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Palaeoenvironmental interpretation based on lithofacies derived from Keera Dome, Kachchh, western India

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***Abstract:*The Keera dome lies in the Kachchh Mainland, exposes ~225 m thick succession of Chari Formation. It comprises siliciclastic and carbonate sediments of the Callovian to Oxfordian age. The present study describes the depositional environment of six lithofacies derived on the basis ofsedimentological characteristics, viz.,Intercalated Shale Siltstone Facies (ISSF), Fossiliferous Limestone Facies (FLF), Shale Facies (SF), Golden OoliteFacies (GOF), Calcareous Sandstone Facies (CSF) and Oolitic Limestone Facies (OLF). The SF is exposed in all the four informal members of the Chari Formation and contains the highest thickness among the six facies. The OLF is an important facies as it contains the Dhosaoolite rocks, which are considered as 'marker horizon' in the Mesozoic sequence of Kachchh Mainland. The shales, siltstones, limestones, and oolitic limestones of ISSF, LF, GOF, and OLFlithofacies comprise bivalves, brachiopods, *Belemnites*, and ammonites, while in microfossils bryozoa are common. The sedimentological characteristics depicted minor transgression-regression events of depositional sediments, ranges from the shoreface to offshore zone in fluctuating energy conditions.**

***Index Terms:*Lithofacies, Depositional environment, Keera dome, Chari Formation, Kachchh.**

I. Introduction

The Kachchh region forms an important site of theMesozoic and Cenozoic sedimentation. Kachchh sedimentary basin is a peri-continental rift basin located at the western continental margin of India (Biswas, 1977). The remarkable contribution of many Indian geologist (viz., Rajnath, 1932; Tiwari, 1948; Krishnan, 1968; Krishna, 1984; Krishna and Pathak, 1991,1993) have attracted the stratigraphers, sedimentologists and palaeontologists of the world. The Mesozoic rocks constitute more than three-fourth of the Kachchh Mainland. Lithostratigraphically, it comprises of Patcham, Chari, Katrol, and Umia Formation in ascending order (Waagen, 1871, 1873-75).This classification is widely accepted and followed by Pandey et al. (2012), Pandey and Pathak (2015), Mamilla et al. (2016) and many others.The study area, the Keera dome located in the Kachchh Mainland towards the north-west of Bhuj city and comprises mainly rocks of the Chari Formation ranging in age from Callovian to Oxfordian (Biswas, 1977). In Kachchh Mainland, limited workers have been studied sedimentology concerning lithofacies study (Bose et al., 1988; Pandey and Fürsich, 1993; Bandhopadhyay, 2004; Ahmad et al., 2006; Mishra and Tiwari, 2006; Tiwari and Mishra, 2007; Misra and Pandey, 2008; Mishra and Jaikrishna, 2008; Mishra and Biswas, 2009; Ahmad et al., 2013). Lithofacies is a mappable subdivision of a designated stratigraphic unit, differentiated from adjacent subdivisions based on lithology. In the Keera dome, a microfacies study of only Golden Oolite Member of the Chari Formation has been done by Ahmad et al. (2006). A detailed aspect of the sedimentological and depositional environment of the rocks of the Keera dome is yet to be done. Therefore, the present study is carried out to understand the palaeoenvironment based on lithofacies study of the Keera dome.

II. GEOLOGICAL SETTING OF THE STUDY AREA

Keera dome is one of the prominent domes in the chain of the very well developed domes all along the southern part of the Kachchh Mainland Fault (KMF). It extends between the Latitudes 23°34'28.89": 23°35'01.41" N and the Longitudes 69°12'54.92": 69°15'04.15" E covering an area of about 5.26 sq km, and located about 25 km away in north direction from Nakhatrana of Kachchh district (Fig. 1). The rocks belong to

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Chari Formation are divided into four informal members, from M-I to M-IV in ascending order (Biswas, 1977, 1993).

In the Keera dome, different facies of the Chari Formation is noticed than the facies found in the Jumara dome (type area of Chari Formation), and it is very characteristic because of the development of golden oolite rocks in the lower part (Biswas, 1993). In the present investigation, all the four members of the Chari Formation are exposed as Member I, Member II, Member III, and Member IV (Fig. 1). In the Keera dome, mostly all the beds of the Chari Formation are highly fossiliferous.

