Chapter – 3

MORPHOTECTONIC DOMAINS

The southwest Saurashtra is covered by perennial and ephemeral rivers flowing towards south, dyke swarms extending from east, cuesta ridges, hills and Quaternary planar region. The study area covers approximately 8400 km^2 from the Veraval (west) to Jafarabad (east) and trappean zone (north) to coastal area (south) (Figure 3.1). However, there is a distinct variation observed in the study area between Rajula in the east to Talala in the west. The Talala region is prone to earthquake swarm activities while few scattered epicenters is observed towards the east of the region. The discrimination of the study area was done after detailed investigation of the entire zone starting from the coastline in the south to the rugged mountainous terrains of the trappean highlands in the north. The unique topographic and geomorphic variations were noted in the satellite imageries, generated Digital Elevation Models (DEMs) as well as data collected during detailed field explorations.

The study area is drained by deeply incising south to southwest flowing rivers from west to east. The major rivers draining are the Hiran, Saraswati, Singwada, Sanagwadi, Rupen, Machundri, Rawal, Malan, Raidi and Dhantarvadi River (Figure 3.1). All the rivers are flowing almost southwards from the rugged topography of trappean rocks to the gently sloping surface of Quaternary miliolite deposits up to coast meeting Arabian Sea. Moreover, the topography observed in the satellite images and SOI toposheets include the formation of sharp meanderings, sudden gradient change, knickpoints, rapids, slope breaks, straight channels, deep incisions and valleys. However, the major contrast in the geomorphological characteristics and topography is observed in the eastern and western side of the Rawal drainage basin. The division of the morphotectonic domains were considered on the basis of geology, geomorphology, structural control and topography. These morphotectonic domains were studied and investigated separately to understand the morphotectonic setting and neotectonic evolution of the study area. The extensive dissimilarity in the geomorphology as well as landscape development of both the domains along with varied river morphology has been explained in detail.

