CHAPTER 4
MODE OF OCCURRENCES

General

The study area was investigated using Survey of India topographic sheets No.41E/3, 4, 7, 8, 11, 12, 16, 41A/12, 16-B3, 41F/1 and 5 along with SRTM-DEM and ISRO, Department of Space maps on 1:50,000 scale and the physiographic relief and drainage map was prepared to appreciate their controls on the mode of occurrences of Miliolites in the study area (Fig. 4.1). On the basis of field study detailed documentation of the Miliolite occurrences in the study area was prepared and that forms the part of this chapter. Detailed documentation on substrate geology, sedimentary body geometry, physical structures, etc. was attempted from four windows viz., Gangeswar area(GA), Fakirwadi area(FA), Kotda-Roha area(KA) and Varli area(VA). In total 32 logs were prepared in the field and the lateral extent of miliolite sequences were traced. Based on this information the miliolite occurrences were classified (O- obstacle, V- valley fill and F- fluvial reworked) and evaluated in terms of its signatures in landscape evolution along the Katrol Hill Range (KHR). More than 100 samples (prefix-GR,FR,KR and VR) were collected from the study area for further laboratory studies that are described in the next chapter.

Style of Miliolite deposition

The Late Quaternary carbonate deposits (Miliolite) occupies various physiographic levels in the Katrol Hill Range, and occurs in a patchy manner lying over the substrate of either Mesozoic rocks or buried colluviums developed over it. These were documented from various localities of the study area and are described in detail in this chapter. Based on the mode of occurrences, sediment body geometry, physiographic level and nature of sediments, three distinct types of mode of occurrences were recognized viz., Type-I Obstacle dune deposits, Type-II Valley fill deposits and Type-III Fluvial reworked sheet deposits (Fig.4.2).

The Type-I deposits are characterized by a typical triangular geometry resting unconformably on the slopes of the Katrol Hill Range. The substrate rocks are mainly shale and sandstone of the

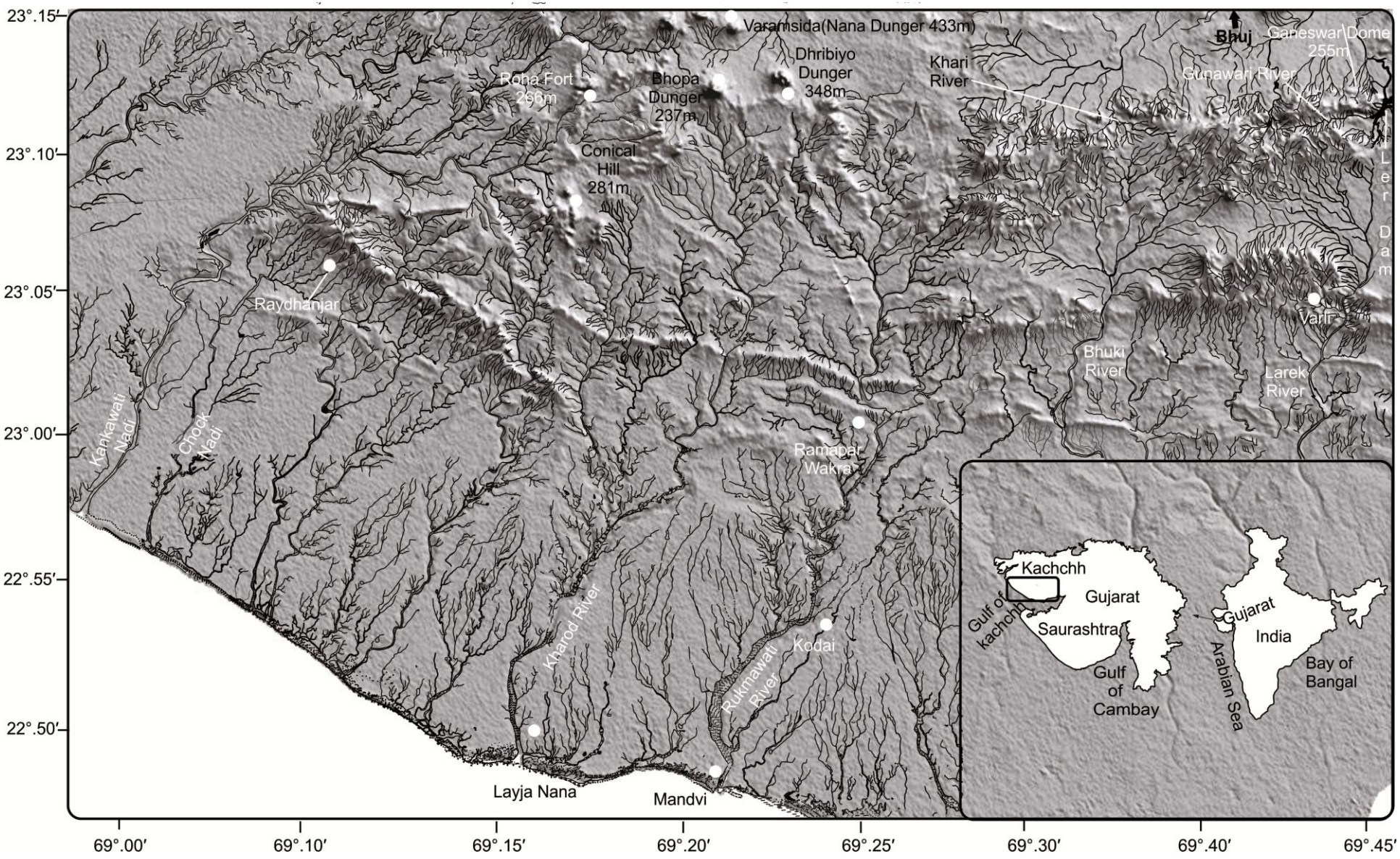

Fig. 4.1 Relief and drainage map of southwestern Kachchh.

Jhuran and Bhuj Formations. In some places, the Deccan Trap Formation basalt hills have also provided obstacles. Type-II deposits are occupying the rocky amphitheatres and valleys associated with these hills, probably as slope wash during the onset of wetter phases. The type-III is secondary reworked deposits of pebbly, gravelly mixed carbonate sand that also contain pebbles of earlier deposited Type-I miliolite. These are younger and have been thought to be deposited by seasonal fluvial activities in Holocene time.

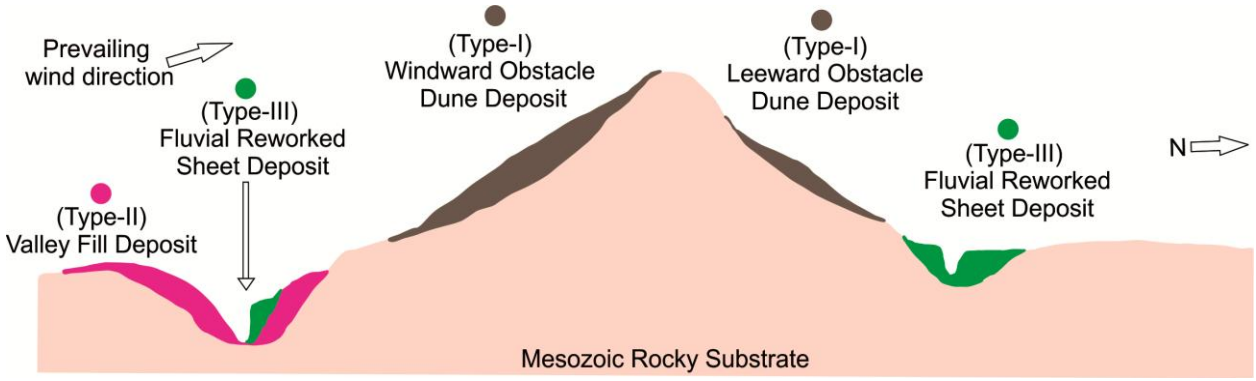

Fig. 4.2 Three principal types of miliolite occurrences in Kachchh.

Type-I Obstacle Dune Deposits

In general the obstacle dune deposits are found on the slopes of the KHR, both on southern and northern direction. However, the deposits on the southern slopes are relatively thicker and more prominent. Based on whether they occur on windward (southern) slope or leeward (northern) slope of the hill, these deposits are further classified as windward deposits and leeward deposits respectively, after Patel and Allahabadi (1988). These deposits are containing medium to fine grained, moderately to well sorted grains of carbonate sand exhibiting distinct large scale aeolian cross beddings and tear drop body geometry.

Type-II Valley Fill Deposits

The valley fill deposits are found occupying depressions in the hills and rocky amphitheaters. Extensively deposited along river valleys and flood plain area, they occur at lower physiographic levels and are incised to some extent by first and second order streams. At its base they have either a sharp contact with the substrate or overlie the colluviums extended from the slopes towards the valley. The deposits are consisting of thick pile of friable miliolitic sand which is

fine to medium grained and dirty white to reddish cream in colour. These are moderately sorted fine grained deposits that do not exhibit prominent sedimentary structures.

Type-III Fluvial Reworked Sheet Deposits

The stratified sandy sheet of impure miliolite deposits containing gravels and pebbles pointing towards its fluvial deposition are recognized as the fluvial reworked sheet deposits. Fluvial reworked sheet deposits found extensively along river a valley. The sheets comprise of horizontally well-stratified sediments, presence of gravel rich layers and pebbles, fluvial sedimentary structures such as small scour and fill, cross bedding and large clasts of Mesozoic rocks pointing towards its fluvial deposition and initiating of monsoon. These are younger and have been thought to be deposited by seasonal fluvial activities in Holocene time.

Gangeswar Area (GA)

The Gangeswar area of about 15 sq. km. was investigated that lies on the eastern part of the KHR between latitudes 23°.10' to 23°.12'N and longitudes 69°.41' to 69°.46'E (Fig. 4.3). The Gangeswar dome 263m is situated in the south of Madhapar village (Bhuj). It is part of the KHR. From flat terrain suddenly topography rises to an elevation of nearly 120m from the Northern flank of this dome where the temple of Gangeswar Mahadev is situated.

The Gangeswar dome is mostly covered by the Bhuj sandstones which are showing radial dipping nature. These sandstones are cross bedded, at places showing herringbone cross beddings and also patches of oysters indicating its deposition in the inter tidal areas. A Doleritic dyke belonging to the Deccan Trap Formation could also be seen in the southwestern part of the study area. It is quite conspicuous and runs for about 3 km length.

