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Biostratigraphy and sea-level fluctuations during the Jurassic of Kachchh region, Gujarat, India

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Total forty-four surficial samples were collected at six locations (J1 to J6) from the Jhurio and Jumara Formations exposed at the Jhurio (Jhura) Dome, Kachchh district of Gujarat. Thirteen major species were considered for the Principal Component Analysis (PCA) out of forty-five identified foraminiferal species. PCA (both factor and cluster analyses) helped us to retain four foraminiferal groups (Sl, Et, Rr, En). The established ecological preferences of each species are used to reconstruct palaeodepositional environment. The basal golden oolitic limestone sequence (locations J5 and J6) is dominated by foraminiferal group Et (*Epistomina turgidula, Epistomina nuda*), suggesting oxygen-depleted, outer shelf environment depositional environment and Bathonian age for the Jhurio Formation. Foraminiferal group En (*Epistomina nuda, Verneuilinoides tryphera, Spirillina polygyrata, Tandonina paula*) dominates in the Jumara Formation sediments suggesting low-oxygenated, outer shelf depositional environment similar to the Jhurio Formation. However, intervals with foraminiferal groups Rr (*Epistomina nuda, Verneuilinoides tryphera, Spirillina polygyrata, Tandonina paula*), and Sl (*Saracenaria latifrons*) indicate relatively shallower depositional depth (inner shelf) in an oxygen-depleted environment. The established foraminiferal assemblage contains some moderately short-ranging species either restricted to Bathonian or frequently reported from Bathonian to Oxfordian strata indicating Bathonian to Oxfordian age of the Jumara Formation exposed at Jhurio Dome. The foraminiferal group distribution pattern also shows variations in depositional depths (outer shelf to inner shelf and vice versa) during the middle Jurassic indicating sea-level fluctuation.

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INTRODUCTION

The Kachchh basin is a pericratonic basin, situated in the northwestern part of India. The Nagar–Parker fault bound this basin in the north, Radhanpur–Barmer arch in the east, and North Kathiawar fault in the southeast, whereas this basin is open on the south and west, merging with the continental shelf of the Arabian Sea. This basin is gently sloping towards the southwest. The total area covered by the Kachchh basin is about 71,000 km^2 of which on-shore area is 43,000 km^2 and off-shore area up to 200 m bathymetry is 28,000 km^2. The basin occupies the entire Kachchh district and western part of Banaskantha district of Gujarat and extends between latitude 22° 30' N and 24° 30' N and longitude 68° E and 72° E (Biswas, 2005; Patel *et al.,* 2020). The central uplifted part of the basin constitutes a thick succession of Mesozoic sediments (about 2,430 m), whereas a thick pile of Cenozoic deposits is bordering the outer part of the Mesozoic uplifts. The stratigraphy of Kachchh comprises middle Jurassic to early Cretaceous strata which are overlain by the thick Paleogene sequence (Biswas, 2016). The onshore Kachchh basin is characterized by the most striking topographic features comprising of highlands surrounded by lowlands. The Mesozoic rocks are exposed in the highland whereas Cenozoic sediments cover the lowlands. The highlands represent tilted horsts bordered by the lowland half-grabens. These half-grabens are filled with Jurassic and Cretaceous sediments below the Cenozoic deposits (Biswas, 2016). The sediment fills in the basin have the syn-rift signature, and the primary source areas for the sediment supply are the rift shoulders, highs, and the hinterland.

Jurassic marine strata are extensively developed in the Kachchh region. The Jurassic sediments show excellent exposures and are characterized by varied and excellently preserved invertebrate fossils, especially ammonoids. These fossiliferous marine strata have been under intensive stratigraphic and palaeontological investigations since 1834. Extensive literature is available on stratigraphic and palaeontological aspects of the Jurassic rocks of Kachchh, which helped to develop the stratigraphic sequence, age fixation of different stratigraphic units, and inter-regional correlation.

