CHAPTER 1

INTRODUCTION

Study of fluvial systems and their response to the external or 'allogenic' controls provide important clues to the geomorphic evolution of an area. It also helps in the research concerning global changes, sequence stratigraphy and the dynamic interactions between tectonic activity and surface processes (Blum and Tornquist, 2000). Recent works have demonstrated that geomorphic evolution in reactivated sedimentary basins is primarily due to complex interaction between sedimentation processes and tectonics (Jones et al. 1999). Sedimentary basins in tectonically active regions show drastic changes in sedimentation rates, styles and spatial organization of alluvial facies (Mather, 1993). Though tectonics is the major dominant factor responsible for the development of present day landscape especially in actively deforming areas (Seeber and Gornitz, 1983; Sloss, 1991; Burbank, 1992) climate and sea level changes also play an important and complicating role which tend to influence the deposition of sediments (Blum et al. 1994). The fluvial assemblage i.e. lithofacies composition, vertical stratigraphic record and architecture, reflects many processes from the wandering of individual channels across a floodplain to long term effects of uplift and subsidence (Maill, 1996). Fluvial deposits are a sensitive indicator of tectonic processes and climate at the time of deposition (Miall, 1996).

Fluvial responses to climate and sea level change can be disaggregated into stratigraphic, morphological and sedimentological components. But rarely, however, is a comprehensive approach involving sedimentologic, stratigraphic and geomorphic studies utilised to investigate the complexity of processes and geologic events responsible for landscape evolution. This approach has the twin advantage for precisely estimating the timing and amount of displacement along faults, which are of considerable importance, especially in areas where seismically active faults occur. Neotectonic studies, which are based solely on geomorphological data, are adequate in documenting the nature and type of movement along the faults (Schubert, 1982; Dumont, 1996) but are inadequate in estimating the timing and amount of fault movement.

The peninsular India has been undergoing high compressive stresses due to the sea floor spreading in the Indian Ocean and locking up of the Indian plate with the Eurasian plate in the north (Subramanya, 1996). A significant part of these compressive stresses are being accumulated along the Narmada – Son Fault (NSF) in the central part of the Indian plate, which is responsible for the moderate to high intensity seismic activity being experienced in the region (Gupta et al. 1972; 1997; Acharyya et al. 1998). Attempts on proper evaluation of seismic risk have been hampered by lack of data on neotectonic activity along the NSF. Landscape evolution in Quaternary fluvial systems is normally controlled by Quaternary sedimentation processes, tectonism and environmental changes. These factors have been crucial in the lower Narmada basin, which has a long history of large-scale tectonic movements and sea level changes.

The Narmada River flows along the ENE-WSW trending Narmada-Son Fault (NSF) an active well-known seismotectonic feature (Biswas, 1987) transecting through the central part of the northward drifting Indian plate. A major part of the course of the Narmada River falls within the rocky area and the true alluvial reach of the Narmada is encountered in its lower part within the state of Gujarat. The lower Narmada basin, which has acted as a major depocenter in Gujarat since the Tertiary, is ideally suited for such a study. The Tertiary evolutionary history of the lower Narmada basin has been well understood, however, the data on the Quaternary sedimentation, tectonics and environmental changes have remained mostly uninvestigated. It is with this background that the present study has been taken up.