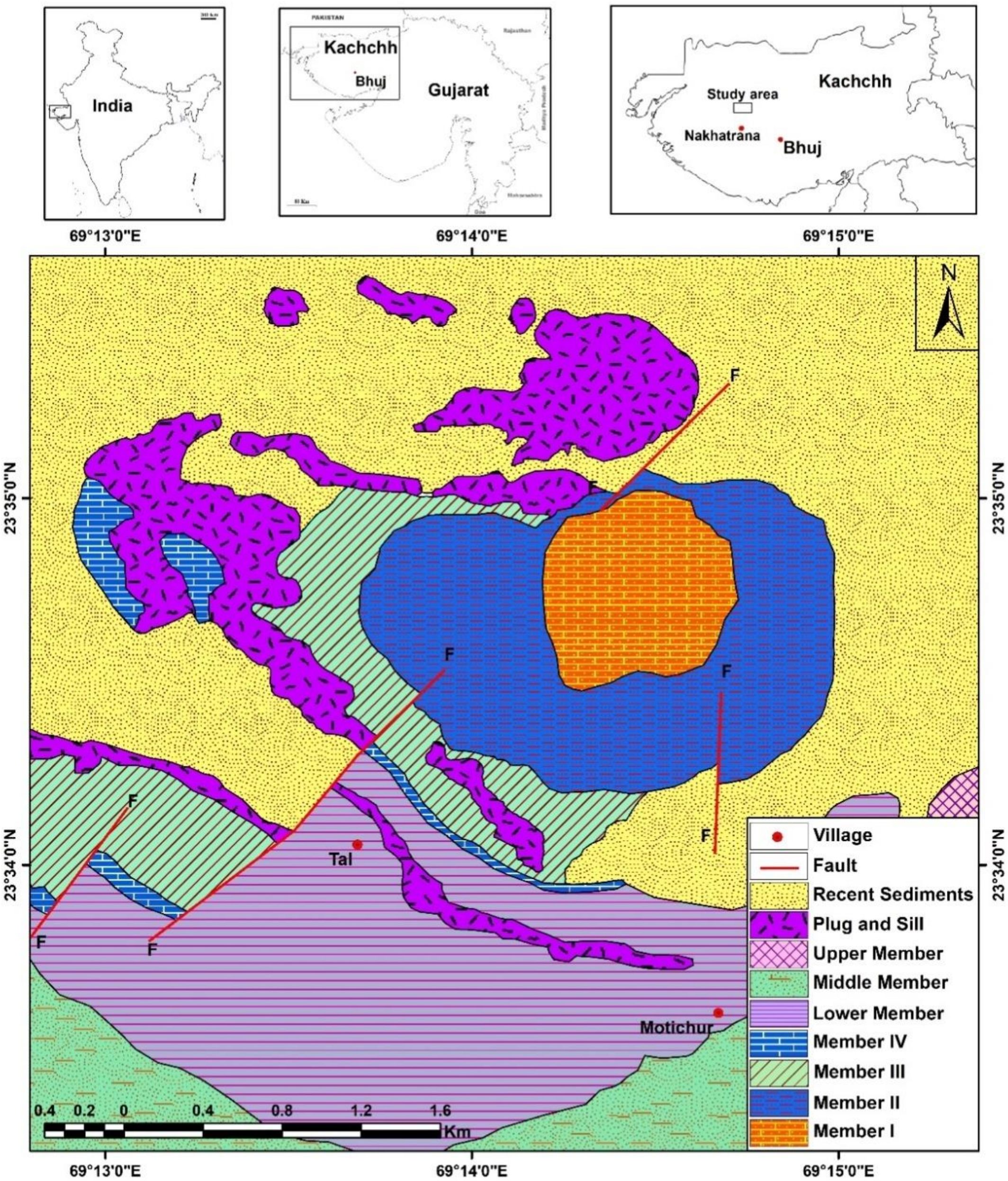

Fig. 1. Location andGeological map of Keera dome, Kachchh.

III. DESCRIPTION OF LITHOUNITS

Only the upper part of Member I of Chari Formation is represented, by yellowish to greyish shale-siltstone partings intercalated with golden oolite. Thinly bedded fossiliferous limestones are also exposed within the shales. The golden oolite is characterized by typical golden color, medium-grained, and oolitic in nature. In the center part of the dome, golden oolitesare exposed almost in a horizontal manner. *Belemnites*, brachiopods, and bivalves are abundant fossils found in the shales, golden oolite, and limestones of M-I. From the lithology of M-I of the Keera dome, it is clear that the major portion of the member is covered by golden oolite/shale facies (Biswas, 1993). The measured thickness of the member is 65 m.

Member II consists of calcareous sandstone, shale, and limestone beds. The calcareous sandstone is medium grained, yellowish to greyish in color, at places bouldery in appearance, and intercalated with shale, which contains thin highly fossiliferous, and ferruginous bands of limestone. It holds a large number of bivalves- *Pecten*, brachiopods, ammonites, and *Belemnites*. One of the beds of calcareous sandstone enclosing *Trigonia* with mud pebbles of ferruginous and yellowish material. The topmost bed of calcareous sandstone marks the top of the M-II. The total thickness of the member is 130 m.

Member III consists of shale sequence which is yellowish, greyish, and reddish- ferruginous, and highly gypseous with few thin ferruginous bands as well as siltstone partings. Thin ferruginous bands are highly fossiliferous in which *Belemnites*, bivalves, and ammonites are most common. At places dolerite dyke traverses the shale sequence, due to which shale becomes hard, indurated, and backed. An intraformational conglomerate is exposed at the top of the member, which marks the boundary with the upper M-IV. This member consists of a thickness of 20 m.

Member IV is the topmost member of the Chari Formation, which consists of oolitic limestones intercalated with shales. The oolitic limestone (DhosaOolite) is a marker horizon that separates the Chari Formation from the Katrol Formation (Biswas, 2016). It is a medium-grained yellowish-green limestone containing ooliths floating in the micritic matrix. The topmost band of the DhosaOolite is conglomeratic, containing yellowish to greenish cobbles of the DhosaOolite enclosed within the fine-grained calcareous matrix. At places, nailhead spar crystals and thin limonitic crust are also found on the surface of the topmost band of the DhosaOolite. Among the fossils ammonites, *Belemnites* and *Terebratula* are most common. The measured thickness of the member is 10 m.

The cumulative thickness of the Chari Formation is 225 m. Basic intrusives are also common in the study area. One of the prominent is a plug of dolerite which is exposed in the northern part, near the Rann. Other intrusives are in form of sills in the western and southern part of the dome intruded into the Chari Formation. It consists of medium-grained, melanocratic, hard, and compact dolerite. It is apparently related to the igneous activity of the Deccan Trap Formation (Ahmad et al., 2006).

IV. MATERIALS AND METHOD

The research work described in the present study is from the three measured sections of the Keera dome. Three different traverses were taken in the south-west, west, and east directions from the core of the Keera dome. The sedimentological characters, type of contacts, and facies variations were studied in each bed of the Chari Formation of the Keera dome and generalized lithocolumns were prepared. The stratigraphic positions were marked in the lithocolumns. Systematic rock samples from each member were collected, photographed, and recorded for further laboratory analysis. The petrographic study was done to understand the textural and mineralogical variations as per Folk's classification.

V. LITHOFACIES

Total six lithofacies following lithological and petrographical variations were identified based on distinct lithologic features, composition, grain size, bedding position, and characteristics, and biological characters are described in the following section. These facies have been encountered at different stratigraphic levels of the ChariFormation which were measured and represented in the lithocolumns of the Keera dome.

A. *Intercalated Shale Siltstone Facies (ISSF)*

Intercalated Shale Siltstone Facies (ISSF) is represented by very closely alternated shale and siltstone rock units. This facies is developed in the M-I of Chari Formation with golden oolite rocks. The collective thickness of the facies in M-I is 22.00 m.