Several workers have documented many research articles on palaeontological aspects. All these studies had helped in

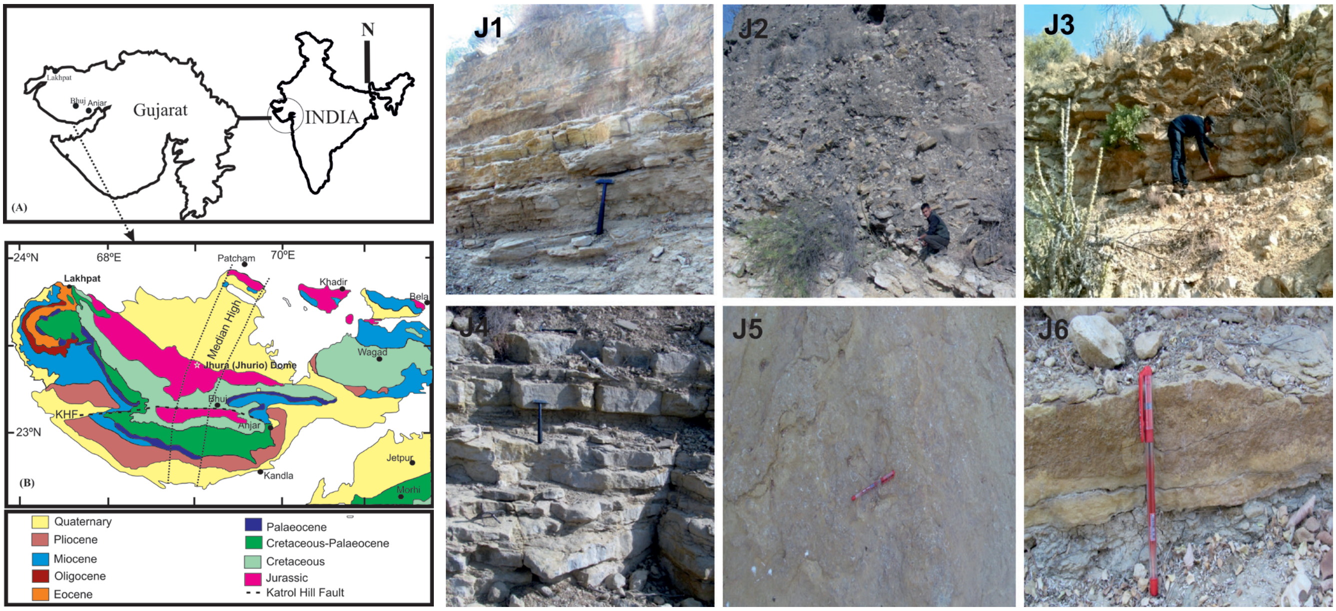

Fig. 1. (A) Geographical outline map showing the position of India and Gujarat; (B). Location map of the studied site in western Kachchh district, Gujarat, India. The map is redrawn and modified after Mishra *et al.* (2014). Solid black star represents the sample collection sites. Solid black circles are representing the township; 1(C). Field photographs of Jhurio Dome from locations J1 to J6. (J1) First sampling location shows alternate layers of calcareous sandstone and shale. The length of scale is 33 cm. (J2) Showing alternate layers of sandstone and shale. (J3) Alternate layers of sandstone and shale. (J4) A thick pile of shale and limestone. The length of the scale is 33 cm (J5 and J6) Golden Oolitic limestone. The length of the pen is 15 cm.

