roads giving reasonable accessibility to the study area.

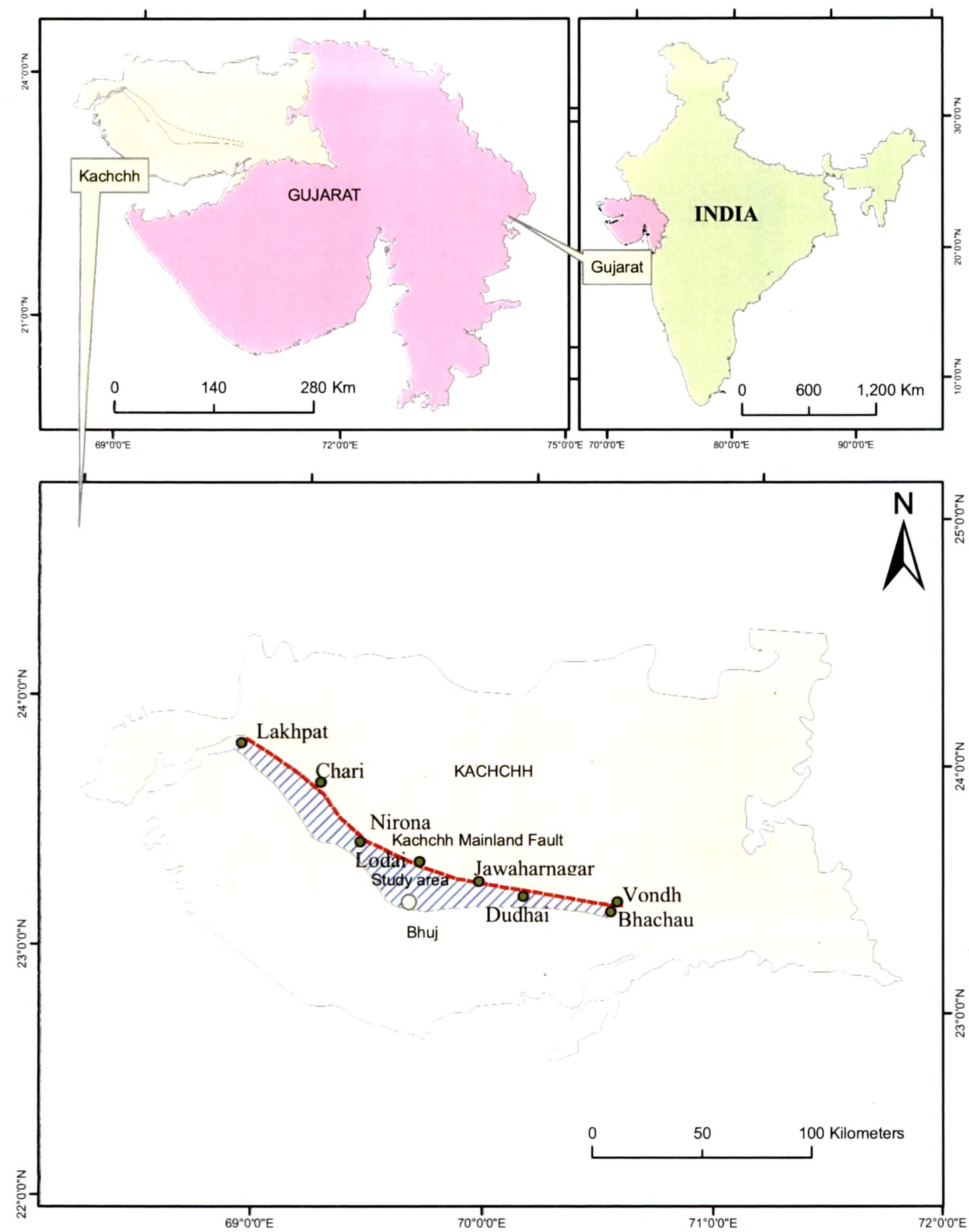


Fig.1.1: Location map of the Study area.

