CHAPTER 2

GEOLOGY AND STRUCTURE

Geology

The Narmada basin comprises rocks ranging in age from Proterozoic to Recent. The striking feature of the geology of lower Narmada basin is the total absence of Palaeozoic and a major part of the Mesozoic rocks. The oldest strata that rest directly over the Precambrians belong to an age as late as Cretaceous (Merh, 1995). Surface exposures of Mesozoic rocks, Deccan basalts and Tertiary sediments occur extensively in the lower Narmada basin (Fig 2.1).

The Cretaceous rocks comprising the Bagh and Lameta Formations also referred to as infra-trappeans unconformably overlie the Precambrian basement (Merh, 1995). These are

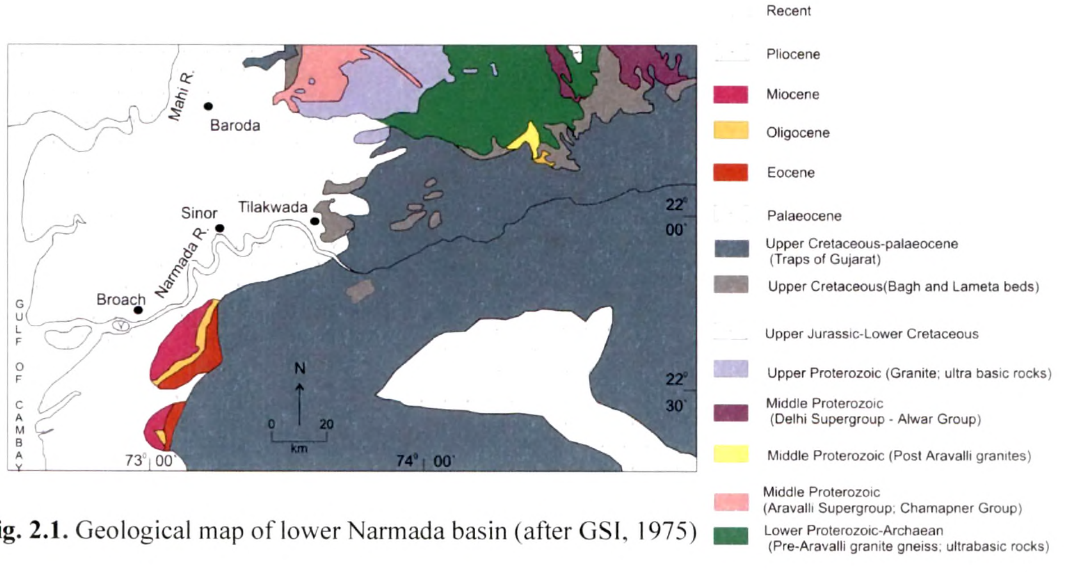

Fig. 2.1. Geological map of lower Narmada basin (after GSI, 1975)

overlain by the Deccan traps at many places (Merh, 1995). The Bagh Formation occurs as detached outcrops along the Narmada River (Merh, 1995). The exposures occur in abundance in Baroda and Bharuch districts forming conspicuous inliers within the basalts or form outliers over the Proterozoic basement (Merh, 1995). The Bagh Formation in the study area is exposed as five inliers within the Deccan Traps north of Narmada while to the south of Narmada River another five inliers occur near Rajpipla area (Merh, 1995). Most of the outcrops show linear WSW-ENE trend and appear to be fault controlled (Merh, 1995). The Lameta Formation mostly occurs below and along the fringes of the Deccan Trap and is stratigraphically younger than the Bagh Formation (Merh, 1995). The constituent rocks are mainly limestones and sandstones of fresh water origin (Merh, 1995). The Cretaceous rocks exposed in the study area are comparable in age with the Himmatnagar sandstone, Songir sandstone, Nimar sandstone, Dhrangadhra Formation and Bhuj Formation of Kachchh (Merh, 1995).