developing the stratigraphic sequence, determination of age, interregional correlation, and estimation of the depositional environment (Rajnath, 1932; Barnard, 1948; Tewari, 1957; Subbotina *et al.,* 1960; Agrawal and Singh, 1961; Singh; 1979, Casshyap *et al.,* 1983; Govindan *et al.,* 1988; Mandwal and Singh, 1989, 1994; Pandey and Dave, 1993; Gaur and Sisodia, 2000, Fursich *et al.,* 2004; Talib and Faisal, 2007; Gaur and Talib, 2009, Talib *et al.,* 2016, 2017). All these works emphasized the micropalaeontological importance to understanding the biostratigraphy, palaeogeography, and palaeoclimate that prevailed during the Jurassic Period. These studies are performed on the exposed Jurassic sediments in Jhurio (Jhura) Dome, Jumara Dome, Habo Dome, Keera Hill, Kaiya Hill, and Ler Hill. There are unresolved controversies regarding the stratigraphic positions of Jhurio (Patcham) and Jumara Formations exposed at the Jhurio Dome. The present study has been carried out to decipher the sea-level fluctuations, biostratigraphy, and depositional environment on Jhurio and Jumara Formations in the Jhurio Dome's exposed samples.

MATERIALS AND METHODS

The Kachchh basin accommodated a huge pile of sediments since the Jurassic time and provided us with an excellent geological study opportunity. The samples are collected from the Jhurio Dome, located 19 km away from NNW from Bhuj. It is situated in the north-central part of the Kachchh mainland. Total forty-four (44) samples were collected from six (6) locations (J1 to J6) (Fig. 1)

The first location (J1, 23º 24.440 ´ N; 69º 35.85 ´ E) comprises alternate layers of calcareous sandstone and shale. Eight (8) samples were collected from this location. The other sampling locations J2, J3, J4, J5, and J6, are situated 84, 148, 178, 385, 593 meters away respectively to the west of J1. Eight samples were collected from the second sampling location (J2), having alternate calcareous sandstone layers and shale layers. Five (5) samples were collected from alternating sandstone-shale layers of the third location (J3). Twenty-one (21) samples were collected from a thick pile of shale and limestone of the fourth sampling location (J4). The sampling locations J1 to J4 belong to the Jhumara Formation. Likewise, one sample from fifth (J5) and sixth (J6) locations was collected from Oolitic limestone, which belongs to the Jhurio Formation.

Approximately 20 grams of consolidated sediment samples were used for the separation of foraminifera. Sediments were fragmented into pea-sized before soaking. The foraminiferal separation was done followed by the process described in Srivastava *et al.,* 2017. Pea-sized fragmented sediments were soaked overnight into the ordinary water with 5ml of 30% H_2O_2 for proper disintegration. Additional H_2O_2 was added as per requirement in case of incomplete disintegration. Disintegrated sediments were then treated in the ultrasonic bath for proper cleaning of foraminiferal specimens. Finally, ultrasonically treated sediments were washed over a 63 µm sieve under a shower of water. The collected residue over the sieve (>63 µm) was then oven-dried and transferred into a labeled glass vial for census count of foraminifera under the stereo-zoom microscope.

RESULTS AND DISCUSSION

Several works have been done on the Jhurio Dome yielding an impressive number of fossil-rich assemblages, *e.g.,* megafossils, ammonoids, bivalves, brachiopods, and microfossils (Bhalla and Talib, 1985; Mandwal and Singh, 1989). Still, there are issues and different schools of thought about the age of the Jhurio and Jumara Formations exposed at Jhurio Dome.

