Chapter - 2

Chapter 2

PREVIOUS STUDIES

A summary of the previous work concerning regional geology, structure, tectonics, seismicity and geomorphology of the study area in particular and Kachchh in general is presented in this chapter with a view to provide a substantial background for the present investigation.

GEOLOGY AND STRUCTURE OF KACHCHH

In the past several workers have investigated various geologic aspects of Kachchh region such as stratigraphy, palaeontology, geomorphology, structure, tectonics and seismicity.

First ever attempt to write a comprehensive account of the geology of Kachchh was made by Grant (1837). The first systematic mapping and detailed geological investigation of the entire region of Kachchh were undertaken by Wynne and Fedden during the years 1868-72. Their pioneering work was published by A. B. Wynne, in the memoir of the Geological Survey of India (Wynne, 1872). They presented most practical classification of the Mesozoic stratigraphy by subdividing Mesozoic rocks into two units. This helped in understanding the stratigraphy as well as structure of the region for the first time. Based on detailed study of the ammonite fauna, Spath (1924) tried to define the limits of the stratigraphic divisions Pachham, Chari, Katrol and Oomia (also spelled as Umia) Group, which were originally suggested by Stokiczka, although he died before he could publish. Later on Waagen (1875) quoted Stoliczka's classification. Rajnath (1934) provided first map of Kachchh region with stratigraphic subdivisions. Stratigraphy and palaeontology of Kachchh were given greater importance because of fossil wealth, outstanding natural sections and reasonable exposures of Mesozoic and Tertiary formations. Biswas and Deshpande (1968) described for the first time and drew important conclusions on the nature of the basement rocks in the region.

Hardas (1968) gave a detailed account of sedimentology and structure of the area to the south of Bhuj. He was first to describe Katrol Hill Fault as south dipping reverse fault. According to him the beds along the Katrol Hill Range have been folded into north verging asymmetric fold with more or less vertical northern limb at the vicinity of Katrol Hill Fault and gently south dipping southern limb away from the fault (Fig. 2.1).

Biswas and Deshpande (1970) gave the best geological presentation of Kachchh geology. They suggested that the Mesozoic rocks of Kachchh rest directly over the Pre-Cambrian basement. Tectonic and geological maps of Kachchh region published by Biswas and Deshpande (1970) provided base for all future work in the region. The tectonic map shows all the major tectonic elements of the region. The geological map presents the rock stratigraphy for the Mesozoic rocks and time stratigraphy for the Tertiary rocks of the region.

For his comprehensive work on stratigraphy, structure and tectonics of Kachchh region Biswas (1980, 1982, and 1987) attracts highest recognition. Biswas (1982 and 1987) gave an outline of the structural and tectonic evolution of Kachchh basin. He has described the presence of monoclinal flexures and domes seen along the E-W trending hill ranges in Kachchh region. According to him the marginal folding along the hill ranges is on the account of vertical up-thrusting of monoclinal blocks.