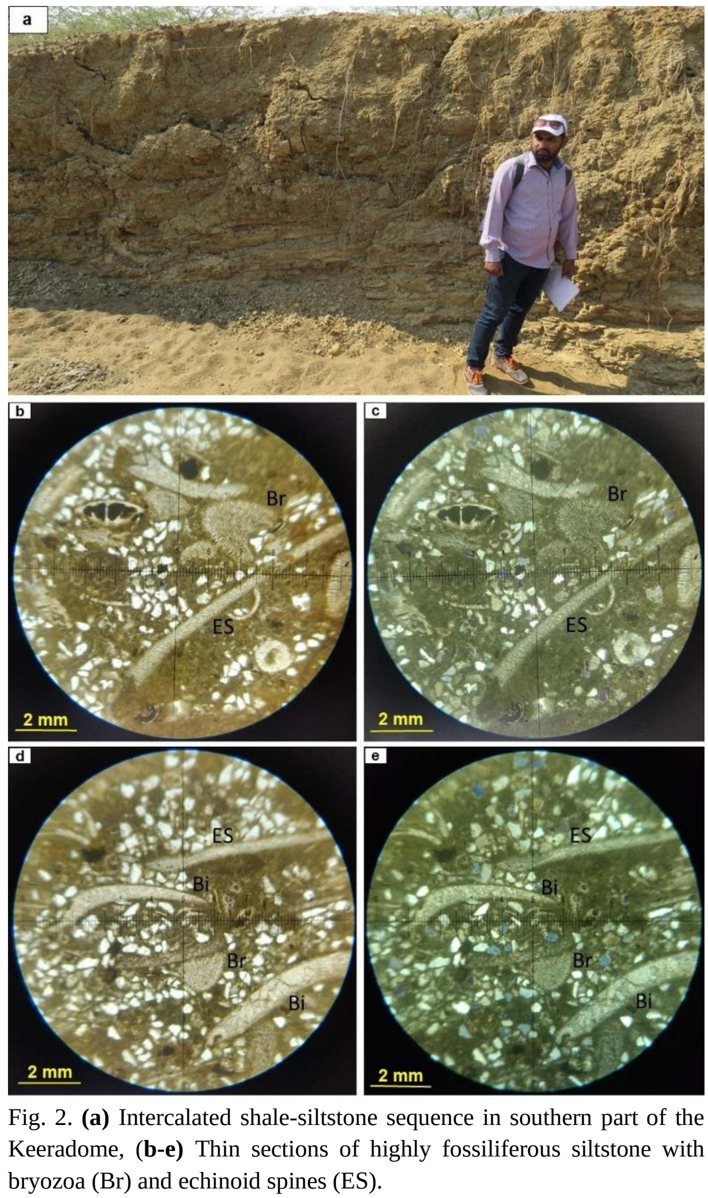

Fig. 2. **(a)** Intercalated shale-siltstone sequence in southern part of the Keeradome, (**b-e)** Thin sections of highly fossiliferous siltstone with bryozoa (Br) and echinoid spines (ES).

Shales are argillaceous in nature and exposed mainly as thinly laminated beds of greyish to yellowish color. Shales are intercalated by siltstone laminae at the various intervals. The siltstones are yellowish to reddish colored laminae with fine-grained size. In between, thin ferruginous bands are exposed which are fragmentary in appearance and producing typical surface features on the overall topography. Among the body fossils, few ammonites and bivalves are found, while trace fossils are abundant along the siltstone laminae. Microscopically, siltstone contains quartz grains floated in the ferruginous matrix. It is highly fossiliferous with numerous bryozoa and shell fragments (Fig. 2).

From the sediments characteristics, it can be observed that the facies is dominated by argillaceous sediments and overall deposition of fine-grained material with alternate laminae of siltstones. Moreover, the absence of any kind of current-induced structure suggests that shales and siltstones were deposited in a low-energy environment (Al-Ajmi et al., 2015). The sediments characteristics of this facies indicate very slow settling of the suspended fine hemipelagic material in low energy conditions below the fair-weather wave-base (Solanki et al. 2017). Overall, the facies reveals the offshore-transition environment of deposition.