The Gunawari Nadi, which is a tributary of the Khari river, originates in the KHR in the upper reaches, between the northern Satpura and the southern Marutonk domes (~265 m amsl). The river flows through a gorge in zigzag course and after crossing the doleritic dyke the river becomes straight and the valley becomes relatively wide following the E-W trending KHF (Fig. 4.3).

In Gangeswar area several marked locations were studied starting from northern fault scarp, Gangeswar dome, and southern catchment slope toward Gunawari river, complete river course from upper part of dyke to Ler dam and southern portion of Gunawari alluvial plain was

investigated. Accordingly, at six locations the obstacle dune deposits at three locations the valley fills and at seven locations the reworked fluvial sheets were examined and documented (Fig.4.3). Vertical lithological logs were prepared from each location and were compared with the general physiographic profile of this part of the KHR (Fig. 4.4).

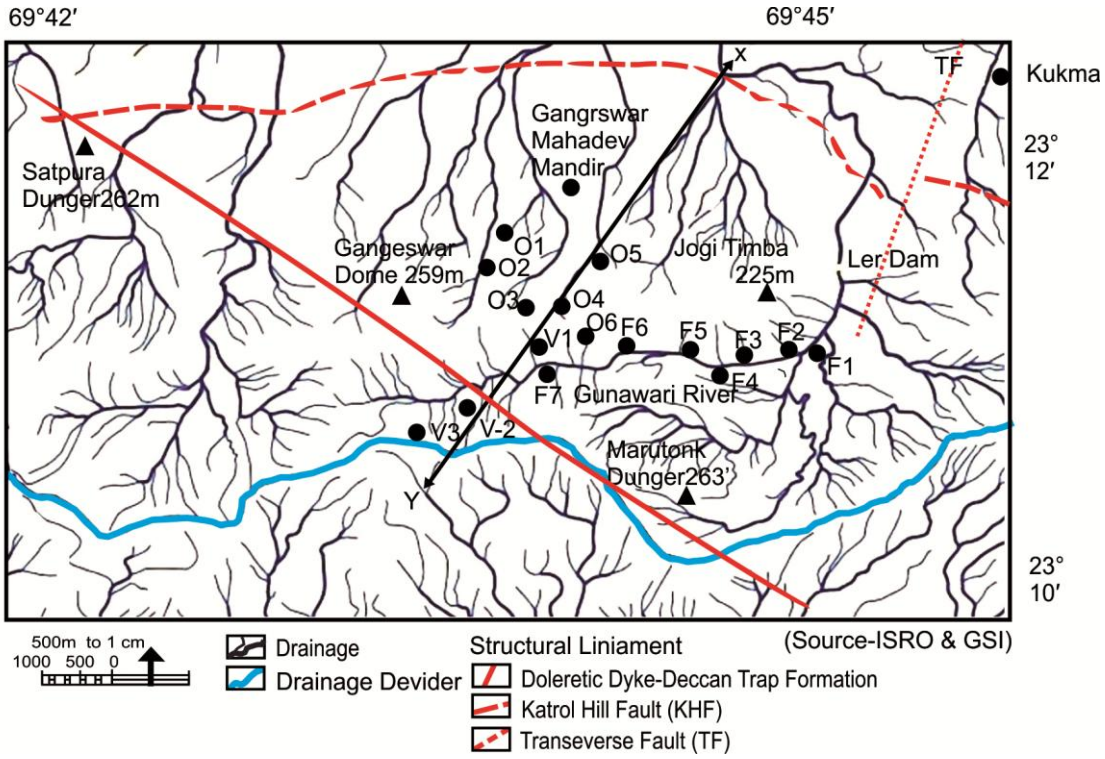

Fig 4.3 Map showing the locations of field occurrences studied and its reference with the local drainages in the Gangeswar area (GA). O- obstacle dune deposits, V- valley fill deposits and F- fluvial reworked sheet deposits.

The area constitutes a part of Katrol Hill scarp on its north where it exposes ammonite bearing fossiliferous shale unit of the Jhuran Formation that abuts against the sandstone of the Bhuj Formation. On its southern part dissected hills of sandstone and shale are seen that are overlain by the miliolite obstacle dune deposits with erosional base. These are mainly windward dune deposits and attain thickness of maximum about six meters, as seen in abandoned quarries. Near to the Gangeswar temple such occurrence could be seen as 3m thick planer cross-bedded unit of miliolite showing porous nature. Moving towards the south before entering in to the Gunawari river valley the dirty white colour, nearly homogenous, friable deposits of miliolite occur filling the ancient valley that is being drained by the present Gunawari river. This valley fill deposit of friable miliolite has a thickness of about 10m in the central part of the rocky amphitheatre that

thins out to 2-3m towards the Gunawari river stream. The reworked fluvial sheets of impure miliolite occurs intercalated within a sequence of about 5 to 8 m that consists 1 to 2 m thick layer of compact clay resting over weathered ferruginous sandstone of Mesozoic age that is overlain by 1 m thick coarse sand and gravel mixed miliolitic layer which in turn is overlain by 1.5 m thick silty clay layer which is capped by slope derived colluvium. Site specific detailed description is given in the following text that has a reference to Figure 4.4 for the relative litho logs.

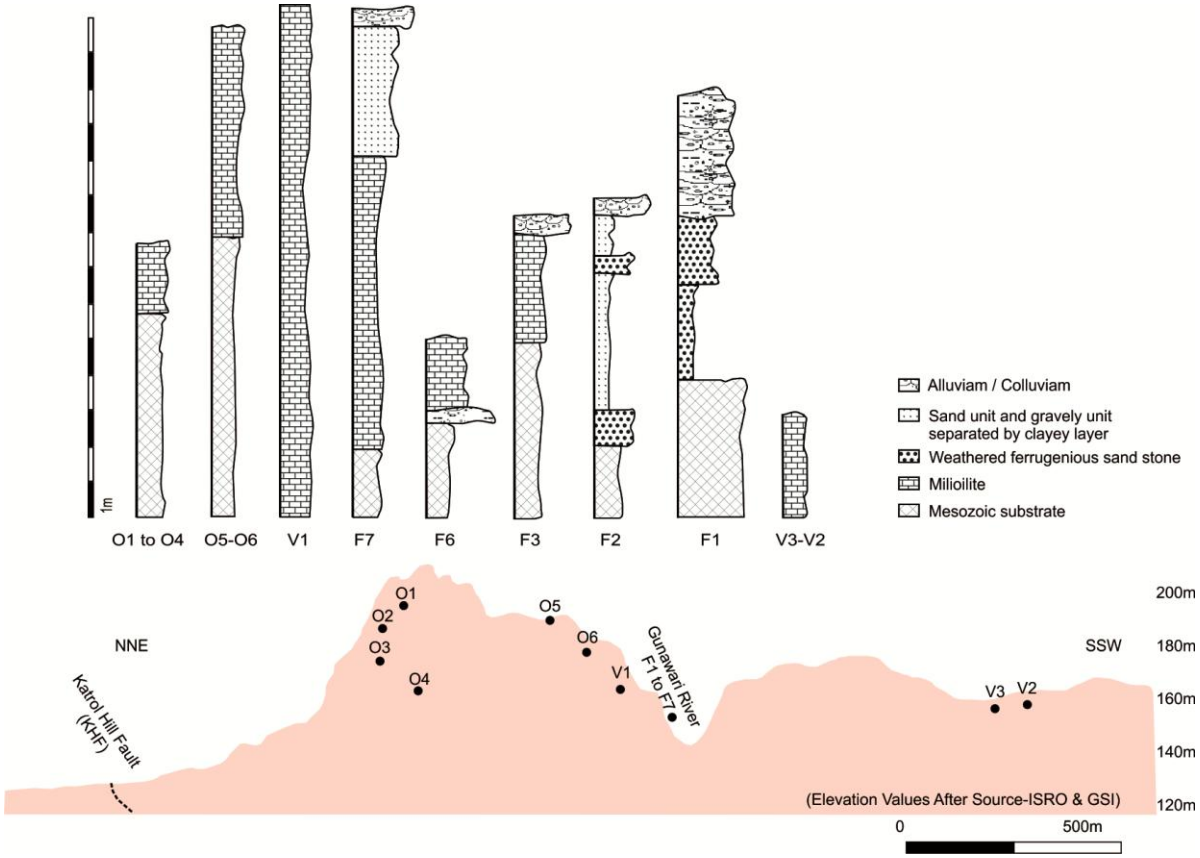

Fig.4.4 Vertical litho-logs from the Gangeswar area depicting the stratigraphic relationships between the miliolite units and associated younger alluvium / colluviums and older Mesozoic rocks. The profile shown in the lower part of the figure indicates positions of various logs, and is drawn along X-Y direction shown in figure 4.3.

O1 to O4

South of the village Madhapar a prominent physiographic high manifests the Katrol Hill Fault scarp. On crossing this scarp near the Ler dam miliolite occurrences starts appearing near to the base of the hill. These are friable and of detrital mixed nature, whereas on the southern slope at higher level typical obstacle dune deposits attain a thickness of about 2 to 3 m and are relatively

compact. Near to the northern flank of the hill southwesterly dipping cross-bedded dirty white coloured miliolite could be seen showing hard surface due to the effects of meteoric water (Fig. 4.5a). Here the bedding plane attitudes are N178°E / 13° due west. Near to this another occurrence showed compact miliolite with a limited thickness that shows the bedding plane trends N10°E / 9° due south. On the southwest side of the dome about 3m thick miliolite occurrences were seen which are being excavated out for local road making purpose. These are cream to pinkish white in colour showing subdued cross stratifications and appear relatively friable in nature (Fig. 4.5 b). Due to the effects of weathering the exposure surface of miliolite appears dark matt black and thus provide an easy criteria to recognize them in the field.

O5 and O6

From Gangeswar temple to southward a typical bowl like or rocky amphitheatre morphology is seen. A semi circular arrangement of hills becomes clearly visible from this point. About 500m from temple in the central depression, typical obstacle deposits of miliolite can be seen. The miliolites are quite friable in nature; upper layer appeared matt blackish due to weathering while cutting the same looks yellowish in colour, very well-sorted grains are dominantly fine to medium sand size and well-rounded. A typical bedding plane trends is along east-west with dip amounts 18° to 25° due south. This occurrence of miliolite extends south ward on the slope of western flank of Gangeswar dome for about a kilometer or so. On the eastern flanks of the rock amphitheater steep slopes do occur, but the author couldn't trace miliolite occurrence on the sides.