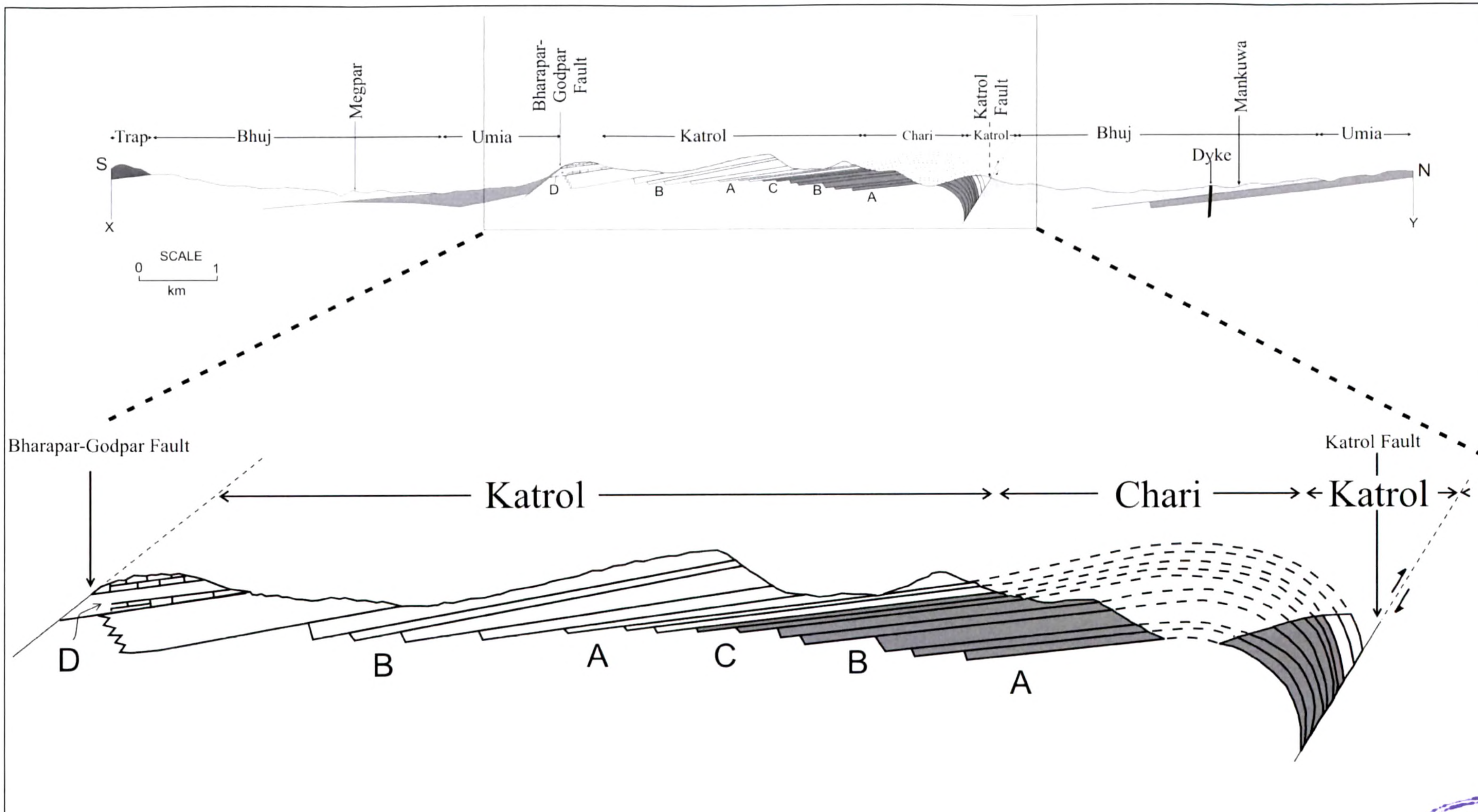

Fig. 2.1: Geologic cross section across Katrol Hill Fault, redrawn after Hardas, 1968

A detailed account of structure and tectonic setting of the region has been depicted by Biswas and Deshpande (1970 and 1983) and Biswas (1987 and 2005). According to Biswas and Khattri (2002) and Biswas (2005) the Kutch Rift evolved within the Mid-Proterozoic-Aravalli-Delhi fold belt by reactivation of pre-existing faults along NE–SW trend of Delhi fold belt that swings to E–W in Kachchh (Kutch) region. Biswas (2005) argued that several intra-basinal sub-parallel strike faults are responsible for the tilted block uplifts, forming a series of half grabens. Structurally, the basin contains footwall uplifts and half-grabens along intra-basinal strike faults. According to him the uplifts are the outcropping areas and the grabens/ half-grabens which form extensive plains covered by Quaternary sediments. He also maintained that the plains are 'residual depression' or structural lows formed around the uplifts which are structural highs form. According to him E–W faults, related uplifts and drape folds design the structure of the region and the marginal hill ranges of the highlands with escarpments facing the plains of the sub-basins are marginal flexures or monoclines along the master faults of the uplifts. The uplifts are interpreted by him as typical geometry of tilted basement blocks draped over by thin sediment cover.

Positive Bouguer anomalies along the lineaments are interpreted as basement highs by Biswas, 2005. Contributing to his previous theory for origin of Kutch (Kachchh) rift basin Biswas (2005) suggested that the basin evolved through three tectonic phases: (1) Rift phase, (2) Late rift divergent wrench phase, and (3) post rift convergent wrench phase. According to him these three phases correspond respectively to break up, drifting and collision of Indian plate. He argued that during wrench tectonics, the KMF became the principal right lateral strike-slip fault and to the east it side steps sinistrally and continues as SWF.

