CHAPTER 4
GEOLOGY OF THE AREA

The geological records of western India in general and Gujarat region in particular, constitute mosaic of the Basement Precambrian rocks in the north and north eastern part of the state. These are followed by Deccan basalts along with Cretaceous age sedimentary rocks confined within narrow basins in the mainland (West, 1981) (Figure 4.1). Subsequently, Tertiary sediments have got deposited in the tectonically controlled basins along the western margin of the Trappean terrain, the basement for Tertiary deposits are Trappean rocks. Quaternary sequences overlie the erosional Trappean and Tertiary rock surfaces. It is important to understand the tectonic architecture of the area to get an insight into the geological and other relevant details of the region.

4.1 Regional tectonic framework

Biswas (1982), has described the western margin of Indian sub-continent as Atlantic type; passive continental margin coming into existence owing to the gradual breakup of the eastern Gondwanaland. McKenzie and Slater (1971), Bose (1908, 1972), Powell (1979), Murthy (1987), Biswas (1987, 1988), Beane *et. al.* (1986) and Powar (1987) have opined that, soon after the breakup, the western margin of Indian subcontinent underwent rifting, followed by the drift and anticlockwise rotation of Indian landmass, experiencing large scale late Cretaceo – Eocene volcanism. Combination of early tensional regime owing to the early rifting stage and subsequent compressional environment developed due to drifting and anticlockwise rotation of Indian landmass has resulted into two important rift systems (Sykes, 1978), namely Cambay and Narmada – Tapi rift systems. The rifting event seemed to have occurred during early Cretaceous time and have undergone periodic reactivations (Biswas, 1987).

In the northern region, Aravallis trending NE-SW is another important tectonic element, this trend extends up to the geographical boundaries of southern Rajasthan and northern Gujarat. The Aravalli trend further south resolves into three directions, the NE-SW trend

