# Chapter - 9

# CONTROLS ON LANDSCAPE CONFIGURATION

The morphotectonic domain-II comprises of highly fragmented upland zone consisting trappean lava flows and dyke ridges. The receding mountain fronts of these basaltic flows is overlain by thin layer of Tertiary deposits. These pediment zone is buried under the coastward dipping Quaternary miliolitic deposits covering majority of the terrain till the coastal zone. The area is drained by south flowing seven major drainages viz., Hiran, Somat, Singwada, Sangawadi, Rupen, Machundri and Rawal (Figure 9.1). The area extends from Veraval coast at the west to Diu Island at the eastern margin (Figure 9.1).

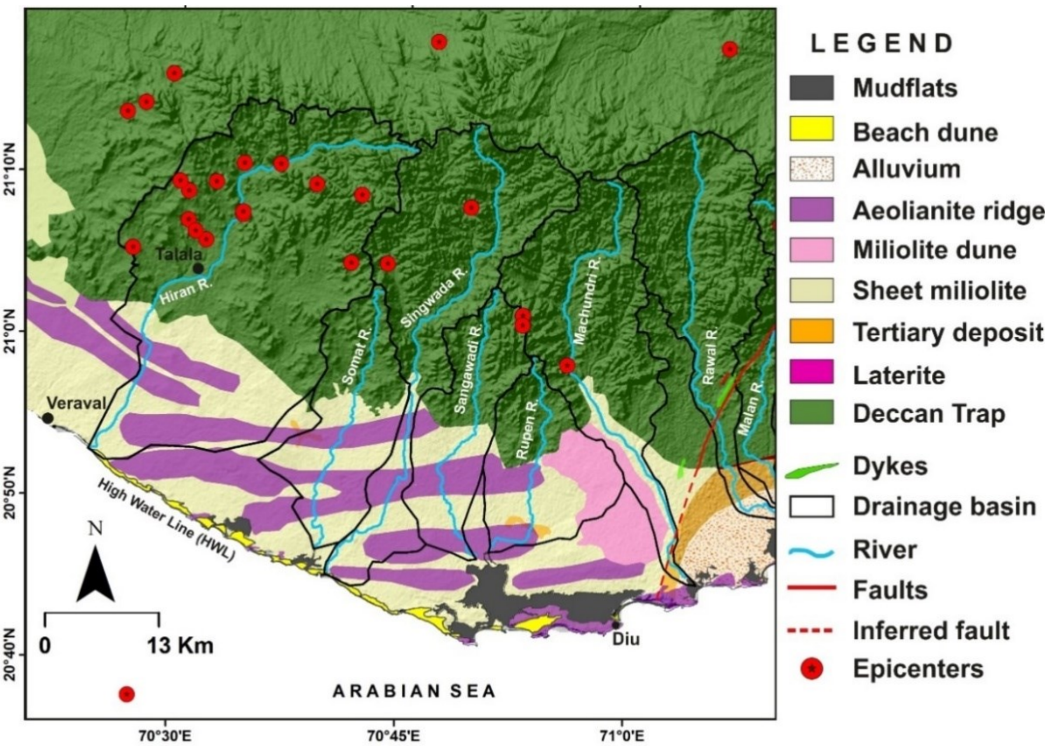


**Figure 9.1** Geomorphological map of morphotectonic domain-II superimposed over DEM. Note two trends of aeolianite ridges.

## 9.1 GEOMORPHIC ZONES

***Upland zone -*** The upland zone falls under reserved forest of Gir national park which restricted the field study of trappean lava flows and dyke ridges. The present study, therefore, was investigated outside the forest zone which comprises of buried pediment zone and coastal zone.

***Buried pediment zone -*** The buried pediment zone comprises of Quaternary deposits overlying Tertiary sediments exposed at places. The zone also consist of several generations of miliolite deposits covering the pediment surface. The southward flowing rivers incise the miliolite deposits forming deep valleys, knickpoints, rapids and sharp meanders. The aeolianite ridges are developed over this zone which are identified from detailed field investigation and mapped.

***Coastal zone-*** The thin patch of coastal zone consists of the coastal cliffs, beach dune complexes, sandy beaches and intertidal flats. The geomorphic features observed in coastal cliffs are notches and sea caves.

## 9.2 AEOLIANITE RIDGE SYSTEM

The aeolianites, also called relict foredunes or Pleistocene beach ridges, are wind deposited, convex upward mounds and shore parallel ridges deposits observed mainly at coastal zone (Hesp, 1984; Searle et al., 1988; El-Asmar, 1994; Taylor and Stone, 1996). The ridges are longitudinal, parallel to sub-parallel formed by the deposition of fine to medium grained well sorted carbonate sand that later cemented and lithified by terrestrial rivers to some extent (Fairbridge, 1982; Fairbridge and Johnson, 1978; Calvet et al., 1980; Frenchen et al., 2001, 2002; Nielsen et al., 2004; Fornos et al., 2009). The ridge morphology predominantly shows the presence of large scale foresets associated with well-preserved and well-structured high angle cross bedding, low angle planar bedding and trough cross-stratification (Nielsen et al., 2004). These aeolianites are mostly asymmetric ridges characterize gentle dip facing windward slope and moderately dipping leeward slope (Fornos et al., 2009) typically forms parallel to sub-parallel strandlines (Otvos, 2000).

The aeolianite ridges or coastal dune landforms are well-preserved and mapped around the globe debated numerous times about its significances related to their Quaternary depositional history. The significant sites of the aeolianite ridges located in Africa, Australia, Bahamas, Bermuda, Brazil, Chile, Israel, Mediterranean, Mexico and western India gave insights about dune morphology, chronology, coastal landscape evolution, tectonic attributes, paleoclimate and sea level studies (Harmon et al., 1983; Gardner and McLaren, 1993; Hearty and Kindler, 1995; McLaren and Gardner, 2000; Khadkikar and Basavaiah, 2004; Bateman et al., 2004; Nielsen et al., 2004; Sivan and Porat, 2004; Hesp et al., 2005; Brooke et al., 2014; Green et al., 2018; Nash et al., 2018).

The Quaternary carbonate deposits in the Saurashtra region, western India locally well-known as 'Miliolitic Limestone' are largely carbonate aeolianites, exposed along the coast and sporadically in the inland area (Fedden, 1884; Biswas, 1971; Lele, 1973; Govindan et al., 1975; Sperling and Goudie, 1975). The origin of the aeolianite deposits have always been controversial in western India, however, few studies established the chronology, petrography, detrital content, depositional environment and sea level indication (Biswas, 1971; Lele, 1973; Agrawal et al., 1978; Baskaran, 1987, 1989; Baskaran and Somayajulu, 1990; Bhatt and Patel, 1998; Bhatt, 2003; Bhatt and Bhonde, 2006; Dasgupta and Bandyopadhyay, 2008; Sharma et al., 2017; Acharya and Bhatt, 2018).

Three coast parallel aeolianite ridges related to strandlines during late Pleistocene to early Holocene, in the coastal zone from Porbander to Veraval were reported with the help of remote sensing analysis (Baskaran et al., 1987; 1989). The area has undergone post-miliolitic tectonic uplift causing the anomalous drainage pattern (Baskaran et al., 1987; Chakrabarti and Basakaran, 1989). The coastal miliolites shows notches, sea caves and raised shore platforms due to tectonism (Bhatt and Patel, 1998) while inland miliolites occurred as obstacle dunes, valley fills and sheet deposits (Bhatt, 2003). The gently southward dipping miliolite rocks in the coastal region observed as high cliffs because of raised platforms and notches (Bhatt and Patel, 1998). However two raised notches near Jafarabad, south Saurashtra, were dated to ~125 ka BP and 6 ka BP suggesting ~7 m coastal uplift since ~125 Ka (Juyal et al., 1995). Recently, OSL chronological data of miliolites of marine, fluvial and aeolian origin gave range from Middle to Late Pleistocene (Sharma et al., 2017).