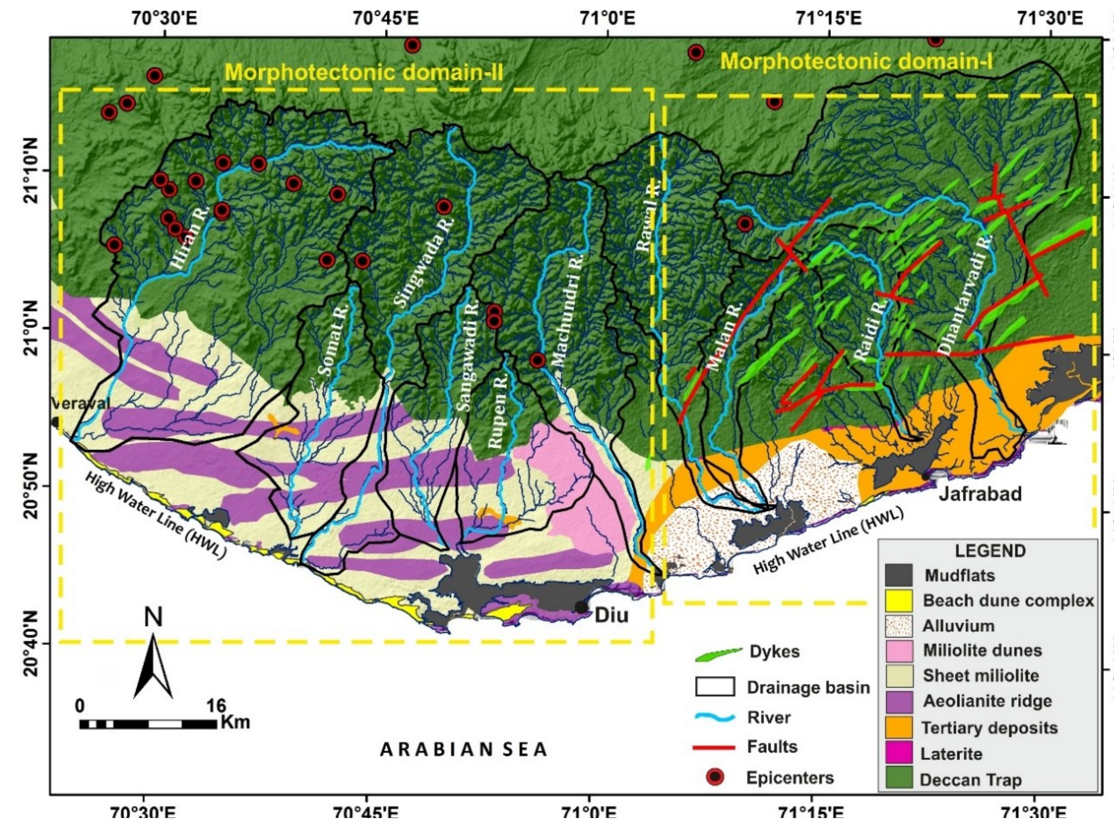

Figure 3.1 Geological map of southwest Saurashtra region, Gujarat, western India showing geomorphic zones, major rivers, drainage basin and faults. Red circles are the earthquake epicenters *(source-ISR).* Yellow dashed boxes shows the two morphotectonic domains identified in the present study.

3.1 MORPHOTECTONIC DOMAIN – I

The morphotectonic domain-I includes three major river basins Malan, Raidi and Dhantarvadi River in the eastern part of the study area covering the approximate area of about 1183 km^2 (Figure 3.1). It consists of rocks of Deccan Trap Formation, Gaj Formation of Tertiary and Miliolite Formation of Quaternary deposits (Merh, 1995).This domain comprises the region around Rajula and consists of mainly the rugged hilly topography developed over the Deccan Traps and the south sloping coastal segment with miliolite deposits of late Quaternary age with present day mudflats. The Tertiary rocks occurs in a coast parallel thin belt to the south of Rajula between the Deccan Traps and miliolite while further west they are buried under miliolites. The area also comprises of an extensive zone of structurally controlled dykes which have been studied mainly for petrology and geochemistry (Chatterjee and Bhattacharji, 2001, 2004; Sheth et al., 2013). However, no structural data or previously mapped faults responsible for uplift or earthquake swarm are known from the area.

3.1.1 Geomorphic characteristics

The morphotectonic domain-I majorly covering trappean dyke swarm that extends from the area to the west of Bhavnagar. The dyke swarms covering the northern part of this domain trending NE-SW to NNE to SSW modifying the structure and drainage pattern. These dykes are observed over the southwest tilted trappean lava flows with several escarpments and cuesta ridges. The presence of ~NE-SW trending lineament from the north of the source of Dhantarvadi River up to the Rawal River detected with the help of remote sensing. In the southern part of the domain, the presence of ~5 to 25m marine cliffs all along the coastline with alternative present day beach dunes and intertidal flats observed far inland. The marine notches, sea caves, sea arcs are also observed all along the coastline inferring neotectonism in the study area (Juyal et al., 1995). The raised coastal notches are reported from coastal cliffs around Jafarabad that suggest a tectonic uplift of ~7 m during the last ~125 ka BP (Pant and Juyal, 1993; Juyal et al, 1995). The sea level changes with the evidence of tectonism observed by some of the geomorphic markers like the wave cut notches, seaward abrasion slope and landward dipping marine cliffs (Burbank and Anderson, 2008). In the present study, this domain is geomorphologically divided into three main geomorphic zones: i) upland zone, ii) pediment surface and iii) coastal zone (Figure 3.2).

Upland zone

The northern two-thirds of this domain shows rugged hilly topography and consists of trappean rocks, southeast tilted lava flows which are profusely intruded with dykes. The dyke swarm is part of the regional swarm that starts from further east near Bhavnagar. Throughout most of its extent, the dykes swarm consistently trends in ENE-WSW direction which parallels the trend of the Narmada-Son Fault (Mahadevan, 1994). The number of dykes is prolific which are massive and resistant to erosion forming prominent positive relief in the form of linear ridges (Mishra, 2008; Dasgupta, 2018). Overall, the topography is mainly dominated by NE-SW to NNE-SSW trending dyke and cuesta ridges with intervening sloping rocky plains. The cuesta ridges show NW facing sub-vertical to vertical escarpments (Figure 3.3 a). This zone shows prominent change in the course of the Dhantarvadi River following the trend of dyke swarm and cuts the ridges to follow the regional slope towards southwest. The upland zone shows several structural and geomorphic features like tilted lava flows, linear structurally controlled ridges and fresh fault scarps. The trappean upland is entirely observed as zone of dissected hills and deep valleys up to the pediment cover.