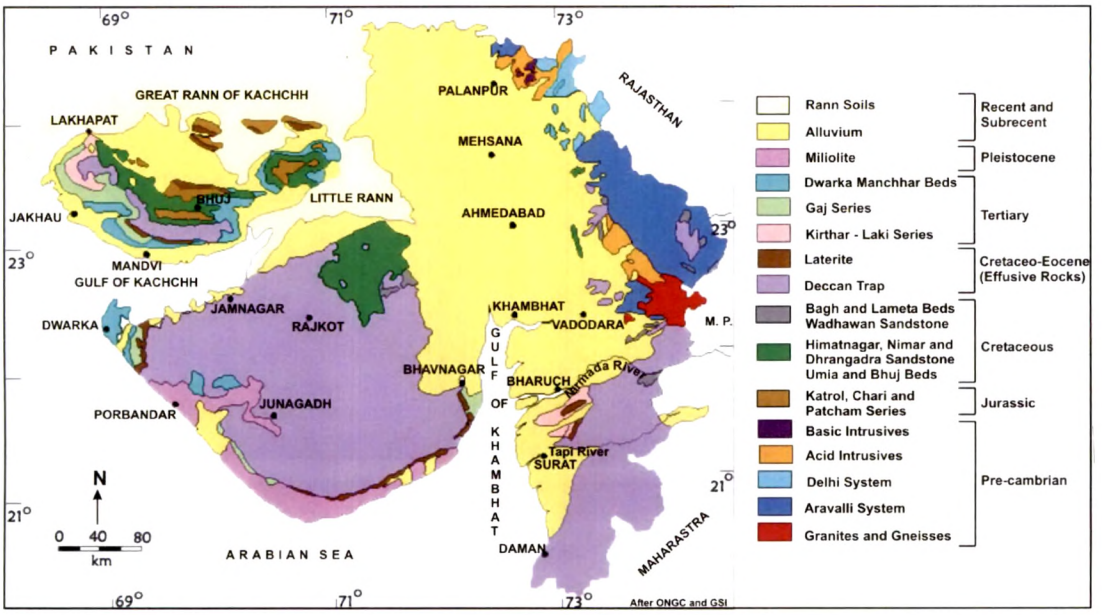
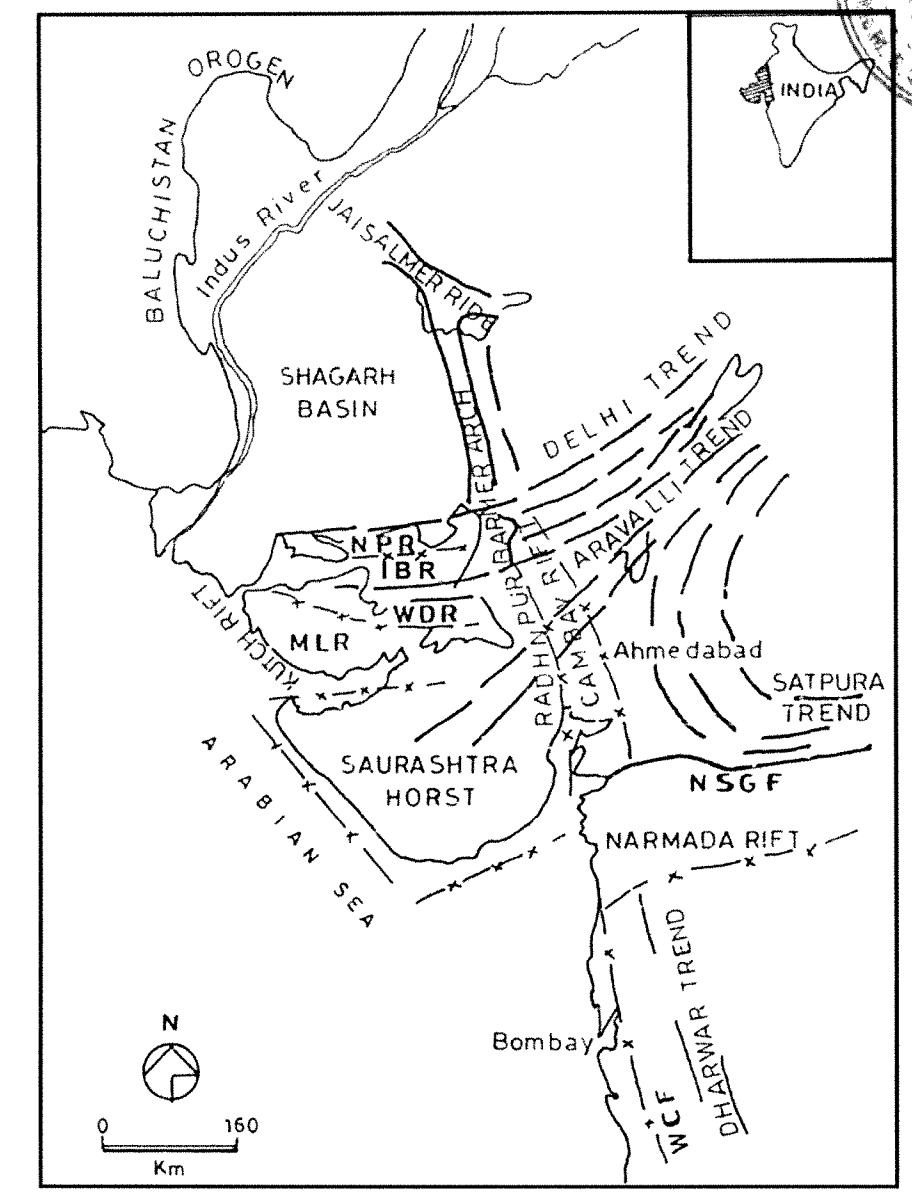


Figure 4.1: Geological map of Gujarat (Merh, 1995)

continuing along the Cambay basin axis and out of the two remaining trends, one trend runs E-W, clockwise along the Kachchh basin and the second one follows E-W anticlockwise direction along the Narmada basin (Biswas, 1987). The Dharwar trend (Krishnan, 1960) has truncated the Narmada rift system whereas the Cambay Graben is aligned to the reactivated Dharwar trend (Figure 4.2).

The Narmada-Son-Tapi rift system is considered contemporaneous to the Pre-Cambrian crustal tectonics (Auden, 1949; West 1962) and has governed the structural fabric of western India (Radhakrishna and Naqui, 1986; Biswas, 1987; Powar, 1993). Out of the two basins mentioned above, details of the Cambay basin are not presented here, as the study pertains to the area falling under Narmada basin in particular and Narmada-Tapi basin in general.