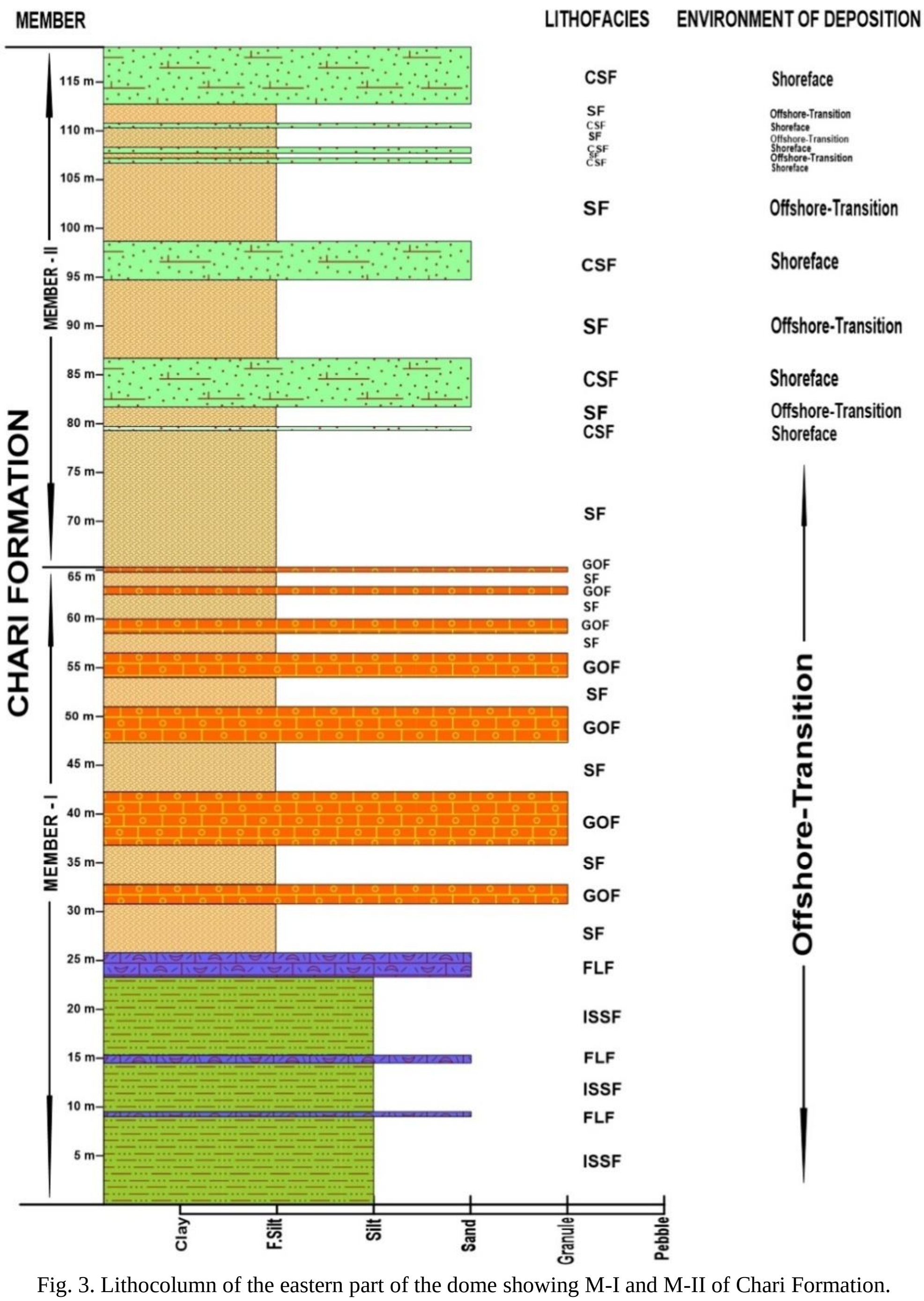

Fig. 3. Lithocolumn of the eastern part of the dome showing M-I and M-II of Chari Formation.

B. Fossiliferous Limestone Facies (FLF)

Fossiliferous Limestone Facies (FLF) is developed in M-I and M-II of Chari Formation (Fig. 3 &6). It is characterized by thin bands of limestones intercalated with shales and siltstones. The limestones are dirty yellowish to brownish in color and consist mainly of ferruginous material along with abundant fossil fragments. The limestones are highly fossiliferous that comprise bivalves, brachiopods, *Belemnites*, and ammonites along with the clay pebbles. A microscopic study reveals that the limestone largely contains bioclasts floating in the sparry calcite matrix.

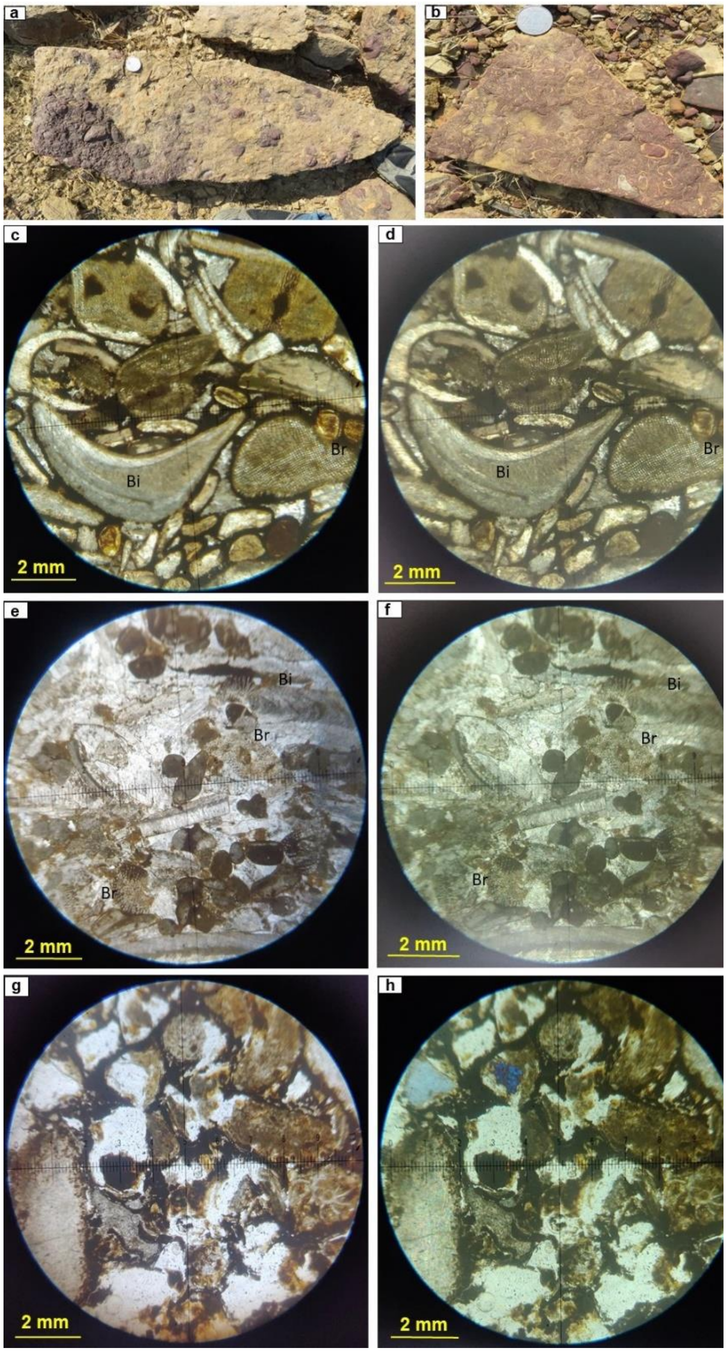

Fig. 4. **(a-b)** Highly fossiliferous limestone of FLF, (**c-h)** Thin sections of highly fossiliferous limestone containing bivalves (Bi) and bryozoa (Br).

The bioclasts include mainly bivalves, bryozoa, foraminifera, and echinoid spines with few grains of quartz. Some shell fragments are more than 3 mm in size and are also composed of sparry calcite crystals. These characters depict that it is abiosparite (Fig. 4).

The intercalations of limestones with shales suggest sediments were deposited below the normal wave base in the transition zone (Solanki et al., 2016). The limestones containing the bioclasts (bivalves, brachiopods, *Belemnites*, and ammonites) were deposited on the platform margin (Patra and Singh, 2015). Thus, the FLF suggests the offshore-transition depositional environment.