The age of Quaternary carbonate deposits in the Saurashtra region have always been a concern because of its origin and morphology. The samples taken from any precise location were dated, however, the stratigraphy suggests several facies of the miliolites deposition (Marathe et al., 1977). The miliolites of marine origin are assumed to be deposited during transgression period (30 kyr BP) whereas later inland miliolites of aeolian origin deflated during marine regression period (post 30 kyr BP) (Agarwal et al., 1978). The inland miliolites of aeolian origin transported from the beach sand are due to NW wind direction (Biswas, 1971; Agarwal et al., 1978). However, the coastal miliolites observed in strandlines from Veraval to Porbandar coast suggests marine origin (Lele, 1973, 1975).

## 9.3 EVIDENCE FROM DEM ANALYSIS

The DEM of the present study area shows various prominent geomorphic features such ~E-W and ~NW-SE trending miliolite ridges in the southern part near coastal zone. Also, the highlands are extremely rugged due to trappean rocks in the north which are deeply incised by south to southwest flowing rivers forming valleys and gorges at places. The linear features observed in the upland area are dykes and ridges showing various trends. The elevation difference is observed in as the topography changes from uneven trappean lava flows to the uniform Quaternary surface. The discontinuous elevation and gradient change between rugged and flat terrain is clearly observed. At the upland zone, the rugged topography shows some specific trends of the linear dykes and ridges. Four major river viz., Hiran, Singwada, Machundri and Rawal are seen as deeply incised channels and prominent straight courses are observed on the Quaternary surface. The sharp bending and meandering of the rivers is observed in both the terrains. The other major river channels like Somat, Sangawadi and Rupen are also draining towards south in between the mentioned rivers which are vaguely visible in the DEM.

The most prominent feature observed other than incised rivers are the ridges parallel to the coastline. These ridges shows two prominent trends in the eastern part (~NW-SE) and western part (~E-W). The straight river channels bends abruptly near the transversely running miliolite ridges and flows towards south incising these ridges. In the southernmost region, near Diu Island, the mudflats emerging inland is also detected cutting the ~E -W trending miliolite ridge. These sharp river bends are identified in the pediment zone is due to the presence of aeolianite ridge system. Before the channel bend, the rivers flow on a gently dipping southward slope on a straight path. Therefore, the abrupt river bends strongly indicates the presence of aeolianite ridge.

**9.3.1 Slope data**

The slope map of the Quaternary covered terrain is classified into three classes viz., 0º to 30° (very gentle to gentle slope), 31° to 50° (moderate slope) and 51° to 80° (steep slope) (Figure 9.2). The abrupt gradient change is observed at the receding fronts of trappean lava flows. The slope change is noticeable where there is sharp lithological contrast between trappean ridges and coastward sloping miliolites. The upland region showing undulating terrain shows moderate to steep slope (Figure 9.2). The distinctive feature observed on the buried pediment zone in the slope map is the aeolianite ridges (Figure 9.2). The coast parallel ridges are observed in the westernmost region of the domain over Hiran river basin (Figure 9.2). These ridges trending NE-SW extended probably from northwest.

The map shows very gentle to gentle slope on these ridges (Figure 9.2). Towards east of the shore parallel ridges around Hiran river, E-W trending ridges are observed extending up to coast at its western end. The slope of these aeolianites are similar to the coast parallel ridges at the west. The aeolianite ridges trending E-W and NW-SE mainly shows gentle slope (windward) and steep slope (leeward). The flat gently sloping (<30°) Quaternary surface covers the southern part separately from the aeolianite ridges up to the coastal zone. The river channels shows strong incision on the gently sloping surface. The coastal zone, in contrast, shows moderate slope due to the presence of these ridges. The steepness of coastal cliffs are demarcated where these ridges extend. There is an alternative gentle and moderate slopes at the coastline from Veraval to Diu due to miliolite cliffs and present day beach dune complex. The direction of these slopes shown in the aspect map.

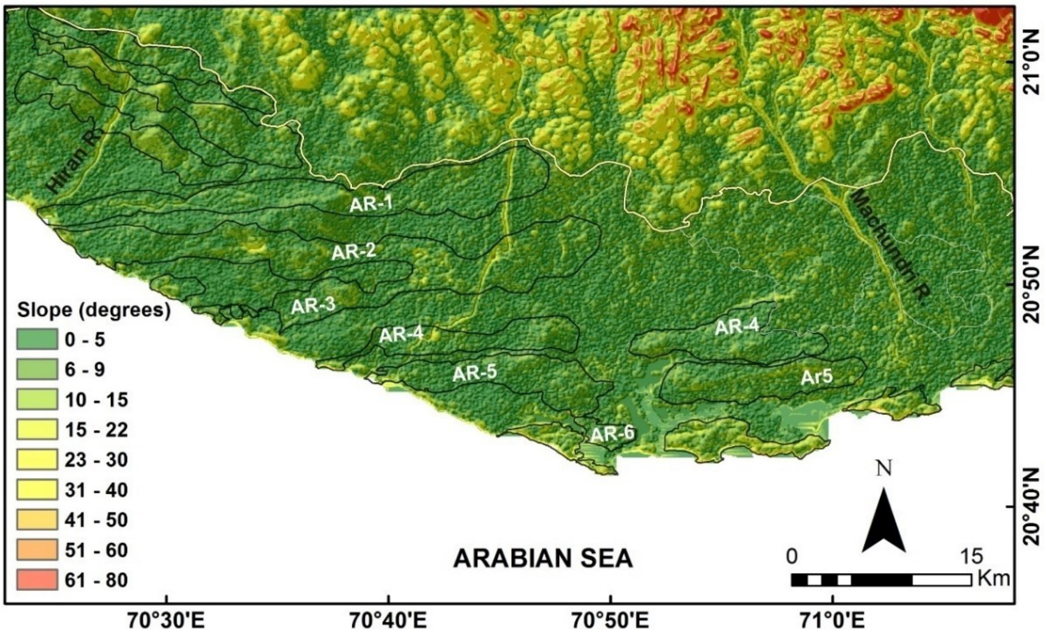


**Figure 9.2** Slope map showing aeolianite ridges marked in black polygons over the buried pediment zone superimposed over DEM. Note coast parallel ridges around Hiran River and AR-1 to AR-6 E-W trending ridges. Note the coastal zone with alternate moderate and gentle slope.

### 9.3.2 Aspect data

The aspect map shows the slope direction of the basalt flows and overlying Quaternary carbonate deposits through various pixels indicating precise inclination trend (Figure 9.3). The study area shows pixels with the majority of the area incline towards south and southwest. Considering the drainage system, the slope trend of river cliffs is towards the main trunk channel. The direction of gradient is scattered in the upland zone due to undulating trappean lava flows. The two prominent slope of the aeolianite ridges shows gentle windward and steep leeward. The buried zone comprises of aeolianite ridges parallel and transverse to the coastline. The coast parallel ridges trending NW-SE shows steep NE slope and gentle SW slope. These might indicate two different wind direction in depositing the aeolian sediments in the study area.

The E-W ridges observed in the slope map shows ENE-WSW to E-W trend (Figure 9.2). The pixels observed along these ridges shows north to northwest steep slope and southward gentle slope (Figure 9.3). These aeolianites are showing gentle southward slope is probably due to the windward side of the ridge. The coastal zone slope towards inland. However, the pixels observed in the entire coastline shows north to northwest slope. The gentler landward slope of the miliolite cliffs at the shoreline suggests the coastal uplift. Overall, the analysis show regional slope towards S to SW and the classification of the topography covering the area. The slope angle and its direction in the present study delineates the presence of aeolianite ridges over the miliolitic cover terrain. The identification of these ridges through the DEM analysis helps to understand the location and extension of aeolianites from highlands till the coast.