MORPHOTECTONICS

Preliminary work on morphotectonics was carried out by Biswas (1974) when he studied the geomorphic attributes of Kachchh Mainland. He receives credit of correlating different geomorphic landforms and geology. He suggested that several periodic unidirectional movements and a very late uplift are responsible for the present day youthful topography.

An account of geomorphology of Kachchh coastline was given by Sharma (1990). Through his work he presented some salient geomorphic features of Kachchh coast. An attempt was made by Kar (1993) to delineate neotectonic influences on Kachchh coastline and Banni tract. He divided Kachchh coast into five morphological segments that are from west to east (i) the deltaic coast, (ii) the irregular drowned prograded coast, (iii) the straightened coast, (iv) the spits and cuspate foreland complex and (v) the mud flat coast. He compared occurrence of these costal segments with known structural framework and concluded that tectonics is major cause for the evolution of these coastal segments.

With careful observations and quantification of architecture of conical shaped conspicuous alluvial fans at the base of Northern Hill Range Malik et al. (2001a) significantly contributed towards morphotectonic studies in Kachchh region. They observed that these fans are incised by very same rivers that were responsible for their deposition. Deposits of abundant angular to sub-angular boulder fragment were attributed to fault generated debris.

Based on morphotectonic studies Sohoni (2000) came on the conclusion that there is strong influence of active tectonic activity on the rivers draining the Central Kachchh Mainland. He obtained various morphometric parameters viz. Pseudo Hypsometric Integral, Sinuosity Fractal Dimension, Gradient Index and Gradient of different streams originating from Katrol Hill range. His observations of paired terraces along these streams led him to conclude that Katrol Hill range is subjected to periodic uplifts during Holocene times.

Maurya et al. 2007 attempted to delineate the late Quaternary morphotectonic evolution of the coastal zone of Kachchh on the basis of detailed field mapping of the various coastal and fluvial landforms and lithostratigraphic studies of the associated sediments. As aforementioned by Kar (1993) Maurya et al. 2007 also divided entire coastline of Kachchh into five morphologically distinct segments from west to east. They argued that the coastal alluvial plain was formed by deposition of fluvial sediments over the peneplained Tertiary rocks during upper late Pleistocene in two separate tectonically created basins. They proposed that deeply incised fluvial valleys were formed in response to tectonic uplift of the coast. The various morphotectonic divisions of the coast are attributed by them to the role played by the inherent structural fabric, the subsurface Median high and general uplift of the coast due to tectonic activity along the E-W trending faults during the early Holocene and the last 2 ka.

Patidar et al. 2006 undertook GPR survey across the Katrol Hill Fault (KHF), to understand near surface nature of the fault. From GPR data they interpreted that the KHF is a south dipping high angle reverse fault which become vertical at depth.

PALEOSEISMOLOGY AND ACTVIE FAULT STUDIES

A number of earthquakes have struck in the region of Kachchh in recent and historic past e.g. 1819 Allah Bund earthquake, 1956 Anjar earthquake and 2001 Bhuj earthquake. The observational accounts of Captain James MacMurdo (1820, 1823, 1824), a British resident at Anjar and an army officer Lt. Colonel Colin Milnes posted at Bhuj, are reliable eyewitness accounts of 1819 Allah Bund earthquake. Burnes (1833) travelled up to Allah

Bund from Lakhpat in boat; his observations provide very useful insight on the morphology of channel of Puran River in the area around Allah Bund and that of Sindree Lake. During his visit, he observed that the bund is composed of soft clay and shells and is elevated about ten feet from the surface of the water. The banks of the channel are perpendicular on either side. Lyell (1855) discusses the deformation in the earthquake including new materials elicited from Burnes and from the notebooks of early travellers. Baker (1846) measured a profile of the uplifted Bund using survey instruments. Levelling survey carried out by Baker in 1844 across the Allah Bund provides precise information on a section northward from the shores of Lake Sindri across the Allah Bund.

