CHAPTER 7
DISCUSSIONS

General

The bioclastic carbonate deposits, popularly known as 'Miliolite' or 'miliolitic limestone' is a conspicuous stratigraphic unit of the Late Quaternary age in the Kachchh and Saurashtra regions of Gujarat. The (KHR) constitutes a prominent physiographic high which has formed due to the tectonic uplift along (KHF) situated south of the Bhuj. Major rock mass of this is composed of the shale and sandstones of Jhuran and Bhuj Formations of Jurro-Cretaceous age (Biswas, 2016b) with thin patchy occurrences of the Miliolite limestone of Middle to Late Pleistocene age. The Miliolite Formation has been investigated in more detail from Saurashtra area for a variety of aspects such as mode of occurrences, petrography, geochemistry, geo-archaeology, geochronology etc. (Bhatt, 2003 and references therein). However, these deposits in Kachchh did not receive much attention and only limited studies are available that indicated aeolian deposition of the carbonate sand largely derived from either Saurashtra coast or local Gulf of Kachchh coast (Biswas, 1971; Allahabadi, 1986). Baskaran et al. (1989a) provided the ^{230}Th / ^{234}U ages for some Miliolite occurrences in Kachchh, whereas and Chakraborty et al. (1993) studied the occurrences of Roha and Kothara area for its ichnological aspects and also provided ^{230}Th / ^{234}U ages. Both the studies in contrast to the previous work suggested higher sea level and the present disposition of these deposits were accounted to the tectonic uplift. The Miliolite formation has been designated as the "Miliolite Problem" in the geological literature due to such controversies regarding its depositional environments, whether marine or continental. In a series of publications Bhatt and Patel (1995, 1996, 1998 a & b) and Bhatt (2000, 2003) attempted to resolve this problem to a satisfactory level to propose that there exists three types of Miliolite deposition viz., near coast marine, aeolian and fluvial, In Kachchh the geological studies on Late Quaternary records mainly remained focused on understanding the neotectonics and seismicity of the area as the area is one of the most active seismic zone of India, and so specific studies on the Miliolite occurrences and its relation with reference to the local tectonic landscape evolution remained neglected. The present study, as could be seen in the fore running chapters, has largely dealt with this aspect and tries to relate the field and laboratory studies to identify, characterize and describe three distinct types of Miliolite occurrences with the evolution of the Katrol Hill Range and associated area in southern Kachchh and the same are discussed in the following text.

Mode of Occurrences

The field set up of the Late Quaternary carbonate deposits indicated three distinct environments of their deposition based on the overall sedimentary body geometry and primary structures. These were aeolian obstacle dune, gravity flow and fall in to the valley and reworking of the same sediments through fluvial activities. The field set up clearly suggests three distinct mode of deposition of miliolites in Kachchh namely, (I) Type-I obstacle dune deposits, (ii) Type-II valley fill deposits and (III) Type-III fluvial reworked sheet deposits (Fig 7.1).

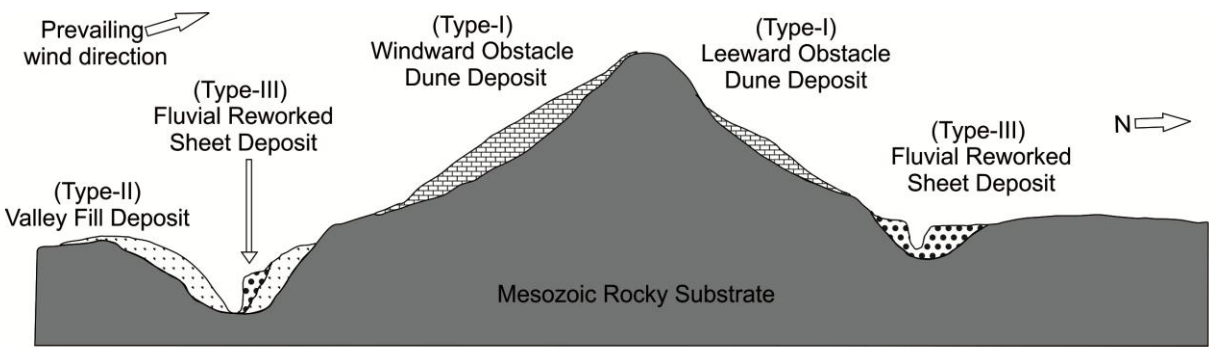

Fig 7.1 Principal types of miliolite occurrences in Kachchh

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 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 and II Miliolites.