Fig. 4.5 (a) O1a- Obstacle miliolite deposit, KHF scarp. **(b)** O1b- Elephant's skin weathered structure. **(c)** O3- Miliolite overlain south west dipping sandstone. **(d)** O4- Patchy obstacle deposit of miliolitic sand, buff yellowish to reddish in colour along with platy block of sand stone, excavation site Southwest. **(e)** V1-About 20 to 25m thick pile of loose valley fill Miliolitic sand, North to Gunawari river. **(f)** V3- Loose valley fill miliolitic sand on plain terrain of southern range of KHR.

Fig.4.6 (a) O5- Patchy deposit of miliolite on rocky amphitheatre, GD,259m **(b)** Aeolianite non conformably rests on an erosional surface (**c)** O11- Valley fill, Khari River Catchment. **(d)** V5- Loose valley fills Khari catchment.

V1-V3

The terrain of Gangeswar is undulating and the south facing hill giving ample opportunity for windward obstacle deposition characterized by its sediment body geometry as well as sedimentary structures like planer tabular and wedge shape cross stratification and well sorted nature. About 200m north to Gunawari river behind F7 location (Fig. 4.3), about 20 to 25m thick

pile of valley fill miliolite sand excavation site was seen. The excavation has exposed deposit of friable nature having fine to medium sand size grains, buff dirty white to yellowish cream colour and almost physical structure less appearance (Fig. 4.5 d & e). Thick valley fills were deposited through down slope transport of the miliolitic sand and reworked gravels as fluvial sheets deposit mixed with the local lithoclast.

The southern valley of Gunawari river is situated between two hill ranges; northern is Gangeswar dome and the southern Sudhera village hills. This depression is full of loose miliolitic sand deposited in the upstream of Gunawari. Local farmers have made a little earthen dam on catchment stream for irrigation purpose. The thickness of the valley fill Type-II miliolite is ranging from 3 to as thick as 15 m and the bedrocks could not be encountered at its base at any site that was studied.

F1

Gunavar river is a seasonal river that drains only during monsoon to drain the rain waters, however, it has incised up to about 12 to 15 m to expose the sections of bedrocks and miliolite along with the overlying colluvial material (Fig. 4.4). After Ler dam further to west towards upstream, on southern flank a cliff of about 12 m height was studied. From its top to bottom four main units were noted. Unit I is about 3 to 4 m thick at the top and is consists of alluvium-colluvium deposit. Unit II is 2 m hard weathered brownish ferruginous sandstone with loosely clayey materials. This is underlain by the Unit III which is about 2.5m thick consisting of hard brownish-yellowish-fossiliferous (Ammonite bearing) weathered sandstone. Bottom of 3.0 m thick Unit IV comprises Mesozoic bed rocks (Fig. 4.4).

F2

On the northern flank towards upstream a cliff section of 10 m mostly consisting of sandy, gravely and clayey unit was recorded. The upper most part Unit-I is around 0.5 m thick and is of clayey alluvium material capping a 1.5 m thick Unit-II that comprises of massive alluvium stratified sand and gravels. This is separated by pedogenised clayey silt layer from the below lying Unit-III of 0.5 m thick brownish sandstone dipping south ward. This is underlain by 3-4 m thick Unit IV that comprises of weathered sandstone. This is further underlain by about 3 m thick another layer of sandstone which is underlain by hard Mesozoic substrate with about half a meter

thick layer of conglomerate. The sandstones are dipping towards south with dip amount 10°to12°.

F3

Further in the upstream, a cliff section on northern flank of the Gunavari river near to a junction with another southerly flowing stream about 9 m thick section was measured. Here about 3 m thick miliolite unit is unconformably resting on south dipping Mesozoic sandstone that attains a thickness of about 5 m (Fig. 4.4). The upper part of the miliolite is covered under about a meter thick alluvium layer. The miliolite unit is friable and crudely horizontally bedded that contains scattered pebbles and gravels of the sandstone.

F6 and F7

Further upstream towards west on northern bank of the river a section of about 5 m was encountered that outcropped 3 m of the bedrocks overlain by about 2 m thick Type-III miliolite with 0.5 m thick layer of fluvial gravels and pebbles. Further west near to a location where basalt dyke is crossing across the river channel, about 14 m thick section (Fig.4.7d) section has exposed a unit that contains several layers of the fluvially reworked sheets of miliolites (Type-III). Earlier Bhattacharya et al (2014) has described this with several sub facies and measured OSL ages of the intervening sandy units that ranges from 7.8 to 11.8 ka. The present author has considered the total thickness of 8 m of this unit a Type-III miliolite unit due to its fluvial nature and miliolitic sand composition in it. The miliolite unit is overlain by about a meter thick alluvial-colluvial material. To summaries, the Gangeswar area constitutes a part of Katrol hill scarp on its north side where it exposes ammonite bearing fossiliferous shale unit of the Jhuran Formation that abuts against the sandstone of the Bhuj Formation. On its southern part dissected hills of sandstone and shale faces are seen that are overlain by the dune deposits with erosional base. These are mainly windward dune deposits and attain thickness of maximum about six meters, as seen in abandoned quarries. Near to the Gangeswar temple such occurrence could be seen as 3 m thick planer cross-bedded unit of miliolite showing porous nature. Moving towards the south before entering in to the Gunawari valley the dirty white coloured, nearly homogenous, friable deposits of miliolite occur as valley faces filling the ancient valley that is being drained by the present Gunawari river.

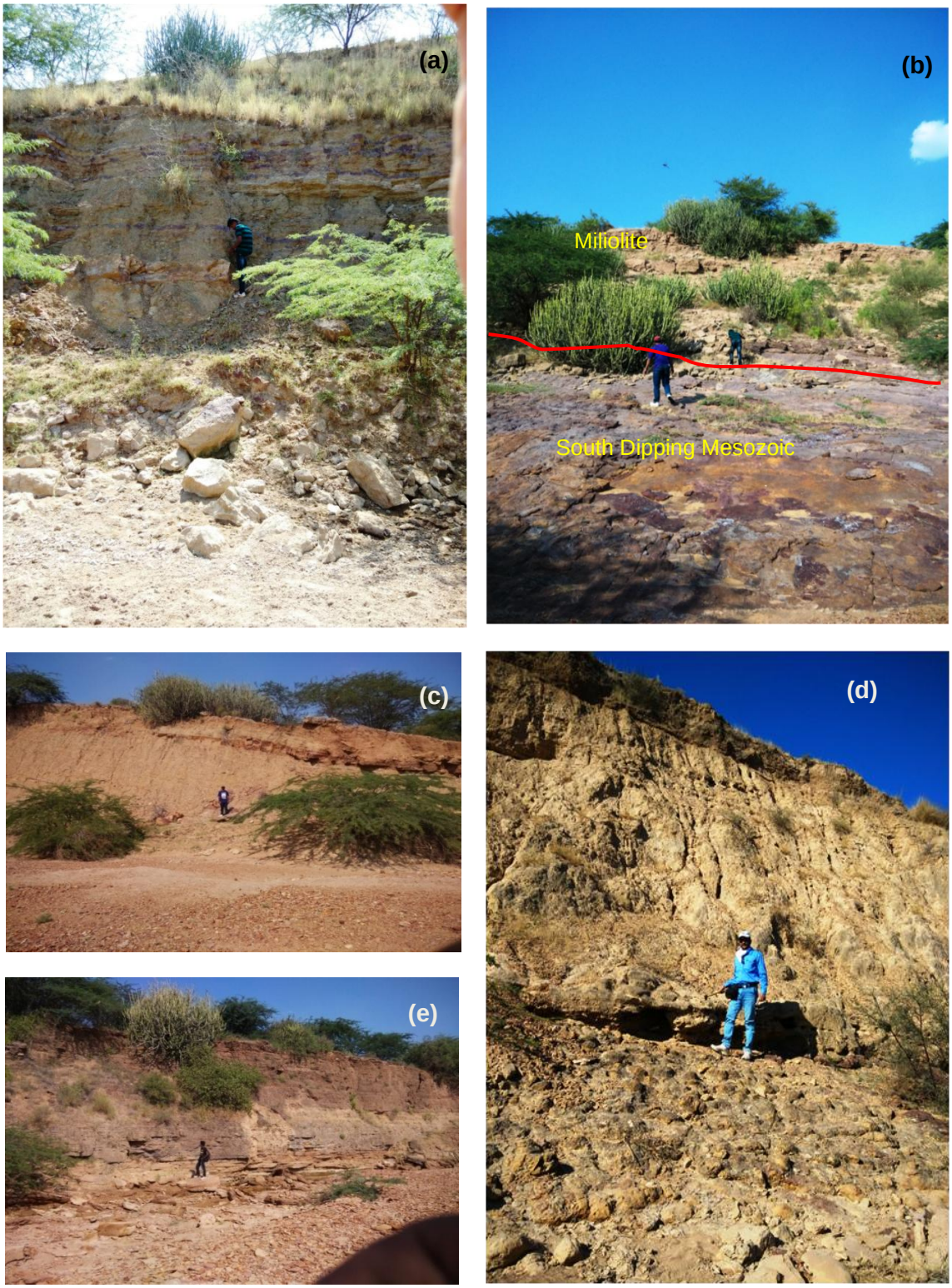

Fig 4.7 (a) F1- Ler Dam Basin-Downstream Gunawari river-Southern flank **(b)** F2- Gunawari Northern Flank **(c)** F3-Lithological contact between Miliolite and fossiliferous sst. **(d)** F7-Gunawari cliff-10m, miliolitic sand, near Gangeswar Mahadev **(e)** F10- Khari cliff, reworked fluvial sheet and valley fill miliolites.

This valley fill type is friable miliolite sand that has a thickness of about 10 m in the central part of the rocky amphitheatre that thins out to 2 -3m towards the Gunawari Nadi stream. The fluvial faces occurs intercalated within a sequence of about 5 to 8m that consists 1 to 2m thick layer of compact clay resting over weathered ferruginous sandstone faces of Mesozoic age. This reworked fluvial sheet of impure miliolite is overlain by 1 m thick coarse sand and gravel mixed miliolitic layer which in turn is overlain by 1.5 m thick silty clay layer which is capped by slope derived colluvium faces.