The sediments of Jhurio Dome are broadly divided into Jhurio (Patcham), Jumara (Chari), and Jhuran (Katrol) Formations. The base of the Jhurio Formation (Bajocian) is not exposed in Jhurio Dome. The faunal study has aimed to understand the palaeodepositional environment of the Jhurio and Jumara Formations. Also, an attempt has been made to assess the ages of these two formations exposed in Jhurio Dome. In the present study, 45 foraminiferal species have been identified out of which few are major dominating forms. Principal Component Analysis (PCA) and cluster analyses were executed on the highest-ranked benthic species' census count to understand the palaeoceanographic reconstructions. PCA has been accomplished by using the software PAST 3 (Hammer *et al.,* 2001). A total of 13 species are selected for the cluster and PCA, having their relative abundance of two percent (2%) or more in one sample and at least five (5) samples. PCA was performed on the correlation matrix. A scree (x-y) plot of Eigenvalues versus the number of principal components and screening of principal component loadings allowed for retaining four foraminiferal groups accounting for 84.13% of the total variance. Cluster analysis was performed to identify sample groups. The foraminiferal census count was normalized into log-ratio before PCA analysis to standardize the data set and alleviate the considerable disparity in the data scale. Based on Euclidean Distance's plot versus the number of clusters, four clusters are identified (Fig. 2). Principal components that show significant species associations with higher PCA loadings were considered to define the foraminiferal group. Principal components that do not indicate substantial species associations were not used to describe a benthic foraminiferal group. In this way, four foraminiferal groups are identified, and their palaeoenvironmental significance is determined based on established ecological preference (Table-1). All the foraminiferal groups are designated by the abbreviated name of the dominant species. Foraminiferal group Sl is comprising of a single species (*Saracenaria latifrons*), foraminiferal group Et comprises species *Epistomina turgidula* and *Epistomina nuda*, foraminiferal group Rr consists of species *Robulus reniformis*, *Epistomina turgidula* and *Saracenaria latifrons*. The fourth foraminiferal group En includes species *Epistomina nuda*, *Verneuilinoides tryphera*, *Spirillina polygyrata,* and *Tandonina paula* (Table 1).

Depositional environment and stratigraphy of the Jhurio Formation

The basal golden oolitic limestone part of the sequence (locations J5, Gol and J6, Gol) contains very few benthic foraminifera (*Epistomina nuda* and *Epistomina turgidula*, Fig. 3). These two samples also show their clustering in foraminiferal group Et (*Epistomina turgidula* and *Epistomina nuda*, Figs. 2, 4). It is well established that species *Epistomina turgidula* and *Epistomina nuda* are well abundant in oxygen-depleted outer shelf environment (Bernhard, 1986; Koutsoukos *et al.,* 1990; Sagasti and Ballent, 2002). Therefore, the characteristic foraminiferal group Et indicates deposition of these sediments in low oxygen outer shelf environment. Limestone possesses less organic carbon than shale. Thus, relatively higher TOC values (~4 wt%) within this limestone indicate a high productive-reducing environment (Table-1). On the other hand, earlier records show the distribution of *Epistomina nuda* is confined within the Bajocian to Callovian age (Bhalla and Abbas, 1978; Mandwal and Singh, 1989; Sagasti and Ballent, 2002) as well as *Epistomina turgidula* is only found within the