KHR has a rugged topography with a number of domal and depression structures forming gorges and valley hosting thick Quaternary deposits especially along south back valley reaches of rivers whereas to the north of the range-front scarps of the Katrol Hill Fault (KHF) zone, the deposits are patchy and mostly concentrated around the north-flowing river valleys. Katrol Hill Range (KHR) hosts Late Quaternary sediments in the form of colluvium, fluvial gravels and carbonate sand (Miliolite). The colluviums constitute buried pedeplain areas and in places underlie the Miliolite units. There also occur thin veneers of alluvium and colluviums resting on the valley fill Miliolite deposits. This suggest that the deposition of coarse grained units were due to local fluvial activities during monsoon time and the large clasts were derived from episodic seismic and tectonic events along the KHF and associated transverse faults. In the absence of perennial drainage system due to the arid and semi-arid climate of the region such detritals could not be transported for long distances from its source regions. The observation further substantiate the inference that the Kachchh region has been experiencing the arid to semi-arid climate since Middle Pleistocene time and the local drainage activities were being able to transport major sediment loads from its channels under flash flood conditions (Prizomwala et al., 2014 a & b).

Texture and Composition

The textural studies of the miliolites were carried out using mechanical sieving technique for friable variety and using thin sections for inudarated ones. Accordingly it was observed that in majority of the samples grain size range from 0.5 to 3.0 phi (sand size), moderate to poor sorting, fine skewed and platykurtic to mesokurtic distribution.

Type-I Miliolite shows better sorting, medium sand size, very fine skewed, leptokurtic to mesokurtic distribution, whereas the Type-II and Type-III exhibits poor sorting, fine to medium grained, fine to symmetrically skewed and mesokurtic to platykurtic nature. The near absence of silt and clay in Type-I and Type-II Miliolites suggest a minimal role of the aqueous agency in their deposition.

The residue analysis_has indicated that the Type-I miliolite contains about 41 % of detritals by weight, whereas it is ca. 55% in Type-II and highest (ca. 68%) in Type-III. This is suggesting that the reworking of the original wind borne carbonate sediments has increased the detrital components mainly derived from the weathering and erosion of the country rocks which are mostly sandstone and shale of the Mesozoic age.

The allochemical contents such as foraminifera tests, shell fragments, coralline algae, bryozoans and echinoide fragments, peloids etc. indicate its derivation from the shallow marine source.

However, the diagentic features such as low compaction, first and second generations of low magnesian sparite and micro-sparite cements and its morphology like meniscus, rim, dripstone-drapstone and partial void filling suggest that the post depositional process i.e. diagenesis has largely occurred in semi-arid condition under freshwater vadose environments which is typical of the dune deposits (Bhatt & Patel, 1998b).

SEM-EDS imaging of the selected samples from all three types of the Miliolite deposits have also revealed interesting results. In general the cement is seen as granular calcite and rhombohedral calcite that indicate the low magnesian nature of the calcium carbonate being precipitated as cement. A sample from Gangeshwar area has also shown the presence of fibrous variety of calcite which is reported by Stoops (1976) as 'lublinite' which is formed under the moist condition largely prevailing in the cave environment, Recently Gazda et al. (2012) demonstrated the effect of radon concentrations in moist environment to form the lublinite. The radon emission or increased concentration in environment has been considered as precursor for seismic activities (Waith, 2015), and hence is the presence of lublinite in Miliolite must be bearing the signature of such activities in KHR during the deposition and diagenesis of the miliolite at Gangeshwar. The SEM study has also shown presence of clay minerals in Type-III Miliolite sample. This must have been derived from the weathering product of the country rock and got mixed with the sediments as it is fluvial reworked deposits.

XRF bond values in % out of 57 bond elements, considering four pertain elements i.e. CaO, SiO_2, Al_2O_3 and K_2O (Fig. 7.2) higher amount of CaO (>45%) in Type-I Miliolite units in comparison with the other two types. It is seen that the SiO_2 percentage also shows similar trend. The Type-II valley fill deposits must have received the increased silica contents due to the quartz grains contributed by the substrate sandstone and shale rocks under gravity fall. Similarly its higher value (27 to 45%) in Type-III is suggestive of its reworked nature. The Al_2O_3 and K_2O however are seen more in Type-II and III deposits in comparison with the Type-I. As stated earlier, the Type-II and III deposits also show presence of clay which might have contributed these oxides to its bulk chemistry. Result of x-ray Fluorescence analysis. Samples were analyzed using XRF facility of the Institute of Seismological Research (ISR), Gandhinagar.