On the basis field study and over all lithologs of Gangeswar area suggest that mainly hosting three sedimentary facies which are scarp derived colluviam on top, miliolite facies in middle and to the bottom Mesozoic stratum of shale sand facies. Most of the miliolitic sand deposits are found stabilized below the erosional line in pre carved Mesozoic substrate. The patchy outcrops and pinch out of miliolite indicating more toward Eastern side of KHR.

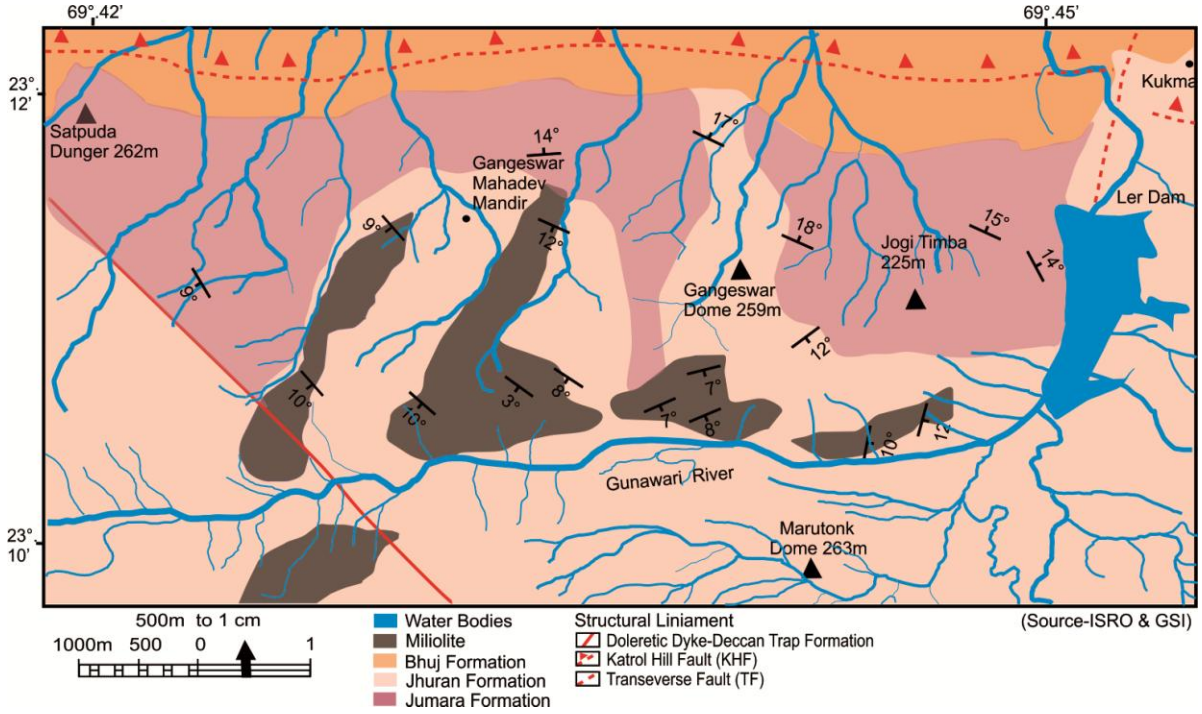

Fig. 4.8 Geological set up of Gangeswar area, KHR.

The youngest geological unit is that of the Miliolite Formation and overlying Holocene sediments. The Holocene sediments are found restricted to the Gunawari valley forming river bank cliffs of about 8 to 10m and consists of distinct units of gravel, silt and sand faces punctuated with thin bands of reworked miliolitic sand from the upslope area. These Holocene

young faces sediments are mostly medium to very fine grained, moderately sorted and fine skewed with mesokurtic to platykurtic grain size distribution. Figure 4.8 represents the local geological map prepared under the present study.

Fakirwadi Area (FA)

Fakirwadi dome is situated on the Bhuj-Mandvi road forming east-west aligned hill range (latitudes 23°10' to 23°13'N and longitudes 69°35' to 69°42'E). About 20-25 sq km area was investigated that largely forms the southern slope of the hill range and westerly to northwesterly dry river bed of the Khari river (Fig. 4.9). At this place the Katrol Hill Fault (KHF) separates the Bhuj Formation and the Jhuran Formation that largely constitutes the Katrol Hill Range. While climbing Katrol hill from Fakirwadi, the plain is consisting of the calcareous sandstone of the Bhuj Formation that on its top also exhibits ferruginous nature. On the ghat road side cuttings outcrop the sandstone-shale intercalated sequence of the Jhuran Formation that also consists gypseous bands. Locally fossiliferous shale and sandstone of Jumara Formation could also be seen. The miliolite occurrences are restricted to the southern and southwestern sides of the hill range (Fig. 4.9) and were studied along the Khari river valley.

The Khari river is a seasonal river, exists and flow through the transverse fault and merges at Banni. In the vicinity of hilly area of Bharasar dome and Fakirwadi dome large size of obstacle miliolite dune deposits support numerous quarries that are abandoned now. Khari river and catchment exhibits two types, fluvial reworked and valley fill miliolite deposits.

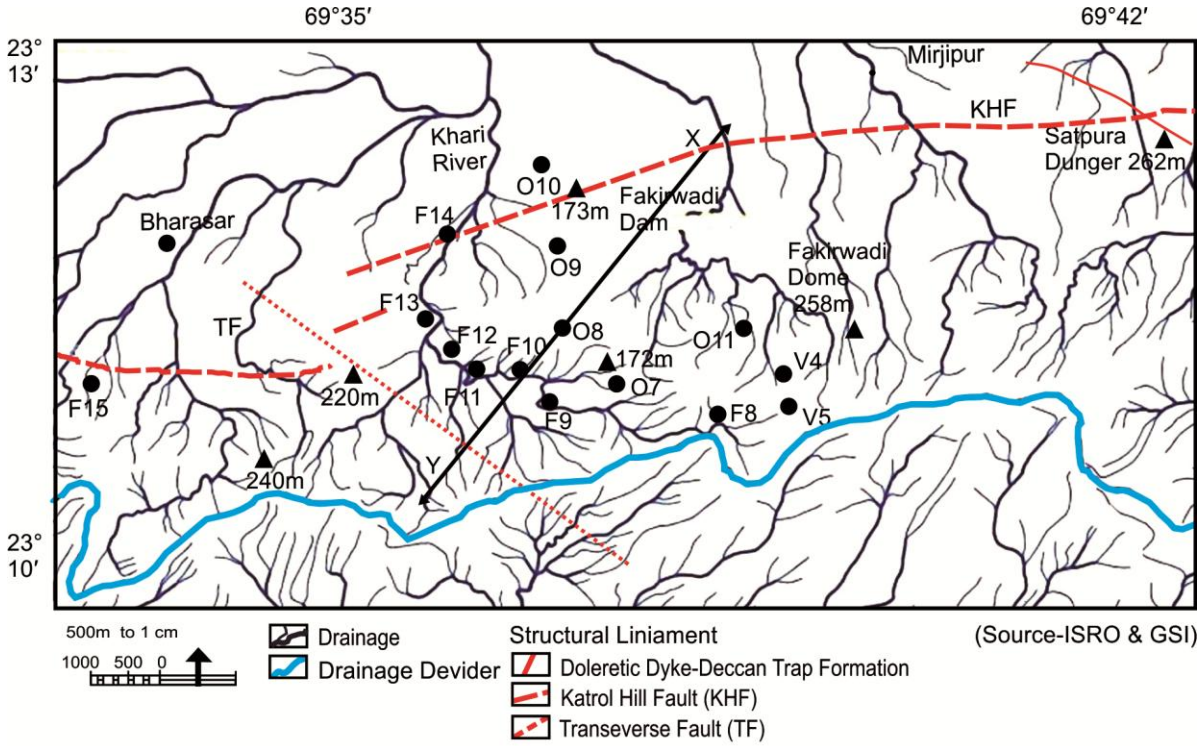

Fig. 4.9 Locations of the Fakirwadi area with reference to Khari river, KHR.

Like that of the Gangeswar area, in this area also detailed vertical exposed litho logs were recorded to understand the stratigraphic relationships between the miliolite and associated Quaternary sedimentary units (Fig. 4.10).

Several samples and photographs were taken from each location on the field traverses for further laboratory studies

O7 and O8

As stated earlier, on the southern side of the KHR many hollows and slopes are hosting medium to large size Type-I miliolite deposits having tear drop geometry constituting windward obstacle deposits. One such occurrence could be seen at a distance of about 1.5 km from the Bhuj-Mandvi road on its eastern side where about 10 m thick unit is seen in an abandoned quarry. Another similar outcrop was seen on further east of this place.