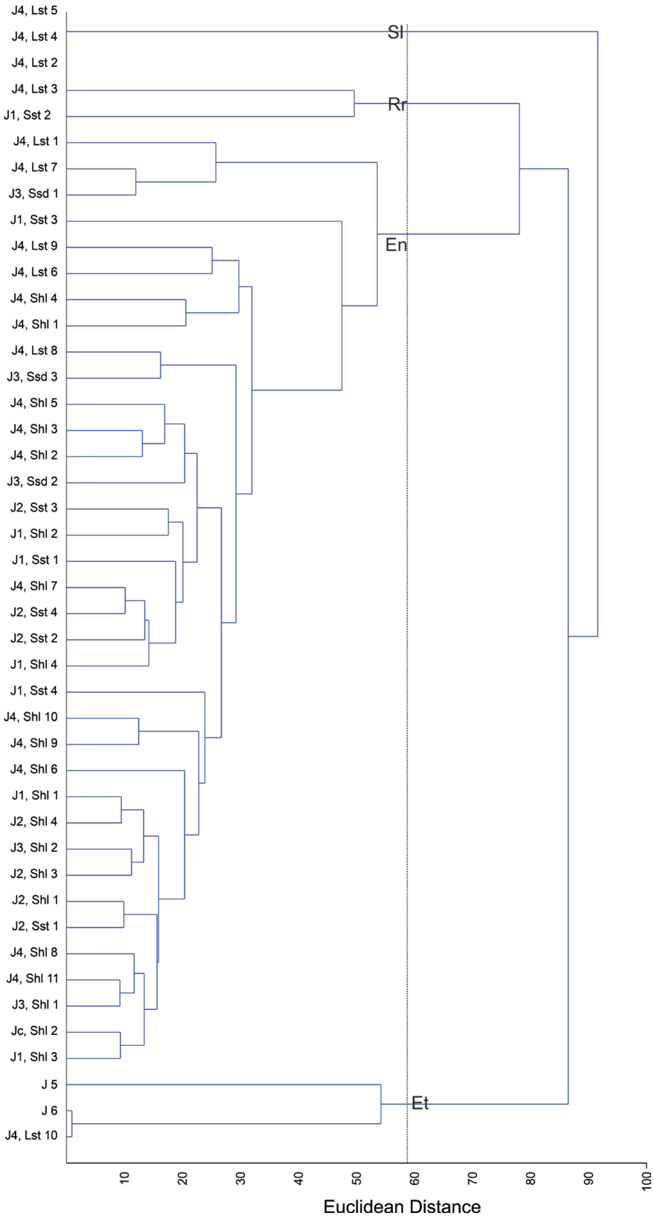

Fig. 2. Dendrogram based on Principal Component Analysis of 44 samples from the Jhurio Dome.

Table 1. Derived foraminiferal groups with components and respective factor scores. The inferred environment preferences are assigned from the published literature.

Foraminiferal group	PCA loading	Environment
Foraminiferal group Sl		High productive, low oxygen, littoral to neritic (inner shelf) environment
(PC 1+ve)	0.91339	
Saracenaria latifrons		
Foraminiferal group Et		
(PC 2+ve)	0.75689	Oxygen-depleted outer shelf environment
Epistomina turgidula	0.11786	
Epistomina nuda		
Foraminiferal group Rr		
(PC 2-ve)	0.56799	Low to moderate dissolved oxygen, organic carbon-rich, inner shelf environment
Robulus reniformis	0.50616	
Epistomina turgidula	0.25782	
Saracenaria latifrons		
Foraminiferal group En		
(3+ve)	-0.52368	Oxygen-depleted outer shelf environment
Epistomina nuda	-0.17139	
Verneuilinoides tryphera	-0.16159	
Spirillina polygyrata	-0.13329	
Tandonina paula		

Bathonian age. Thus, we suggest the Bathonian age for this formation. It is important to note that some workers assigned Bathonian as the age of Jhurio Formation (Rajnath, 1932; Krishna, 1987; Mandwal and Singh,1989) whereas Biswas (1977, 1986, 1993) has broadly assigned Bathonian to Lower Callovian age of the Jhurio (Patcham) Formation exposed at the Jhurio Dome.

Depositional environment and stratigraphy of the Jumara Formation

Sediments lying over the Jhurio Formation consist of alternate limestone, shale, and calcareous sandstones (J1, Shl-1 to J4, Lst-10). These sediments are rich in fossils. The most abundant benthic foraminiferal species are *Awhea sinalata*, *Epistomina nuda*, *Epistomina turgidula*, *Howchinia bradyana*, *Nodosaria hortensis*, *Robulus reniformis*, *Singhamina jaisalmerensis*, *Saracenaria latifrons*, *Spirillina polygyrata*, *Tandonina paula*, *Texularia valeriae*, *Verneulinoides tryphera* (Fig. 3).

Species *Awhea sinalata* shows its distribution rarely at upper and middle bathyal and common at lower bathyal in the offshore region (Hayward, 2002). *Howchinia bradyana* is found in the shallow marine environment (Krainer and Vachard, 2015). Genus *Robulus* shows low to intermediate dissolved oxygen, organic carbon-rich environment, warm and sluggish deep water (Verma *et al.,* 2013). Genus *Nodosaria* and *Saracenaria* are preferred to flourish in a shallow marine environment (Murray, 1989; Reolid *et al.,* 2008). Species *Verneulinoides tryphera* generally occurred in the inner and outer neritic environment. As a whole, the foraminiferal assemblage represents the deposition of sediments in a relatively deeper outer shelf environment (Fig. 3).