C. Shale Facies (SF)

The shale lithofacies is very well developed throughout the Chari Formation with a total aggregate thickness of 166.90 m (Fig. 3 & 9), out of which the maximum thickness of 117.40 m is found in M-II (Fig. 6). Shales are mainly yellowish to greyish in color, fine-grained, and well laminated. Thin bands of cherry red ferruginous material are present in between the shales. The shales often contain authigenic gypsum crystals (Biswas, 1993). The fossil content is comparatively less and mainly represented by the ammonites (Fig. 5).

Fig. 5. Section showing **s**hale facies with thin ferruginous bands.

The dominance of fine-grained argillaceous material suggests that the sediments were deposited in quiet water conditions in an offshore-transition environment (Solanki et al., 2016).

D. Golden OoliteFacies (GOF)

The golden oolite unit belongs to the early Callovian age represents the basal part of the Keera dome, M-I of Chari Formation. It is characterized by the typical golden color of oolitic limestones. The golden oolites are intercalated with shale-siltstone partings. GOF attaining the collective thickness of 16.50 m in the eastern flank of the Keera dome from more than 7 beds (Fig. 3 & 6). The golden oolite is basically medium-grained, oolitic limestone that contains golden-colored ooliths. This lower Callovian golden oolite shows greater enrichment of iron relative to the younger DhosaOolite of Oxfordian age (Rajeevan et al., 2013). At some places, clayey pebbles of ferruginous material are found embedded in the calcareous matrix. Beds are highly fossiliferous and show the presence of bivalves, *Belemnites*, and ammonites. Microscopically, the rock is dominated by fossil fragments and ooids which are embedded in the fine-grained calcareous micritic matrix. The size of the fossils ranges from 1 mm to more than 2.5 mm and includes bryozoa (abundant), foraminifera, and echinoids. Ooids are characterized by typically brown colored and ranges in size from 0.4 to 2 mm having spherical to oblate shape. Few grains of sub-rounded quartz are enclosed within the micritic matrix. Based on the dominance of fossils and micritic matrix, the rock can be termed as Oobiomicrite (Fig. 7).

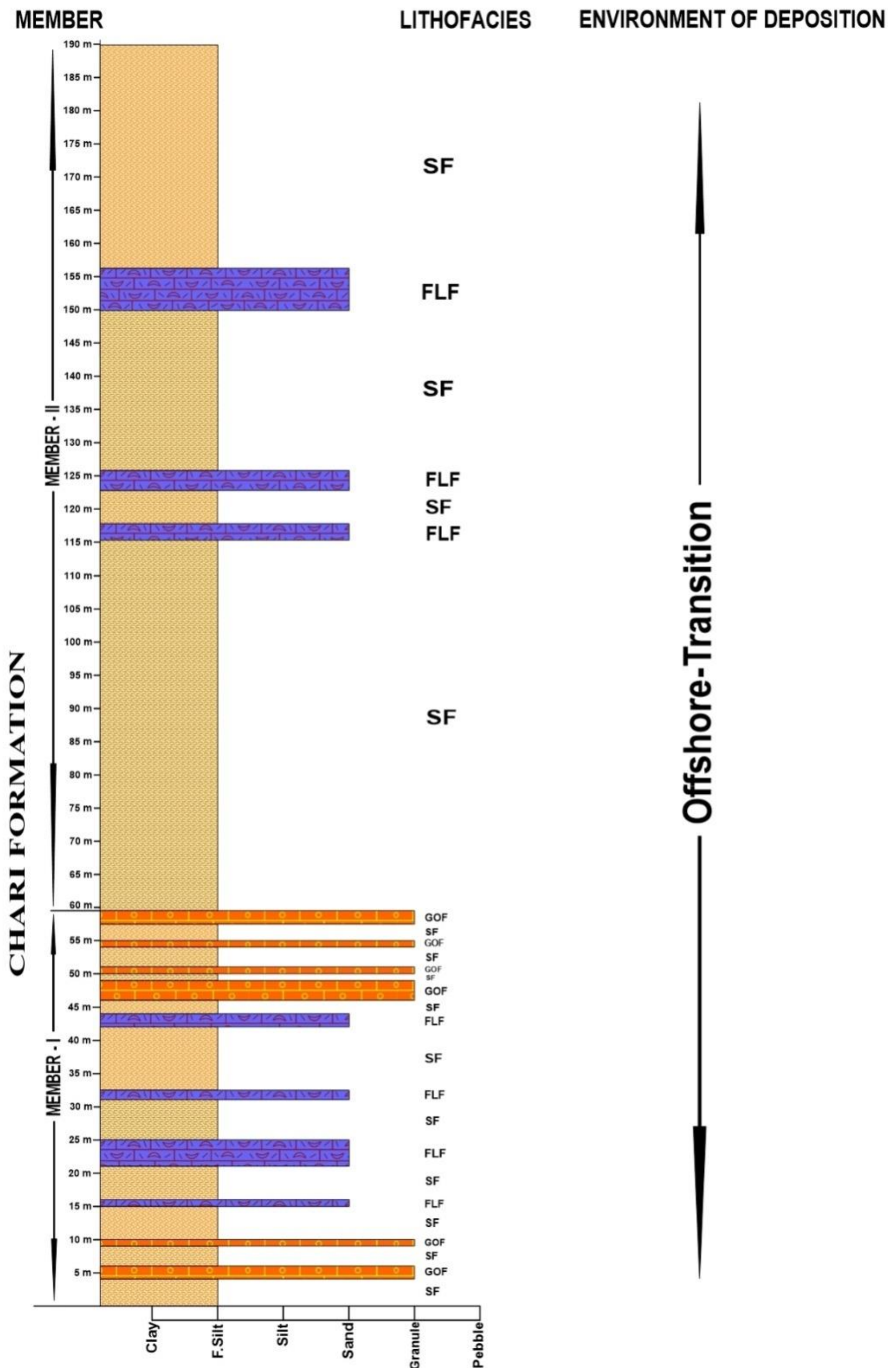

Fig. 6. Lithocolumn of the western part of the dome showing M-I and M-II of Chari Formation.