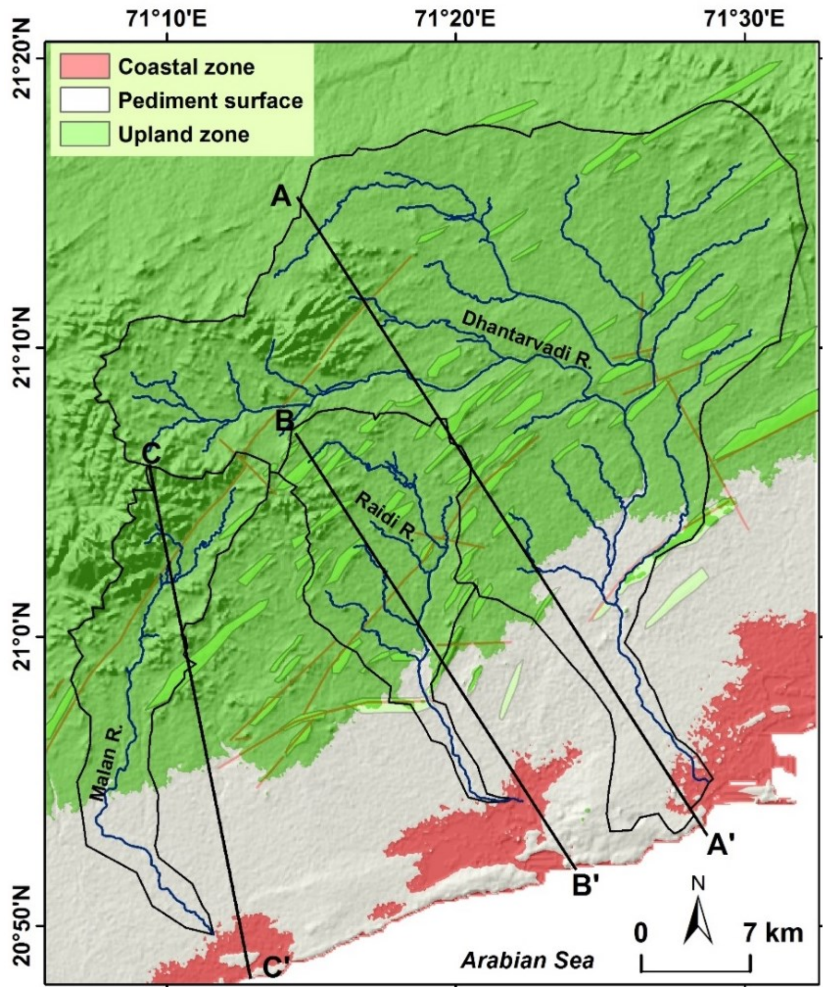

Figure 3.2 Geomorphic map of morphotectonic domain-II showing three significant geomorphic zone and three major river basins. Lines A-A′, B-B′ and C-C′ show the alignment of topographic sections in figure 4.1.

Pediment surface

The pediment surface covering the base of the trappean lava flow surface, comprising coast parallel narrow strip of south to southeastward gently sloping rocky surface developed over the Laterites and Tertiary rocks. Most of this zone is covered by Tertiary rocks consisting of fossiliferous limestones and sandstones belonging to Gaj Formation of Miocene age (Merh, 1995). These rocks are gently dipping i.e., ~1 to 6° in SSE direction and are highly jointed (Figure 3.3 c, d). These are mostly buried under thin cover (1-3 m) of alluvial sediments. The Tertiary joints are exceedingly exposed in the river channels and the tributaries flowing from this zone. Due to the presence of major south slowing channels, the recent alluvial deposits also covers some part of this zone.