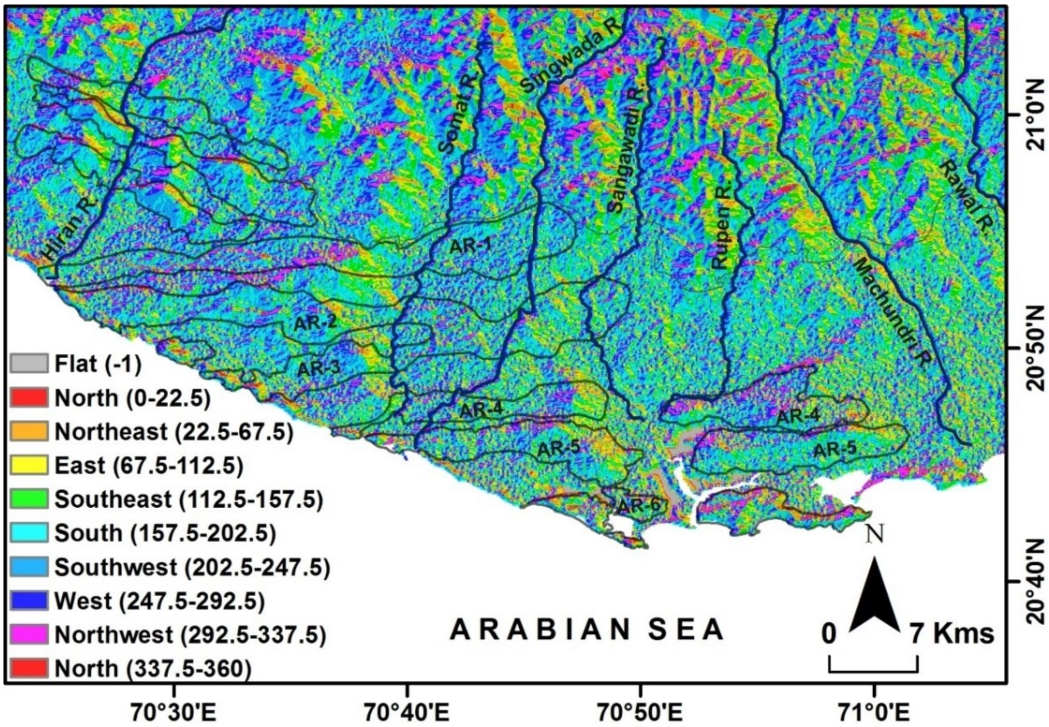


**Figure 9.3** Aspect map of the buried pediment zone of morphotectonic domain-II showing direction of the slope. Note the linear ridges showing two slope trend. Note coast parallel ridges around Hiran River and AR-1 to AR-6 E-W trending aeolianite ridges.

## 9.4 FIELD EXPRESSION

We explored two trends of the aeolianite ridges with the help of DEM analysis, however, detailed field investigation helped in recognizing the morphology of these ridges. The coast parallel ridges observed to the westernmost part of the study area shows NW-SE trend. These ridges are extended from the northwest Saurashtra with four shore parallel strandlines observed up to Veraval. Three coast parallel ridges observed around Hiran river basin and six E-W trending aeolianite ridges AR-1 (innermost) to AR-6 (outermost) are extended up to the coast. The coastline shows alternate prominent exposure of beach dune complex and these coastal ridges throughout the shoreline from Sutrapada at the west to Diu Island at the east. These aeolianite ridges were identified and observed individually resulting in better understanding of the morphology.

### 9.4.1 Aeolianite ridges

The E-W trending aeolianite ridges were identified and the satellite data shows gentle slopes in either side of the ridge (AR-1 to AR-6). The detailed field investigations shows these ridges extending up to SW coastline forming alternate deposits of aeolianite coastal cliffs and beach dune complexes from Sutrapada to Diu Island.

***Aeolianite ridge (AR-1)***

The E-W trending aeolianite ridge (AR-1) extends from Ghontvad to Veraval coast. The miliolites appear as grayish to light brownish colored compact limestone with well-preserved laminations. However, these beds are exposed mainly in the river sections of Somat and Singwada River (Figure 9.4). The miliolites observed along the river sections are showing numerous joint sets. Near Ghontvad, the ridge is eroded and incised deeply by Singwada River flowing southward. ~12 m thick miliolite beds overlying the trappean basalt incised by the Singwada River (Figure 9.4a). These miliolites showing compact limestone rocks in the uppermost deposit showing prominent joint sets. The joint patterns also exhibits columnar shaped joints (Figure 9.4b). Such characteristics also seen in the Somat River cliff section where the extension of AR-1 is observed. To the downstream of Singwada River, south of Ghontvad, several small rapids formed over the aeolianite deposits (Figure 9.4c). The section shows well developed stratification. The lower part of the section shows planar laminations while the upper part or the surface of the cliff exhibits cross-bedding (Figure 9.4d). These bedding are dipping towards north.

At few places, trough cross bedding was also observed in the river cliffs. The foreset and bottomset is clearly visible in the section incised by the river channel (Figure 9.4d). The extension of aeolianite ridge towards east crosses the Somat river basin. The south flowing main channel incising miliolite beds forming small knickpoint (Figure 9.4e). The miliolitic limestone bed shows planar stratification and two prominent joint sets (Figure 9.4f). The formation of knickpoints and rapids are observed where the aeolianite ridge crosses. This might be due to the southern slope of the ridge got retreated by the river channel. The river engraving the aeolianite ridge from south up to the present day location of the rapids and knickpoints.