The Deccan Trap is by far the most extensive geological formation in lower Narmada basin (Fig.2.2). It is bracketed within a short interval spanning the late Cretaceous to early Eocene with a major peak in eruptive activity around 60-65 my ago (Venkatesan et al. 1986). During this period, the Indian plate was migrating northward at a rapid rate (Biswas, 1987). Various circumstantial evidence place the eruptive sources in the western part of the Deccan province between Bombay and Khambhat (Cambay) areas (Merh, 1995). The main constituent rock is tholeiite and alkalic varieties (Merh, 1995). The trappean rocks occur between the Unch River, a tributary of the Heran River that further extend eastward into Madhya Pradesh. Towards the west, beyond Garudeshwar and Naswadi, the traps occur below the alluvium (Merh, 1995). The basalts and their variants here indicate explosive activity accompanied by emplacement of lava along rift related NNW-SSE and WSW-ENE faults (Merh, 1995). The dykes show two trends ENE-WSW and NNW-SSE and comprise several varieties of alkaline rocks (Merh, 1995).

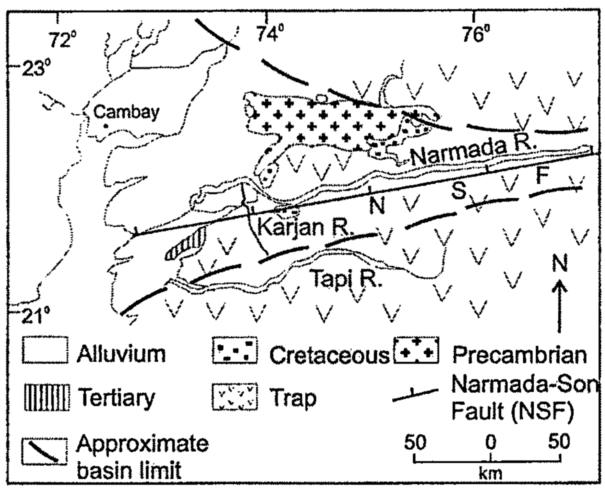

Fig 2.2. Geological map of lower Narmada basin (after Biswas. 1987)

To the south of the Narmada River, the trappean rocks occur around Rajpipla and highlands of Dangs district. The area is hilly and is characterised by E-W trending rows of hills that rise upto 200-300 amsl. The basaltic rocks show an enormous thickness rising to about 600 m above mean sea level (Pattanayak and Shrivastava, 1999) further east, the main bulk of which consists of horizontal lava flows of 5-15 m thickness comprising both basaltic and alkaline derivatives (Merh, 1995). Hard massive basalts, porphyritic basalts, amygdaloidal basalts are encountered, and quite often tuffaceous or agglomeratic layers are seen intervening the flows (Merh, 1995). Moreover, extensive jointing of these trappean rocks has not only facilitated weathering and erosion, but also controlled the drainage pattern. In addition, the basalt flows are traversed by numerous ENE-WSW trending dolerite dykes which vary in width from a few meters to hundreds of meters or more and some can be traced for many kilometers (Krishnamachary, 1972). The basaltic flows in the study area show tilting of 5-20° due south whereas they are found to be horizontal in the adjacent Deccan and Malwa regions (Blanford, 1869). Towards the north, the trappean highlands terminate at the north facing and ENE-WSW trending mountain front scarps that mark the surface trace of the Narmada-Son Fault which down throws to the north.

The Tertiary rocks are buried below the thick alluvium of Gujarat alluvial plains to the north of NSF which correspond to the Broach block of the Cambay graben, while they are exposed to the south of Narmada River which forms the Narmada block (Merh, 1995). A large part of the Tertiary sediments lie within the Cambay basin. The outcropping Tertiary rocks south of NSF occur between the Narmada and the Tapi rivers forming two patches separated by the Kim River alluvium (Merh, 1995). The Tertiary rocks exposed between the Narmada and Kim rivers are delimited by the ENE-WSW trending NSF in the north and the N-S trending Rajpardi Fault in the east (Agrawal, 1986). The exposed sequence comprises Dinod Formation (Late Eocene), Kand Formation and Jhagadia Formation of Miocene to Pliocene age (Agarwal, 1986). The rocks have been folded into several narrow anticlinal structures separated by synclinal lows which have geomorphological expressions as well (Agarwal, 1986). The Quaternary sediments occur on the top and are represented by a variety of sediments pointing to diverse processes and environments. In Mainland Gujarat the Quaternary sediments occupy the structural depressions related to Narmada and Cambay graben and constitute thick layered sequences of sediments of flvio-marine, fluvial and aeolian origins and are designated as 'Gujarat Alluvium' (Merh, 1995).