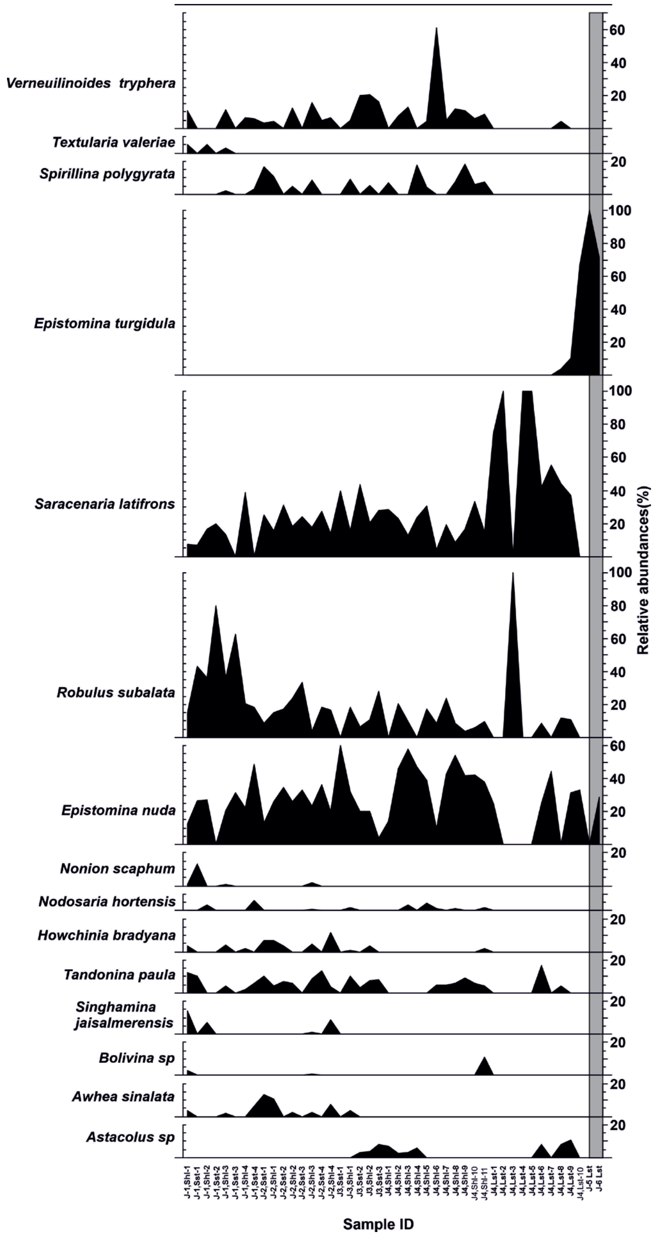

Fig. 3. The composite plot of dominant foraminiferal relative abundance as documented in the Jhurio Dome.

Sediments of this formation are mostly dominated by foraminiferal group En (Fig. 4). However, there are two intervals when foraminiferal group Sl and Rr are dominating over a short period (Fig. 4). Species *Saracenaria latifrons* is considered shallow infaunal (Reolid *et al.,* 2008), preferred to flourish in organic-rich shelf sediment accumulation within the OMZ (Hermelin and Shimmield, 1990). A study of Amakrane *et al.* (2016) shows its association with littoral species *Ammonia beccarii* in Northeastern Morocco. This species is also recorded from Ayeyarwady Continental Shelf, Myanmar, up to 130 m (Panchang and Nigam, 2014). Species *Epistomina nuda* is well abundant in an oxygen-depleted outer shelf environment (Bernhard 1986, Koutsoukos *et al.,* 1990; Sagasti and Ballent, 2002). Genus *Robulus* (also known as *Lenticulina*) is considered as epifaunal to deep infaunal (Reolid *et al.,* 2008), shows low to intermediate dissolved oxygen, organic carbon-rich, warm, and sluggish relatively deeper water environment (Verma *et al.,* 2013). A study by Bernhard (1986) shows that lenticular shape species are associated with a low oxygenated environment. Species *Verneulinoides tryphera* are generally found in the inner and outer neritic environment (Shahin, 2000) whereas *Spirillina polygyrata* prefers to live in a marginal shelf environment (Collins *et al.,* 1996). Thus, the distribution of foraminiferal group En shows that sediments of this formation deposited in oxygen-depleted outer shelf environment similar to Jhurio Formation. However, intervals dominated by foraminiferal groups Rr and Sl indicate prevailing of relative shallower depositional depth (inner shelf) in an oxygen-depleted environment (Figs. 3, 4).