Aim and Scope

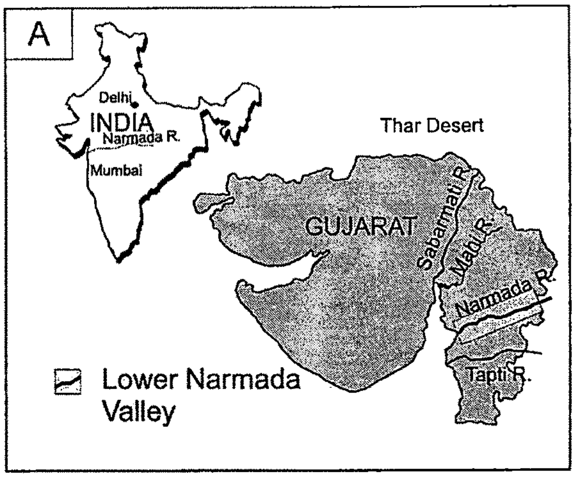
The present study aims at delineating the Late Quaternary tectonic movements along the ENE-WSW trending Narmada-Son Fault (NSF), a seismically active but rather poorly understood tectonic element in the Indian plate and palaeoenvironmental changes. In the present study emphasis has therefore, been laid on applications of detailed geomorphic, stratigraphic, sedimentological and climatological approaches to understand the Late Quaternary geology and resulting landscape in the lower Narmada basin, which astrides the seismically active Narmada-Son Fault (NSF). A variety of data including detailed geomorphic mapping, vertical and lateral mapping of Quaternary sediments exposed in incised valley sections, neotectonic and deformational features, composite landform assemblage, and their morphostratigraphic relationships and palaeoenvironments have been used to decipher the hidden secrets in the evolution of the lower Narmada basin. The study provides insight into the neotectonic movements along this fault and has revealed that the NSF has been tectonically active throughout late

Quaternary and has played a significant role in the geomorphic evolution of lower Narmada basin.

Preface to Study Area

Location

The Narmada River, the third biggest river of India and the largest river of peninsular India originates from Maikala ranges at Amarkanthak in Madhya Pradesh (Fig. 1.1). The study area is however, confined to the lower reaches of Narmada basin in Gujarat, which is enclosed by N latitude 21° 30' to 22°30' and E longitude 72°30' to 73°45'



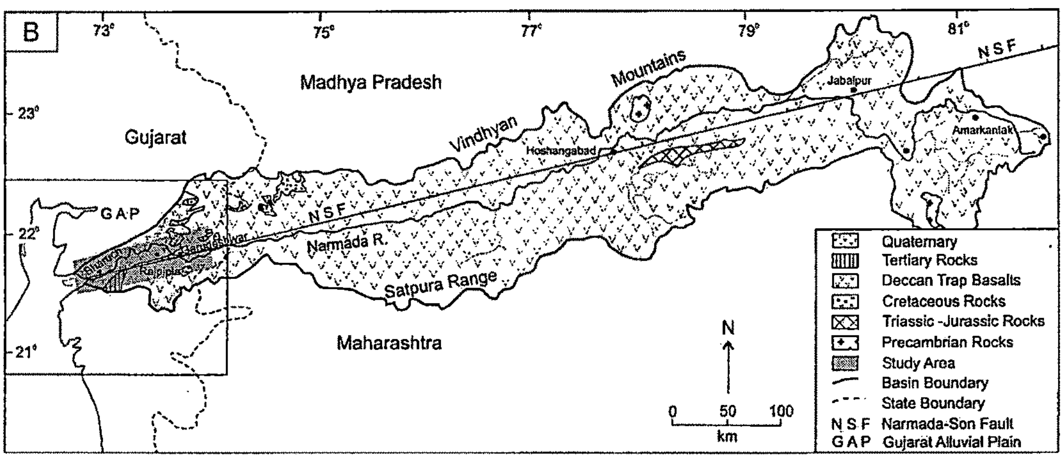


Fig. 1.1. A. Location map. B. Generalized geological map of the Narmada basin. Shaded area is lower Narmada basin

(Fig 1.1). The area of study includes parts of Narmada, Bharuch, Panchmahal and Vadodara districts. The area is well connected by roads including National and State highways and railways. A good network of metalled and unmetalled roads connects small towns and villages. Cart tracks motorable in dry season and numerous foot tracks criss-cross the area.

Climate

The State of Gujarat lies on the tropic of Cancer falling in the sub-tropical climatic zone (Fig. 1.2). It has varied climate divisible into five climatic regions. The study area falls into a semi-arid to sub-humid climate zone with hot summers and general dryness throughout the year barring the monsoon season. March to middle of June is the period of hot summer, followed by SW monsoon, which continues up to the end of September. October and November constitute post monsoon periods. Cold season starts from December and ends in February. After February there is rapid increase in temperature. May is the hottest month with mean daily maximum temperature at 45 ^{0} C and mean daily minimum at 26 ^{0} C. Dust laden winds are common during the summer making weather uncomfortable. January is the coldest part of the year with mean daily maximum at 30 ^{0} C and mean daily minimum at 12 ^{0}C.