Structure and Tectonics

The western continental margin of the Indian plate (Fig.2.3) has evolved as a result of rifting along major Precambrian trends (Biswas, 1982). The Kachchh, Cambay and Narmada basins are the three major marginal rift basins bounded by intersecting sets of faults whose trends follow the three important Precambrian tectonic trends viz. the Aravalli, Dharwad and Satpura trends (Fig. 2.3). The ENE-WSW trending Narmada-Son Fault which parallels the Satpura orogenic belt, is a major tectonic boundary (West, 1962; Mathur et al. 1968; Choubey, 1971) dividing the Indian shield into a northern peninsular block and a northern foreland block. These basins opened up one after another from north to south as the subcontinent drifted northward at an increasing pace and rotated counter-clockwise during the Mesozoic (Biswas, 1982). The basins developed seriatim, starting with the Kachchh basin in the Early Jurassic, Cambay basin in Early Cretaceous and Narmada basin in Late Cretaceous (Biswas, 1982).

The two major conjugate rift systems, the Cambay and Narmada rifts cross each other in the Gulf of Cambay region and together with the west coast fault define an area which has been identified by many as a triple junction (Burke and Dewey, 1973; Bose, 1980). The Narmada, Tapti and the west coast tectonic belts are characterised by positive gravity anomalies, high thermal gradients, high heat flow and seismic activity (Fig. 2.4) (Kailasam et al. 1972).

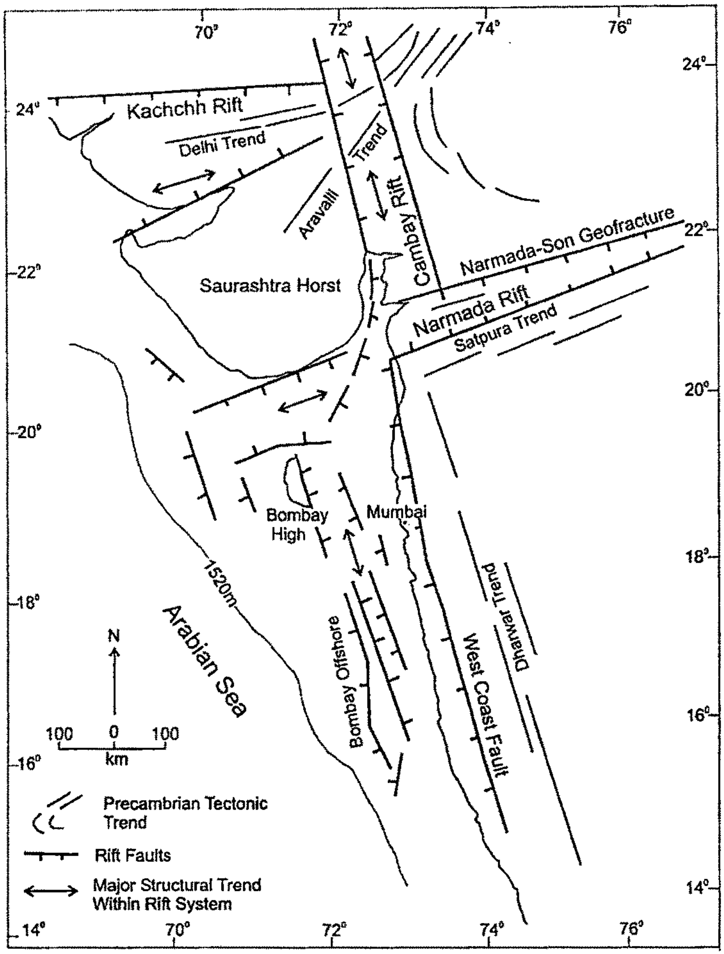

Fig. 2.3. Map showing tectonic trends (after Biswas, 1987)