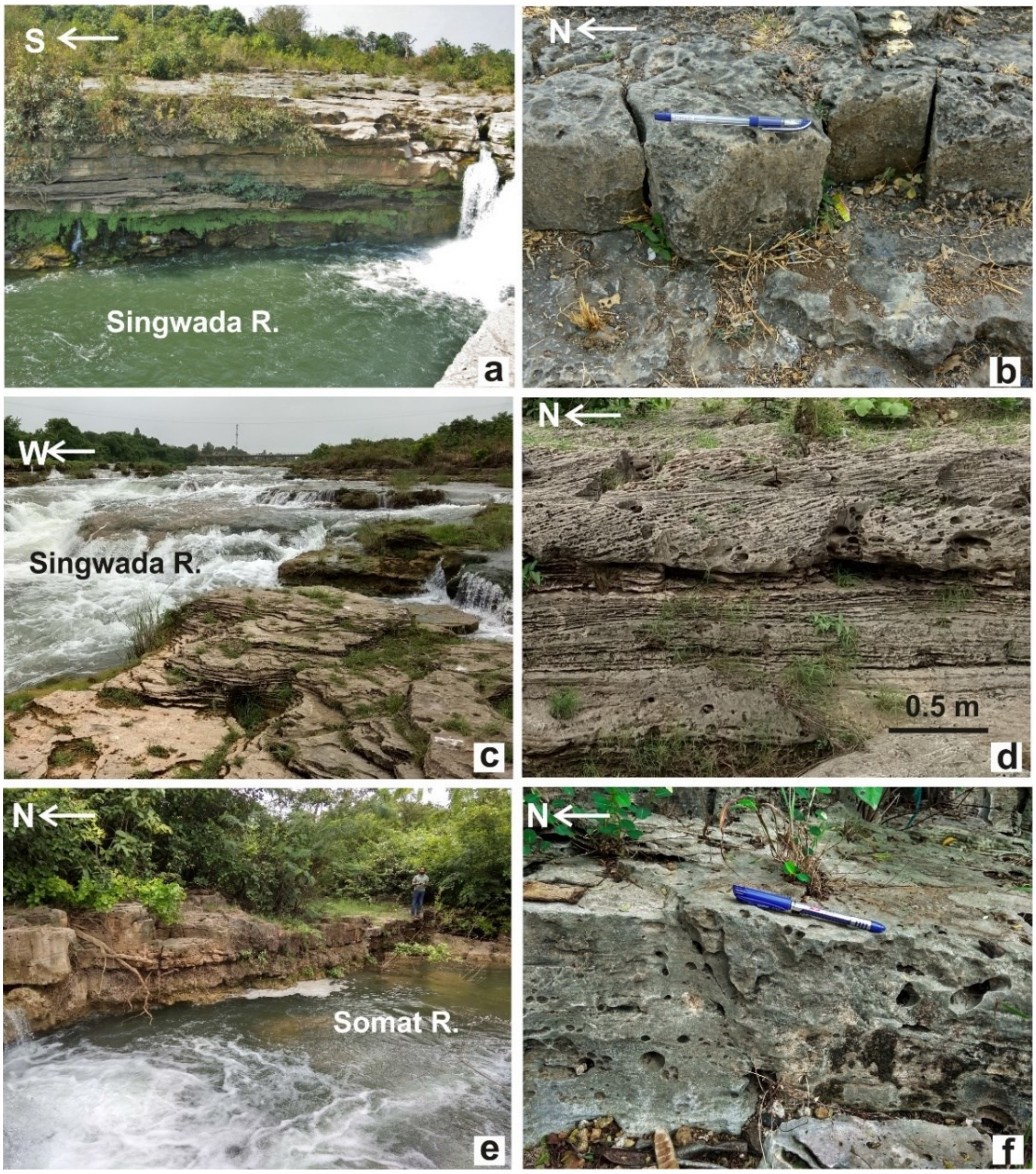


**Figure 9.4** Aeolianite ridge (AR-1) trending E-W from Ghontvad to Veraval coast. a) Singwada River incising the trappean bedrock underlying the miliolite beds showing cross bedding at Jamjir waterfall. b) Close view of the miliolite beds incised by Singwada River with prominent two joint sets. c) Downstream of Singwada River showing several rapids and exposed miliolite cliff with planar deposits. d) Cliff section of miliolite beds showing cross- bedding (upper unit) and planar beds (lower unit). e) Somat River incising the miliolitic limestone bed with planar stratifications. f) Close view of joint planes of miliolite rocks incised by Somat River. Note the knickpoints and rapid formation at the ridge zone.

### *Aeolianite ridge (AR-2)*

The aeolianite ridge (AR-2) extends from the Sutrapada coast up to Vadnagar covering ~30 km from coast to pediment zone. The majority of the Quaternary sites, specifically aeolianite ridges are mined out in the inland area. The coastal zone shows few sites with prominent ridges exposed showing distinct stratifications.

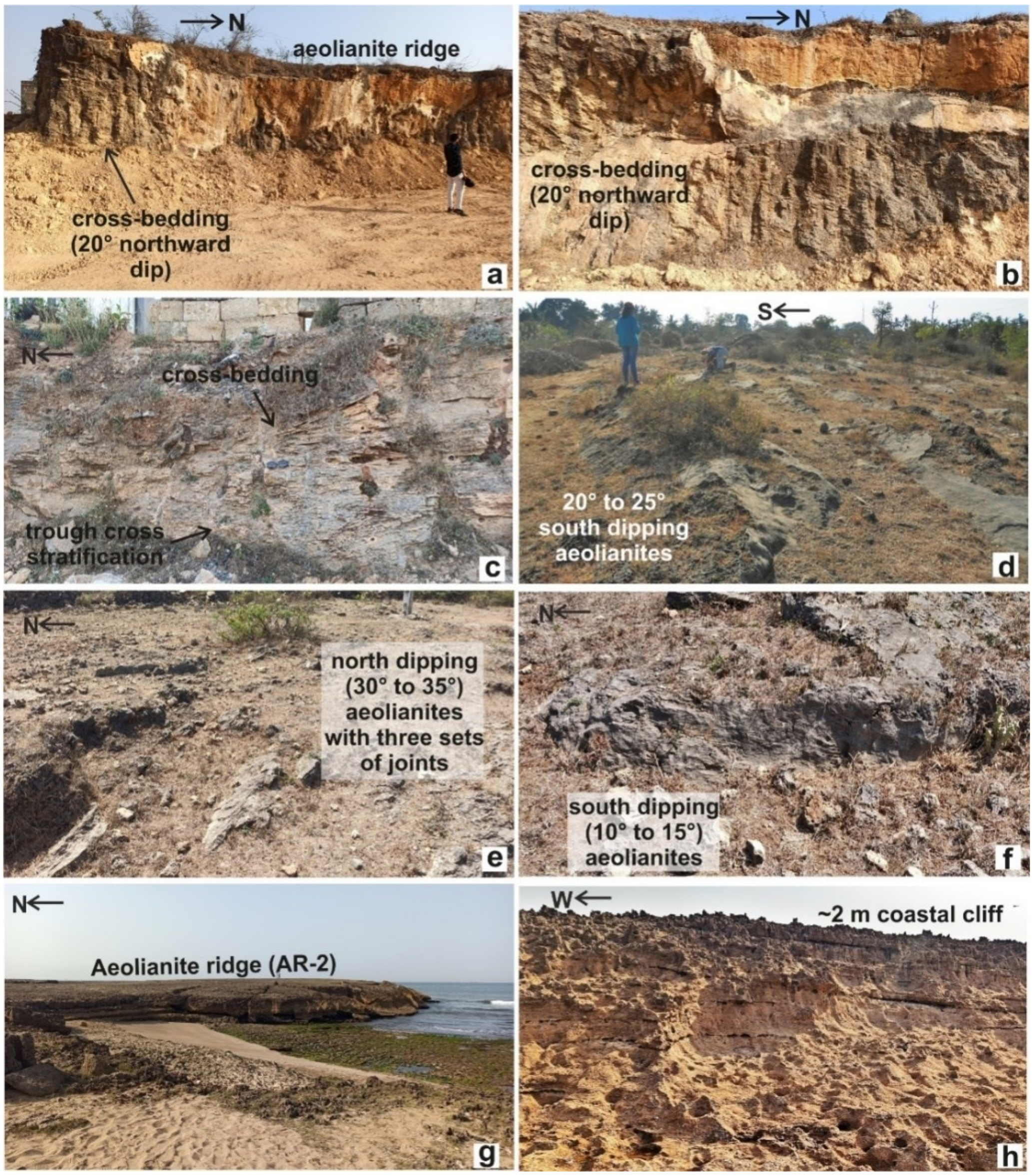


**Figure 9.5** Aeolianite ridge (AR-2) trending E-W showing distinct morphology extending up to Sutrapada coast. a) & b) Ridge surface exposed at a mining site showing cross-bedding and northward dipping beds. c) Close view of the cross-bedding at the exposed surface showing faintly visible trough cross bedding. d), e) &f) Locations near Vadnagar showing two slopes, northward dipping beds (30° to 35°) and southward dip (<25°). g) & h) Sutrapada coast showing extended aeolianite ridge forming ~2 m coastal cliff with well bedded aeolian deposits.

The north dipping cross-bedded miliolite ridge was observed where mining was undertaking. The section shows cross-bedded fine to medium aeolian sand deposits (Figure 9.5a, b). The angle of the bedding was >20° dipping away from the coast. These characteristics define the aeolian nature of deposition and formation of aeolianite ridges. The ridge extending towards inland shows another in-situ outcrop of the ridge. The cross-bedding with high angle dip towards north was identified and trough cross bedding was seen at the lower unit (Figure 9.5c). Further west, the ridge shows prominent exposure consisting steep northward and gentle southward dipping miliolites were identified (Figure 9.5d-f) and AR-3 merges at this location. At the coastal zone, ~2m high miliolite cliff showing horizontal stratification and few low angle northward cross-bedded deposits (Figure 9.5g, h).

***Aeolianite ridge (AR-3)***

The aeolianite ridge (AR-3) observed up to ~15km from coast to inland area where AR-2 merges with it. This ridge is eroded by south flowing rivers forming large boulders that are observed along the river bed (Figure 9.6a). The Singwada River erodes the ridge and forms an anomalous fish hook meander and flows in a straight path towards coast. The presence of few knickpoints along the Somat River shows the miliolite bedrock with prominent two sets of joints (Figure 9.6b). The miliolite coastal cliff shows low angle northward dip and formation of present day marine notch and sea cave (Figure 9.6c, d).