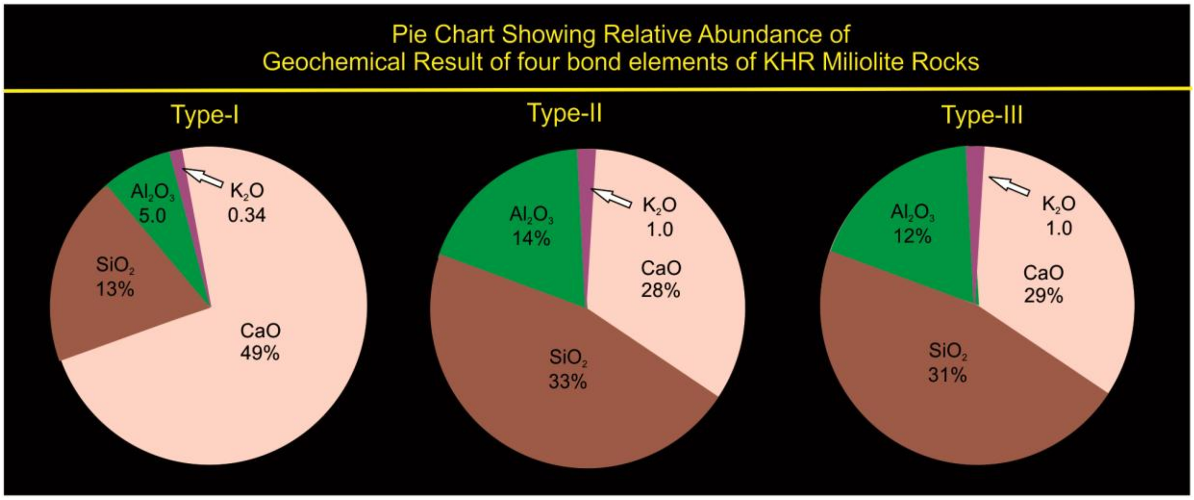

Fig 7.2 Geochemical Result of four bond elements of KHR, Kachchh Miliolite

Magnetic susceptibility (MS) measurements on carbonate rocks are considered as a proxy for impurities delivered to the carbonate environments. In strong climatic or tectonic variations, increases clastic supply and therefore increases in magnetic mineral deposition. The influences of varying clastic supplies, varying carbonate accumulation rates and of potential diagenesis are probably key factors influencing the MS signal in KHR sediments. Different diagenetic processes (secondary origin) are able to modify MS after deposition, but the effects of these secondary processes on the MS of carbonate rocks are not well known.

The Magnetic susceptibility_analysis has not shown any typical trend amongst these three types of Miliolites (Fig. 7.3). Overall the SI mean value range from 377 $X10-^{6}$ (SI) to $483x10^{-6}$ (SI) which are low and thus indicate not much presence of magnetic minerals in to it. However, MS values are comparatively higher in Type-III.

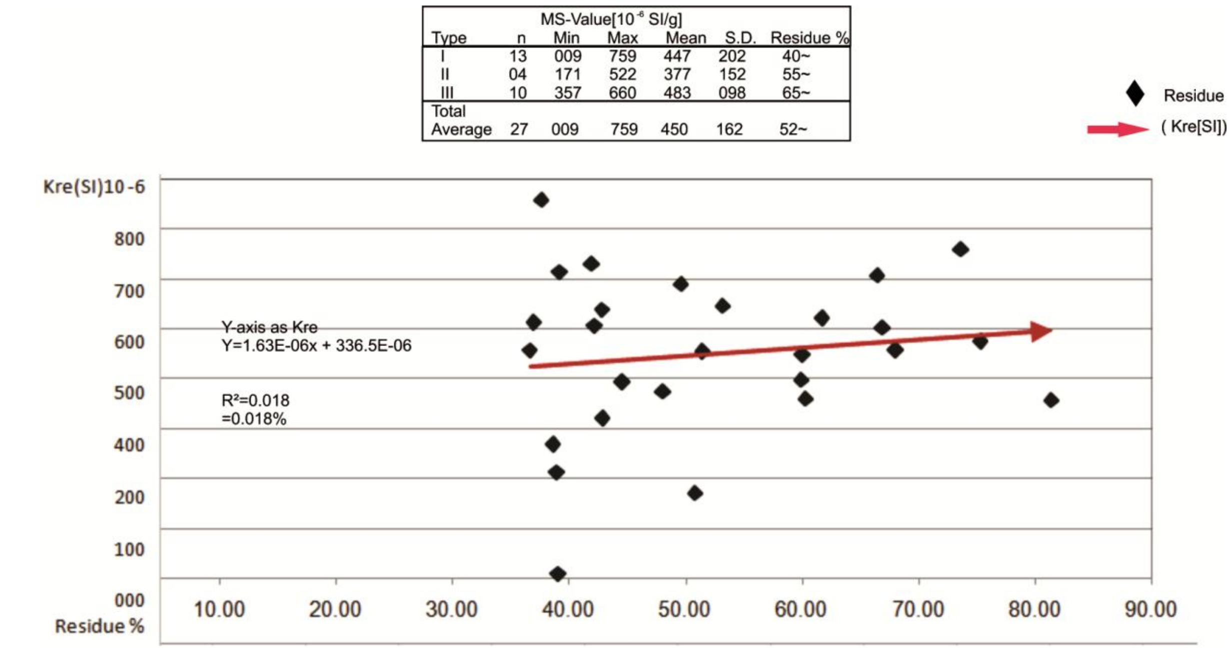

Fig.7.3 The relationship between types and mean magnetic susceptibility and linear relations.