The deep seismic sounding study has indicated that the region from Surat to Bombay is of Moho upwarp (Kaila, 1986; 1988). Deep seismic sounding data also indicates the depth of the mantle as 20-25 km near Surat north of Bombay (Fig. 2.5) (Kaila et al. 1986). The thinning of lithosphere and consequent rise of asthenosphere (Royden et al. 1980) seems to be the cause of the heat flow in this region. The present high geothermal gradient indicates that the marginal rifting is still active and thermal equilibrium by cooling of the lithosphere has not yet been attained (Biswas, 1982). The manifestation of thermal activity in the form of hot springs is taken by Murthy (1981) to indicate that magma beneath the west coast chamber has not cooled completely. Chadha (1992) established the relationship of hot springs to geological contacts, tectonic units and earthquakes. These thermal springs occur either near the contact of two geological units or along prominent tectonic units.

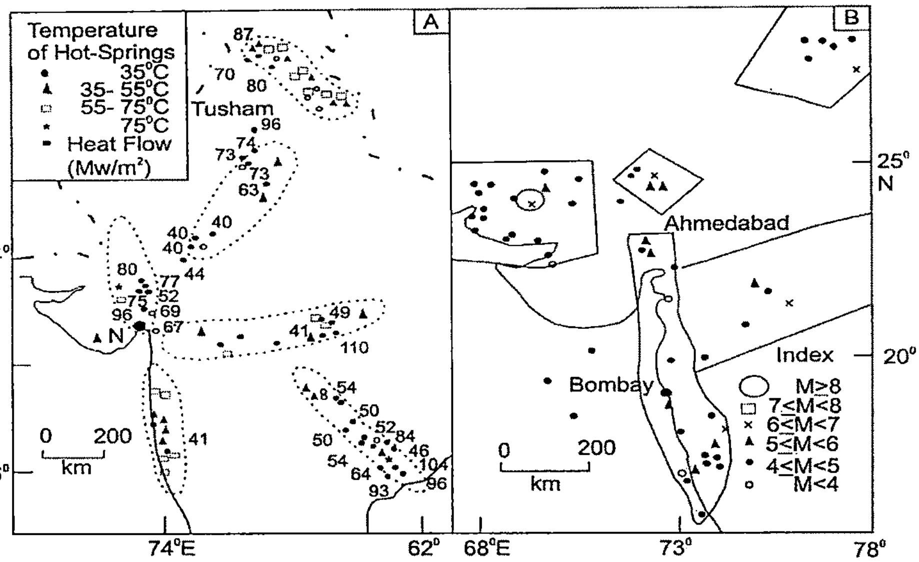

Fig. 2.4. A. Heat flow and hot spring (after Gupta, 1991) B. Seismic events in Western India (after Khattri et al. 1984)