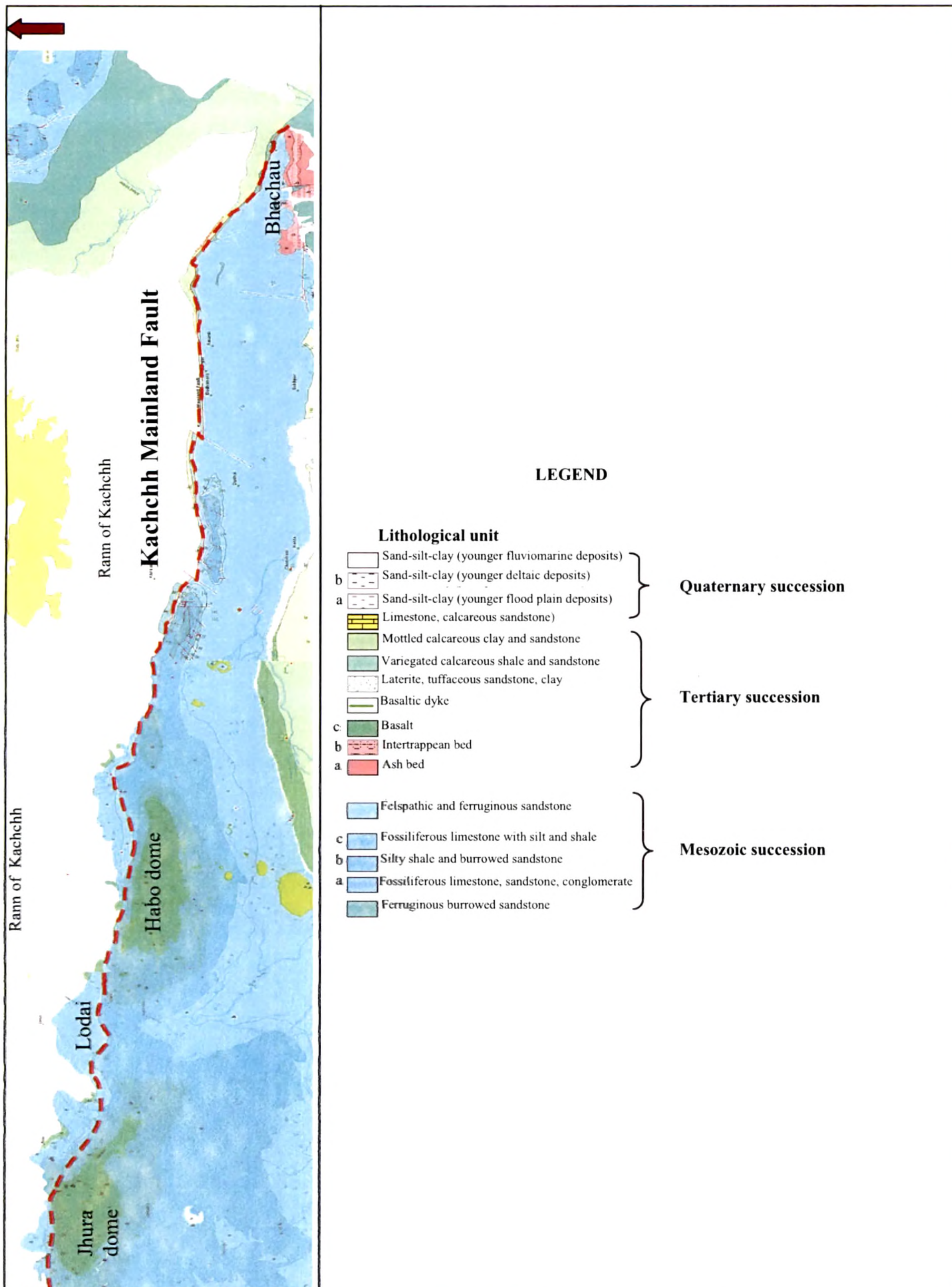


Fig. 1.2: Geological map of the area around Kachchh Mainland Fault (Generalized after Singh et al., 2008).