Abrasion Analysis

To measured the weight loss of the rock sample after subjecting it to abrasion with water and 120 grade polishing powder on Struers made Labopole-35 grinding and polishing machine with iron plate rotating at speed of 50 rpm for 10 minutes applying 1kg weight.

Sample No	Type of rock	Initial weight (gm)	After abrasion weight (gm)	Loss of weigh (gm)	Loss of weigh in %
KR-62	Miliolite	250.07	200.1	87.60	30.44
FR-3	Mesozoic sandstone	198.16	190.80	37.70	16.49
GR-21	Mesozoic compact sand-shale	109.30	107.03	04.07	3.66
FR-4	Miliolite	103.17	92.16	15.84	14.66
FR-57	Miliolite	132.35	112.36	40.44	26.44

Table 7.1 Abrasion test values.

Miliolite is more vulnerable to abrasion in comparison with the substrate strata. Obstacle miliolite dune deposit which is comparatively harder than valley fill and fluvial sheet deposit shows 15 to 30 % of abrasion value, while stratum rock strata shows average 4 to 16% abrasion(Table 7.1) Erodibility measurement experiment that indicates almost twice the erodibility of Miliolite in comparison with the substrate rocks like sandstone and compact sand-shale units.

Looking at the porous and friable nature of miliolites, it can be eroded easily in comparison with the substrate rocks; therefore arithmetic estimate of uplift rate using incision of miliolites as suggested by Das et al. (2016a) could be misleading.

Geochronology

Geochronology of the reworked sedimentary deposit like the milolites has remained a challenge for the fact that the conventional radiometric dating methods provide the age of the sediment generation, while the interest is to estimate the age of its deposition at site (Sharma et al., 2017). Baskaran (1986) provided a number of ^{230}Th / ^{234}U ages from Saurashtra Miliolites which were challenged by Bruckner et al. (1987) who suggested that the carbonate diagenesis could have altered these ages and more reliable results can only be obtained from mega shells of coastal beach rocks. They also obtained ^{230}Th / ^{234}U and ESR ages of the mega shells collected from Chorwad (Saurashtra) occurrences and could successfully linked it to the last interglacial higher sea level of MIS-5. Unfortunately very limited ^{230}Th / ^{234}U ages of Kachchh Miliolites are available (Baskaran et al. 1989a, Chakraborti et al. 1993). These ages range between 42.4ka and 167ka. The present author is of the view that this range can be used as suggestive of a period of carbonate sand production in the region, and not as their deposition in the KHR. The OSL is a more suitable technique that provides an age estimation for the burial of the quartz grain for such kind of reworked carbonate deposits. Therefore, although very limited samples were analyzed for the OSL geochronology with the kind help of the ISR, Gandhinagar.

OSL ages of Saurashtra Miliolites (Sharma et al., 2017) indicated that the carbonate sediment generation occurred during high sea level stands related to the MIS-5 and MIS-3. The near-coast aeolianite deposition was nearly time coeval with the higher sea stands, whereas the inland aeolianites were deposited during the periods of lower sea level when aridity was much effective and long distance aeolian transport was possible (Sharma et al. 2017). The inland aeolian deposits of Miliolites in Saurashtra is time bracketed to 20-8ka by these workers. The OSL ages of Kachchh Miliolites (all are Type-I) range between 20-11ka. Some OSL ages of the fluvial reworked and valley fill Miliolite deposits in the study area are provided by (Bhattacharya et al., 2013; 2014) that range from 11.8-7.1ka. Kundu et al. (2010) dated the coarse grained fluvial sand overlying the thin miliolitic unit in the Khari rivers section by OSL and suggested its deposition around 3.0ka. Figure 7.4 gives a summary of the OSL ages of Miliolite and associated sedimentary units in KHR area. This clearly indicates that the dune building (Type-I Miliolite) process in the KHR started during the LGM largely deriving the carbonate sand from the far south Saurashtra coast as there is no coastal carbonate deposits on the Kachchh coast. The reworking of these sediments must have been initiated during 12 to 8 ka when the southwest monsoon activities were established. The age difference between the valley fill deposits and fluvial reworking is not much. However, the second prominent fluvial deposition phase recorded by sandy gravels and pebble units overlying the Miliolite units is much younger (~3.0 ka) that doesn’t contain the miliolitic sand because by this time being sensitive to the moisture, the carbonate deposits have attained stability and perhaps remained below the erosion line.