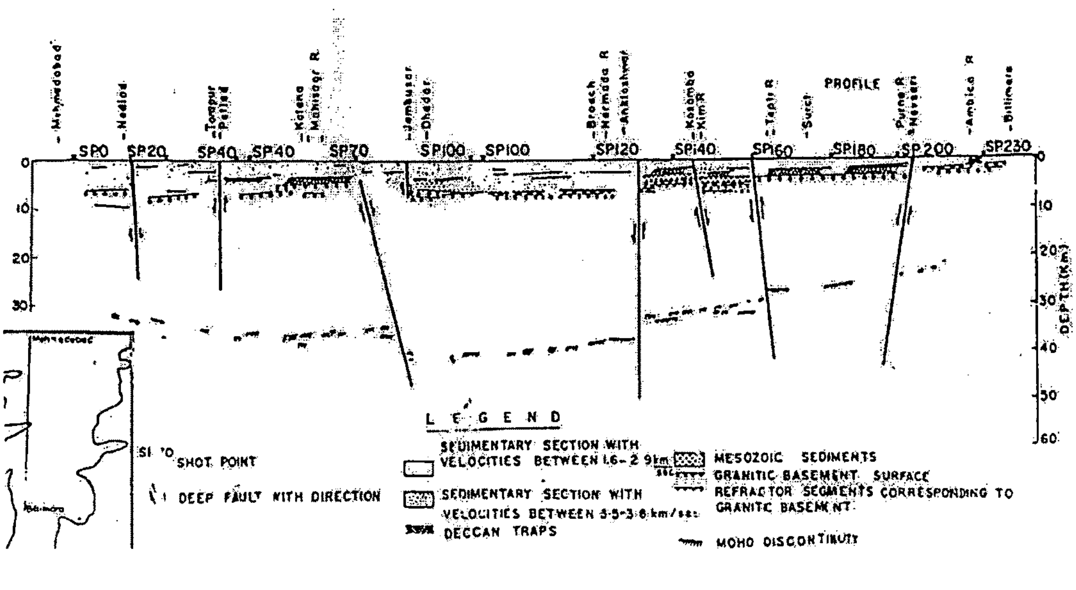

Fig 2.5. DSS profile from Memdabad to Billimora showing basement configuration (after Kaila et al. 1981)

Narmada-Son Fault

The Narmada–Son Fault (NSF) divides the Indian plate into two halves and has a long tectonic history dating back to the Archaean times (Ravi Shankar, 1991). The NSF trends in ENE-WSW direction and is laterally traceable for more than 1000 km. It demarcates the Peninsular India into two geologically distinct provinces- the Vindhyan-Bundelkhand province to the north and the Deccan province to the south. Ravi Shankar (1991) regards the Narmada –Son Fault as a part of the composite tectonically controlled zone in the middle of the Indian plate and termed it as the SONATA zone (abbreviated form of Son-Narmada-Tapti Lineament zone). The Narmada and Tapti Rivers all throughout their course follow these tectonic trends. West (1962) was the first to discuss about the NSF and named it as Narmada Son Lineament. He stated it was a line of weakness since early times, with the area to the north and south moving up and down relatively to each other along this line. Other synonyms used in literature to describe this zone include – Narmada-Son Lineament (Choubey, 1971), Central Indian Shear - CIS (Jain et al. 1995) and Central Indian Tectonic Zone - CITZ (Radhakrishna and Ramakrishnan, 1988; Acharyya and Roy, 2000).

Geophysical studies in the central part of SONATA zone reveal this to be a zone of intense deep-seated faulting (Reddy et al. 1995). The zone witnessed large-scale tectonothermal events associated with large granitic intrusions around 2.5-2.2 Ga and 1.5-0.9 Ga (Acharyya and Roy, 2000). It was again reactivated during the Deccan volcanic eruption during Late Cretaceous-Palaeocene (Agarwal et al. 1995). Profuse occurrence of E-W trending dykes suggests that the zone formed the main centre of eruptive activity (Bhattacharji et al. 1996). The entire zone is presently characterised by high gravity anomalies, high temperature gradient and heat flow and anomalous geothermal regime (Ravi Shankar, 1991) suggesting that the zone is thermo-mechanically and seismically vulnerable in the framework of contemporary tectonism (Bhattacharji et al. 1996). On the basis of crustal structure, three major phases of tectonic activity during the Archean-Proterozoic, Jurassic-Cretaceous and Late Cretaceous have been identified in the Narmada region (Tiwari et al. 2001).

The westward extension of this zone into the lower Narmada basin exhibits a less complex structural setting (Fig 2.6). Data on the NSF in this part is mainly the result of extensive geophysical surveys for commercial exploitation of petroleum reserves in the subsurface (Agarwal, 1986; Biswas, 1987; Kaila et al. 1981; Roy, 1990). In the lower Narmada basin, it is expressed as a single deep-seated fault (NSF) confirmed by the Deep Seismic Sounding studies (Kaila et al. 1981). Seismic reflection studies have firmly established that the NSF is a normal fault in the subsurface and becomes markedly reverse near the surface (Fig 2.6B)(Roy, 1990). Reactivation of the fault in Late Cretaceous led to the formation of a depositional basin in which marine Bagh beds were deposited (Biswas, 1987). The NSF remained tectonically active since then with continuous subsidence of the northern block, designated as the Broach block, which accommodated 6-7 km thick Cenozoic sediments (Biswas, 1987).