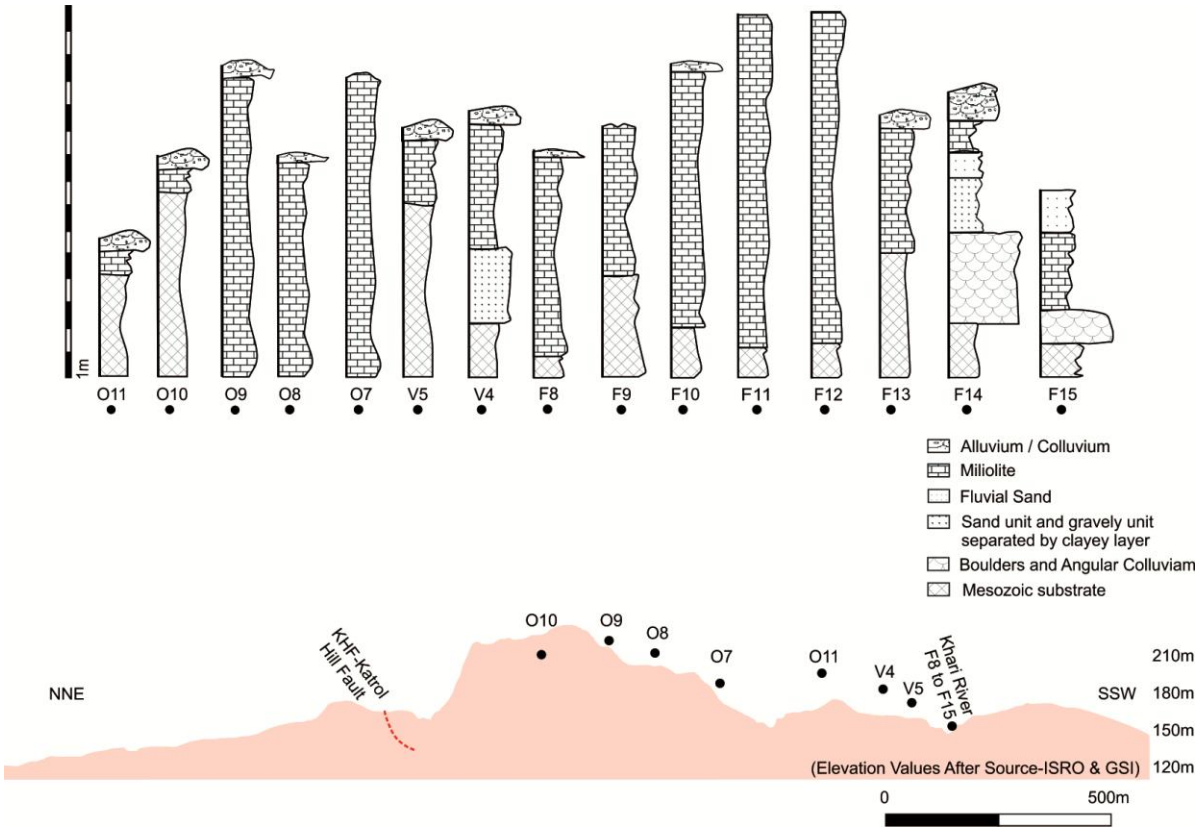

Fig.4.10 Vertical Profile FR high land of KHR, showing successive development of the erosional surfaces of Mesozoic stratum cross section is drawn along XY Lines shown in (Fig.4.9).

To reach this place is quite difficult, you have to move upstream and then traverse to eastward which is full of thorny vegetation with scrub about 2 km, you have to walk in knee bending position finding best narrow path. The quarry wall is more than 8 m in height that has exposed dark matt black in colour, compact miliolite showing southerly dipping planer cross-beddings (Fig. 4.11 a). The upper 1 m of the unit has numerous solution channels and vugs indicating the effect of the meteoric water weathering. Overall the rocks are dipping at 25^{o} towards southwest.

O9

On the Bhuj-Mandvi road side on southwestern slope of the hill range, an abandoned quarry was examined that has a thickness of 10 to 12m of Type-I miliolite (Fig. 4.11 b). The miliolite is typically yellow cream in colour and medium grained nature with some coarse grained laminations. The cross-stratification is although not conspicuous, but can be seen in faint forms again indicating southwesterly azimuth directions. A chunk of about 20x20x30 cm was collected for the purpose of OSL chronology.

Interestingly, in this quarry few lenses of angular gravels and pebbles of the country rocks could be seen having restricted extent. These must have been derived from the steep slope of the KHR as gravity fall. In places even small lenses could also been seen which might have been deposited by local down slope channels.

O10

In the Fakirwadi area where a gently rising slope start of the KHR on Bhuj to Mandvi road about 500 m, before the main cut section on the western side of the road, a low mound of miliolite could be seen; due to weathering upper surface became black. However, on close examination due to granular nature and off white colour, the miliolite can be easily identified (Fig. 4.11 c). The rock is showing gentle, tabular, planar cross-stratifications with prominent inclinations towards north. The thickness of the mound is 3-5 m and the width is about 500 m. The mound rests on slightly weathered Jhuran shale. On the same location nearby, in the stream the section of about 3 m exhibit Jhuran Formation characterized by belemnites-bearing lower clay units having its top of greenish and reddish sand unit.

O11

The extension of the main obstacle dune deposits could also be traced out on the fringes of the Khari river valley. One such occurrence of limited thickness of miliolite could be seen on its northern bank where about 1 m thick aeolian miliolite unit was found resting unconformably over the Jhuran shale unit having 2-3 m thickness. The miliolite unit is overlain by half a meter thick pebbly gravel unit. The trend of miliolite unit was noted as N 95°E /13° due south.

V4

The valley fill deposits (Type-II) are not very conspicuous in thickness in the Fakirwadi area, however they could be traced along the Khari river valley. Their present limited thickness could be due to the incision and erosion by the river stream. On southwest part of the hill in the Khari river stream about 6 m of exposed miliolitic sand unit was found that also contained thin layers of gravels and sandy silt.

Fig. 4.11 (a) O8-Abandoned Miliolite Quarry, 170 m at Khari catchment, Fakirwadi. **(b)** O9-Abandoned Miliolite subsurface Quarry,165m at Bhuj-Mandvi Road, Fakirwadi **(c)** O10- Fakirwadi mound, the rock are showing gently, tabular, planar cross-stratification, width prominent inclination towards North on an average. The thickness of the mound is 3-5m and the width is about 500 m. The mound rests on slightly weathered Jhuran Shale. **(d)** O10a-Fakirwadi Dome colluviam

V5

After crossing the undulating river catchment terrain, flat miliolitic sand sheet seen within thorny scrub vegetation in the flood basin plain. The area is about more than 100 m in width approaching main river towards eastern cliff. The miliolitic sand samples are checked dilute HCL acid test on spot at the site. It gives high effervescence. This valley fill loose miliolitic sand deposit thickness is estimated to be more than 10 m considering the pre miliolite ruggedness of the Mesozoic terrain.

F8

A prominent 8m thick miliolite deposit cliff on eastern side of river documented. It has vast extension. The thickness of sheet decreases towards further traverse to the north. The 4 m top unit is compact fluvial miliolite sheet deposit (Type-III), matt black in colour resting either directly on valley fill miliolitic sand unit or sandstone, and shows low angle cross beddings, lenses of gravels and pebbles, oriented flat gravels defining coarse stratifications (Fig. 4.12 a). Valley fill of about 4m thick which turn buff white yellowish in colour became compact and very hard due to water level during monsoon, difficult to take samples.

F9

Further downstream to northern side on the west-east flowing curve a cliff of about 12m thickness was observed. Top 6 m is constituted by compact fluvial miliolite sheet deposits with intercalated layers of sandy gravels and sand. The unit is seen resting over the Jhuran Formation (Fig.4.12 b).

F10

Following the same downstream towards the north, on the eastern side flank of the stream about 12m of thick cliff section could be seen. Almost top 5m layer is covered with fluvial reworked miliolite sheet deposit. Below 5 to 7m thick cover with valley fill miliolitic rocks, harden due to water level during monsoon had underlain 1 to 2 meters thickness Mesozoic unit. Also eroded miliolitic boulders from cliff lying on the bottom of the stream are seen.

F11

Along the river valley further toward northern traverse about 13 to 16m crescent shape exposed cliff section was seen on the southwestern flank of the river. The top layer of about 5 to 7 m is made up of fluvial reworked miliolitic sheet deposit, underlain by 2 to 5 m valley fill miliolite deposit along with white sand-gravel layers.

F12 to F15

Crossing the Bhuj-Mandvi road bridge and moving toward northeast direction, several cliff sections were examined. These are variously showing about 2-3 m thick Type-III fluvial miliolite sheets that are sharply resting over the Mesozoic sand-shale substrate (Fig. 4.10). The thickness of the unit is varying, largely controlled by the pre-miliolite topography and local incisions of the cliff. Interesting (F14) cliff section downstream of the Khari river dam near Bharasar village was studied earlier by Patidar et al. (2008) and Kundu et al. (2010) for the manifestation of the Katrol Hill Fault that traverses through the younger Quaternary sedimentary units too. Here deformed layers of fluvial miliolite units could be seen resting over the Jhuran shale units and are found associated with few sandy gravel and sand units. The site provides a clear cut evidence of neotectonic activity along the KHF and is demonstrated and discussed by the op. cited workers, and hence is not much elaborated here.

Fig. 4.12 **(a)** F8- Khari cliff-8m reworked fluvial sheet and valley fill miliolites. **(b)** F9- Khari cliff-12m, valley fill Miliolite and Jhuran shale. **(c)** F16a- Fluvial signature. The stratified sandy sheet of impure Miliolite deposits containing gravels and pebbles pointing towards its fluvial deposition are recognized as the fluvial reworked sheet deposits. **(d)**F11-Khari cliff-12 to 13m, and valley fill miliolite. **(e)** F16- 3rd order Chock Nadi about 2m cliff of miliolite sheet resting on Mesozoic, SE of Rayadhanjar village

On the basis field study in Fakirwadi area it can be deduced that the bottom most Mesozoic shale-sand units are covered with miliolite dunes and also by valley fills and fluvial reworked sheets of the miliolites. Top most sedimentary facies having scarp derived angular colluviam, brownish to reddish in colour, largely unconsolidated and thick colluviam deposited below erosional line along river bank terraces and thinning reworked colluviam deposited due to small gullies action observed on dip bedding planes. Most of miliolitic sand deposit found stabilized below the erosional line in pre carved Mesozoic basin. FR area is hosting huge and waste obstacle dune deposits compare to eastwards Gangeswar area, where thickness is reducing towards the east. Figure 4.13 is the geological map of the Fakirwadi area that shows occurrences of miliolite in association with the older rocks and KHF.