Climate

Gujarat lies in the tropical region however its proximity to the Arabian Sea reduces the climatic extremes and makes the climate more pleasant, comfortable and healthy. Kachchh region is characterized by arid climate (Fig. 1.3). The tropic of cancer passes through Kachchh. The area is far from the rain bringing influence of the monsoon. The monsoon prevails for a very short period (June-August) with a meager rainfall, which too is erratic (Fig. 1.4). Summers are scorching hot (Fig. 1.5). Hot gusty wind with finer sand makes the sky pale brown in summer storms. Sandstorms are common and obscure visibility beyond a few meters at times. Winter, especially during the months of December and January, is severe with mercury often dipping to 8°C or less (Fig. 1.3). Diurnal variation in temperature can be as large as 20°C. Humidity is less than 25%.

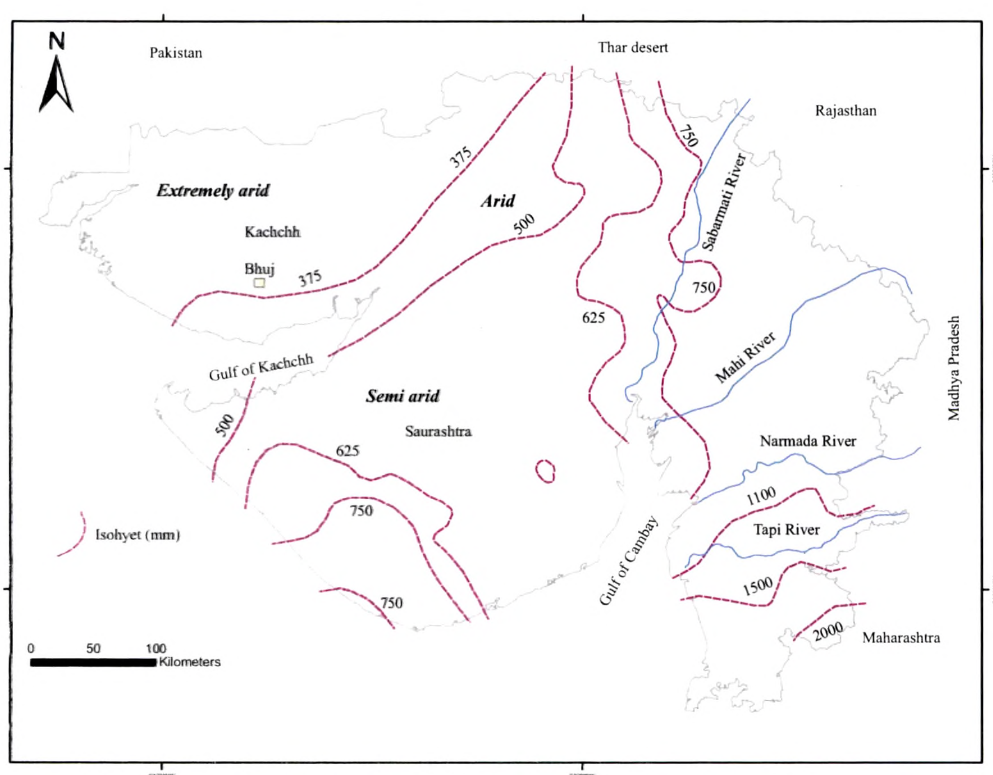


Fig.1.3: Map showing major physiographic divisions, isohyets and climatic zones of Gujarat (after Singh et al., 1991 and Department of Agriculture, Government of Gujarat).