NSGF - Narmada Son Geofracture
NPR - Nagar Parkar Ridge
WCF - West Coast Fault
IBR - Island Belt Ridge
WDR - Wagad Ridge
MLR - Main Land Ridge
—x— Major Faults
——— Tectonic Trends

Figure 4.2: Tectonic map of Western India (After Biswas, 1987)

4.2 Narmada -Tapi basin

Blandford (1869) gave the first account on the geology of the area between the Tapi and Lower Narmada region. This basin is the westernmost part of the Narmada-Son geo-fracture (West, 1962; Choube, 1971; Crawford, 1978). Subsurface tectonic structures, magmatic crustal accretion and upwelled mantle signatures have been revealed in the geophysical evidences (Singh and Messner, 1995; Singh, 1998). Biswas (1987) has described the chronological evolution of Narmada rift basin. According to him, basin initiation took place around Mid-Jurassic as a consequence of counter clockwise rotation of Indian plate; late Mesozoic sediments were covered by the Cretaceo-early Paleocene Deccan volcanism. Soon after this, N-S trending Cambay rift system formed. Post Deccan tectonics has created the Tertiary sedimentation basins, confined by the Cambay and Narmada rift systems.

These basins received sediments from the Trappean country, giving rise to the Tertiary sedimentary sequences. These rocks have suffered mild deformation and partial erosion during their aerial exposure (Figure 4.3) facilitated by the differential basement movements. Quaternary period tectonics has given rise to the linear and oriented basins under the influence of Narmada lineament reactivation; well developed Quaternary alluvium is deposited within these basins. The litho-stratigraphy of the region (Krishnan, 1960; Chandra & Chaudari, 1969; Agarwal, 1984) based on the surface and sub-surface records are presented in Table 4.1.

4.3 Lithology of the study area

The oldest sedimentaries, though quite far from the study area, are famous Bagh beds (Bose, 1884) of Cretaceous age exposed near Damanganga river basin and in the Surpaneshwar forest boundary. Deccan basalts of Cretaceo-Eocene time occupy most of the area around Rajpardi and other important locations under study (Figure 4.4). Tertiary rocks constitute the main rocks in the area under investigation. Quaternaries have deposited over the tectonically controlled Tertiary basin as well as at places directly over the Traps. The litho-stratigraphy for the region is presented in Table 4.1. A brief lithological account is as follows,

Table 4.1 – Lithostratigraphic Succession of the Study area

AGE	FORMATION	LITHOLOGY
Holocene	Alluvium	Residual soils, flood plain deposits (new alluvium), coastal beach, dune sands and estuarine mud flats.
Late Pleistocene		Older Alluvium
----------Unconformity----------(at places directly over Deccan Trap)		
Upper Miocene	Jhagadia	Calcareous, micaceous sandstone with occasional conglomerate
Middle Miocene	Kand	Grey clays, fossiliferous marls and limestone, sandstone, agate conglomerate
Lower Miocene	Babaguru	Ferruginous sandstone, conglomerate which sandstone and clay
	Tarkeshwar	Grey bentonitic clays, thin lateritised bands and lignite
Upper Eocene	Dinod	Foraminiferal, impure, argillaceous limestone, clay, marl
Paleocene	Vagadkhol	Grey clay, tuffaceous sandstone and conglomerate
Cretaceous – Eocene	Deccan Trap	Basalt, trachyte, andesite, dykes of dolerite
----------Unconformity----------		
Cretaceous	Bagh	Sandstone and limestone

(Krishnan, 1960, Chandra & Chaudari 1969 and Agarwal 1984)