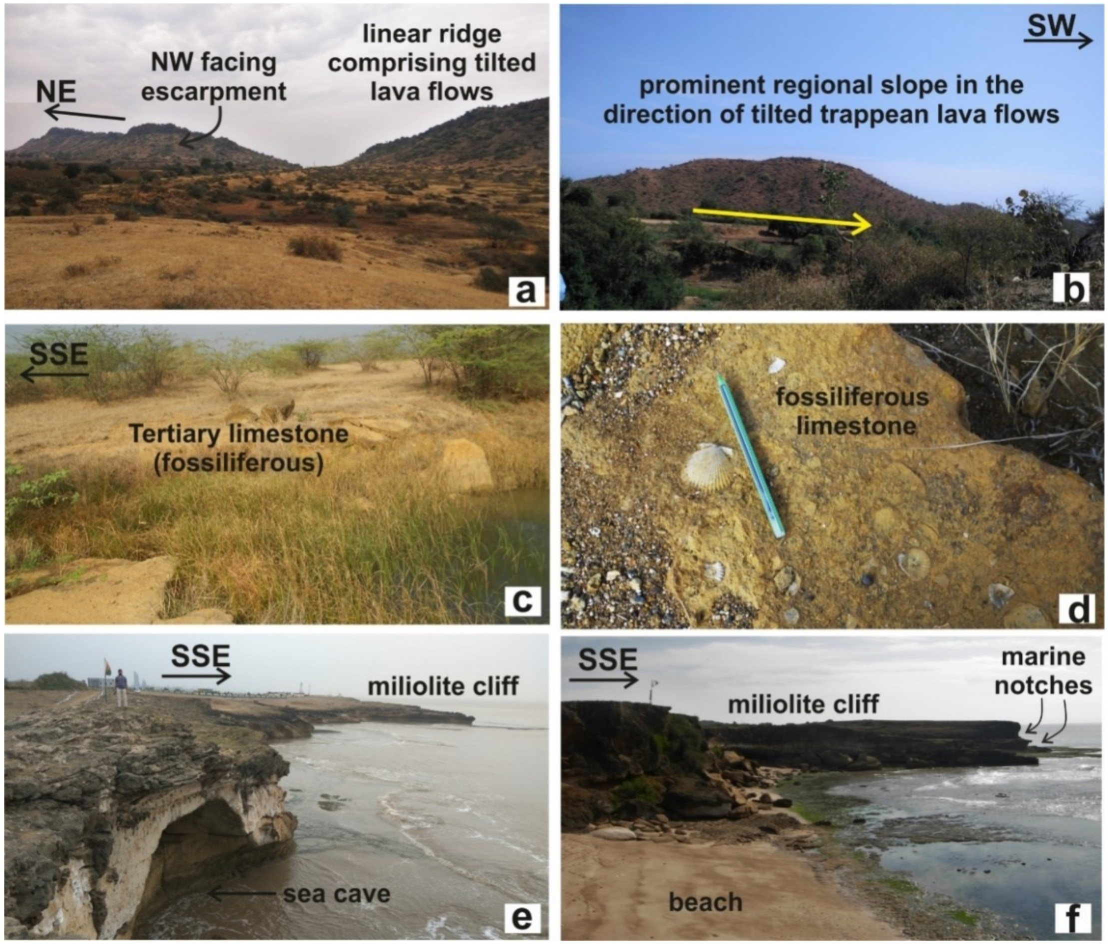

Figure 3.3 Field photographs showing geomorphic characters in different geomorphic zones in morphotectonic domain-I. a) Structurally controlled cuesta ridge developed over tilted trappean lava flows near Katar village. Note the prominent scarp face and the NE alignment of the ridge b) Prominent regional in the direction of tilted trappean lava flows near Dedan village. c) Pediment surface developed over fossiliferous Tertiary limestones (Gaj Formation) north of Pipavav. d) Close view of the fossiliferous limestone. e) ~10-15 m high coastal cliff, marine notch and sea caves in miliolites near Jafarabad. f) ~15 m high coastal cliff and two marine notches to the west of Jafarabad.