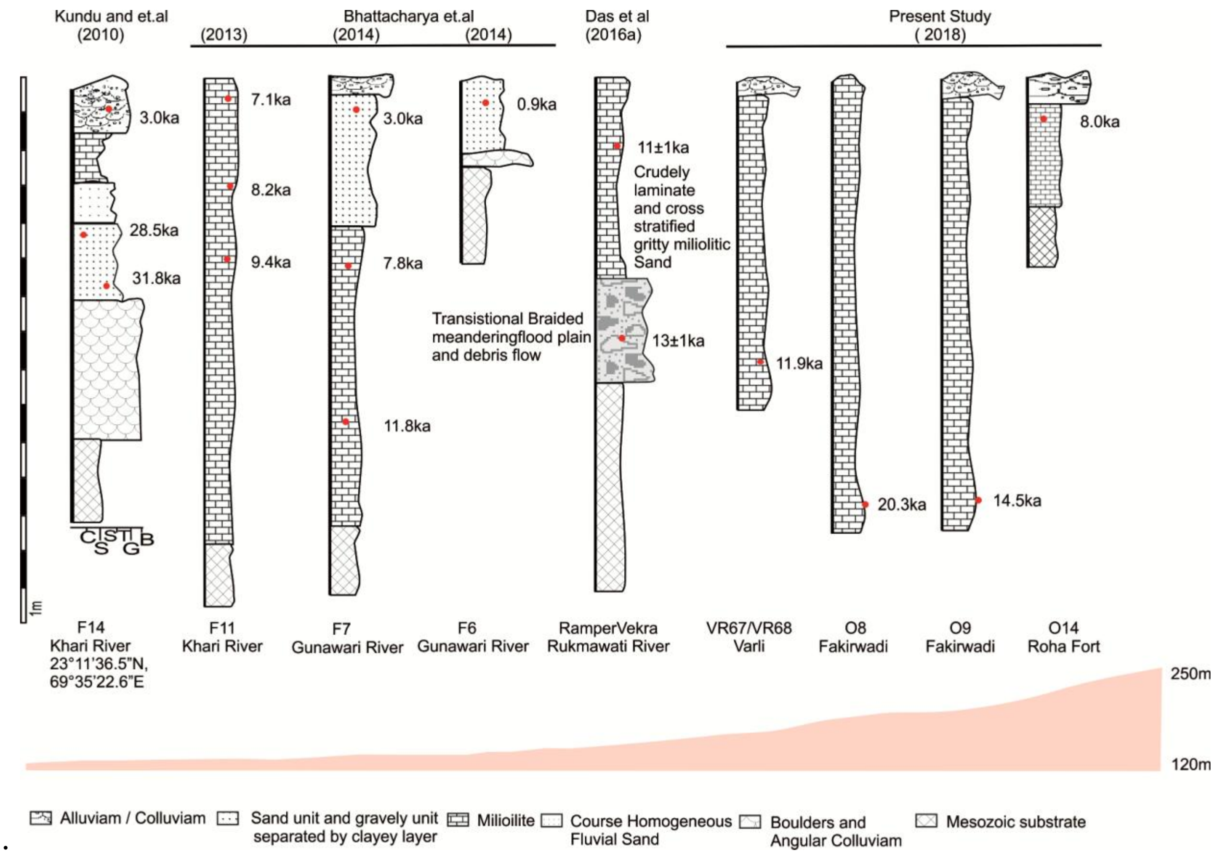

Fig.7.4 Summary of the available OSL geochronology of Miliolites in the KHR.

Landscape Evolution

Maurya et al. (2003b) on the basis of the exposed Late Quaternary fluvial sequences of southern Mainland Kachchh recognized three distinct geomorphic surfaces S1, S2 and S3. Accordingly, S1 developed over the coarse gravelly facies is the oldest defining the featureless alluvial plain that has gentle southward slope; S2 surface is the extremely dissected surface characterized by deep ravines, essentially produced by incision-gully erosion faces that carved on the pre-exist S_1 surface, whereas S3 surface is developed by significant amount of incision of young streams and exposed Quaternary sequences and characterized a low flat terrace surface .

The late Quaternary faulting events and tectonic uplift along the KHF has been studied by Patidar et al. (2007 and 2008) that was further also provided the OSL geochronology by Kundu et al. (2010) have suggested that the Faulting (F1) episode in the Khari river section is of < 30ka whereas, the F2 is of < 2ka age (Fig. 7.5). Neotectonic activities along the KHF then must have intensified the incision of the Quaternary sequences (Patidar et al. 2007, 2008; Kundu et al.