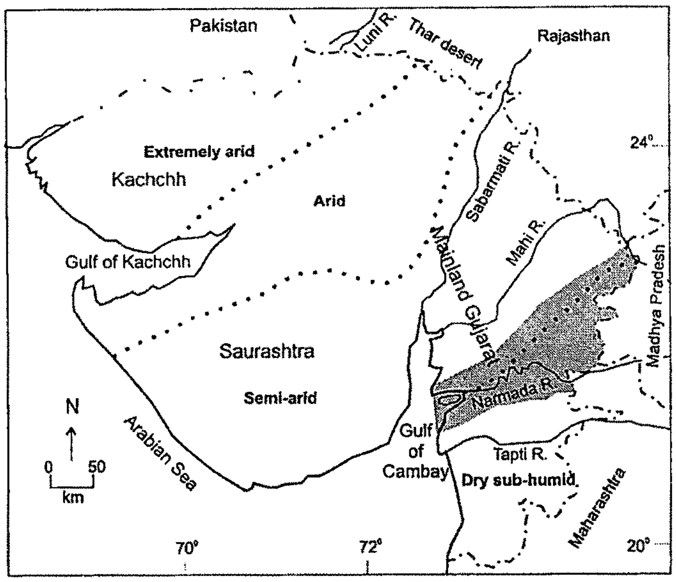


Fig.1.2. Map showing the major physiographic division, rivers and climatic zones of Gujarat. Shaded area is the lower Narmada basin (after Singh et al. 1991)

Rainfall

The Gujarat State comes under the influence of SW Indian monsoon from June to September. The State receives precipitation over a period of four months starting in June. The regional rainfall isohytes decrease towards northwest (Fig 1.3). Mean annual rainfall is the highest in southeastern Gujarat. The average annual rainfall in the study area varies from 750 mm in the alluvial area to 1150 mm in the uplands.

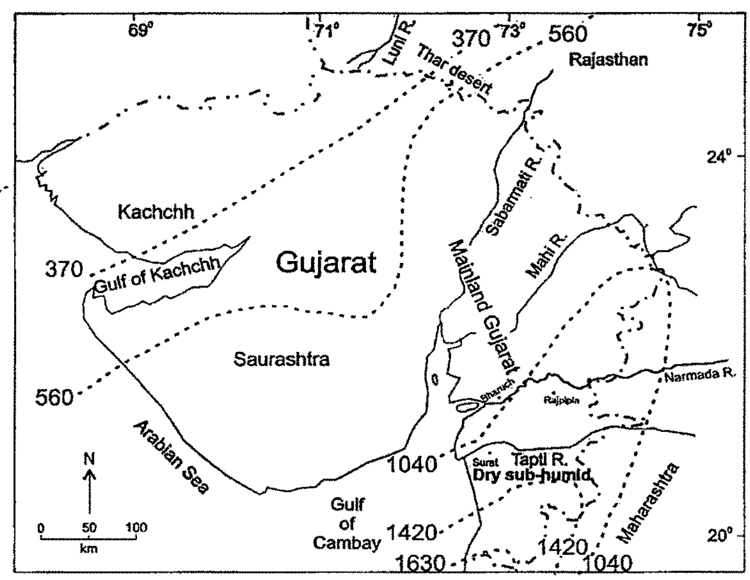


Fig. 1.3. Isohyte map of Gujarat (after Singh et al. 1991)

About 75 percent of the annual normal rainfall in the area is received during the monsoon months from June to September, July being the rainiest month. The variation in annual rainfall from year to year is large. The average discharge in the Narmada River recorded at Sardar Sarovar from 1991 to 2004 is 998.78 cumec (Fig 1.4).