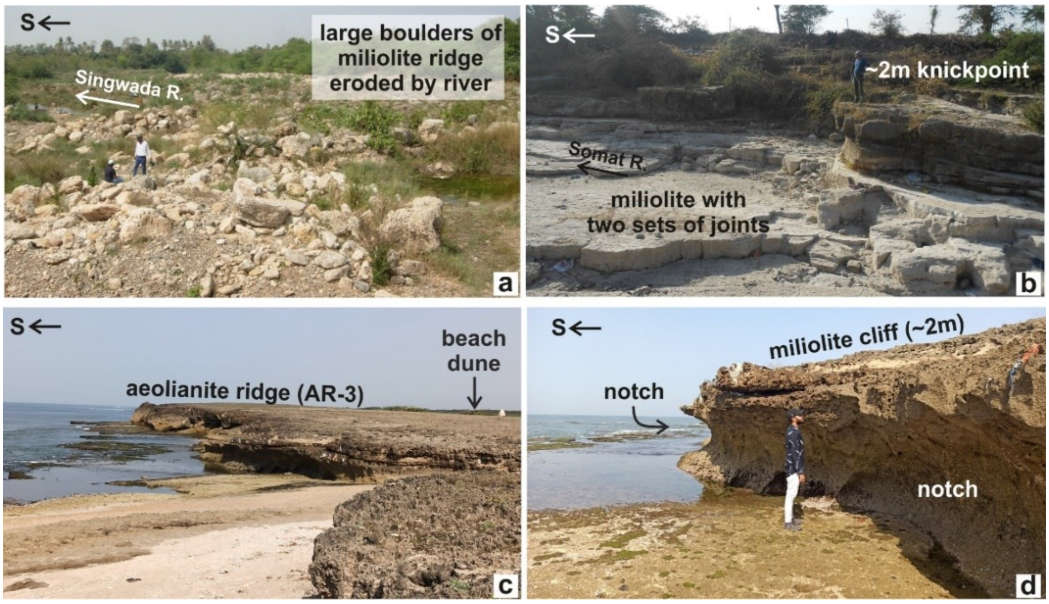


**Figure 9.6** a) Anomalous fish-hook meander near Chachhar village with large boulders of miliolite are exposed. The meander might have formed because of the response of Singwadariver to E-W trending aeolianite ridge. Boulders are observed remarkably within this stretch formed due to local erosion of the ridge. b) 1.5 m knickpoint observed marking gradient change within small distance. Two joint sets in miliolites are observed. c) & d) Aeolianite ridge coastward extension showing northward dipping beds in ~2m high coastal cliff, present day marine notch and sea cave.

***Aeolianite ridge (AR-4)***

This ridge extending approx. 20 km from Dhamlej coast to Una town with very less exposure observed. The best exposure is near a tight meandering of Rupen River where the presence of small boulders formed due to the erosion of the aeolianite ridge (Figure 9.7a, b). The meander is sharp hook shaped as observed along Rupen river bend cutting AR-4. The miliolites are fine to medium grained with faintly preserved cross-bedding observed. However, the sheet miliolite is observed overlying the incised aeolianite bedrock. The extension of this ridge at the coastal zone shows northward dipping ~2 m high miliolite cliff (Figure 9.7c, d).

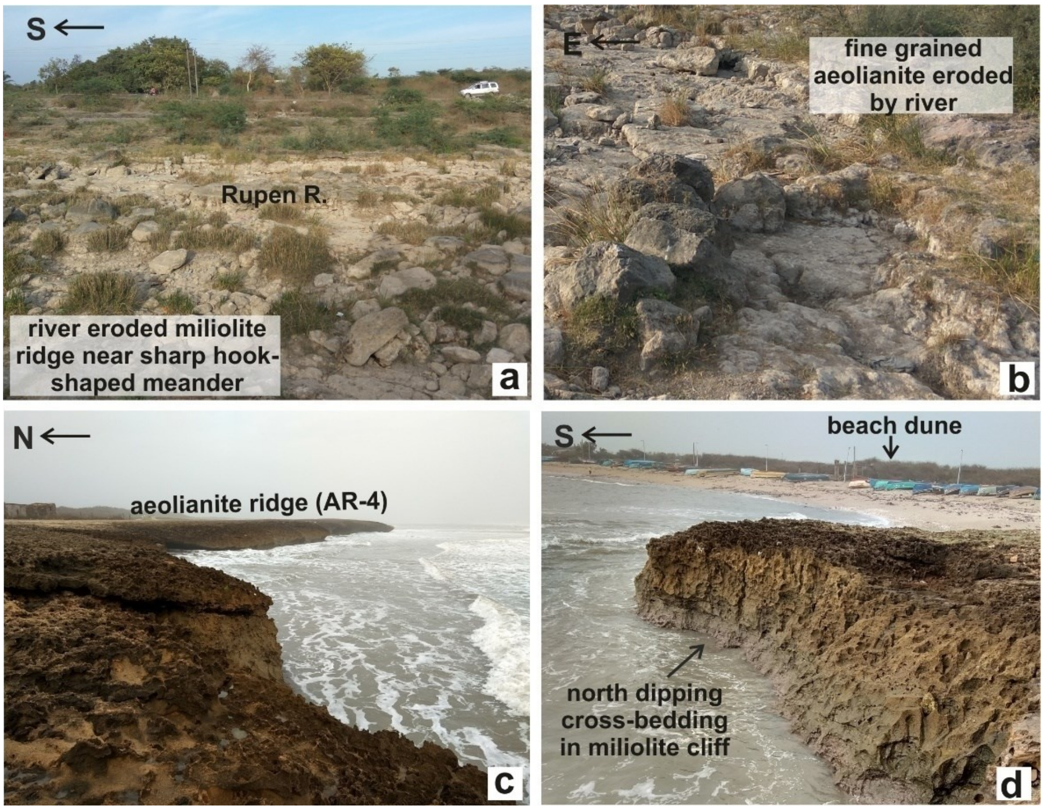


**Figure 9.7** a) & b) aeolianite ridge eroded by Rupen River forming boulders near the meander due to local erosion of the ridge. Boulders are observed within this stretch only. c) & d) extension of ridge forming miliolite cliff with prominent landward dipping cross-bedding near Dhamlej coast.

***Aeolianite ridge (AR-5)***

The E to NE trending aeolianite ridge AR-5 observed north of the Diu Island shows very poor exposures all its extent. The coastward extension of the ridge was identified with prominent southward dipping cross-stratification in the coastal cliff (Figure 9.8).

***Aeolianite ridge (AR-6)***

The Diu Island consists entirely of aeolianite ridge and the exposures are well-structured, well-bedded and well-preserved (Figure 9.9). The limestone caves, Nayda caves, were excavated and >20m sections were observed with very well preserved trough crossbedding, planar laminations and cross-bedding. It is very fine to fine grained aeolian deposits with prominent foresets, topsets and bottomsets. The section shows varied depositional facies forming the aeolian dune before lithification process.

Mostly the cross bedding shows northward high angle dip and few low angle coastward dipping laminations. The age of these deposits were dated 126±12kyr BP by Sharma et al., 2017 inferring this of aeolian origin.

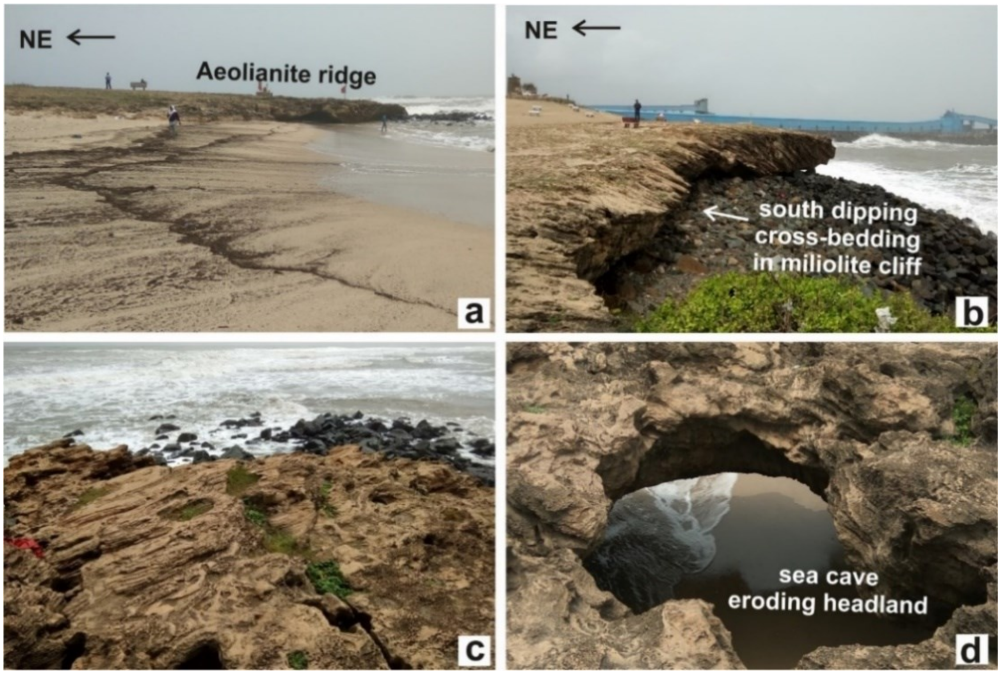


**Figure 9.8** NE-SW trending aeolianite ridge (AR-5) near MulDwarka coast showing southward dipping cross-bedding. Sea cave eroding headland observed from the horizontal surface.