The stratigraphic distribution of *Epistomina nuda* suggests that this formation belongs to either Bathonian or Callovian because these species are known to occur in Bathonian as well as Callovian (Mandwal and Singh, 1989). The first occurrence of genus *Spirillina* is documented in Bathonian age (Jain and Garg, 2014). Although it is considered long-ranging taxa, species *Spirillina polygyrata* has been recorded within Callovian to Oxfordian of Kachchh (Bhalla and Abbas, 1978; Pandey and Dave, 1993; Talib and Faisal, 2006, 2007; Gaur and Talib, 2009). *Singhamina jaisalmerensis* and *Tandonina paula* show their stratigraphic distribution within the Bathonian age of Chari Formation (Garg and Singh, 1986). Genus *Saracenaria* shows its first occurrence in the Bathonian age (Jain and Garg, 2014). The last occurrence of *Lenticulina tricarinella* is documented in Callovian age (Jain and Garg, 2014). Species *Nodosaria hortensis* shows its restricted occurrences in Bathonian to Callovian age (Jain and Garg, 2014). Species *Verneulinoides tryphera* represents the Oxfordian age (Bhalla and Abbas, 1978). In the present study, overall foraminiferal species assemblages are restricted to Bathonian or Bathonian to the Oxfordian. This study records benthic foraminifera only from the Jurassic sediments. It is a fact that benthic foraminifera are usually long-ranging taxa. Several workers were already warned to consider Jurassic benthic foraminifera from Kachchh and Jaisalmer regions for biostratigraphic correlation due to more extended stratigraphic distribution (Kalia and Chowdhury, 1983; Talib and Gaur, 2008; Gaur and Talib, 2009). The present foraminiferal assemblage contains few moderately short-ranging species restricted to Bathonian or frequently reported from Bathonian to Oxfordian strata. Therefore, it is suggested that the age of the Jumara Formation exposed at Jhurio Dome might be Bathonian to Oxfordian, which corroborates observations of earlier workers (Biswas 1977, 1986). On the contrary, few workers assigned Callovian to Oxfordian age for the Jumara Formation (Rajnath, 1932; Krishna, 1987; Biswas, 1993, 2016).

The foraminiferal group distribution pattern shows fluctuations in depositional depth within the studied interval. The Jhurio Formation and basal sediments of Jumara Formation (J4 Lst-6 to J4 Lst-9), were deposited in the outer shelf environment. Sediments within interval J4 Lst-1 to J4 Lst-5 were deposited in relative shallower depth (probably inner shelf). Deposits within J1 Shl-4 to J4 Shl-11 were deposited in the outer shelf environment. Whereas, sediments within J1 Sst-2 and J1 Sst-3 were deposited in a shallow water environment (probably inner shelf) and the sedimentation of the topmost sequences was done in the outer shelf environment (Fig. 4). These variations in depositional depths probably indicate fluctuations in sea level during the Bathonian-Oxfordian ages. Three major transgressive phases witnessed the middle Jurassic period (at the beginning of Bajocian, at the boundary of Bajocian and Bathonian, and within the Callovian-Oxfordian ages (Haq and Qahtani, 2005). However, the studied interval also documented two phases of significant transgression (middle of Bathonian, Bathonian-Callovian boundary) along with at least two minor regression phases (within Callovian-Oxfordian sea level high stand, Haq and Qahtani, 2005) (Fig. 4). In general, and globally also the Bathonian-Callovian transition is distinct by the transgression phase until the European ammonite Bullatus Zone (= Madgascariensis Zone) and after that regression took place for the entire Callovian (Haq 2018; Jain *et al.,*2019). The present study is also corroborated with the above observations on sea-level fluctuations.