2010; Das et al. 2016b). Based on the incision of these sequences including the Miliolites Das et al. (2016b) also proposed a rate of uplift along the KHF to be about 2 to 5 mm / yr. However, their estimates of rate of uplift cannot be precise due to the fact that the erodibility of miliolitic units is almost twice than that of the substrate rocks

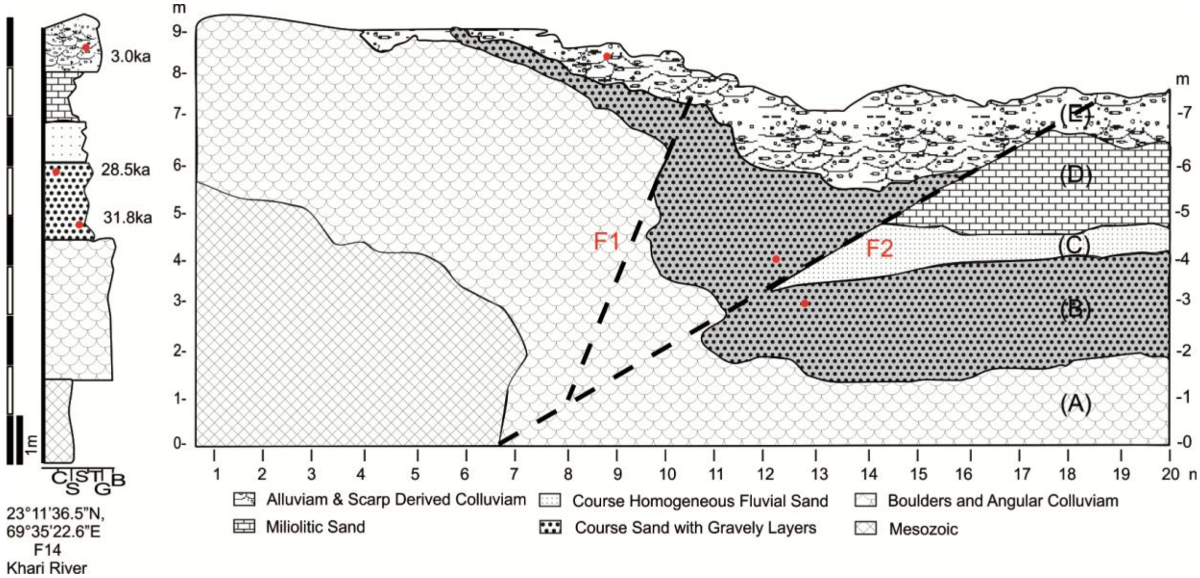

Fig.7.5 Schematic diagram shows overlay of exposed cliff section along the Khari river to the SE to Bharasar showing various lithologies, fault and offsetting in the Quaternary sediments, also optical stimulated luminescence (OSL) dating sample location; (Kundu et al.2010).

The phases of deposition and erosion during Late Pleistocene and Holocene have followed climatic changes of regional dimension and imprinted as facies and sub facies that characteristics of sediments are pre, syn and post miliolite phase. As per the available ages of Type-I deposits, covered 20 to 10ka (Late Pleistocene to Early Holocene), whereas the Miliolites of Type-II and III occurred during 10 to 7ka. Table 7.2 presents a summary of the stratigraphic set up and its relation with various episodes recorded in the late Quaternary sedimentary record of the KHR area.

Overall the miliolites of the KHR suggest that these marine sediments must have been deposited during the drier periods as obstacle dune deposits (aeolian) on the hill slopes which were then reworked with the initiation of monsoon activities as valley fills characterized by much more sediment availability than the stream power. Later the sediment availability has decreased and incision of valley fill deposits stared giving rise to thinner reworked fluvial sheets.