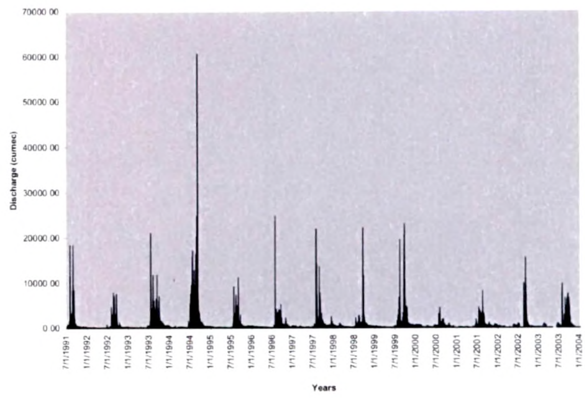


Fig.1.4. Discharge in Narmada River at Garudeshwar gauged from 1991to 2004 (Data for Garudeshwar Gauging site collected from Sardar Sarovar Nigam Ltd., Vadodara)

Physiography and Drainage

Physiographically, the lower Narmada basin is divisible into the following two broad zones- the rocky uplands and the alluvial plain (Fig. 1.5). The rocky upland shows an altitude range of 300 to 1100 m which is actually the extensions of the major mountains of western India - the Sahyadri, Satpura and Aravalli. The course of the Narmada River lies between the Vindhyan range on the right and Satpura hills on the left until it reaches the Gujarat alluvial plains. The hilly terrain between the Narmada and Mahi rivers, are made up of Archaean metamorphics and granitic rocks. The Aravalli hills to the northwest fall within an altitude range of 300 to 600 m. The Rajpipla hills which are the terminal end of the Satpura and Sahyadri ranges are mostly trappean hills placed in the southern part of Lower Narmada basin. The hilltops are flat and the valleys are shallow and wide showing an altitude variation from 150 to 300 m. The western alluvial plain comprises Quaternary continental unconsolidated

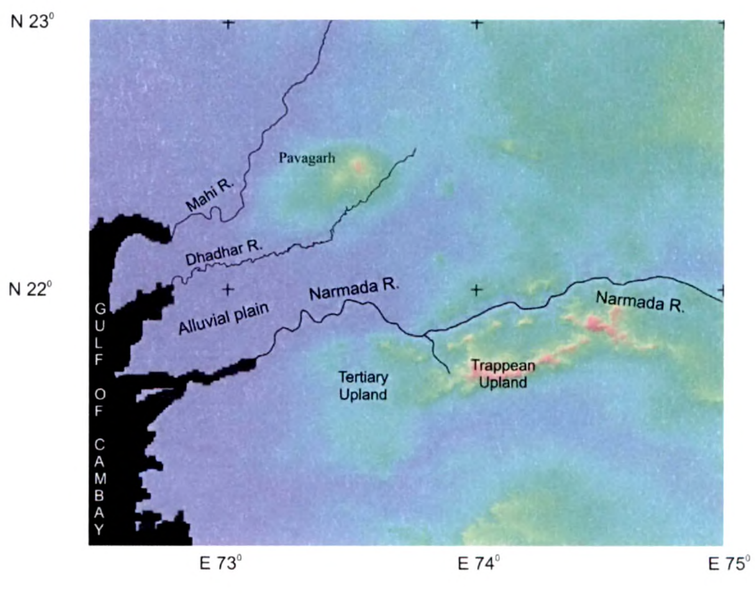


Fig.1. 5. Digital Elevation Model (DEM) of lower Narmada basin

sediments and falls within the altitude range of 25 to 75 m with a gradual southwestward slope. The Narmada River and its various tributaries flow across the alluvial plain.

The Narmada River in Gujarat emerges from the trappean uplands near Garudeshwar and follows a northwest oriented course upto Tilakwada. Downstream of Tilakwada, it flows in a general WSW direction and finally debouches into the Gulf of Cambay. The river in this reach shows large meanders with wavelengths of 5-8 km. The Karjan River, which drains a major part of the trappean uplands in the lower Narmada basin, meets the south bank of Narmada River. Arising from the trappean hills, it flows in north direction and drains the Rajpipla uplands before meeting the Narmada from south at Rundh. The Karjan River has two important tributaries, the Mohan Nadi rising in the south and joining the Karjan at Thava. The Tarav Nadi, which rises near Chich Amli joins the Karjan on its right bank west of the fort of Rajpipla. The other major tributary, the Madhumati River drains the western fringe of the trappean upland. Between the Karjan and Madhumati rivers there flows Amrawati, Kaveri and several other north flowing small streams meeting the Narmada. These streams drain the low high lands consisting of Tertiary rocks and join the Narmada in the estuarine part.