The golden color of the golden oolite beds suggests an iron oxide layer on the calcareous ooliths, indicate conditions of oxidation in shallow water conditions and development of the facies reveals lower shoreface to transition environment (Patel and Patel, 2015). Mishra and Tiwari (2006) suggest a shoreface depositional environment for the facies. These sedimentological characters suggest a shallow, open shelf environment. Moreover, the facies along with the presence of biogenic fragments indicate the depositional environment as an offshore-transition zone.

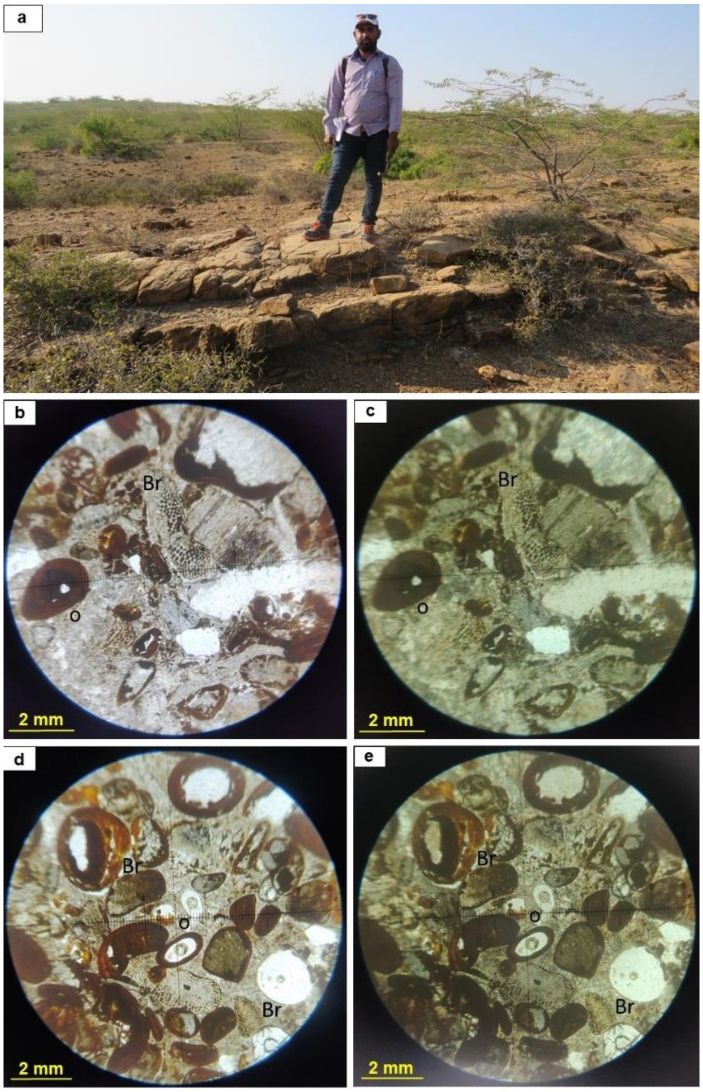

Fig. 7. **(a)** Outcrop of golden oolite of GOF, (**b-e)** Thin sections of fossiliferous golden oolite comprising oolites (O) and bryozoa (Br).

E. Calcareous Sandstone Facies (CSF)

This facies is mainly composed of calcareous sandstone. Calcareous Sandstone Facies (CSF) developed in the eastern part of the dome in M-II of Chari Formation, attains a cumulative thickness of 15.85 m (Fig. 3). It is exposed as prominent, hard, and thick beds that can be measured easily in M-II.

The sandstones are yellowish to greenish in color, very hard and compact, and contain occasional boulder. The rock is mainly moderate to well-sorted, medium-grained sandstone and gives effervescence of CO_2 when treated with dilute HCl, which indicates its calcareous nature. No physical structures are present in the calcareous sandstone, but body fossil *Trigonia* is present in the rock. Microscopically, the sandstone is well sorted, where the quartz grains are sub-rounded to sub-angular along with few feldspars, embedded in the calcareous matrix, which suggests it is sub-feldspathicarenite (Fig. 8).

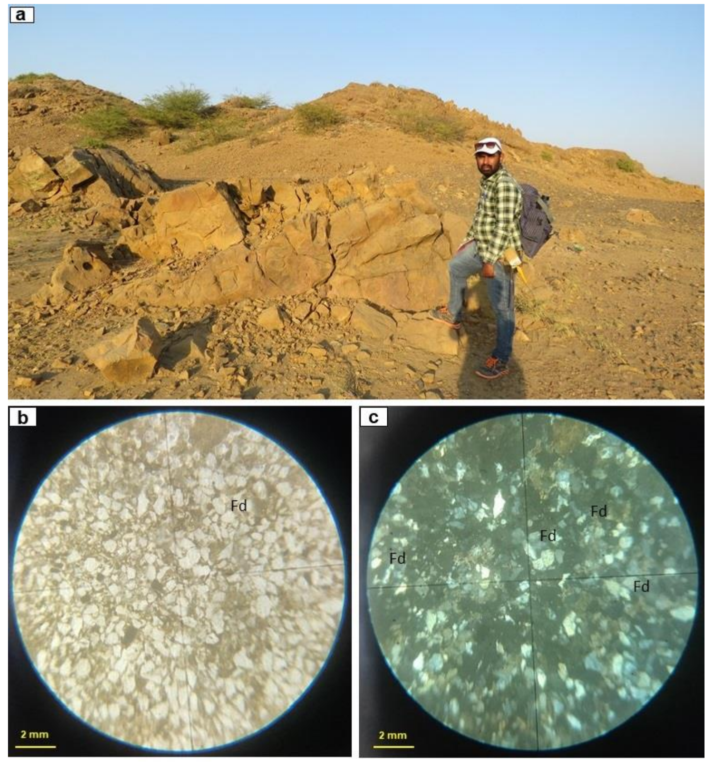

Fig. 8. **(a)** Calcareous sandstone of CSF in eastern part of the dome, (**b-c)** Thin sections of calcareous sandstone having 10-15% feldspars (Fd).

For the Calcareous Sandstone Facies, wave action is interpreted to be the dominant mode of sediment transport in the nearshore zone and records shallow water deposition during shoreline transgression (Pietras and Carrol, 2006). The sedimentary characteristics and the presence of body fossils suggest that this facies deposited in the shoreface environment.Here, wave action is the primary transport process as fluctuating energy conditions are dominated.