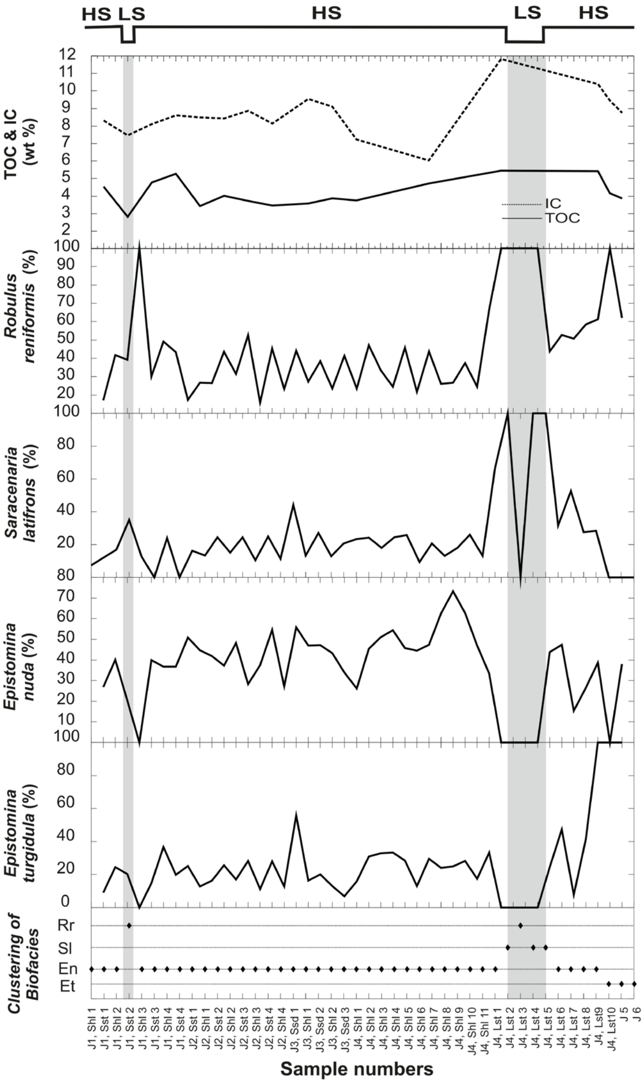

Fig. 4 Foraminiferal cluster and foraminiferal group plots of Jhurio Dome. Grey bars indicate intervals of sea-level low stand in the Bathonian-Oxfordian age. IC = Inorganic Carbon, TOC = Total Organic Carbon, HS = Sea-level High Stand and LS = Sea-level Low Stand.

CONCLUSIONS

The present study is pursued on the exposed sediment samples collected from the Jhurio and Jumara Formations at the Jhurio Dome. The following findings are inferred:

a) Jhurio Formation is less fossiliferous than the Jumara Formation.
b) Sediments of both the formations (Jhurio and Jumara) were deposited under high productive-low oxygenation conditions with variations in water depth restricted within the shelf environment.
c) Bathonian age is suggested for the Jhurio Formation and Bathonian to Oxfordian age assigned for the Jumara Formation exposed at the Jhurio Dome.
d) The variations in depositional depths indicate fluctuations in sea level during the Bathonian-Oxfordian ages. The sea-level fluctuations show two phases of transgression (middle of Bathonian, Bathonian-Callovian boundary) and recognizable two minor regression phases (within Callovian-Oxfordian boundary).

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