The Orsang, Aswan, Men and Bhuki are the major rivers joining the Narmada from the north. The Orsang River which is another important tributary of Narmada rises near the village of Pava of the Jhabua district in Madhya Pradesh and enters Gujarat near Bhorda in the Chhota Udepur taluka and meets the Narmada River from north at Chandod. The Heran River is a major tributary of the Orsang River. It meets the river Orsang near village Bhilodiya. The Kara River is also an important river of the Lower Narmada valley, which originates in Madhya Pradesh and meets the river Heran River near village Narukot. The Men River, which arises near the village Bhundmaria of Chhota Udepur taluka, meets the Narmada River near Tilakwada.

Review of Previous work

The Narmada River basin is spread along the 1500km long Narmada-Son Fault running in east west direction, which is partially filled with sediments and whose north and south boundaries are marked by Vindhyan mountains and Satpura range. These mountains are mainly of sandstone, conglomerate and shales of Cambrain and Triassic periods. The rest of the Narmada basin comprises of Deccan traps, flood basalts of Cretaceous-Eocene age. The uplands of the Lower Narmada valley is mainly made up of basaltic rocks of Deccan Volcanic Group predominantly consisting of horizontal lava both of basaltic and alkaline derivatives (Merh, 1995). Over the traps there is thick and huge deposition of Tertiary and Quaternary sediments having an approximate thickness of about ~5000 m (Roy 1990). The Narmada – Son Fault and the different types of vertical tectonics associated with it has been studied and described by Auden (1949), West (1962), Choubey (1971), Crawford (1978), Biswas (1987), Roy (1990). It was Ravishanker (1991) who gave the term SONATA (Son-Narmada-Tapti lineament zone) and stated that NSF divides the Indian plate into two halves and has remained active since Archean times. Rao and Talukdar (1980) discussed the regional tectonic set-up of Narmada and Bombay offshore area. Further Biswas and Deshpande (1983) discussed the tectonic framework, stratigraphy and structural features and depositional history of the basin. The structural and geomorphic studies between Kim and Narmada rivers by Agarwal (1986) suggesting various highs that coincide with the anticlinal flexures developed over Tertiary rocks are the projections of neotectonic activity in the area. The subsurface studies carried out by Roy (1990) established the continuation of Narmada - Son Fault into the Cambay basin which acts as a near vertical normal fault at depth but becomes reverse near the surface because of compressive stresses due to continued northward push of the Indian plate.

Although a lot of literature exists on the hard rock geology, hydrology and archaeology of the area, very little information is available on the Quaternary sedimentation, geomorphology and paleoenvironments of the lower Narmada basin. Kale et al. (1994), Rajaguru et al. (1995), Gupta et al. (1999) have studied the channel forms, fluvial processes and hydrological aspects in detail but their studies were mainly restricted to central Narmada valley.

The Quaternary deposits of Gujarat were first studied by Blanford (1869) who reported the alluvial deposits of the Narmada and Tapti Rivers. Foote (1898) described the alluvial successions in his book 'Geology of Baroda State'. Sankalia (1946) reported the palaeolithic industry near Sankheda on the banks of Orsang River, a major tributary of Narmada in its lower reaches. He also reported palaeolithic implements from the Karjan river deposits at Rajpipla.

Zeuner (1950) gave a detailed account of the Quaternary deposits in a regional context. He studied the exposed Quaternary sediments of Sabarmati, Mahi and Orsang Rivers in particular and stressed on the changes in palaeoclimatic conditions in the deposition of the continental Quaternary sediments deposited during this period. He pointed out that the deposition of river deposits at the same height above the present water level in successive periods of aggradation, were separated by periods of erosion. He also stressed on two cycles of increasing aridity in Sabarmati separated by a fossil soil. Wainwright (1964) gave a detailed account of the Pleistocene deposits in the lower Narmada basin and the role of sea level fluctuations during the Pleistocene period which is known to have occurred globally.