Coastal zone

The zone is largely occupied by miliolite rocks of Quaternary period and recent deposits. The miliolites observed all along the coast shows ~10 to 15 m high cliffs which are interrupted by indentation of shoreline with wide mudflats near Rajula and Jafarabad. These intertidal flats are extending behind the coastal cliffs and sandy beaches. Two levels of raised coastal notches around Jafarabad attributed to high seal levels as ~125 ka and ~6 ka BP (Pant and Juyal, 1993; Juyal et al, 1995). They are reported from coastal cliffs that suggest a tectonic uplift of ~7 m during this period. The coastal zone of this domain consists of extensive cliffs with the presence of sea caves, sea arcs, marine notches, beach dune complex and extensive mudflats (Figure 3.3 e, f). Due to the presence of coastal cliffs, the topography of this zone varies from the pediment covered area.

3.2 MORPHOTECTONIC DOMAIN – II

The morphotectonic domain-II includes 07 drainages and comprises of trappean lava flows of elevation up to ~611m and coastal plain of altitude of ~0.1 m amsl (Figure 3.1). It comprises of Hiran, Somat, Singwada, Sangawadi, Rupen, Machundri and Rawal rivers covering approximately 2908 km^2 in the western part of the study area. The area covers the coastline from Veraval to Nava Bandar and inland area from Gir Reserved Forest to Bediya village. The entire domain covers the area about ~3000 km^2 with majority of the area covered by rocks of Deccan Trap Formation and extensively exposed Quaternary deposits near coastal area.

3.2.1 Geomorphic characteristics

The northern part of this domain consists of highly rugged terrain along with several dykes and linear ridges with multiple trends. The rivers flowing over the trappean surface forms deep valleys, gullies, knickpoints and sharp meandering. Other prominent linear features observed all through the study area like ridge crests, mountain fronts, straight channels and dykes are also major indicators. The coastline is rocky and cliffy at this domain with several present-day beach dune complexes as well as intertidal zones observed from Veraval up to Diu Island. Geomorphologically, this part of the study area is divided into three zone, viz., 1. Upland zone, 2. Buried pediment zone, 3. Coastal zone (Figure 3.4).

Upland Zone

Majority of the study area is covered by the hills, linear ridges and peaks of trappean basalt of Deccan Trap Formation forming an undulating topography. These highlands provide a zig-zag outline and a rugged topography forming three nearly parallel elevated areas striking ENE-WSW connected by a NNE-SSW ridge. Some relicts of the tableland also can be encountered either as an erosional conical hill or as circular hill. The hills expose basaltic lava flow of Deccan Trap formation. Abundant linear dyke ridges protruding above the basaltic surface reach heights up to 10m above the general level of the ground. This highland zone forms the watershed of practically all radially flowing rivers. Majority of the basin is covered by this uneven landscape of trappean basalt lava flows with multiple dykes extending in different directions. At places, sharp elevation change and gradient changes are observed with abrupt variation in topography. However, most of the upland zone falls under reserved forest of Gir national park so geological studies were restricted outside the forest area that includes pediment surface and coastal zone.