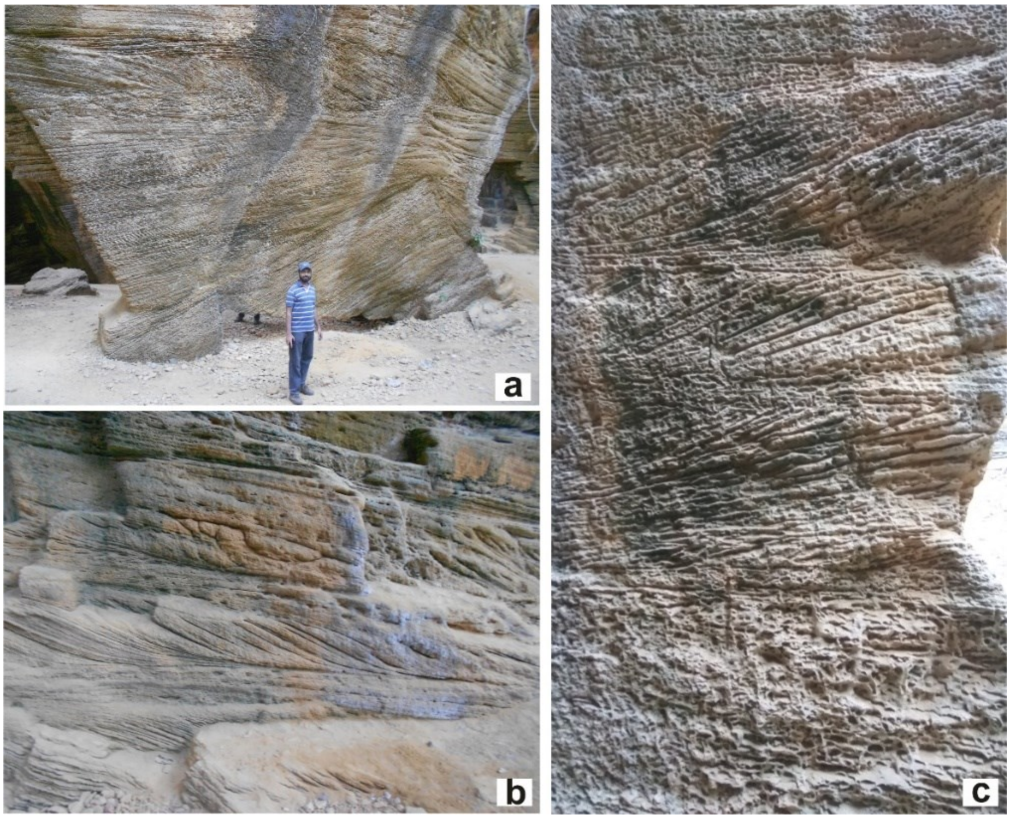


**Figure 9.9** Nayda limestone caves in Diu Island showing best exposure of aeolianite ridge (AR-6). Note the different depositional facies forming several foresets with distinct cross-bedding and planar laminations.

### 9.4.2 Aeolianite ridges around Hiran River

Three to four shore parallel ridges were identified by Sood et al., 1983 in the northwest trending Saurashtra coastline. However, three of these miliolite ridges, also called strandlines, were further investigated by Baskaran et al., 1987 and chronological data was established. These ridges are associated with tectonic instabilities obtained from the chronological evidences and uplift rates (Baskaran et al., 1987). Four coast parallel ridges extending from the northwest up to Veraval is showing different morphological characteristics. We identified three NW-SE trending ridges around the Hiran River, south of Umrethi Dam in the present study area.

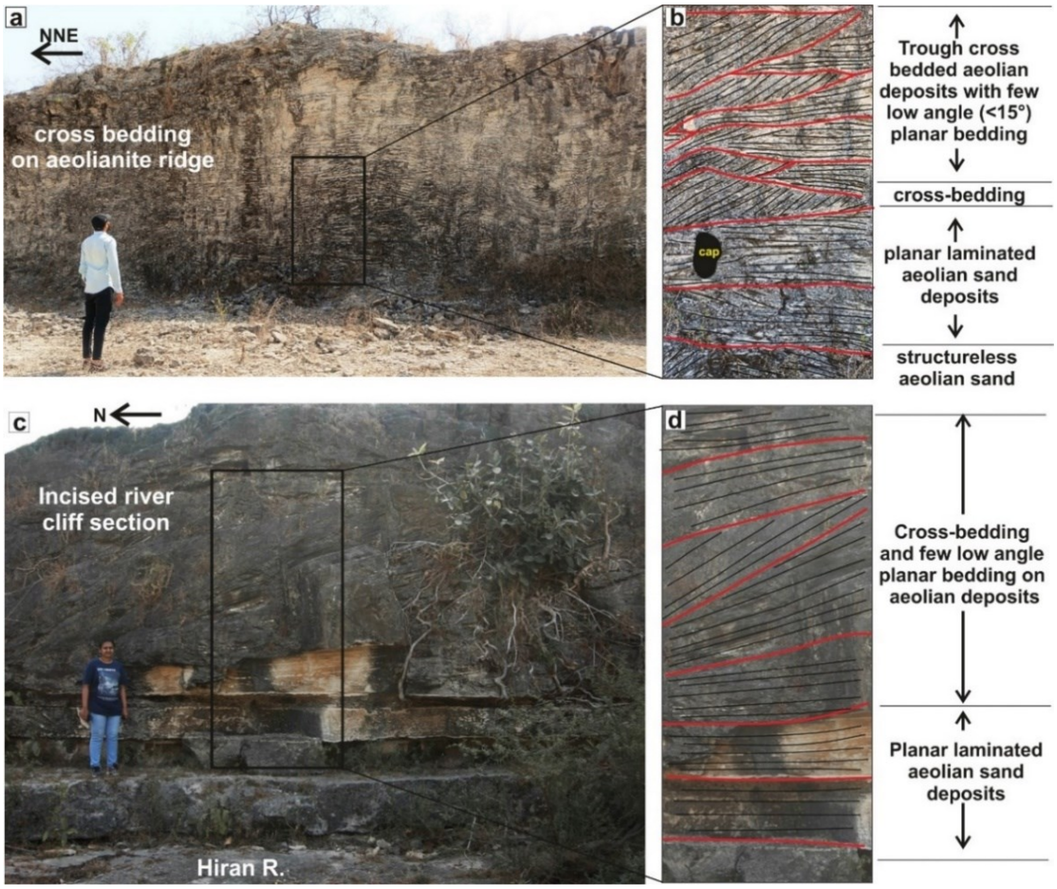


**Figure 9.10** a) Aeolianite ridge observed near Umrethi Dam with prominent cross bedding, trough bedding and planar stratifications. Note the well preserved bedding structure. b) Interpreted section of the ridge showing cross-bedded aeolian sand deposits. Red line indicate change in facies. A cap (20cm) is used as scale. c) ~15 m miliolite incision by Hiran River at Umrethi dam site showing prominent cross bedding and Planar bedding. d) Interpreted river cliff section showing prominent cross bedding in the upper unit and planar bedding in the lower unit. Note the comparison of the ridge morphology.