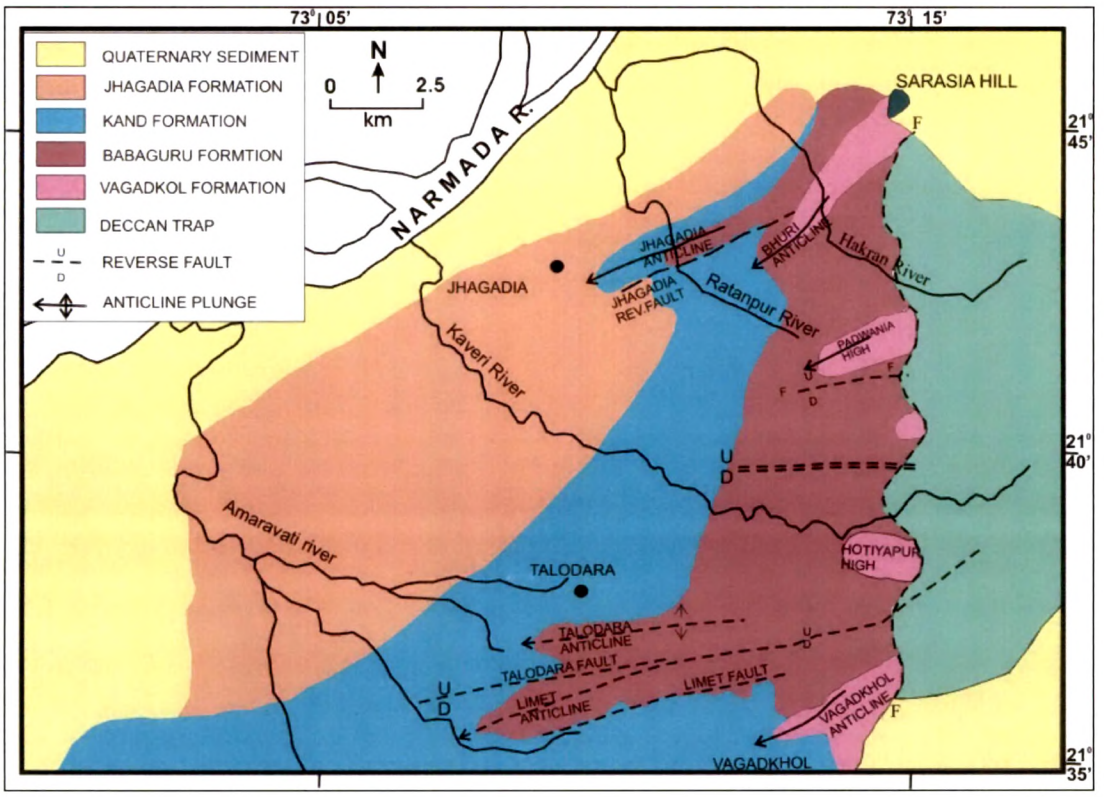


Figure 4.3: Structural and Tectonic map around Study area (modified after Agarwal, 1984)