F. Oolitic Limestone Facies (OLF)

Oolitic Limestone Facies (OLF) is characterized by oolitic limestone beds, which represent the most fascinating sedimentary unit in Jurassic of Kachchh- DhosaOolite (Fürsich et al., 2001). The prominent ridges of oolitic limestone beds are found alternating with shales. The OLF comprises highly fossiliferous limestone with yellowish-grey to greenish colored ooids embedded in varying proportion in the fine grained calcareous matrix. The size of the ooliths varies from fine to medium-grained. The topmost bed of the M-IV of the Chari Formation is conglomeratic and is highly fossiliferous (Fürsich et al., 2001) (Fig. 9). This bed contains mainly *Belemnites*, ammonites, *Ostrea*, and *Terebratula*. This unit containing the most characteristic fossil assemblage suggests an Oxfordian age (Patel et al., 2009). In the topmost conglomeratic bed, cobbles are spheroidal, calcareous, and yellowish-green in color which are found enclosed in the micritic matrix. Thin limonitic crust (Spath, 1933) and at some places nailhead spar crystals are also

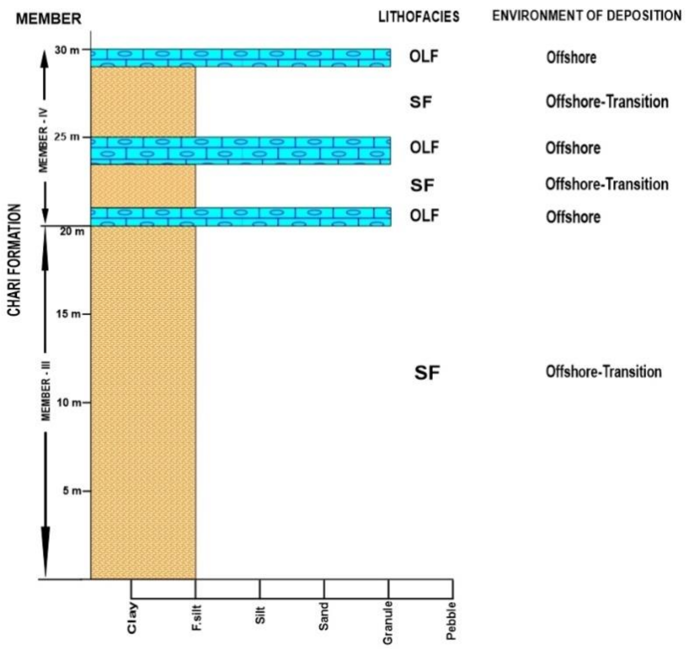

Fig. 9. Lithocolumn of the western part of the dome showing M-III and M-IV of Chari Formation.

developed on the surface of DhosaOolite. The microscopic study shows that the rock contains elongated to sub-rounded, well-sorted ooids, and quartz grains. The ooids are brownish, concentric type, and 0.5 to 2 mm in size. The matrix is of calcareous material which is a fine-grained micrite type. These characteristics suggest that the rock is Oomicrite (Fig. 10).

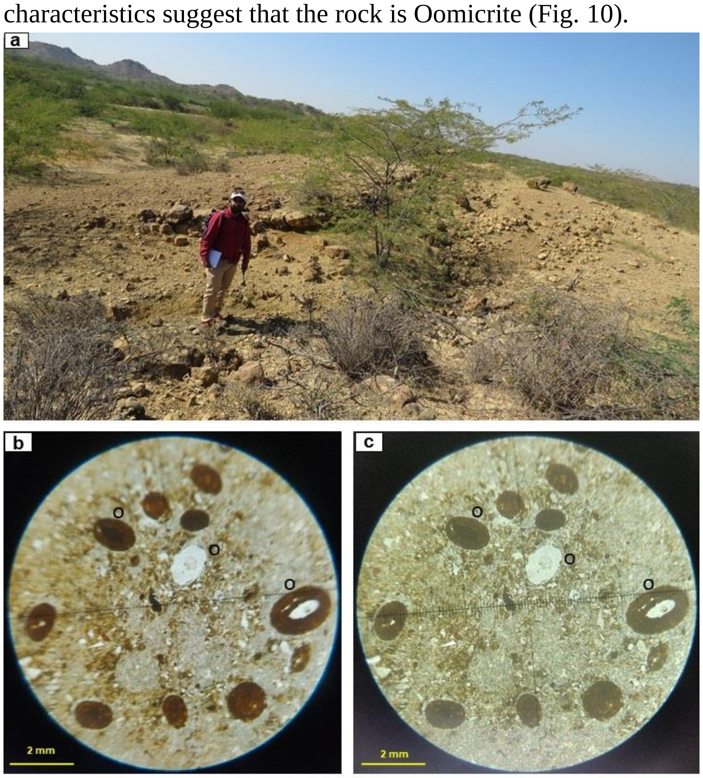

Fig. 10. **(a)** Outcrop of Dhosaoolite of OLF, (**b-c**) Thin sections of Dhosaoolite with the presence of oolites (O) floating in micritic matrix.

Large ooids of the Oolitic Limestone Facies were most probably derived from the nearshore source in very shallow agitated water from where they are transported to a lower shelf environment by storm events (Aigner, 1985). While the carbonate components, large bioclasts (bivalve and cephalopods) were probably formed locally by biological or mechanical degradation of shells. The wide geographical distribution of these features of facies also indicates an offshore position, well below the fair-weather wave base (Patel and Patel, 2015). Thus, the deposition of Oolitic Limestone Facies took place in a relatively uniform offshore setting.

DISCUSSION AND CONCLUSION

The rocks of the Keera dome comprise siliciclastic and carbonate sediments ranging in age from Callovian to Oxfordian (Biswas, 1977). The composite lithocolumn of the Keera dome comprises ~ 225 m thick succession of rocks that exposed in four informal members of Chari Formation (Fig. 11).