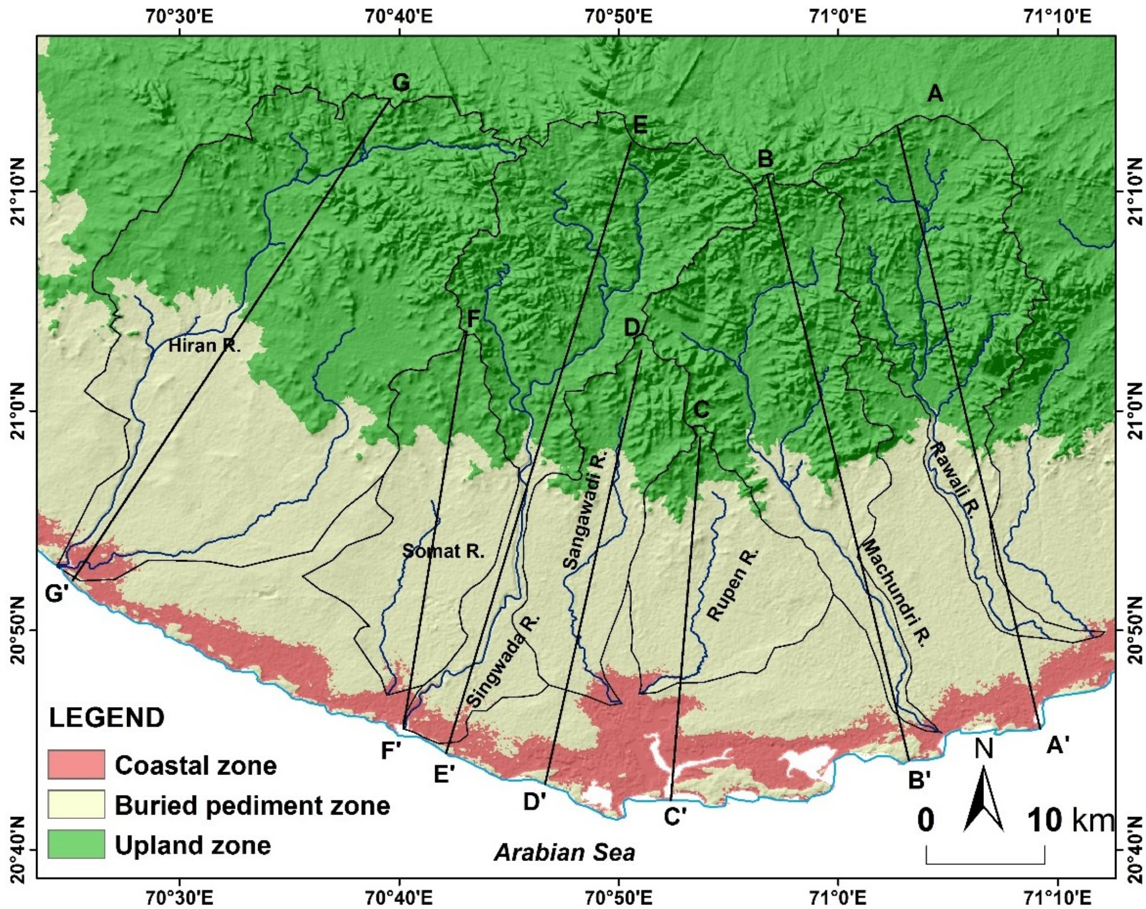

Figure 3.4 Geomorphic map of morphotectonic domain-II showing three distinct geomorphic zones. Note that the buried pediment surface covers vast area compared to domain-I. Topographic profile sections A-A′ to G-G′ from east to west explained in figure 4.5.

Buried Pediment Zone

The rest of the area apart from the upland zone is covered by Quaternary cover consisting of miliolites and alluvial deposits and slopes gently towards south (Figure 3.4). The cliff sections showing Quaternary deposits overlies on Deccan trap basalts. The patches of Tertiary rocks, mainly fossiliferous limestone of Gaj Formation is exposed at few places (Figure 3.1). The southward gently sloping surface with several mounds consisting of miliolitic aeolian dunes shows very gentle slope southward till coast (Figure

3.1). This zone also comprises of miliolite deposits of varying morphology. The miliolitic dunes, valley-fill deposits and aeolianites are dominantly covering the pediment surface. The presence of huge waterfalls and rapids along the river on the Deccan traps were also observed deeply incising Quaternary deposits (Figure 3.5 a, b). These makes the surface undulating as observed in the topographic profiles.