Burnes (1833), Wynne (1872) and Oldham (1883) adjudged subsidence of the southern side thereby causing complete submergence of Sindri fort, a customs check post of then Kachchh state situated about 8 km south of Allah Bund. Oldham (1926) provided a comprehensive description of available literature on Allah Bund earthquake and carried out elaborate scrutiny of it. He collated and evaluated the available data, providing for the first time isoseismic maps and estimates of epicentral uplift and subsidence due to 1819 Allah Bund earthquake. In recent times a few workers such as Bilham (1999) and Rajendran and Rajendran (2001) have suggested possible mechanisms for 1819 Allah Bund earthquake. Bilham (1999) suggested more than 11 m of coseismic reverse slip for 1819 Allah Bund Earthquake on a north-easterly dipping fault, terminating in the shallow subsurface. He assumed that slip was oriented NE, normal to the strike of the Allah Bund. He estimated geometric moment magnitude M=7.7±0.2 for the event. Rajendran & Rajendran (2001) explored the area between 1999 and 2001, 180 years after the earthquake, to measure the height of the Bund and to examine other aspects of the event. They measured several profiles across the Allah Bund and declared that maximum elevation across the Allah Bund is now 5.3 m. They argued that peak height of the 1819 uplift was only 4.3 m and Baker's profile may indicate the cumulative height of the uneroded previous scarp. They concluded that the Allah Bund was formed by sequential uplift in at least three earthquakes in the past two millennia. This conclusion has focussed concern that the NE Rann of Kachchh is a setting for frequently repeated earthquakes.

Malik et al. (1999) catalogued the historical (non-instrumental) and modern (instrumental) seismic data obtained from various sources. From the available record of earthquakes that occurred in Kachchh from 1668 to 1997 they suggested that maximum earthquakes (3 to 5 M) are confined along the ABF, KMF and KHF. By satellite photo interpretation, for the first time, several traces of active faults were identified along the northern margins of Katrol Hill Range and Northern Hill Range, by Malik et al. (2001b). They observed that the active faults have displaced along them the Late Quaternary alluvial fan deposits and colluvial debris, resulting into formation of the north facing fault scarplets.

Malik et al. (2008) reported first active fault exposure from Kachchh region along the Kachchh Mainland Fault (KMF) other than the 1819 Allah Bund earthquake. They recognized active fault scarps striking E-W near Lodai village along KMF. They suggested that occurrence of discontinuous linear mound ranging in height from 3-5 m aligned along the strike about 100 m north of the main scarp are suggestive of younger tectonic movement and progressive shift of tectonic activity towards north along new imbricate fault. Their preliminary observations revealed occurrence of at least two large magnitude earthquakes in late Quaternary time.

Based on satellite photo interpretation and field survey Morino et al. (2008a) identified several new active fault traces along Katrol Hill Fault (KHF). They also identified a new fault that extends into the Bhuj Plain and named it as Bhuj Fault (BF). Trenches were excavated to identify the paleoseismic events, pattern of faulting and the nature of deformation along these faults. Trench survey indicated at least three large magnitude earthquakes along KHF during Late Holocene or recent historic past.

SEISMOLOGY

Many authors have attempted to interpret ongoing tectonic processes and structural setup of Kachchh region with the help of seismology (Chung and Gao, 1995; Kayal et al. 2002; Mandal et al. 2006). During instrumental era Kachchh region has experienced two devastating earthquakes (i) magnitude 6.1 (Ms) (Chung and Gao, 1995) Anjar earthquake of July 21, 1956; and (ii) magnitude 7.7 (Mandal et al. 2006) Bhuj earthquake of January 26, 2001; both the events caused considerable damage and casualties. Other then these two earthquakes number of minor earthquakes and aftershocks of 2001 Bhuj earthquake have given good insight into the causative faults in particular and structure of the region in general.

Tandon (1959) attempted to determine the epicentre and origin time for 1956 Anjar Earthquake by the method of least squares and placed the epicentre at 23° 20′ N, and 70° 00′ E. He also proposed that earthquake occurred at a depth of 13 to 18. Although during 1956 Anjar earthquake, World Wide Standardized Seismograph Network (WWSSN) was not established Chung and Gao, (1995) attempted to investigate source mechanism of the 1956 Anjar earthquake using teleseismic long-period P and SH-waveforms. The determined the focal depth of 15 ±3 km and obtained a pure thrust mechanism for the event with strikes $Ø1 = 235° \pm 15°$ and $Ø2 = 62° \pm 15°$, dip $\delta1 = 47° \pm 8°$ and $\delta1 = 43° \pm 8°$, and rake $\lambda1 = 85° \pm 12°$ and $\lambda2 = 85° \pm 12°$ for the two nodal planes, both striking in NE-SW direction. They compared source parameters of Anjar event with those of other events in peninsular India.