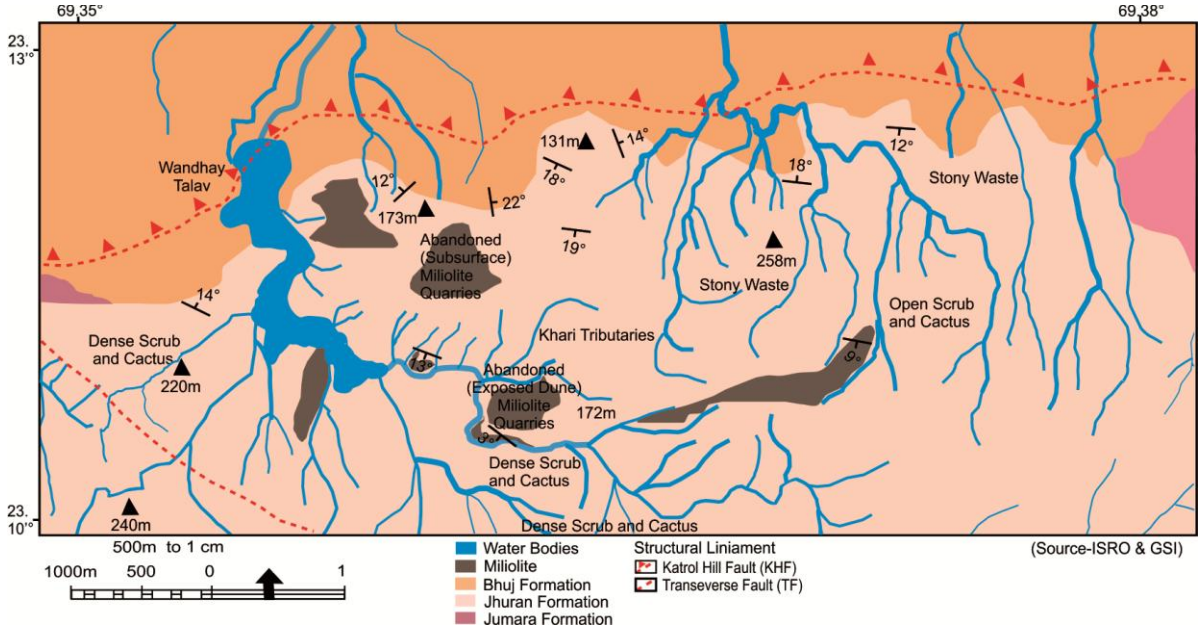

Fig. 4.13 Geological set up of Fakirwadi area (FA), KHR

Kotda-Roha Area (KA)

The Kotda-Roha area located 43 km WSW of Bhuj city occur within an approximate area of 1200 sq.km, lies in between Naira and Kharod rivers, both south flowing, exiting from KHR, and dominantly comprise of obstacle deposits and valley fill sheet miliolites resting over the Deccan Trap Formation. Physiographically, the trap hill ranges show WNW-ESE trend and varies from 1.5 to 4 km in width. The southern and northern slopes of the ranges have provided ideal sites for the accumulation of windblown material and formation of obstacle miliolite dune deposits that support numerous building stone quarries. Considering the fact that the majority of the miliolite

occurrences are not found confined any river, unlike Gangeswar and Fakirwadi areas, a contour map was prepared to understand the possible disposition the miliolite deposits in this part of the study area (Fig. 4.14). The southern and northern slopes of the range support a number of rain gullies and 3rd order channels that meet the Vengdi, Kankawati and Kharod rivers.

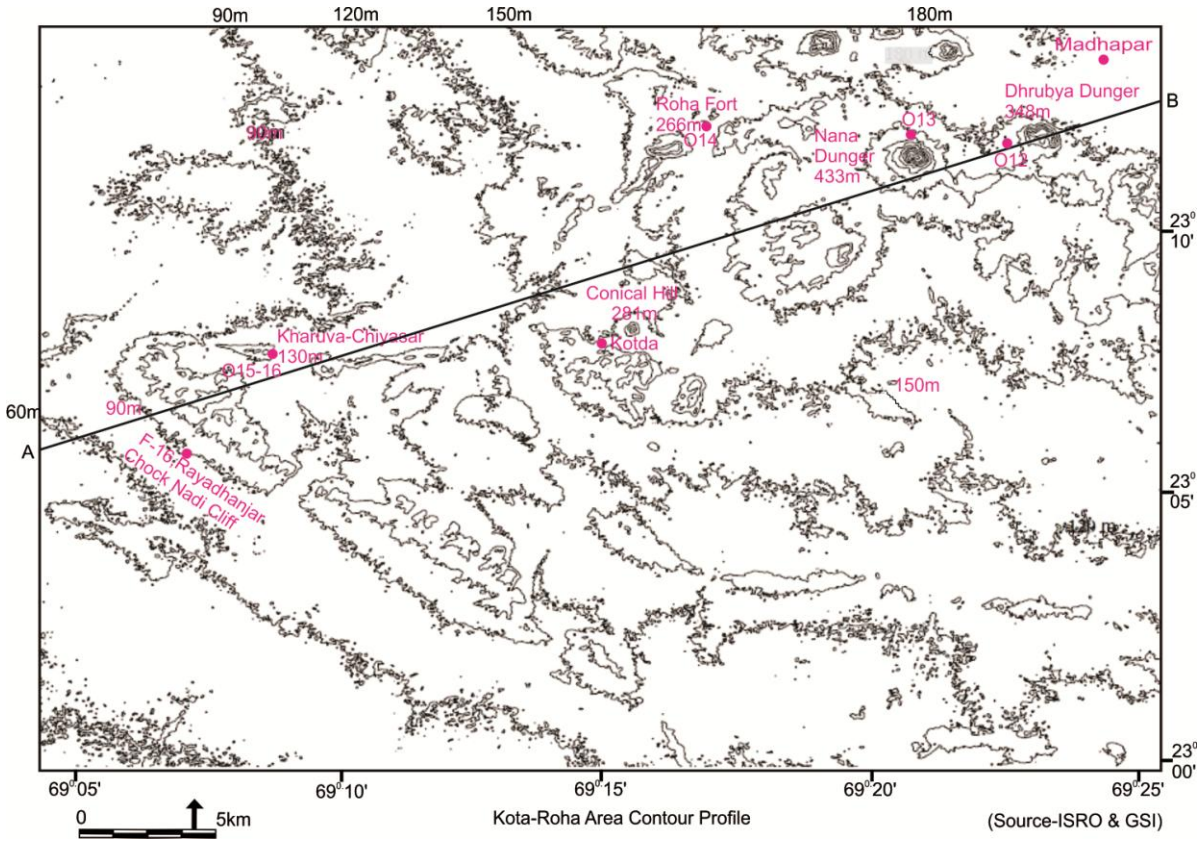

Fig.4.14 SRTM DEM based contour map of Kotda-Roha Area (KA).

Figure 4.15 presents the litho logs prepared from various locations in this area with its corresponding elevations from msl. The exposed obstacle deposits of field locations O12 to O16 are large in size and the quarry faces reveal well-developed wedge-type cross-beddings. These obstacle deposits occur at the altitude between 160m to 245m and above

O12

At Drubiyo Dunger (234m), about 2km SW of Madhapar village on Bhuj-Roha-Kothara road an east-west trending Deccan Trap basalt ridges rises up to about 80 m from the ground level non-conformably rest on the Bhuj Formation sandstone. This hill provides an obstacle to the wind

born carbonate sand due to which windward obstacle dune deposits of about 2 to 5 m thickness occurred. The dune extends southward where it pinches out after reduction in its thickness to about 0.5m. In the adjacent areas the miliolites also occur as leeward obstacle dunes where the wind borne sand could cross the low hills and spurs.

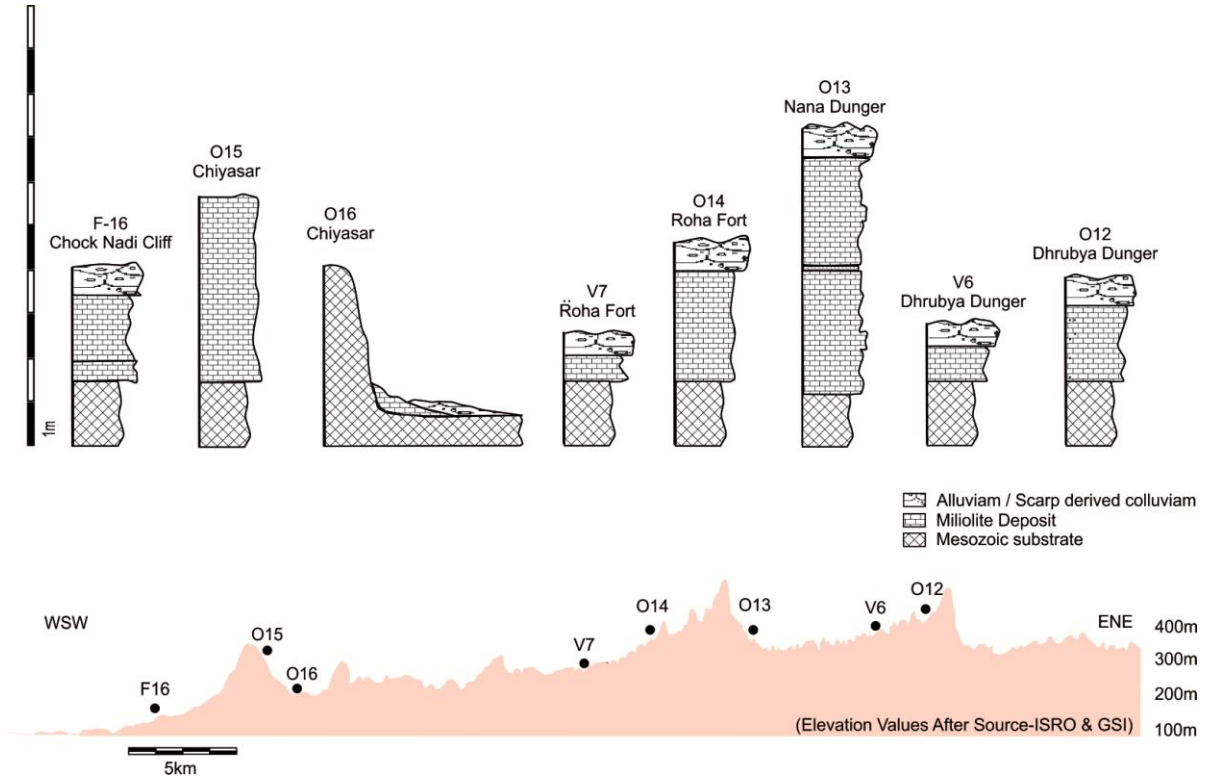

Fig.4.15 Vertical profile of KA high land of KHR, showing successive development of the erosional surfaces of Mesozoic-Deccan stratum From Pos 23º 05'N, 69º 01E to Pos 23º 12'N, 69º 30'E; with stratigraphy exposed and excavated litholog, depicting successive development of miliolite deposits. Cross sections drawn along AB lines (Fig.4.13).

conspicuous hill made of Deccan Trap basalt famous as the Nana Dunger (433m), south of Varamsida village hosts Type-I dune deposits of miliolite on its western slope. On the northern side an abandoned quarry has exposed 7 m thick miliolite that extend downward for another 3 m. This is a typical leeward obstacle dune deposit of miliolite (Fig. 4.16). The miliolite is dirty white in colour, fine grained, very well sorted and exhibits planner wedge shape as well as locally curved stratifications. It is possible to appreciate at least a stacking of two dunes here which are separated by a very thin erosion surface where physical structure are terminating and even locally at lower level thin blanket and lenses of basalt fragments which are angular in nature are seen that indicate very minor break in deposition (Fig.4.17).