Phases	**Sedimentary Units / Facies Association**	**Sub facies characteristics of Sediments**	**Occurrences**	**OSL Age and Environment (Bhattacharya et al., 2013, 2014, Das et al., 2016a, Sharma et al.,2017, Present study.,2018)**	**Geomorphic Surfaces (S1,2 & 3) (Maurya et al. 2003b) and Faulting event 1,2 & 3 (Patidar et al. 2008) (Kundu et al. 2010)**
Post Miliolite **(7.1ka to Rec)**	Scarp derived colluviums Youngest Deposit. Terraces facies	Angular to sub angular pebbles and cobbles embedded in sandy to gravelly matrix. The deposit comprises of debris facies consists dominantly of class with subordinate matrix, whereas the wash facies is comprised of dominantly sandy matrix with dispersed clasts and occasional nested (embedded, surrounded and fixed) set in clasts.	At base of the front scarp. Scarp-derived colluviam is the youngest of the Quaternary deposits. At places overlies the alluvium whereas at other places it rest on directly on the fluvial miliolite.	<u>Late Holocene</u> Shallow braided stream channels under reduced level of neotectonic activity. **(~3.0ka)**	F2(event 3) **< 2ka** Khari section Fault.
	Alluvial deposits. Incision-erosion facies.	Fine sand, silt and clay. Scattered distributions fine-grained channelized alluvium. Incision3to5m and erosion 8 to15 m deep gully form high cliffs along the river banks. Comprise fine to coarse sands with layers of cross-stratified gravels.	Sporadically along the various north flowing streams.		Uplift of S3 - significant amount of incision by young streams and exposed Quaternary sequences
	Reworked miliolite fluvial-Sheet facies **(Type-III)**	The horizontally stratified sandy sheet of miliolite deposits having fluvial deposition signature mixed with pebbles, cobbles of country rocks. It include well-stratified sediments, presence of gravel rich layers, fluvial sedimentary structures such as small scour and fill, cross bedding and large clasts of Mesozoic rocks.	Extensively deposited along river valleys.	fluvial-Initiation of monsoon **(11.8 to 7.1ka)**	
Syn Miliolite phase OSL ages **(20-7.1 ka)**	Valley fill miliolite Facies **(Type-II)**	Thick pile of loosely uncontaminated-clean in nature, full of miliolitic sand fine to medium sand size grains, buff dirty white yellowish to reddish cream in colour.	Occupying Mesozoic depression along river valleys flood plain.	<u>Early Holocene</u> Gorges formation	
	Obstacle Facies Wind ward and lee ward miliolite **(Type-I)**	Distinct internal large scale aeolian cross bedding and uniformly well sorted fine to medium sand grains size carbonate rich sand, friable, moderately cemented, upper surface became matt black due to weathering.	Obstacle dunes, all higher evaluation on along the south slope of the hill range and at the base of the north facing front scarp.	**MIS-2 (LGM)** Declining monsoon on set of aridity **(20.3ka to 8.0) Dustier-MIS-3**	S2- Incision-erosion **>20Ka** Vertical incision and lateral planation of Mesozoic and Tertiary F1, (event 2)< 30ka. Khari section Fault. F3,(event 1) occurred sometime in
Pre-Miliolite phase **(> 20ka)**	Oldest Coarse gravelly faces Reactivation of KHF	Boulder unsorted colluviam Boulder-size fragment of Shale, thin bedded of sand stone and siltstones. Degradation of scarp. These deposits suggest pre-miliolite neotectonic activity along the KMF.	Alluvial fans in front of the scarps.Colluviam at the base of range front scarps (Base of Quaternary, at places colluviam overlies the Mesozoic)	Debris flows and sediment gravity flows, as small Coalescing and denudation in KHR. <u>Late</u> <u>Pleistocene</u> **MIS-5**	<u>Late Pleistocene</u> S1- featureless alluvial plain-gentle Southward slope. Where S2 & S3 are developed
Mesozoic Stratum					

Table 7.2 Stratigraphy, lithological characteristics, occurrence, ages and depositional events of Late Quaternary sequences in KHR, Kachchh

The evolution of the landscape of the KHR in Kachchh can be summarized in four distinct stages as described below and figure 7.6 (Talati and Bhatt, 2018).

Stage-I: Due to the onset of inversion tectonic the Kachchh basin was closed by the end of the Pliocene time and major structural elements such as Nagarparkar Fault, Kachchh Mainland Fault and Katrol Hill Fault started manifesting the uplift of the area that gave rise to prominent physigraphic highs oriented along east-west (Maurya et al., 2017). These faults were dissected by the transverse fault system to accommodate the stresses built up along the major faults.

Stage-II: During the Middle to Late Pleistocene time the coastal areas of Saurashtra and Kachchh experienced relatively higher sea levels and warmer climate that could provide better habitat conditions for marine biological activities to generate bioclastic carbonate sand along its coast. The radiometric ages of the Miliolite (Baskaran et al., 1989a) support this inference in context with the global sea level changes.

Stage-III: During Late Pleistocene time i.e. 60-20ka the sea level started dropping and lowered to about 110m from the present day level by the 20ka (Hashimi et al., 1995; Muhs, 2013). This made the carbonate sand available to the deflation process by onshore winds. These miliolitic sands must have been deposited on the slopes of the obstacles provided by the prevailing physiographic highs to form obstacle dune deposits on its windward and leeward sides. During this time the earth atmosphere was much drier and gusty dust storms were common (Muhs, 2013). A prolonged period of aridity provided ample time window for episodic long distance transport of the coastal biogenic carbonate sand that were on route mixed with detritals from local sources. Due to the gravity and also due to the seismicity / tectonic activities, the down slope movement of aeolian sand must have occurred that filled up the dry valleys. The Type-I and Type-II Miliolite deposits therefore must have been deposited during this period.