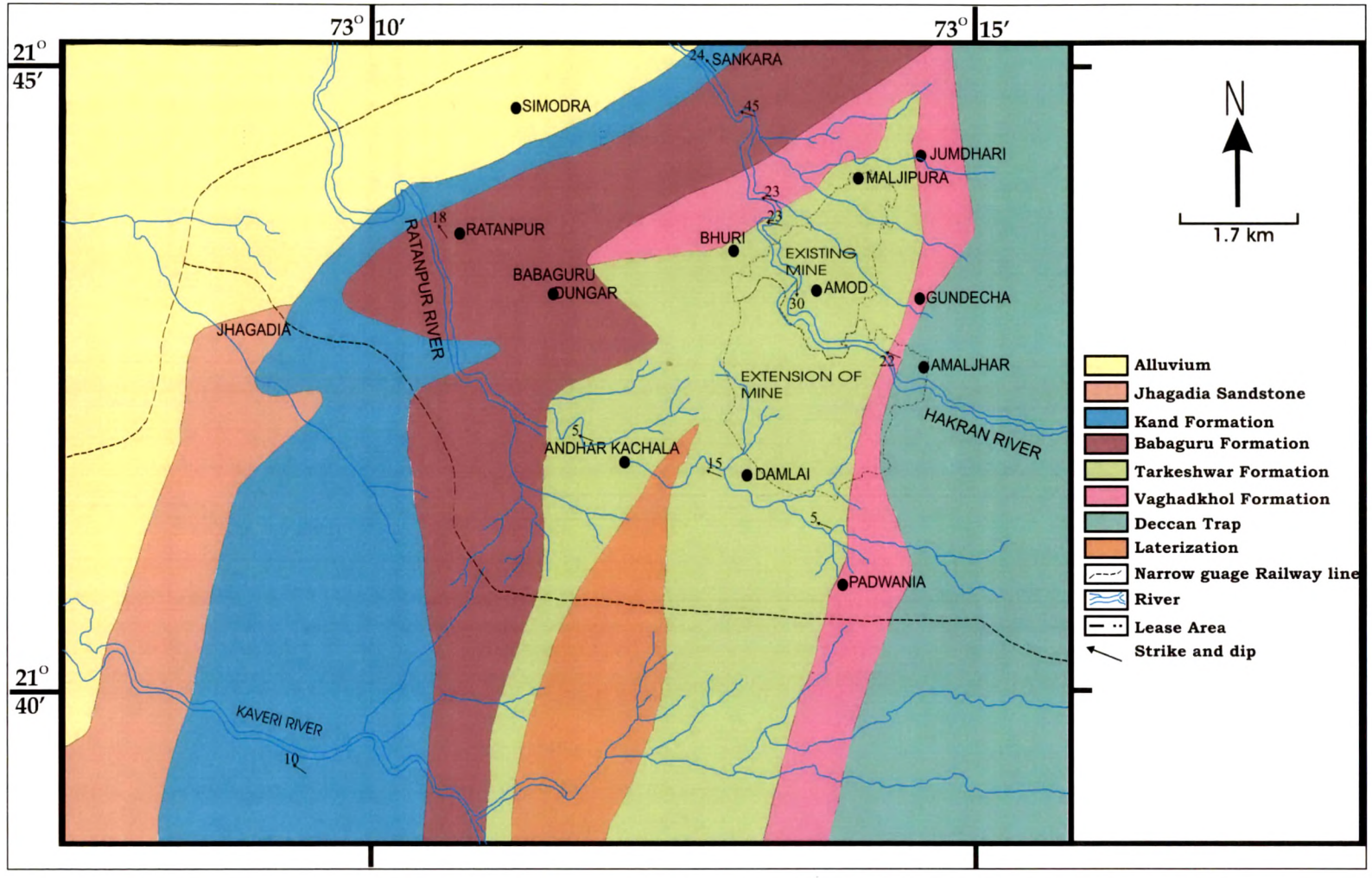


Figure 4.4: Geological map of study area (modified after Bhatt, 2002)

4.3.1Bagh Formation – These sedimentary rocks of Cretacous age occur as inliers within the Deccan flood basalts; the general trend of the inliers is ENE-WSW. The nearest outcrop of these sedimentaries is at Surpaneshwar, the thickness of Bagh beds is around 200m at this location. The sequence constitutes; Gritty sandstones with well developed basal conglomerate band followed by alternating shale-sandstone units which are overlain by shale-limestone lithology. The top unit is predominantly limestone beds with shale bands. These rocks are of no significance in the present study owing to the limited occurrence and distance of the occurrence from Rajpardi project (Agarwal, 1984).

4.3.2 Deccan volcanics – Deccan Traps form two distinct landforms in the region, namely, highlands north of Rajpipla onwards and low lying flows between Rajpipla and Rajpardi, at places sharp contact is seen between Traps and the Tertiaries. Traps have undergone early Tertiary faulting as a result, served as the basement for the Tertiary deposits along the westernmost margin of the Trappean terrain in the Mainland Gujarat. These rocks constitute the flows of variable thickness in the region and are hard and compact in nature. Basalts show variation from porphyritic type to very fine grained variety as well as glassy at places. Tuffs and agglomerates are also seen in the area. Occurrence of andesites, trachytes, rhyolites and other volcanic differentiates have been reported from the region. Another important feature is the occurrence of doleritic dykes in the region mostly trending ENE-WSW and occur as linear hills in the region. The terrain has inherited its landscape dominantly from the Trappean rocks. Thin section reveals dominance of fine and glassy matrix followed by fine to medium phenocrysts. The phenocrysts are generally of plagioclase and pyroxenes. Basalt flows rich in olivine have also been reported from the area.

4.3.3 Laterites – The exposed Trappean rocks have experienced subaerial weathering, as a consequence, the residual laterites have formed. Well developed laterites are noticed at Tarkeshwar, Valia, Mandvi and Gandevi localities (Photo 4.1).

Photo 4.1: Exposure of laterite in Ratanpur river section near Andhar Kachala

4.3.4 Tertiaries – The Tertiary rocks fringe the eastern margin of the Cambay basin. Outcrops of these rocks are best exposed between Narmada and Tapi rivers, comprising of two patches separated by the Kim river alluvium of Quaternary age and occupy area between Jhagadia in the NE to Kosamba in the SE. The Tertiary exposures provide a fairly contrasting topographic expression from NE to SW. The outcrops near Jhagadia stand out as conspicuous hills against the low lying south-western grounds. The latter typically characterizes a terrain made up of gentle hummock and mounds. Tertiaries span in age from Palaeocene to Mio-Pliocene which is overlain by Quaternary sediments with a pronounced unconformity. Following is an account of the different formations of Tertiaries in the area.

4.3.4.1 Vagadkhol Formation – This unfossiliferous formation occurs along the eastern margin adjoining Deccan Traps, consists of conglomerates, sands and variegated clays

(Merh, 1993). The conglomerates consist of subangular pebbles and gravels of basalts, claystone and agate in ferruginous and calcareous matrix (Agarwal, 1984) (Photo 4.2).