Mandal et al. 2006 tried to answer mechanism of stress concentration in the aftershock zone of 2001 Bhuj earthquake by focused investigation of subsurface velocity structures using aftershock data that delineated a hidden E-W trending fault (NWF) about 25 km north of KMF, as the causative fault for the 2001 Bhuj earthquake.

To comprehend the seismo-tectonic process of the aftershock zone of the 26 January 2001 Bhuj earthquake sequence Mandal et al. 2006 relocated 999 aftershocks (Mw 2.0-5.3) using HYPODD relocation technique and delineated a hidden E-W trending fault (North Wagad Fault) about 25 km north of KMF, as the causative fault for the 2001 Bhuj earthquake. They observed that aftershock zone confines to a 60 km long and 40 km wide region lying between the KMF to the south and NWF to the north, extending from 10 to 45 km depth. They also carried out tomography of the region using travel time of 600 aftershocks. Their tomography results suggest presence of a regional high velocity body (characterized by high Vp (7-8.5 km/s), high Vs (4-4.8 km/s) and small σ (0.24-0.55)) with a head extending 60 km in N-S and 40 km in E-W at 10-40 km depths. This high velocity anomaly is inferred to be a mafic pluton/rift pillow, which might have intruded during the rifting time (~135 Ma). They also detected a low velocity zone (low Vp (6.5-7 km/s), low Vs (3.6–4 km/s) and high σ (0.26-0.265)) within the mafic body at the hypocentral depth of main shock (~18-25 km), which is inferred to be a fluid-filled (trapped aqueous fluid resulted from metamorphism) fractured rock mass.

The stress inversion using the selected earthquake focal mechanisms in the aftershock zone of the 2001 Bhuj earthquake shows that the axis of maximum principal stress is oriented N181°E with a shallow dip (=14°) (Mandal et al. 2006).

GROUND DEFORMATION STUDIES

Bhuj Earthquake of 26th January 2001 not only provided ample data to seismologist to study its seismo-tectonics, but also it opened up vast treasure of coseismic surface features, ground deformation, soft sediment deformation and liquefaction features for geologists. A number of authors attempted to interpret occurrence of these features. Karanth et al. 2001 considered 2001 Bhuj earthquake as one of the modern analogue for studying ground deformation caused on account of large magnitude earthquake in the stratigraphic record. They observed mainly four different kinds of ground deformation features in Kachchh: (a) large scale ground fissuring, (b) lateral spreads/faulting, (c) rock falls and slumping and (d) liquefaction and fluidization. They noted that intense ground deformation is restricted to the domain of Kachchh Mainland Fault and most of intense liquefaction and ground rupture sites fall along the extent of KMF. This observation encouraged them to believe that a segment of KMF forming a blind thrust is been activated during this event. Nakata et al. (2001) observed gentle north-facing warping surface extending E-W in the epicentral area of 2001 Bhuj Earthquake. They found that the deformation was generated in water saturated surface soil horizon resulting in numerous E-W striking extensional cracks or normal faults forming longitudinal pressure ridges. Rajendran et al (2001), observed that epicentral region of 2001 Bhuj Earthquake is characterized by the development of secondary features such as flexures and folds related to compressional deformation. Based on the spatial distribution these structures and their inferred mechanism, they proposed that the earthquake originated on an imbricate blind thrust, located north of Kachchh Mainland Fault. From the preliminary assessment based on ancient monuments and temples in the region and comparison of 2001 Bhuj event with 1819 Allah Bund event they reasoned that the source of 2001 Bhuj Earthquake may not have experienced similar size events at least since 9th century A.D. From the damage distribution and seismogenic effects, Mahajn e al. (2004) inferred that the main shock was initiated along an E-W trending fault, north-northeast of Bhachau. They anticipated that the pear shaped isoseismal pattern might be caused by different seismic moment-rate release along propagating rupture. Rajendran et al (2008), highlighted the potential of a secondary rupture and proxies like lateral spreads and sandblows in unravelling the past activity related to the 2001 Earthquake source.