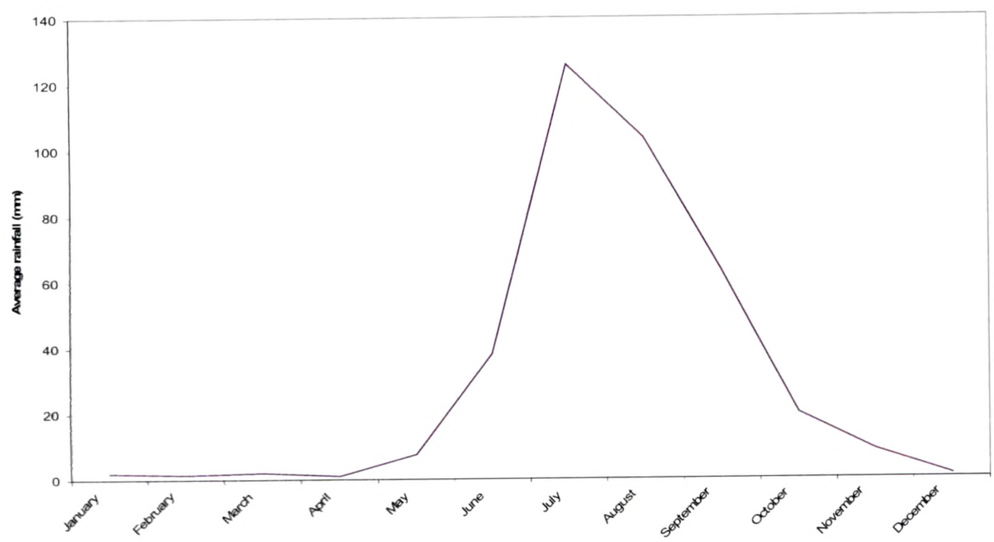


Fig.1.4: Graph showing average month wise rainfall in Kachchh district.

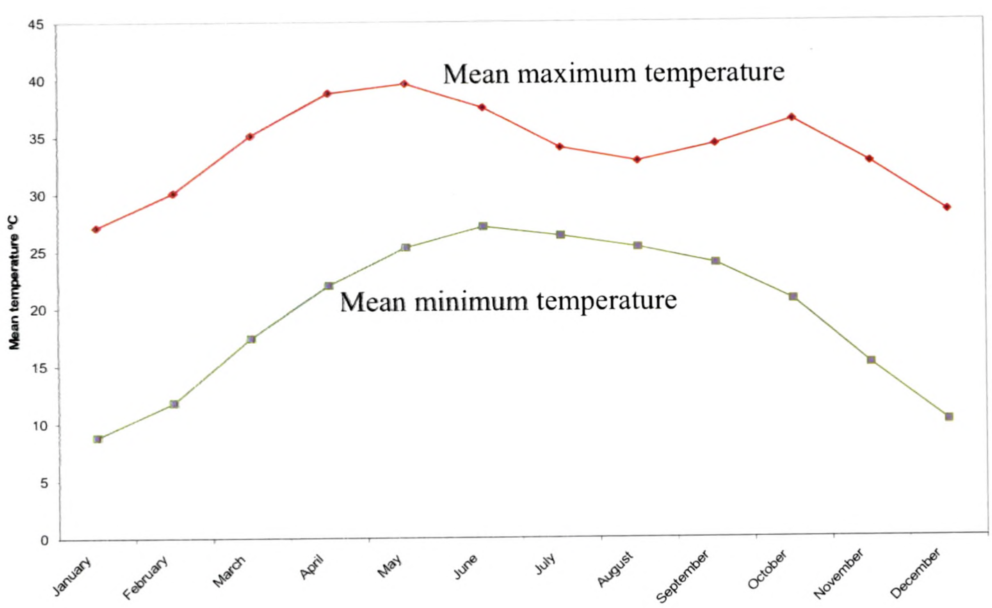


Fig.1.5: Graph showing average month wise temperature in Kachchh district.

Flora and Fauna

The most conspicuous vegetation in the area is cactus. Wild grass, bushes as well as wild maize are also found. There is a luxuriant growth of Acacia in the vicinity of check dams and local water bodies. In general, the area is devoid of trees. Local inhabitants cultivate jowar, maize, wheat, vegetables and pulses in the plains.