Photo 4.2: Contact of calcareous sandstone of Vagadkhol formation and the Quaternary sediments exposed near Gundecha.

At places patches of gritstones and sandstone formed by the weathered basalt sediments and smaller bands of claystone and agate bands occur as discrete bodies. The depositional environment is fluvial, near shore, shallow, under oxidizing conditions and the deposition seems to be with rapid pace. The proposed age for these rocks is from Palaeocene to Lower Eocene based on indirect stratigraphic evidence (Merh, 1995). These sandstones have calcareous cementing matrix and have moderate to high porosity.

4.3.4.2 Dinod Formation – Dinod formation is absent in the Rajpardi area, however to get the complete stratigraphic picture of the region, these rocks were also studied in their type area locations i.e. Dinod, Dungri,etc.The fossliferous limestones of Dinod formation occurs

along anticlinal axes of Nandev, Dinod and Dungri anticlines (Merh, 1993). The limestone is hard, massive and yellow colored, brown coloration observed occasionally is due to the weathering of ferruginous matter present in these rocks. The occurrence of *Discocyclina, Dispansa* and *D.Sella* with *Nummulites tabiani* indicates that the sediments were deposited during the Late Eocene epoch (Agarwal, 1984). The flooding of larger foraminifera with few species indicates the initiation of regressive phase during the late Eocene. A prolonged phase of non deposition after Dinod formation is envisaged based on the lithological records (Agarwal, 1984).

4.3.4.3 Tarkeshwar Formation – The sediments of this formation are thought to have been derived from the reworking of upper Cretaceous Bagh beds exposed in the Narmada Valley (Agarwal, 1984). The red and brown volcanic arenites and agate rudites imply the provenance from the nearby volcanic terrain. This formation is overlain by the Babaguru formation and is about 175 m thick; the age assigned to this formation is Oligocene. The sandstones are highly porous, and have high quartz content. The lignite seams are also occurring within this formation.

4.3.4.4 Babaguru Formation – The Sedimentary sequence of Babaguru formation consists of cherry red sandstones and highly ferruginous conglomerates. The typical outcrop of the Babaguru formation occurs near Babaguru and Dongri hills.
(Photo 4.3)

Photo 4.3: Exposure of Babaguru conglomerate showing agate pebbles in a ferrugeneous matrix in the Ratanpur river section

The lower part of the Babaguru formation consists of cherry red sandstones, generally friable and devoid of agate pebbles occurring along NW flank of the Dungri anticline, whereas, the upper part of the formation consists of cherry red lateritic type of sandy lithology with agate conglomerate.

Good exposure of cherry red sandstones and agate conglomerates are found north of Limet village forming a gentle topographic high, agate conglomerate of Babaguru formation are well exposed in the axial part of the Jhagadia anticline along the Ratanpur river section. The pebbles are embedded in ferruginous matrix and weathering of iron oxides has imparted compactness and hardness to the rock.

The agate pebbles have been derived from the weathering of Deccan Traps from the near by areas. The deposition took place in a fluviatile oxidizing environment (Agarwal, 1984). As no fossils are reported, therefore on the basis of indirect stratigraphic evidence, the age of the Babaguru formation is considered as Lower Miocene (Agarwal, 1984).

4.3.4.5 Kand Formation – The calcareous sandstones, clays, marls, and thin fossiliferous limestone bands constitute the Kand formation (Agarwal, 1984). It overlies the Babaguru formation with an erosional unconformity (Merh, 1993). The limestone with microfossils is easily visible in the outcrops. Kand formation rocks are mainly found around the Kand village. The limestone bands are hard, compact and occur as mounds. The sandstones and clays are light grey in color and have calcareous matrix. A good exposure of ferruginous pebbles and cobbles is seen along the stream section near a road bridge between Kosamba town and Mahuvej village.

The fossils reported from the limestone beds include species of Lamellibranchia, Gastropods, Echinoids, cypripedium, doubtful fish teeth, calcified fossil wood and leaf impressions, assigned Lower Miocene age for the Kand formation.