Fig. 4.16 (O13) South to Varamsida a conspicuous Trap Hill, famous as Nana Dunger, 433m Obstacle leeward, tabular dune bedding of miliolite deposit as abandoned quarry exposure

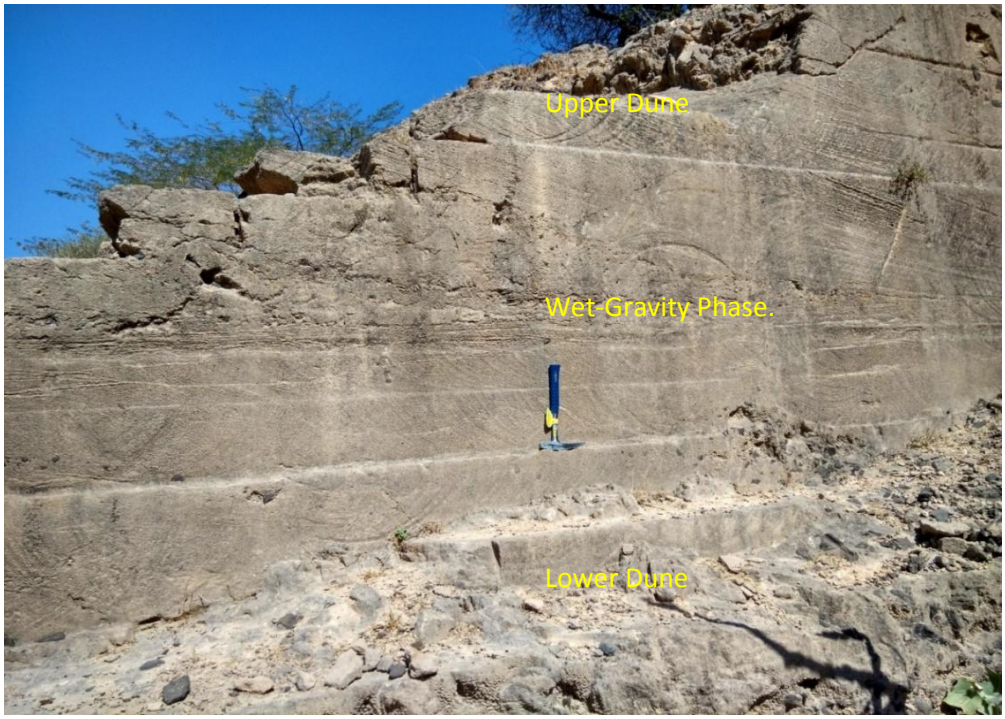

Fig.4.17 (O13) Obstacle Miliolite dune deposit, abandoned quarry, Nana Dunger sst covered with miliolitic sand

Interestingly on the Southern face of this quarry i.e facing towards the obstacle, quite a few lenses of pebbles and cobbles are seen and mixed with miliolitic sand (Fig. 4.18). These lenses have concave bottom and nearly flat top. It is more or less appearing like score and fills assorted angular basalt fragments and miliolitic sand that must have developed some local channels which are filled assorted angular basalt fragments and miliolitic sand. The lenses are about 200cm in cross sectional length and 25 cm is maximum thickness. The cross sectional length and thickness varies in different lenses on same stratigraphic level. It appeared that these lenses must have formed due to gravity flow from the Deccan basalt obstacle due to a shower rain of very small time span in otherwise arid dune building environment. Towards the top of the lenses very thin horizontal and ripple drift lamination in carbonate sand is seen, which forms in calm shower water. Another level of similar basalt lenses is seen about second dune i.e. towards the top of quarry face. It appears that this aeolian deposit have experienced have formed during transition phase of extreme aridity to semi aridity climate phase. No distortions in the sedimentary dune structures are seen.

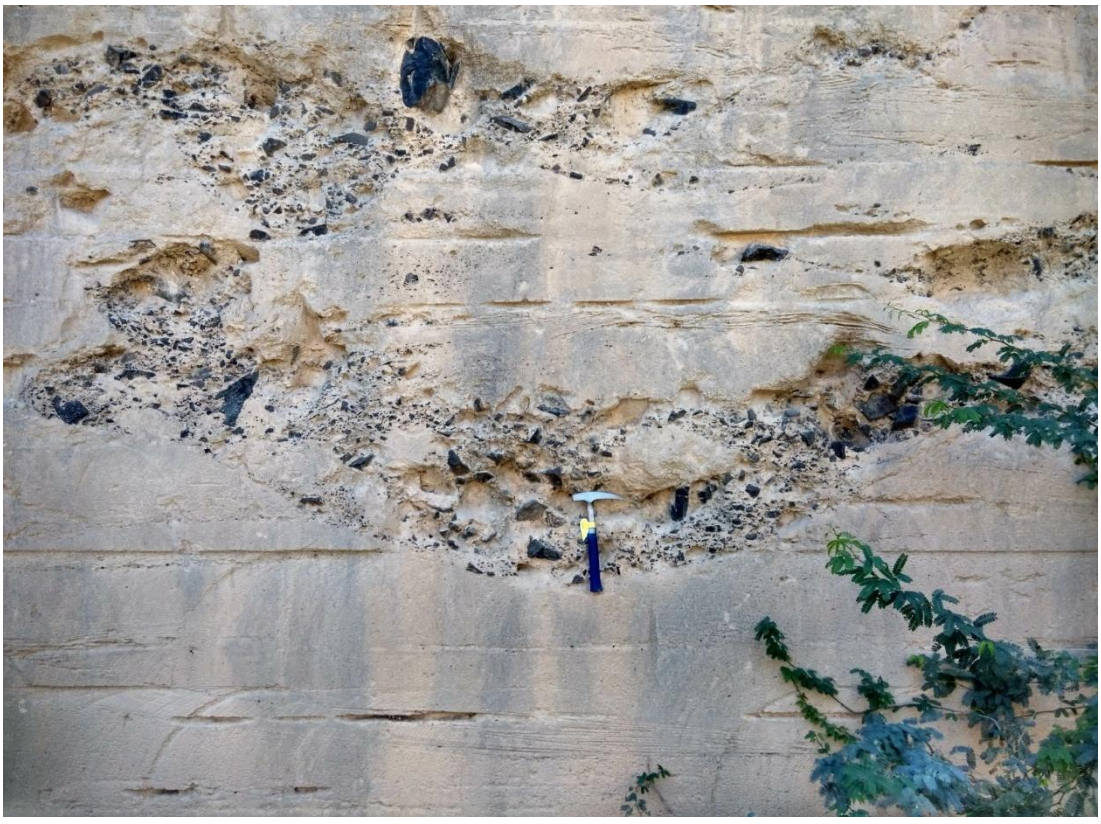

Fig.4.18 (O13)Field photograph showing the lenses of angular basalt fragments in miliolite at Varamsida

O13 and O14

Kotda village lies within the 1km to 4 km width east west trend trap hill range. North is Roha and South extension is Poldiya. Northern side of the hill range is covered by first order stream and tributaries of Kankavati river and southern with first order stream and tributaries of Vengdi Nadi. Further west traverse at Roha Fort a basalt hill (266m) just at the northern edge of Roha village, about 4 m thick windward obstacle dune deposits occurred that is medium to fine grained, moderately to well sorted dirty white colored miliolite (Fig. 4.19). This wind ward dune accumulation contains angular fragments of local lithology such as ferruginous sandstone and basalt (Fig.4.20). Here also more than 7 m of thickness of obstacle miliolite deposit is expected as seen previously in Varamsida quarry. Towards the base of the hill the miliolite extends forming 1 to 2 m thick sheets in to the local valley. As the deposit is devoid of gravel and sand lenses and also fluvial sedimentary structures, it is considered as a valley fill deposit

Further toward southwest of Roha and southwest to Sanosara, in-between Naredi, Bhittar and Chiyasar intervening tributaries of Kankawati River is devoid of miliolite. On traverse from Sanosara-Naredi-Chiyasar-Rayadhnagar-Boha-Kotdi-Nagrecha-RotidiyaNala to Mau Moti no miliolite exposures encountered.

Fig. 4.19 (O14) Roha fort trappean hill, 266m just north edge on Roha village, windward obstacle dune deposits.

Fig. 4.20 (O14) Gravity derived weathered sandstone fragments as well as Deccan basalt angular fragments

O15-O16

Near village Chiyasar about 160m high hill has provided obstacle to the miliolite sand deposition. About 4 m thick unit of dirty matt black due to weathering which was when hammered appeared as dirty buff white coloured, medium to fine grained 2 m thick deposit. miliolite could be seen on the northeastern slope of the hill resting unconformably over the basalt. About 500 m away on the roadside 1 m thick sheet of miliolite also occurred. Allahabadi (1986) explained this occurrence at two different levels as a result of tectonic uplift of the hill. However, there occurs no evidence of any fault in between nor the rocks are showing any deformation. In the author's view the occurrence at two levels is due to the pre-deposition topography that has regionally controlled the disposition of miliolites in the study area. Chiyasar trappean hill (160m) was the first highest summit that provides an obstacle to the south westerly winds on edge of south KHR and lies between NKHR and SKHR.

F16

A typical reworked fluvial sheet deposit of miliolite forming cliffy bank resting on Mesozoic stratum encountered in this area in the third order of Chok River near SE of Raydhanjar village (90m). Here, a very compact 2 to 3 m thick sheet of miliolite containing significant amount of the gravels, pebbles and coarse sand derived from the country rocks could be seen constituting the river bank cliffs of about 5 m height (Fig. 4.12 c & d). Miliolitic sand is mixed with pebbles and cobbles of country rocks and also cobble has been removed forming mould in photographs clearly seen. This miliolite unit also exhibits trough cross-beddings, local thin lenses of clay and irregular lower contact with Mesozoic substrate.

The Kotada-Roha area is largely hosting dune deposits and huge obstacle wind ward and leeward deposited formed due to the highest east west trend trap hilly ranges that provides first obstacle of the south westerly wind encounter in the southern Kachchh.
The obstacle dune deposits are found between 160m to 245m and above elevation, the exposed thickness of deposit is mapped 0.5 m to 10 m and more, having huge deposit and vast extension comparing to FA and GA.

Fluvial reworked miliolite sheet facies is rare in KA, having identical fluvial signature with mixed miliolitic sand, pebbles and cobbles of country rocks and mould.