Jackals, rabbits, scorpions and snakes are very common. Antelopes are also seen at some places. Little Rann is famous for its wild ass sanctuary. Wild ass and peacocks are seen in other area as well. Siberian crane and flamingos are reported to be the migratory birds, which visit the marshy lands of Rann during the December to March. Only less than 10% of the total land area of Gujarat is covered by forest. Gir forest in Gujarat is the only abode of Asiatic lions in the world.

Physiography and drainage

Gujarat State with an area of 1,96,077 sq. km lies in the western part of India with a coastline stretching over 1600 km along the Arabian Sea. The engulfing Sea has physiographically divided the state into three units the Kachchh, Saurashtra and Mainland Gujarat. The Kachchh region is an excellent example of a tectonically controlled landscape whose physiographic features are the manifestation of the earth movements along the tectonic lineaments of the Pre-Mesozoic basinal configuration that was produced by the primordial fault pattern in the Precambrian basement (Biswas, 1971; 1974). Topographically, the Kachchh region is made up of east-west trending hill ranges i.e. the Island belt, the Kachchh Mainland and the Wagad. The hill ranges in each of these areas are separated by large tracts of low ground. All hill ranges and the intervening low grounds run almost parallel, a characteristic feature indicating that the topography has been controlled to a large extent by the geological factors of folding, faulting and lithology. Taking into consideration the factors like altitude, slope and ruggedness of relief, Kachchh can be divided into four main physiographic units from north to south, viz; the Rann, the low lying Banni Plain, the Hilly Region, and the Southern Coastal Plains (Fig. 1.6 to 1.8). The above four units show considerable diversity within each of them, depending on the rock types, their mode of occurrences and fault patterns. The highest peak in Kachchh is that of Kaladongar (Δ 465 m) in the Pachchham Island (Fig.1.9). Among various peaks in the Kachchh Mainland the Nanadongar showing the maximum altitude of 430 m. A specialty of the Rann of Kachchh is that the area gets submerged in water during rainy season which is otherwise completely dry.

The main rivers of the Mainland Kachchh are Kankawati, Kharod, Rukmawati, Phot, Lerakh and Song, which originate from the central Mainland, flow towards south and debouch into the Arabian Sea; whereas the Kaswali, Pur (Khari), Kaila, Nirona (Trambo) and Charee Rivers originate from the northern part of the central Mainland, flow towards north across the KMF and debouch into the Rann making conspicuous alluvial fans. The Kankawati, Kaswali, Kharod, Rukmawati, Pur and Nirona Rivers show very broad channels and vertical cliffy banks in their lower reaches. The Pur (Khari) River is showing meandering between east of Bhuj to Rudramata whereas the Kaila River shows entrenched meandering in the south of Jhura dome. The Dhrung and Kaswali Rivers show high vertical cliffs (10-15 m) with boulder beds above the current base level.

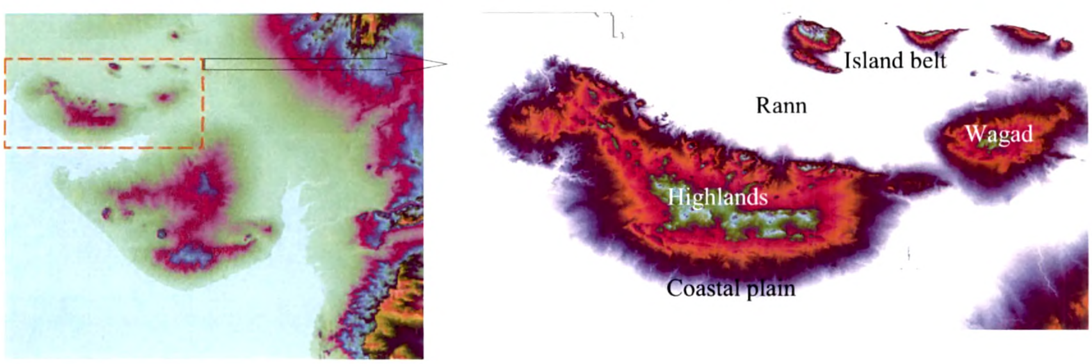


Fig.1.6: DEM of Gujarat showing general physiography of Gujarat and Kachchh region.