4.3.4.6 Jhagadia Formation – The sedimentary sequence of the Upper Tertiary constitutes the Jhagadia formation, represented by sandstones, grit-stones and pebble-cobble conglomerates. The conglomerates contain pebbles, marls, sandstone, claystone, agate and occasionally fragments of weathered basalt. There are clay and silt bands in the lower part of Jhagadia formation. The sediments of Jhagadia Formation are devoid of fossils but considering its place in the order of superposition, Middle Miocene to Lower Pliocene age is assigned. The lithology of Jhagadia formation suggests continental fluviatile depositional conditions (Merh, 1993).

4.3.5 Quaternary Deposits – Quaternary sediments cover mostly the alluvial plains and coastal zone deposits with a maximum thickness of ~ 800 m (Maurya *et. al.*, 1995). Quaternary sediments either overlie the Tertiaries or Deccan Traps on eastern fringe with a marked unconformity (Table 4.1).

The older Alluvium, which represents the ancient floodplain deposits of Narmada and Kim rivers form a soil horizon of variable thickness, measures about 100 m in the western areas. Ideal section of these alluvial deposits is seen in the various cliff sections of the river Narmada and Kim which mainly consist of silt and clays. On account of its greyish black color and derivation from the basaltic rocks, these are generally referred to as black cotton soils. The top part of these soils up to the depths of several meters invariably contains thick calcrete bands. The newer Alluvium mainly constitutes sediments of the present day floodplains and is restricted to the broader parts of the channels of river Narmada and Kim, Tapi, Purna, Ambica, Auranga and Damanganga. Generally, the Quaternary sediments form well defined terraces at levels lower than that of the older alluvial plain.
(Photo 4.4)

Photo 4.4: Cliff section showing the Quaternary deposits of clayey silts exposed near Avidha village

The younger alluvium constitutes the silt and clayey bands, but do not contain any significant organic matter and calcretes. The older and newer alluvium is distinguished on the basis of altitudes, organic content and presence or absence of calcretes.

4.4 Depositional history

According to the observations made by Raju (1968) and Agarwal (1984), the sedimentary sequence of the Cambay basin is considered to have been deposited in distinct cycles, resulting in to different litho-suites; these litho-suites are co- relatable to the tectonic evolution of the Cambay basin.

The end of Cretaceous is marked by large scale Deccan volcanism, simultaneous to the reactivation of Narmada and Cambay rift system. Initially the basin, primarily of graben type got filled by thick pile, consisting of trap derived conglomerates, sandstones, silt and mudstones of varied colors deposited over the basaltic basement. These initial tertiary sedimentaries are given the name Vagadkhol formation. The end of Vagadkhol formation is marked by significant tectonic movement causing faulting and folding in the depositional basins. As a consequence the uplifted Vagadkhol formation suffered partial erosion.

The next important phase is the large scale marine transgression of the Early to Middle Eocene times reaching the deeper parts of the basin. By Late Eocene, the basin was completely under marine transgression; giving rise to Dinod marls and limestones having foraminiferal fossils.

Subsequent to Dinod deposition, there was a regressive phase during Oligocene time. During this phase Babaguru sandstones and conglomerates are deposited. Babaguru overlies the Dinod formation with a profound unconformity and represents continental basinal conditions. The basin has further suffered tectonic movements, causing uplifiting of Babaguru and older Tertiaries.

The Miocene time is again a stage of marine transgression, giving rise to fossiliferous limestones, conglomerates, clays and sandstones belonging to Kand formation. The basin had become shallow due to sediment fill of Miocene time; i.e. Kand formation and the last phase is represented by shallow marine to continental sequences of Jhagadia formation, characterized by sandstones, conglomerates and clays of low calcareous matrix. The environment of deposition at the end had become fluviatile.

The Tertiary sedimentation has ceased by the Mio-Pliocene due to the uplift of the sequences. Later climato-tectonic events are responsible for the deposition of Quaternary sediments in the region.

4.5 Geomorphology

For any geo-environmental study, knowledge of geomorphology becomes an essential component of the investigation. The study area is part of tectonically active terrain, i.e., NSGF. The geomorphology of the region is largely tectonically controlled. The observation of Davis (1909), "the geomorphic processes and the prevailing litho-tectonic framework along with the climate, with increasing time, plays a significant role in controlling the successive sculpturing of the landscape configuration of that region", is quite validated for the NSGF region.

South Gujarat terrain, exhibits a complex interplay of various erosional and tectonic processes (Vyas, 1984, Scheideggar et. al., 1982) which has resulted into an assemblage of diverse geomorphological features. Various workers (Agarwal, 1984; Alavi, 1990; Chamyal *et. al.*, 2002; Mulchandani, 2004) have attempted to describe various geomorphic attributes of south Gujarat.