The innermost NW-SE trending coast parallel ridge exposed at few places, south of Umrethi Dam site. Few road cut sections were observed as maximum part of the aeolianite is either eroded by south flowing Hiran River or mined for the industrial purpose. The distinctive characteristics observed in one of the exposure, which was ~5 m high, is the cross-bedding. The aeolian sand deposits formed well-developed cross laminations, trough and low angle planar bedding (Figure 9.10). Several facies were noted with foresets, topsets and bottom sets. The aeolian fine to mediums and was observed throughout the ridge section. The well preserved cross-beddings are interpreted from a section of the ridge (Figure 9.10). The 5 m thick trough bedding and few low angle planar laminations shows NNE dip. The bottom of the ridge shows structureless fine to medium aeolian sand deposits. However, the lower unit of the interpreted section shows low angle planar bedding. Such morphology of the aeolianites is observed at few other places of the same ridge extension. This aeolianite is incised by the Hiran River at Umrethi Dam showing well developed cross stratification (Figure 9.10). The river incised up to ~15 m near dam site and the aeolianites are also observed with several foresets dipping NNE.

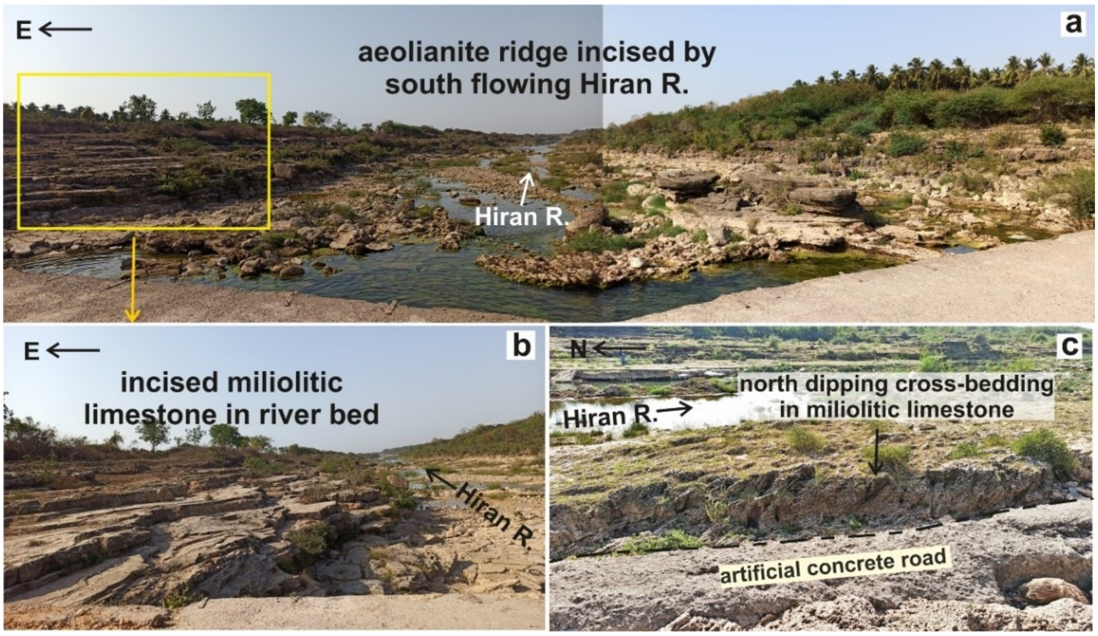


**Figure 9.11** Aeolianite ridge trending NW-SE exposed in the cliff sections and channel bedrock of Hiran River. a) river incising aeolianite ridge up to ~10m. Note the aeolianite ridge observed at either side of the main channel. b) Close view of the cliff section showing terrace like structure formed due to the channel erosion. c) Channel upstream showing prominent northward dipping cross-bedded miliolite deposits.

Another ridge running parallel near the sharp right angle river bend of southward flowing Hiran River (Figure 9.11). This ridge extends up to 18 km trending NW-SE in the study area. The miliolitic limestone shows varied characteristics and morphology from the innermost ridge to its north. The beds are greying to light yellowish colored limestone with faintly developed laminations. The best exposures are observed at the river cliff sections incising the aeolianites forming channel valleys. The width of the ridge is approx. 1.5 km incised by the main channel. The sharp meandering of the river is due to the presence of the ridge. The aeolianites observed are hard, compact and deposited sheet like structures with poorly preserved cross bedding structures (Figure 9.11a, b). The ridge exposed in the cliff sections towards downstream shows very gentle southward dip. However, channel upstream shows northward dipping cross-bedded miliolitic limestone (Figure 9.11c). Towards the east of the river, the maximum area has been mined out by the locals and for the industrial purposes. This resulted in the exposure of underlying Tertiary deposits at few places.

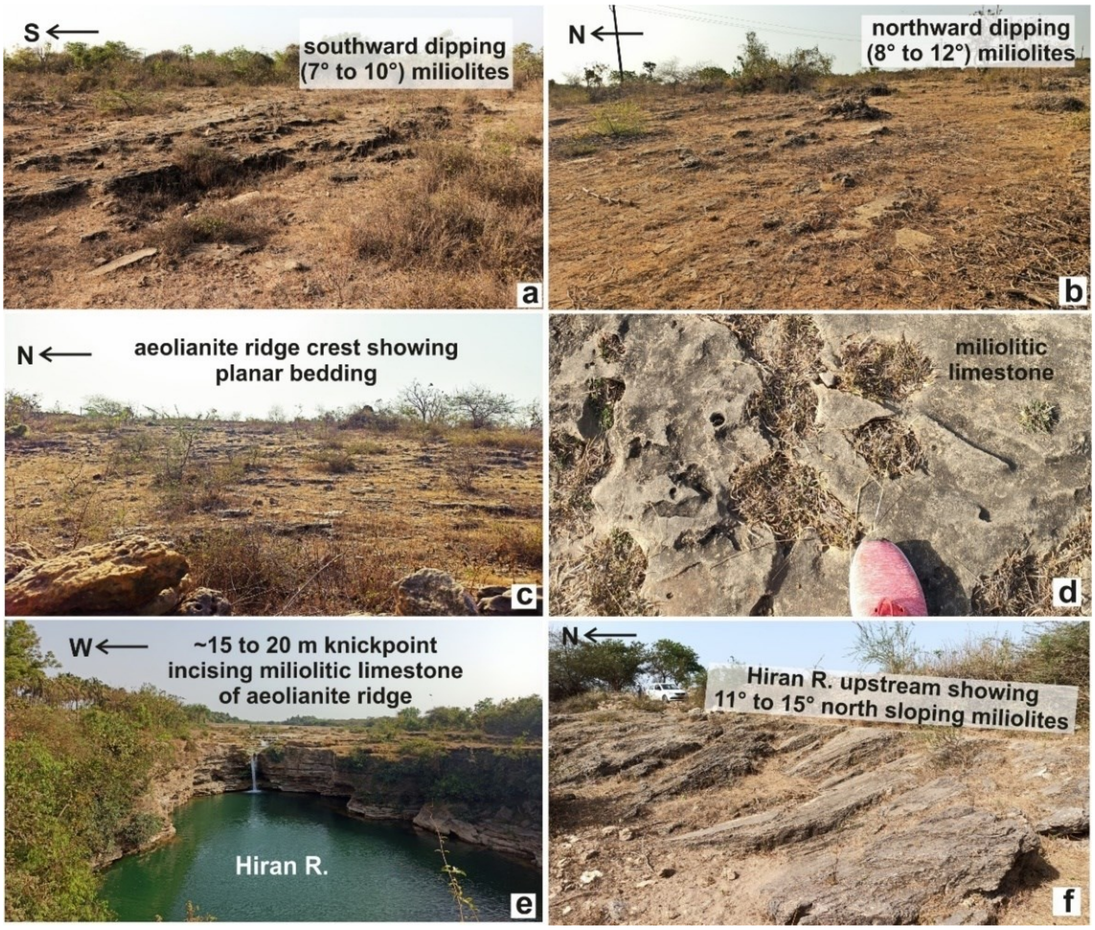


**Figure 9.12** Aeolianite ridge trending NW-SE incised by south flowing Hiran River. a) Southward dipping (7° to 10°) miliolite beds. b) Northward dipping (8° to 12°) dipping beds covered by alluvial deposits. c) Ridge crest showing very gentle southward tilt with planar laminations. d) Close view of the miliolite deposits over the horizontal surface. e) Miliolite deposits incised by Hiran River forming 15 to 20 m high waterfall retreating aeolianite ridge towards north. f) Northward dipping (11° to 15°) miliolitic limestone beds. Note the northward slope is steeper than the southward slope of the ridge.