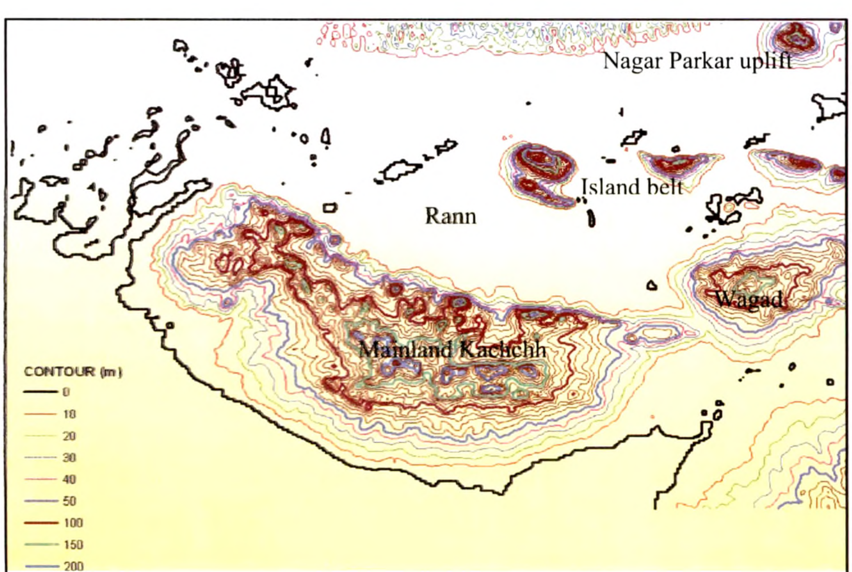
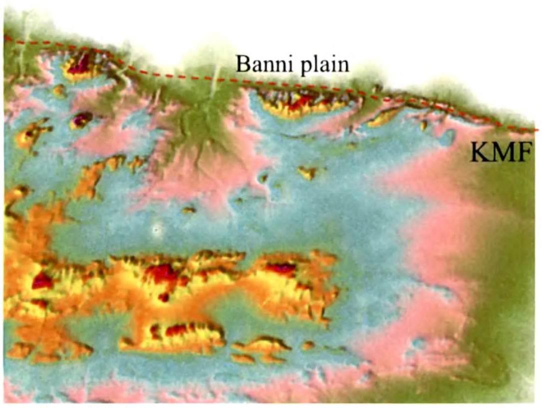


Fig. 1.7: SRTM generated contour map of the area showing topography.



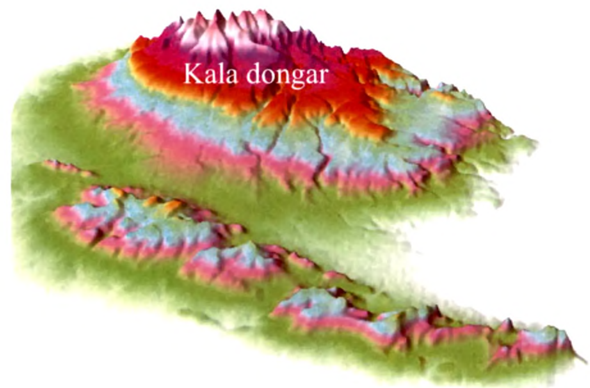


Fig.1.8: DEM of the area around the eastern part of Kachchh Mainland Fault.

Fig.1.9: DEM of Khadir Island (height exaggerated).