The study area is more or less flat terrain (Figure 4.5) having a few highlands. Eastern part of the study area shows rising topography formed by the Deccan Trap. There is a vast pediment zone between the high lands of Deccan hills and Tertiary flat terrain beginning from the Rajpardi and nearby areas. While topographic highs present in the regions are a result of eroded structural highs such as Dinod and Dungri anticline. Other such topographic highs include Ankleshwar and Kosamba highs. The geomorphology and drainage of the area has structural control over it. Majority of the geomorphic features in the study area exhibit circular to elliptical geometry, generally trending NE – SW direction (Agarwal, 1984).

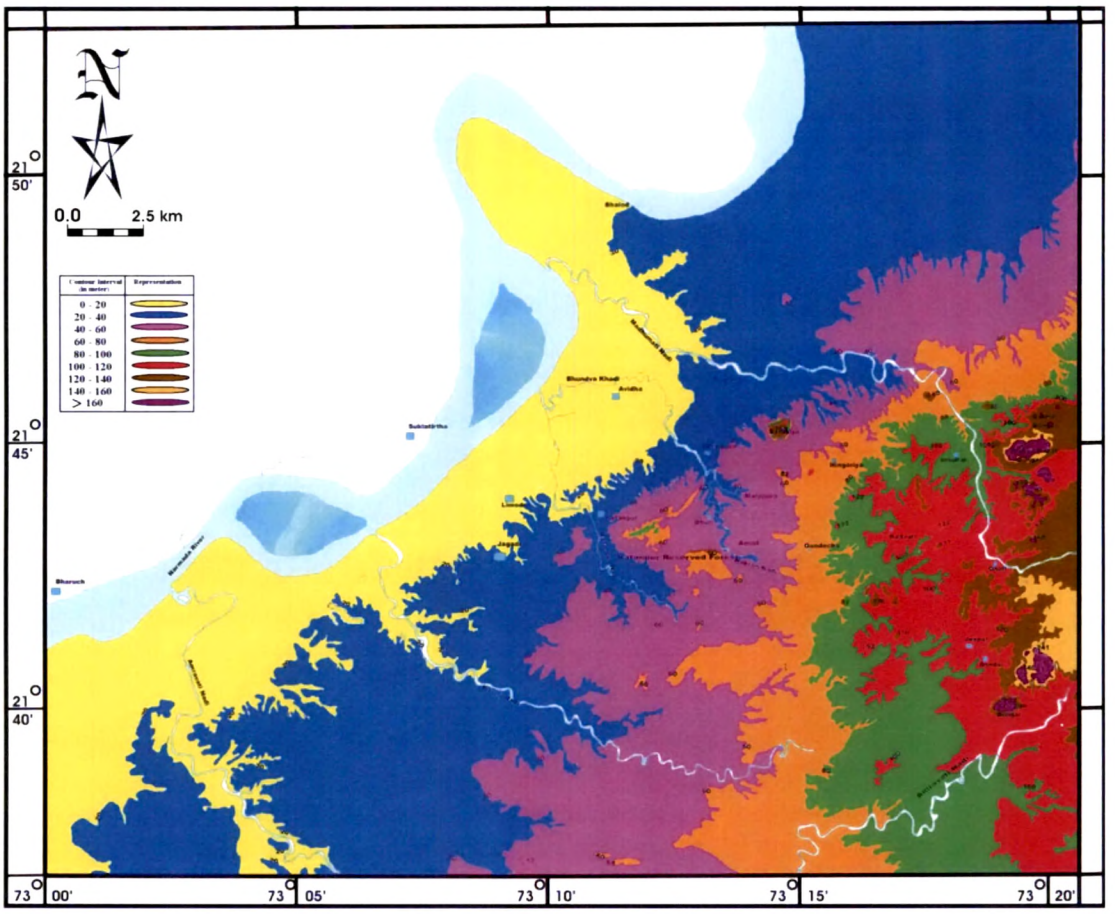


Figure 4.5: Contour map of the area

There are four drainage basins in the region, the study area is located on the origin of Hakran stream and shares its extension in to the Ratanpur and Madhumati river basins (Figure 6.1).Based on the evidence of the northward drifting of the Narmada river (Agarwal, 1984) and the seismic record of the region one can say that the area is presently tectonically active.