Stage-IV: After the onset of Indian Summer Monsoon by about 13ka (Das et al., 2017) the availability of the carbonate sand was reduced and with increased moisture, it started stabilizing. Episodic surface runoff reworked the sediments from the slope and from the valley that got mixed with the locally derived gravels and pebbles to form fluvial sheets on the banks that contained Miliolite pebbles and gravels also, along with carbonate sand that contributed to cement and consolidate these sheets (Type-III Miliolite). The OSL ages of about 11.8-7.1ka of valley fill Miliolite at Gunavari (Bhattacharya et al., 2014) support this inferences.

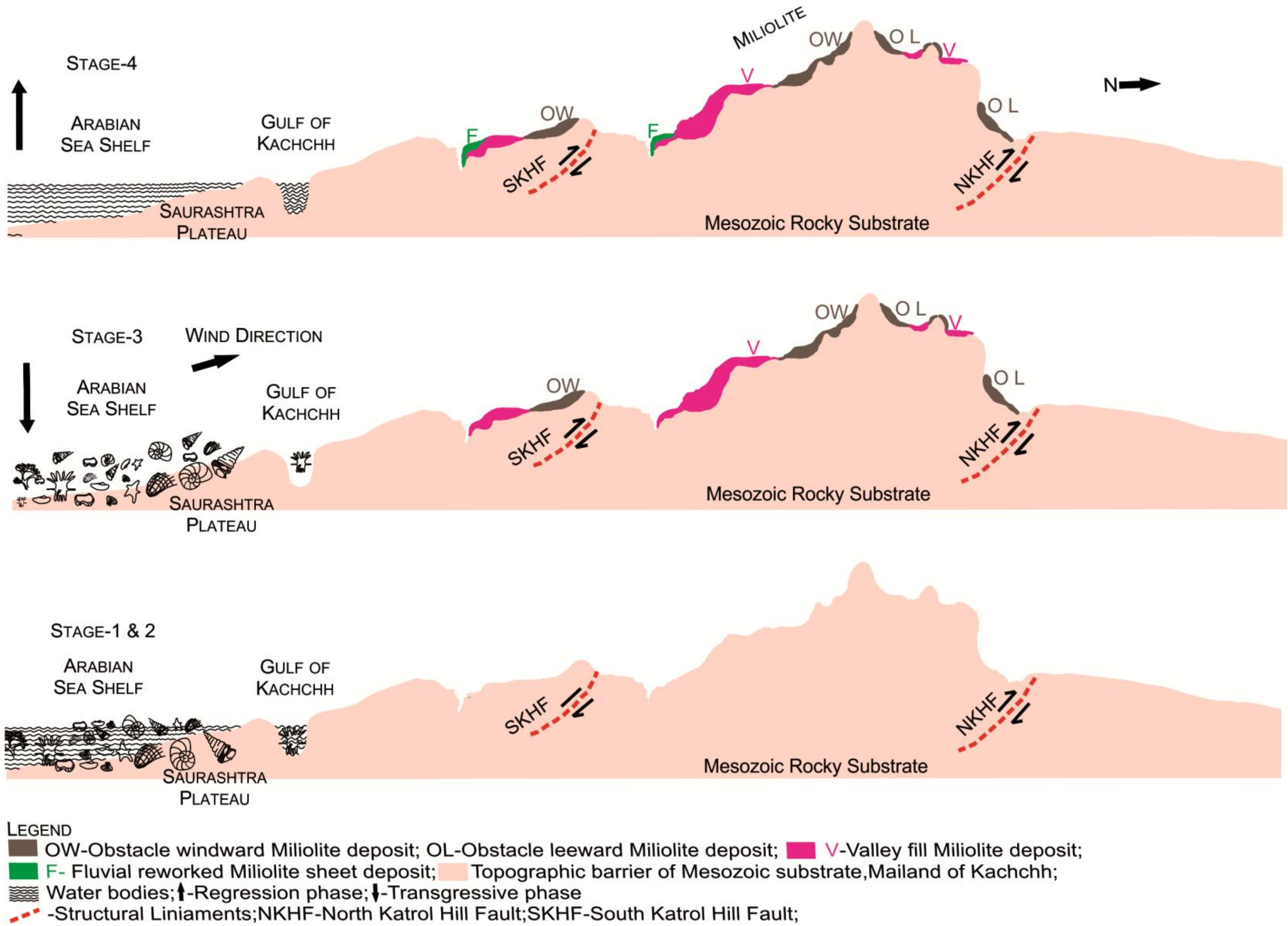

Fig.7.6 A conceptual model of Late Quaternary history of Katrol Hill Range with reference to the Miliolite deposition in Kachchh.