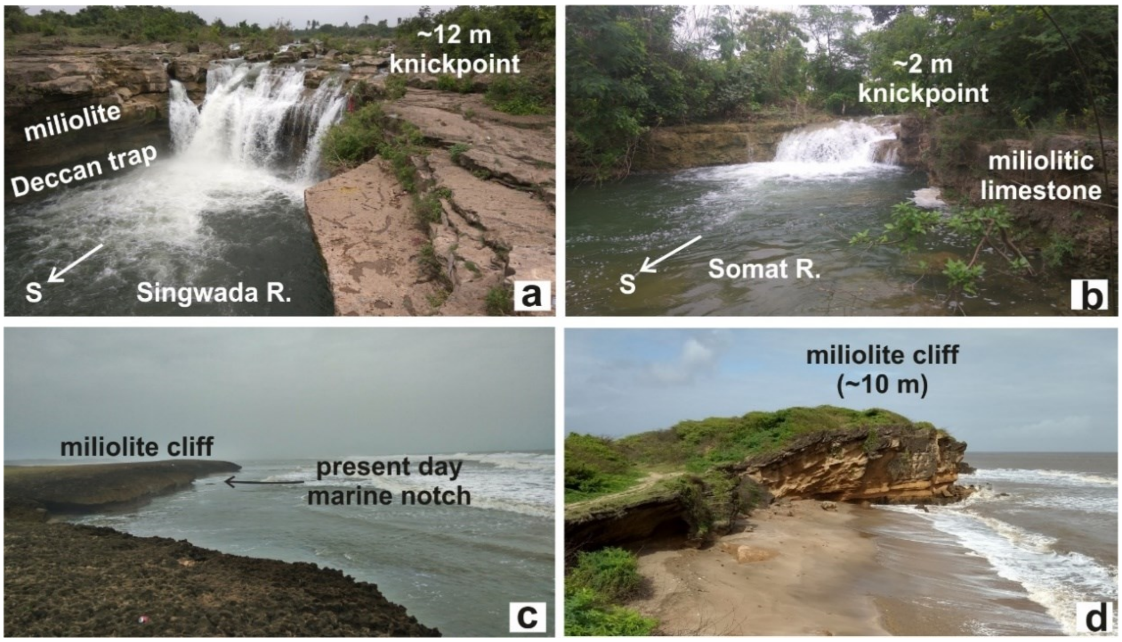

Figure 3.5 Field photographs of morphotectonic domain-II. a) ~12 to 15 m knickpoint, at Jamjir waterfall, deeply incising trappean bed rock and miliolitic limestone near Ghontvad. b) ~2 m knickpoints incising miliolitic limestone near Vithalpur. c) Coastal cliff near MulDwarka and present day notch. d) ~10 m high miliolite cliff gently dipping landward showing prominent cross bedding near Dharabandar.

Coastal Zone

The coastal zone consists of coastal dunes, intertidal flats, shore platforms, aeolinite ridges and present day beach dune complexes (Figure 3.1). The rivers flowing from the uplands merge in the Arabian Sea and some in the mudflats. The geomorphology of the coastal zone in the SW region, generally, shows such ridges which cuts the straight channels forming sharp hook shaped meander (Figure 3.1). The coast parallel aeolinite ridges observed might have been eroded after its deposition due to river or climate. Some of the ridges shows southward dipping while some shows northward dipping indicating that the sediment deposition is either due to the wind carrying sediments or the transgression/regression phenomenon. The rock type is limestone of miliolite formation might have compacted after the deposition and due to erosion the either side of the dune is observed showing two opposite slope. These beach ridges are coastal parallel and ~E-

W trending playing a major role in changing the river course of south flowing straight channel courses of major rivers. These ridges shows prominent cross-bedding and shows certain trend of its deposition. These are extended up to coast showing prominent landward dipping beds and various erosional features such as present day marine notch (Figure 3.5c, d). Apart from these ridges, several mudflats are observed within few distance (Figure 3.1). Moreover, the present day beach dune complexes are observed alternatively deposited between the aeolianite ridges that extended till coast (Figure 3.5c, d). These coastal dunes are observed more in this area compared to morphotectonic domain-I. However, the coastal cliffs height also descends west of Diu Island compared to the eastern side of the coastline till Jafarabad. The aeolianite ridge system is explained elaborately further to understand its role in geomorphic evolution of morphotectonic domain-II.