To the south of the Narmada–Son Fault (NSF), the Tertiary rocks occur on the surface (Fig 2.6) while to the north they lie in the subsurface and are overlain by Quaternary sediments. This suggests continued vertical movements along the NSF throughout the Tertiary and

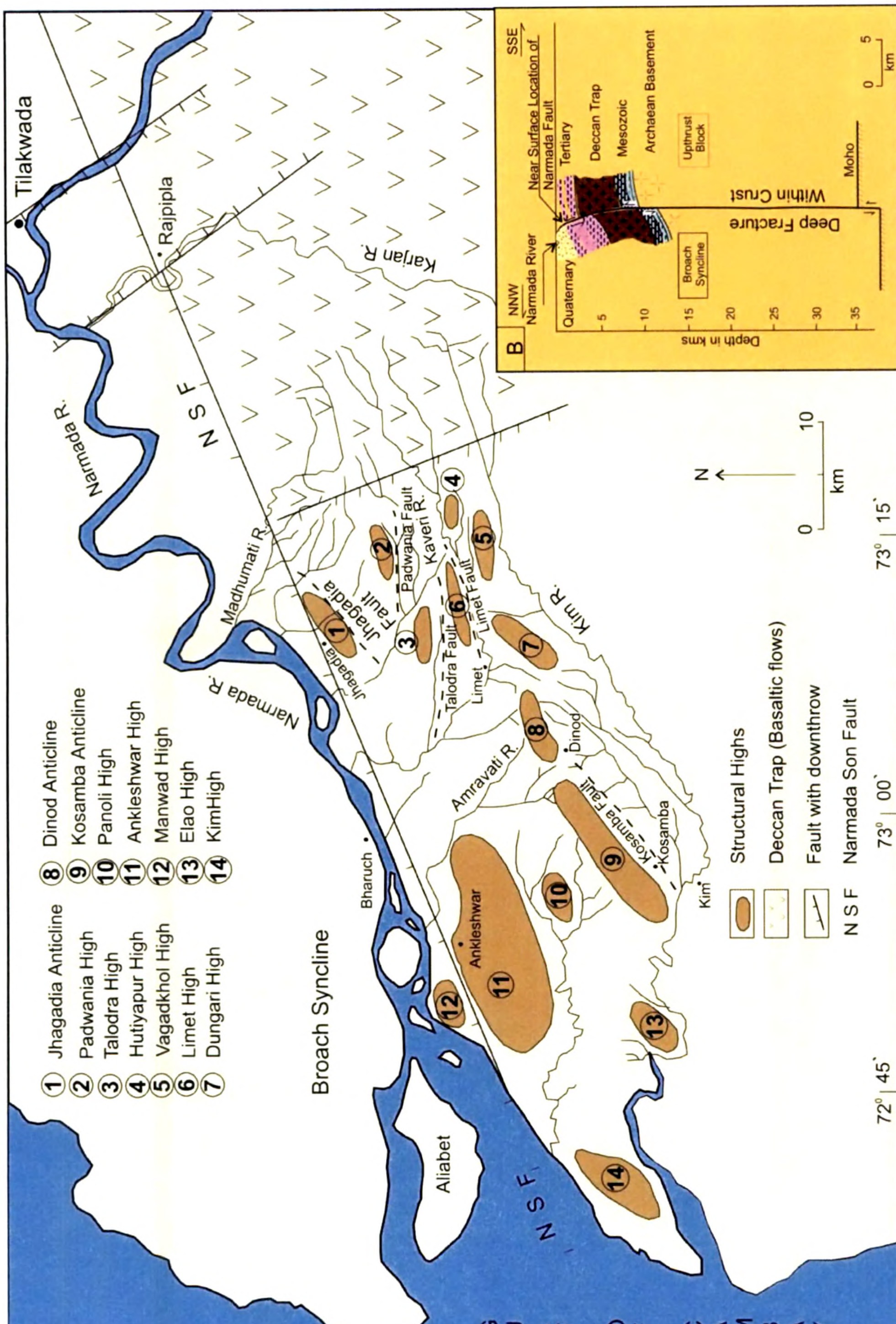

Fig. 2.6. A) Tectonic map of the lower Narmada basin (after Chamyal et al. 2002) Note the structural highs and reverse faults to the south of Narmada –Son Fault (structural data from Agarwal, 1986) B) Simplified cross-section across the NSF based on seismic reflection data showing the nature of the fault in the subsurface (after Roy, 1990)