Previous work

The Kachchh region has attracted the attention of geo-scientists since long due to its unique exposures of Mesozoic rocks and their rich fossil records. The first comprehensive geological report on Kachchh was prepared by Grant (1840) in which he gave a complete description of the area and collected invertebrate fossils, which were studied by Sowerby (1840). Wynne (1872) is another pioneer worker who gave a detailed account of geology of Kachchh with a quarter-inch map. He classified the Mesozoic sediments of Kachchh into two major units i.e. marine and non-marine. Waagen (1875) studied the ammonites and correlated them with known European Zones to fix their age and gave four fold classification of the Mesozoic rocks into Patcham, Chari, Katrol and Umia in ascending order. Since then this four fold classification has been adopted widely with modifications from time to time. Subsequently Gregory (1893), Spath (1933), Cox (1940) added information about the area especially on invertebrate fossils.

Rajnath (1932) modified the classification by distinguishing Bhuj stage and later on established it separate as Bhuj Series. He subdivided Katrol Group into Lower, Middle and Upper Stages. Agrawal (1957) proposed Habo Series to replace the Chari Series from the four fold classification of Waagen (1875). He also suggested Mebha oolites for Dhosa oolite beds but these suggestions were not accepted by subsequent workers. Mitra & Ghosh (1964) carried out biostratigraphic work in Jhura dome area and gave more importance to brachiopods. He suggested that the brachiopod assemblage zone should be used for correlation and classification instead of ammonite zones.

Biswas (1971, 74) proposed a comprehensive lithostratigraphic classification of Mesozoic and Tertiary rocks of Kachchh in accordance with the code of stratigraphic nomenclature of India. He subdivided the Mesozoic rocks in to Jhurio, Jhumara, Jhuran and Bhuj Formations in ascending order. Biswas (1987) has discussed the sequential development of the Kachchh basin and its regional tectonic framework. The Jhurio, Jhumara and Jhuran Formations in Biswas' classification approximately correspond to Patcham, Chari and Katrol Formations of Waagen respectively. Lower part of Umia series of Waagen is included with Jhuran Formation of Biswas. He included the non-marine sequence with Bhuj Formation and the boundary between Jhuran and Bhuj Formation is based on first appearance of Iron Formation or last appearance of calcareous sandstone. Biswas (1982) has invoked a unique feature in the Kachchh, a meridian high across the basin. Evidence of sediment thickness and the facies present indicates that this high came into existence in late Oxfordian time. Biswas (1987, 2005) has described the regional tectonic framework, structure, tectonics and the evolution of the Kutch basin, with special reference to earthquakes in detail. Biswas and Khatri (2002) have made an attempt to work out a geological model to explain the cause of earthquake rupture nucleation.

Ghevariya et al. (1982, 1984), Ghevariya (1985) and Ghevariya and Srikarni (1987, 1991) have extensively carried out mapping in the area and added valuable information about the stratigraphy and paleontology of the area.

The main structural elements recorded by various workers (Srivastava, 1964; Biswas, 1980, 1982 and Biswas and Deshpande, 1970; Sharma, 1990), played significant role in the post-Mesozoic geological and geomorphological evolution of Kachchh Mainland.

Rajendran et al. (2001) described the coseismic surface features resulted due to 2001, Bhuj earthquake and their significance. According to them, although the main fault rupture did not reach the surface, the epicentral area is characterized by the development of secondary features, including flexures and folds that are related to compressional deformation, in a wide area of the Banni Plain.