The outermost coast parallel aeolianite ridge trending NW-SE shows good exposure along the ridge and in the river section. The northward gentle slope and southward very gentle dip showing leeward side and windward side respectively. The aeolianite beds dipping southward of this ridge shows 7° to 10° slope (Figure 9.12a). The ridge extending northward shows 8° to 12° aeolianite beds dipping towards north (Figure 9.12b). The ridge crest shows planar bedding with very gentle southward dip i.e., the windward side of the aeolian sand deposits (Figure 9.12c). These aeolianites are lithified and the crossbedding is not well preserved. However, the horizontal surface of the bedding shows greyish hard limestone beds with few joint patterns (Figure 9.12d). The ridge incised by the Hiran River near Savni shows ~ 15 to 20 m high knickpoint (Figure 9.12e). The knickpoints must have retreated from the southern slope towards north. The waterfall is near the ridge crest with southward tilting low angle planar beds observed on the cliff section. Towards the upstream of this fall, the miliolite beds shows >12° northward dips indicating the steeper lee ward side of the aeolian dune deposits (Figure 9.12f).

### 9.5 MORPHOSTRATIGRAPHY

The miliolite samples from Hiran valley ranges from 56.8 to 190 kyr BP associated with the presence of early man of lower Paleolithic cultures (Baskaran et al., 1986). These samples are mainly taken from the river valley irrespective of the morphostratigraphy. However, later, some samples were dated from the coast parallel ridges observed in the southwest Saurashtra inferring tectonic instability (Baskaran et al., 1987). As these chronological data gave results about coastal tectonics and depositional history, Baskaran et al., (1989) dated all the miliolites exposed at the shore and inland region. Three phases of miliolite deposits were established by these ages i.e. 50-70 kyr, 75-115 kyr and 140 to 210 kyr BP (Baskaran et al., 1989) which later linked with the sea-level data (Moore, 1982; Somayajulu et al., 1985). The miliolites were characterized and described based in its depositional environment, sedimentology and geomorphic setting (Chakrabarti et al., 1993). These miliolite categories include coastal plain deposits, inland valley fill deposits and blanket deposits. Sharma et al., 2017 dated the miliolite categories viz., shell limestone, fluvially reworked and inland and coastal aeolianite showing age range from 165 to 44 kyr BP, 75-17 kyr BP and 80-11 kyr BP respectively (Sharma et al., 2017).

In the present study, aeolianite ridges were identified with the help of DEM analysis and detailed field exploration by perceiving its morphological characteristics. Due to anthropogenic activities, many important Quaternary sites has been mined changing the present day geomorphic setting. However, the field investigation gave several evidences in the river cliffs and coastline that helped in generating the morphostratigraphic units in the study area (Table 9.1). The miliolite deposits showing aeolian origin, fluvial origin and marine origin were previously studied and dated few sites. The chronology of the Quaternary deposits are ranging from 235 kyr BP up to 11 kyr BP. These dates are classified into two time range for the present study, deposits younger than ~125 kyr and older than ~125 kyr BP (Table 9.1). However, the chronological data for the samples collected for present study was not done unfortunately. The morphostratigraphy of the miliolite deposits for the present study was made to understand the formation of various miliolite deposits during Quaternary period (Table 9.1).

**Table 9.1** Morphostratigraphy of the Quaternary miliolite deposits observed in the present study area.

| | **Field characteristics** | **Approx. time range** |
|---|---|---|
| **Dune shaped miliolite** | Light yellowish to creamish outcrop, fine to very fine and very well sorted aeolian sand, small barchans shape dune deposits, scarce vegetation cover, well preserved cross-bedding, mostly eroded and mined out | **younger than ~125ka** |
| **Valley-fill/sheet miliolites** | Grayish to creamish medium grained poorly sorted aeolian sand, fluvially reworked sediments, planar laminations overlying the cross-bedded aeolianite ridges, mostly observed along river sections | |
| **Aeolianite ridges** | Grayish to creamish dune shaped ridge with one steep slope landward and one gentle coastward slope, fine to medium grained well sorted aeolian sand deposits, cross-bedding, low angle planar bedding and trough cross-stratifications observed, several depositional facies, prominent northward dipping foresets | **older than ~125ka** |

The chronological data of Quaternary miliolites covering in the present study area were integrated (Table 9.2). The aeolianite ridges are the oldest miliolite deposits by aeolian processes. The valley-fill deposits or sheet miliolites are observed widespread over the pediment surface. These deposits are well exposed in the river sections. However, valley-fill miliolites are dated older than ~125 kyr BP. The miliolite dune field is observed only near the Machundri and Rawal river basin at the buried pediment zone. Few such deposits are also observed in patches towards west and are either eroded or mined out at several locations. These deposits are the youngest aeolian deposits observed in a dune field area near Una town. These are also called inland aeolianites and dated younger than 35 kyr BP (Sharma et al., 2017).

**Table 9.2** Table showing the chronological data of Quaternary miliolites covering the present study area.

| Location | age (kyr BP) | Environ-ment | Reference | Approx. time range |
|---|---|---|---|---|
| Una-Kodinar road, Quarry section, Base of upper unit | 11±1 | Inland aeolianite | Sharma et al., 2017 | **younger than ~125ka** |
| Una-Kodinar road, Quarry section, Base of lower unit | 20±1 | Inland aeolianite | Sharma et al., 2017 | |
| Una | 29.5±1.3/1.2 | | Baskaran et al., 1989 | |
| Una | 33.4±4.0/3.9 | | Baskaran et al., 1989 | |
| Between Diu and Verval | 37.5±2.7 | | Baskaran et al., 1989 | |
| Phudam village, 5m amsl | 45±3 | Aeolianite | Sharma et al., 2017 | |
| Damn site Hiran river, lower part | 48±2 | Aeolianite | Sharma et al., 2017 | |
| SR-1 | 52±3.2/3.1 | | Baskaran et al., 1987 | |
| SR-3 | 55.2±3.3/3.2 | | Baskaran et al., 1987 | |
| Umrethi dam site, Hiren river | 65.4±3.6/3.5 | Marine? | Baskaran et al., 1986 | |
| SR-3 | 65.4±5.5/5.2 | | Baskaran et al., 1987 | |
| Una | 69.0±5.7/5.4 | | Baskaran et al., 1989 | |
| Jafarabad | 78.7±6.3/5.9 | | Baskaran et al., 1989 | |
| Between Diu and Verval | 80.8±6.4/6.1 | | Baskaran et al., 1989 | |
| Sasan, Junagadh road | 91.8±12.2/11 | Aeolian | Baskaran et al., 1986 | |
| Talala | 96.5±7.5/7.0 | Marine? | Baskaran et al., 1986 | |
| SR-3 | 99±16.1/14 | | Baskaran et al., 1987 | |
| SR-1 | 112±9/8 | Marine | Baskaran et al., 1987 | |
| Diu, Nayda caves, upper part | 126±12 | Aeolianite | Sharma et al., 2017 | **older than ~125ka** |
| Umrethi dam site, Hiren river | 142±16/14 | Marine? | Baskaran et al., 1986 | |
| SR-2 | 142±26/21 | Marine | Baskaran et al., 1987 | |
| Damn site Hiran river, upper part | 150±12 | Coastal sheet | Sharma et al., 2017 | |
| Badalpur | 158±32/34 | Marine? | Baskaran et al., 1986 | |
| SR-2 | 168±22/18 | | Baskaran et al., 1987 | |
| Ghantwad, upper part, Singwada river section | 174±12 | Fluvially reworked | Sharma et al., 2017 | |
| SR-4 | 177±19/17 | | Baskaran et al., 1987 | |
| Diu | 178±41/28 | | Baskaran et al., 1989 | |
| Umrethi dam site | 190±29/22 | Marine? | Baskaran et al., 1986 | |
| SR-4 | 204±35/26 | Marine | Baskaran et al., 1987 | |
| SR-4 | 235±36/27 | Marine | Baskaran et al., 1987 | |