The M-I comprising the basal part of the dome is characterized mainly by the argillaceous material intercalated with carbonate material. The sediments exposed in the member are represented by the SF, GOF, ISSF, and FLF, out of which the maximum thickness of 23 m is comprised by the Shale Facies. The thickness of the member is almost the same in the eastern and western flank of the dome, but the SF is comparatively thicker in the western flank than the eastern flank. The FLF within the shales are comparatively thin in the eastern flank and thick in the western flank, where the maximum thickness of the bed reaches up to 4 m. This indicates the better development of facies in the western flank. All four facies contain fossils in a significant amount. Overall, the fine-grained nature of the sediments belong to SF and ISSF, the oolitic nature of the golden oolite rocks, and bioclasts of limestone in greater amount indicate the deposition of sediments in low energy conditions of the offshore-transition environment.

The maximum thickness of the succession of the Keera dome is covered by M-II of Chari Formation and is characterized by shales intercalated with calcareous sandstones and fossiliferous limestones. It includes SF and CSF in the eastern flank, while SF and FLF in the western flank. The SF having the highest cumulative thickness which is exposed in the western flank, thus the M-II is fully developed in the western flank compare to the eastern flank. It may be assumed that the sediments were transported by the wave action from the nearshore zone and deposited in form of calcareous sandstone in shoreface (Pietras and Carrol, 2006), and remaining fine-grained sediments along with bioclasts were further transported to the transition zone due to fluctuating energy conditions. Thus, facies of this member show fluctuating environment of deposition ranges from shoreface to offshore-transition.

M-III is entirely covered by the Shale Facies which comprises only shales and exposed only in the western flank of the dome.

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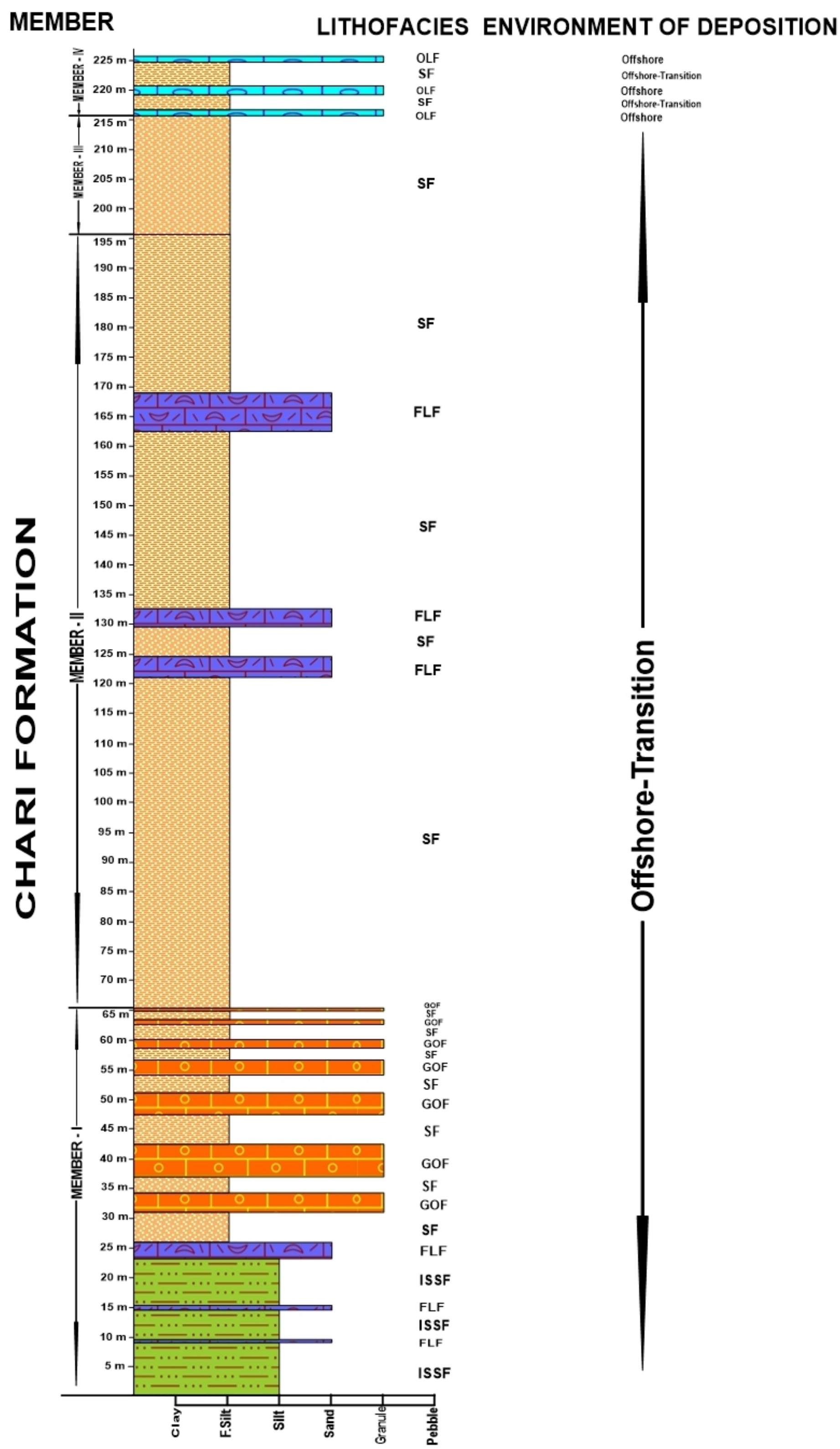

Fig. 11. Composite Lithocolumn of the Chari Formation.

The dominance of argillaceous material showing a single episode of deposition of sediments in quiet water conditions. The SF developed in this member contains comparatively fewer fossils than the other members. The deposition of the fine-grained material indicates an offshore-transition environment for the entire M-III.

M-IV is represented by the OLF and SF, which comprises the intercalated sequence of oolitic limestones and shales. The facies characteristics suggest the fluctuating environment of deposition from offshore-transition to offshore.

The sediments of the Chari Formation of Keera dome reveals overall low energy conditions with minor fluctuations. The basal part shows the transition environment which is continued up to the middle part of the M-II. Shoreface environment of deposition during the upper part of M-II reveals the regression phase, which is again followed by transition environment in M-III depicts transgression phase. Finally, transition and offshore environmental conditions of deposition of M-IV indicate the continuation of the transgression phase.

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