Chamyal, et al. (2003) described fluvial systems and landscape of the dry lands of western India. They synthesized data on the fluvial systems of Mainland Gujarat, Saurashtra and Kachchh to evaluate the roles of geological factors in the evolution of these dry lands. They have recorded marine sediments of the interglacial (~125 ka) and post-glacial maximum (6 ka) above sea level, marking transgressed phases of the sea. Maurya, et al. (2002) have investigated the Quaternary Geology of the arid zone of Kachchh in detail and suggested that Late Quaternary sedimentation and geomorphic evolution of Kachchh have followed regional pattern of palaeoenvironmental and tectonic changes. Maurya et al. (2006) investigated two large closely spaced sand blow craters of different morphologies using Ground Penetrating Radar (GPR) with a view to understand the subsurface deformation, identify the vents and source of the vented sediments. The study comprises velocity surveys, GPR surveys along selected transect that is supplemented by data from trenches excavated. Study of seismic aspects of the region has been attempted by number of workers like Johnston, 1989, 1996; Chung and Gao, 1995; Rajendran et al., 1998; Sohoni and Malik, 1998 which are based on palaeoseismological studies.

Sedgeley et al. (1997) reported that a seismic traverse across the basin identified an asymmetric half graben structure with its axis near the Kachchh Mainland Fault. They have labeled this as the Banni Graben. The ENE-WSW trending bathymetric low on the continental shelf is collinear with the proposed Banni Graben and may be related to it, providing a channel for the influx of sediments from the Indus River basin. Suggestions that the Great Rann may have been under water as recently as 712 A.D. come from historical accounts. Sivewright (1907) recounts that in the accounts of Alexander's military raid to India (325 B.C.) Periplus (Alexander's historian) describes the Rann as being navigable. Alexander sailed south on the Nara (an eastern branch of the Indus, now dry) past a group of Islands between 22°45' and 24°00'N latitudes and 68°30' and 71°00'E longitudes and on to the Arabian sea. Different aspects of the Rann have been described by a number of workers (Frere, 1870; Ghosh, 1981; Glennie and Evans, 1976; Roy and Merh, 1977 and Gupta, 1975, Merh, 2005).

The Geological Survey of India (GSI) has been carrying out macroseismic survey (post-earthquake damage surveys for assessment of intensity) of earthquakes. An intensity map of 2001 Bhuj earthquake was prepared by GSI (Pande et al., 2003). Kayal et al. (2002)

conducted an aftershock investigation of 2001, Bhuj earthquake. A micro earthquake network with 12 stations was set in operation in the main shock epicentral area which consequently recorded more than 3000 aftershocks of magnitude 1 and above during the period from 28th January to 15th April 2001. The epicenter map of the 450 events showed a cluster area between latitudes 23.3°-23.6°N and longitudes 70.0°-70.6°E. It reflected the rupture area of the main shock at depth. Waveform modeling of the main shock, however, revealed a rupture dimension of 90 km × 30 km. The estimated focal depth of the Bhuj earthquake was at 25 km. The main shock could not be correlated with the KMF, which is dipping to the north. The main shock was generated by a south dipping hidden fault, and it is inferred that it propagated along a major rupture trending NE-SW direction and a conjugate rupture along the NW-SE direction. Both the ruptures occurred simultaneously. Based on the fault plane solutions, there were many interesting observations. The NW trending inferred fault showed reverse faulting with a right lateral slip at shallower depths of 2 to 8 km. At depths of 15 to 25 km, the solution showed pure reverse faulting, with no strike-slip component (Kayal et al., 2002b).

Based on their studies Thakkar et al. (1999, 2006) and Maurya et al. (2002, 2003) constructed a Quaternary stratigraphy and tectonic evolution of Mainland Kachchh, respectively and emphasized that the Quaternary tectonic uplift took place in two major phases. The Early Quaternary tectonic activity took place along the E-W trending faults while the Late Pleistocene phase took place along the NNE-SSW to NNW-SSE trending transverse faults. The E-W trending faults were more active during Early Quaternary, as evidenced by miliolites overlapping the colluvial deposits along the Katrol Hill Fault (Thakkar et al., 1999). This geometry suggests that the present configuration of the landscape came into being during the Early Quaternary due to differential uplift along E-W faults, *viz.* the Kachchh Mainland Fault and Katrol Hill Fault. The Early Quaternary physiographic setting has been modified by the Late Pleistocene-Holocene tectonic activity along transverse faults (Thakkar et al., 2001).