Quaternary times. The total displacement along the NSF exceeds one kilometre within the

Cenozoic section (Roy, 1990). However, the movements along this fault have not been unidirectional throughout. The general tendency of the basin to subside have been punctuated by phases of structural and tectonic inversion (Roy, 1990). The N-S directed compressive stresses during the Early Quaternary, folded the Tertiary sediments into a broad syncline, the Broach syncline, in the rapidly subsiding northern block (Roy, 1990). The Broach syncline extends from the NSF to the Mahi River in the north. The E-W trending axis of this syncline lies to the north of the Narmada River. Corresponding ENE-WSW trending anticlinal structures are found in the Tertiary rocks exposed in the southern upthrown block (Fig. 2.6). These structures show a southwesterly plunge and are generally bounded by ENE-WSW trending reverse faults close to their SE limbs (Agarwal, 1986). Towards the east, these structures terminate against the N-S trending Rajpardi fault beyond which lie the trappean uplands (Fig. 2.6).

The contrasting tectonic architecture of the Tertiary rocks to the north and south of the Narmada River, points towards the strong control exercised by the Narmada-Son Fault (Agarwal, 1986). The N-S directed compressive stresses during Quaternary, accumulating on the NSF due to the northward movement of the Indian plate formed a broad syncline, the Broach syncline, in the rapidly subsiding northern block while the corresponding anticlinal structures (Fig 2.6) were formed in the Neogene rocks exposed in the southern block (Roy, 1990). Historical and instrumental records indicate that the compressive stresses still continue to accumulate along the NSF due to continued northward movement of the Indian plate. This is evidenced by the fault solution studies of the earthquakes at Broach (23rd March, 1970) and Jabalpur (22nd May, 1997) which suggest a thrusting movement (Gupta et al. 1972; 1997; Chandra, 1977; Acharyya et al. 1998).

However, the underlying cause of the seismicity in the NSF zone is not yet understood (Quittmeyer and Jacob, 1976). Though the NSF facilitated the deposition of a huge thickness of Quaternary sediments to the north (Fig. 2.7), the exposed sediments comprise a very small part

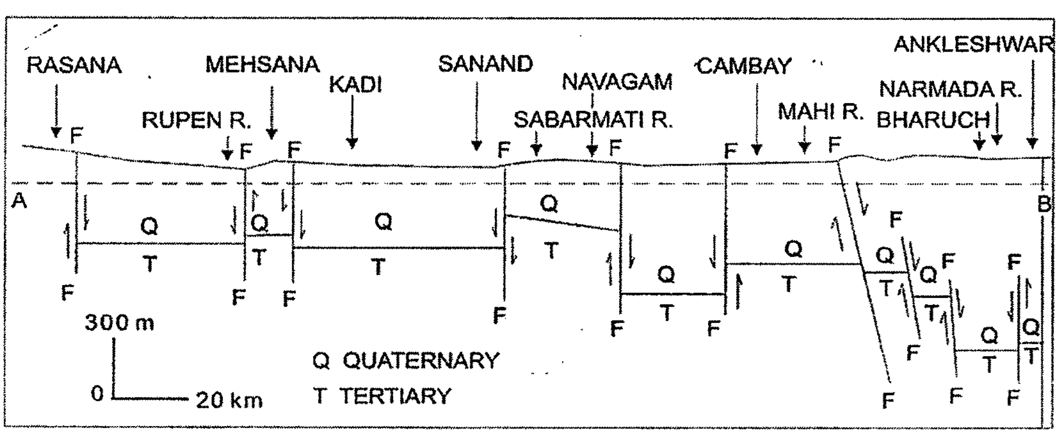

Fig. 2.7. N-S cross section across Gujarat alluvial plains based on thickness data obtained from ONGC showing uneven Quaternary basement (after Maurya et al. 1995)

(~50 m thick) of the total thickness of Quaternary sediments (~800 m) in the Lower Narmada valley. These, nevertheless, reveal a complete picture of the Late Quaternary geomorphic evolution of the area, which is important for understanding the seismic activity in the seismic zone.