Varli Area (VA)

The Varli area (VA) situated on the southern part of the KHR that lies between latitudes 23°.00' to 23°.10'N and longitudes 69°.30' to 69°.70'E, about ~15–20 km south of the Gangeswar area. Occupying a 15 to 20 km E-W trend hill range about 160 to 260m high picks associated with South Katrol Hill Fault (SKHF) (Fig. 4.21).

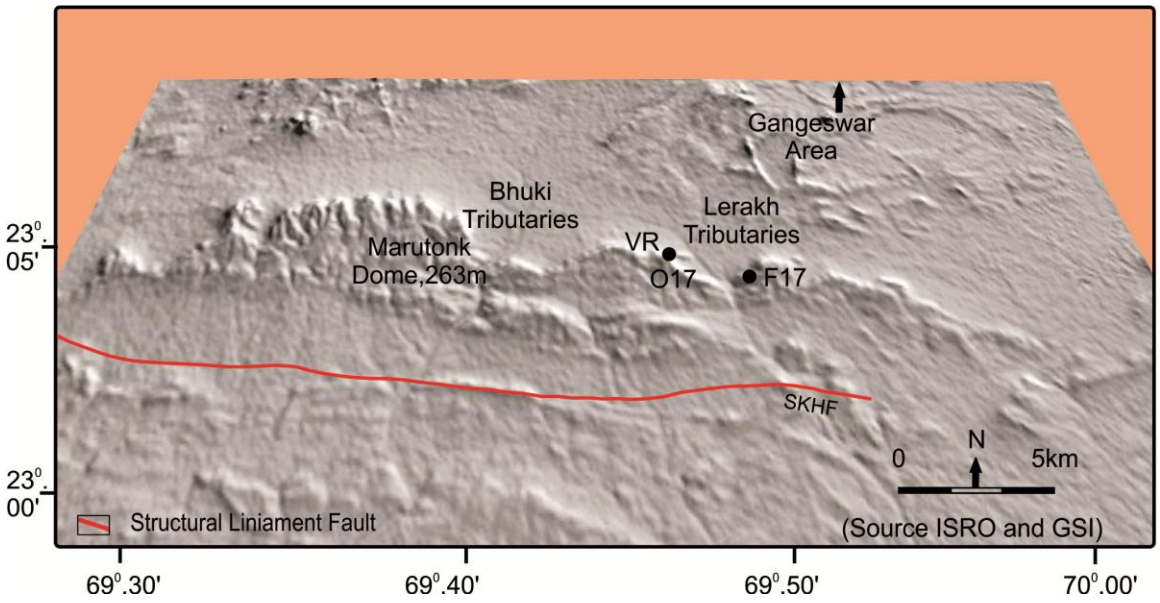

Fig.4.21 DEM of the Varli Area (VA) showing the position of the Varli Miliolite occurrences and South Katrol Hill Fault (KHF).

The scarp associated with Katrol Hill Range (KHR) is further divisible into two main geomorphic domains NKHF (North Katrol Hill Fault) and SKHF (South Katrol Hill Fault). SKHF is a younger and relatively smaller scarp, located ~15–20 km south of the NKHF. SKHF provide natural drainage barrier. At this point tributaries of south flowing rivers making a junction point and gives opportunity to built a dams on rivers Sai, Vengdi, Kankawati, Kharod, Rukmavati, Khari, Nagvanti, Bhuki and Mitti and Larek. All tributaries abruptly change their river course due to the SKHF and pass through gap along lower altitude of SKHF range and debouched in Gulf of Kachchh. Around 30 sq km area was investigated. Documentation made on the basis of field characteristics of the miliolites. While traverse on Bhuj-Bharapar-Baladiya-Kera-Baladiya-Jambudi-Varli, on the South Katrol Hill Range (SKFR) about 160m showing whitish appearances from the road side. At this site about 6 m thick obstacle dune deposit of friable miliolite with thin laminations could be seen (Fig. 4.22). This site is lying between two hills, west side is about 266m high pick and on south to site is about 200m hill. Crossing over the crest through a gap deposited as leeward deposits giving rise to slip-face deposits. Further down slope, these extend up to the foothills, merging into thin sheets.

Table 4.1 is a detailed list of the sample numbers along with its field location details. These sample numbers are used to enlist the results of various laboratory studies in the next chapter. Therefore, this table may be referenced for the detail, if desired.

Fig. 4.22 (O17) An outcrop of the Type-I miliolite deposit showing thin laminations at Varli

Table 4.1

Sr. No.	Sample No	Fig Ref 4.3, 4.9 & 4.14	Locality	Fig Ref 3.1	~Latitude	~Longitude	Altitude Amsl (~m)
1	FR-1	O10	Bhuj-Mandvi Road	17	23° 11'30"N	69° 36' 10" E	160
2	FR-2						165
3	FR-3		Fakirwadi-Jhuran Dome		23° 11' 18"N	69° 35' 58" E	165
			Deep southern on Bhuj Mandvi Road		23° 04' 00" N	69° 30' 20" E	160
4	FR-4	O9	Abandoned Quarry		23° 11' 17" N	69° 35' 57" E	170
5	FR4(2)						
6	FR-5		Trap hill		23° 04' 00" N	69° 30' 20" E	170
7	FR-6						
8	GR-7	O5-O6	Gangeshwar Mahadev	22	23° 11' 36" N	69° 43' 37" E	165
9	GR-8		Gangeswar Dome-Amphitheater towards Gunawari River		23° 11' 24" N	69° 43' 35" E	175
10	GR-9	F7	Gunawari River Cliff	23	23° 11' 06" N	69° 43' 29" E	159
11	GR-10						
12	GR-11						
13	GR-12	F1	Ler Dam	34	23° 11' 03"N	69° 45' 08"E	152
14	GR-13						
15	GR-14						
16	GR-15		Near Ler Dem Gunawari River Cliff		23° 11' 03"N	69° 44' 56."	142
17	GR-16						
18	GR-17						
19	GR-18						
20	GR-19						
21	GR-20						
22	GR-21	F2	Further upstream Gunawari River section	23	23° 11' 07"N	69° 44' 52"E	143
23	GR-22						144
24	GR-23						
25	GR-24	F3	Lithological contact-further upstream Gunawari River section.		23° 11' 07"N	69° 44' 51"E	145
26	GR-25						
27	GR-26				23° 11' 10"N	69° 44' 26"E	
28	FR-27	O11	Bhuj-Mandvi Road-Incised stream miliolite in Khari catchment	26	23° 10' 50" N	69° 36' 53"E	195
29	FR-28	V4	Slop Replacement Features in Khari River Catchment		23° 10' 50"N	69° 36' 54"E	190
30	FR-29						
31	FR-30						
32	FR-31						
33	FR-32	V5	Khari River Catchment		23° 10' 42"N	69° 36' 47"E	180
34	FR-33	F-8	Khari River western flank cliff		23° 10' 40" N	69° 36' 46." E	180
35	FR-34	F9	Eastern Khari River flank Cliff	26	23° 10' 42"N	69° 36' 45." E	162
36	FR-35						163
37	FR-36						164
38	FR-37						165
39	FR-38						166
40	FR-39						167
41	FR-40						168
42	FR-41	F10	West-East flowing Curve Khari River Cliff		23° 10' 45"N	69° 36' 15"E	158
43	FR-42						
44	FR-43	F11	Khari River Eastern flank cliff		23° 10' 54"N	69° 35'59"E	155
45	FR-44						
46	FR-45	F12	South-West flank of Khari River Crescent shape Cliff		23° 10' 53"N	69° 35'47."E	150
47	FR-46	F13	Khari River eastern flank cliff		23° 11' 10N	69° 35'32"E	145
48	Patidar (2008) and Kundu (2010)	F14	Khari River-Vandhay Talav Bharasar Village		23° 11'36"N	69° 35'22"E	132

Sr. No.	Sample No	Fig Ref 4.3, 4.9 & 4.14	Locality	Fig Ref 3.1	~Latitude	~Longitude	Altitude Amsl (~m)
49	Patidar (2007)	F15	Bharasar Village	3	23° 12'N	69° 33'E	
50	GR-47	O1	South flank scarp Gangeswar Dome-	22	23° 11' 30"N	69° 43' 26"E	168
51	GR-48		South gentle dipping SST Gangeshwar Dome				174
52	GR-49						
53	GR-50	O2			23° 11' 14."N	69° 43' 12"E	190
54	GR-51						
55	GR-52	O3			23° 11' 6"N	69° 43' 3"E	
56	GR-53	O4					
57	GR-54	V2	Farm sand	24	23° 10' 49"N	69° 42'59"E	165
58	GR-54(A)	V3	Digged Miliolitic Sand.				
59	GR-55						
60	GR-56						
61	GR-56(A)	V1	Miliolitic Excavation site north to Gunawari.		23° 11' 2"N	69° 43'8"E	172
62	FR-57, FR-58	O8	Abandoned miliolite quarry,Khari catchment	26	23° 10' 53"N	69° 36'09"E	167
63		O7					
64	KR-59	O12	Madhapar (Deshalapr) Dhrubiyo Dunger	15	23° 12' 03"N	69° 23'28"E	234
65	KR-60	V6	Varamsida.-Nana Dunger				245
66	-						
-	KR-61	O13		51	23° 12' 11.N	69° 20'35"E	
67	KR-62						
68	KR-63	O14	Roha fort Trappean Hill	50	23°11'53"N	69°16'26"E	200
69	-	V7	Roha fort Trappean Hill				
-	KR-64	O15	Sanosara-Naredi-Chiyasar (Kharva).	9 & 36	23°08'03"N	69°08"35"E	160
70	KR-65	O16					130
71	KR-66	F16	Rayadhanjar.	46	23°06'08"N	69°06"56."E	90
72	VR-67	O17	Varli Hill-266m	53	23°05'39"N	69°47'39."E	145
73	VR-68						160
74	VR-69						160
75	VR-70	F17	Baladiya,Jambudi,Chakar Varli-Larek Tributary	8	23°05'50"N	69°48'14"E	

Table 4.1 Details of the sample codes(Gangeswar-GR, Fakirwadi-FR, Kotda-KR and Varli-VR) and its locations in the field (Fig Ref-3.1, 4.3, 4.9 & 4.14).Type identification's on site-Obstacle dune deposit; V-Valley fill deposit; F- Fluvial reworked sheet deposit.