Allchin et al. (1978) studied the terrace sequences of Narmada, Mahi and Sabarmati Rivers. The two main terraces identified by them broadly show similar records suggesting a characteristic phase of substantial aggradation followed by incision. According to them, Gujarat's rivers show evidence of a major phase of aggradation, a phase of downcutting, represented by cliffs and gullies cut into terraces and a second and lower phase of aggradation represented by lower terrace. Hegde and Switsur (1973) and Allchin et al. (1978) also dated Narmada alluvium by radiocarbon technique.

Bedi and Vaidyanadhan (1982) investigated the geomorphology of the area around lower Narmada basin. They have discussed about the polygenetic landscape of the area which perhaps originated during Late Quaternary and emphasized on the palaeohydrological and neotectonic activity in the morphogenesis of the landscape.

A good picture of the Quaternary fluvial sequences of Gujarat alluvial plains has been given by Pant and Chamyal (1990), Chamyal and Merh (1992), Merh and Chamyal (1993), Sareen et al. (1993), Sridhar et al. (1994), Chamyal and Merh (1995), Maurya et al. (1995, 1997a, b, 1998, 2000), Merh and Chamyal (1997), Chamyal et al. (1997; 2002, 2003), Tandon et al. (1997), Raj et al. (1998a, b, 1999 a, b), Jain et al. (1998), Juyal et al. 2000, Khadkikar et al. (2000). They have described the exposed Quaternary sediments of the various river sections of Sabarmati, Mahi and Narmada. Chamyal and Merh (1992) described the lithostratigraphy of the exposed Quaternary deposits of Gujarat alluvial plain. Merh and Chamyal (1997) describing the Quaternary geology of the Gujarat alluvial plain provided the lithostratigraphy, depositional environment and sedimentary facies. They have correlated the sediments of Sabarmati, Mahi and Narmada Rivers.

Pant and Chamyal (1990) discussed about the bluish green (marine) clays, based on field investigations and physical characteristics of the basal clay they identified them as marine clays. Merh (1993) suggested that these were deposited during Middle Pleistocene high seas. Chamyal et al. (1994) were the first to discuss about the alluvial gravels deposited by debris and sheet flows in the lower Narmada valley. Later, Chamyal et al. (1997, 2002) documented these as Late Pleistocene alluvial fan deposits. The deposition of the fan sediments took place in a tectonic graben bounded by faults related to Narmada Son Fault (NSF). Downstream of the fan sequence, the alluvial sediment succession is corelatable to the successions exposed in other river valleys of the plain (Maurya et al. 2000).

In the central Narmada and neighbouring basins, a lot of palaeo and modern flood data and related geomorphology has been worked out by Kale et al. (1993, 1994 and 1996) and Rajaguru et al. (1995). They have provided excellent records on Quaternary environments, Holocene flood deposits and variations in monsoon activity. A chronological data was given by Juyal et al. (2000) and Kusumgar et al. (1998) for Mahi river basin and the chronology for Sabarmati River was given by Tandon et al. (1997). In western India, the first post glacial wet phase was recorded around 12-8 ka in lake sediments (Wassan et al. 1984) of Thar desert. They showed a dry episode during 11-10 ka interval. Marine records of past change from the Arabian Sea yield a similar record (Duplessy 1982, Van Campo et al. 1982, Prell 1984, Prell et al. 1990, Sirocko et al. 1991, Overpeck et al. 1996). The moist period in the Holocene the first between

9.3 to 7.8 ka and ending before 6 ka and the second one peaking around 4.2 ka was given by Yan and Petit-Maire (1994). The monsoons were strongest between 9.5 and 5.5 ka (Sirocko et al. 1993). It is important to know how a fluvial system responds to the environmental changes. No data is available on the palaeoenvironmental studies of the lower Narmada basin.