Journal of Sedimentary Environments (2021) 6:681–692
https://doi.org/10.1007/s43217-021-00077-0

ORIGINAL ARTICLE

Occurrence of foraminifera in Jurassic sediments of Jhurio Dome, Kutch, India: first report of species from the Indian region and preliminary interpretations regarding palaeoecology and age

Ainul H. Ansari[1] · **Abu Talib**[1,2] · **Avneet Kumar**[1]

Received: 7 May 2021 / Revised: 28 August 2021 / Accepted: 9 September 2021 / Published online: 17 September 2021

Abstract
Middle to Late Jurassic rocks of Jhurio Dome, Kutch, India yielded fairly rich foraminiferal assemblages comprising 87 species, including 27 species reported for the first time from the Indian region which are illustrated with the help of SEM photomicrographs. Preliminary interpretations regarding palaeoecology and age are attempted. Based on the dominance of Family Vaginulinidae followed by Nodosariidae, Morphogroup J, calcareous hyaline species, and genus *Lenticulina*, the foraminiferal assemblages of Jhurio Dome appear to be flourishing in an open oceanic deep shelf environment, ranging from mid to outer shelf, with normal to high oxygen level and normal salinity. On the basis of foraminiferal assemblages, a Bajocian to Oxfordian age is assigned to the studied rocks of Jhurio Dome, Kutch, India.

Keywords Benthic foraminifera · Jurassic · Jhurio Dome · Kutch · Palaeoecology · Age

Abbreviations

m	Meter
µm	Micrometer/micron
SEM	Scanning electron microscope
USIF	University sophisticated instruments facility

1 Introduction

Kutch is an important Indian sedimentary basin of Mesozoic Era. Located on the western end of the Indian landmass, it is a remarkable site exposing good marine Mesozoic strata which are potential source of natural gas, oil and minerals. Of these, Jurassic rocks are famous all over the world for their varied and exceptionally preserved macrofossils particularly ammonites and subjected to extensive geological and palaeontological studies for quite a long time. The disastrous earthquake of 2001 in this region drew the attention of global geo-science community with renewed interest. Jurassic sediments in Kutch range from Bajocian to Tithonian (Biswas, 1993; Fürsich et al., 2001; Rai, 2003; Rai & Jain, 2012; Talib et al., 2016b) which have been the subject of a large number of studies mainly focused on macrofossils but relatively little research has been done on the microfossils of these sediments including foraminifera.

In view of the above, a detailed study of the Jurassic foraminifera of Kutch is undertaken by us to work out the taxonomy of Jurassic foraminifera in India and their application in interpreting depositional environment, biostratigraphy, and palaeogeography. For this purpose, a large exposure of Jurassic rocks exposed in Jhurio Dome (23° 25′ 45.48″ N and 69° 36′ 33.78″ E) is selected, about 35.4 km northwest of Bhuj, the district headquarters of the Kutch region in Gujarat State of India (Fig. 1).

In the present study, a preliminary account of the work done so far, especially the documentation of the species reported for the first time from the Indian region with some interpretations regarding the palaeoecology and age on the basis of recovered foraminiferal assemblages. Detailed study is in progress and a comprehensive account of the systematics of the foraminiferal assemblages and detailed

Communicated by S. H. de Mello Sousa.

✉ Ainul H. Ansari
ainulgeo@gmail.com

Abu Talib
talib04@gmail.com

Avneet Kumar
avneetchauhan12@gmail.com

[1] Department of Geology, Aligarh Muslim University, 202002 Aligarh, India

[2] Present Address: 4/717B, Friends Colony, 202001 Aligarh, India

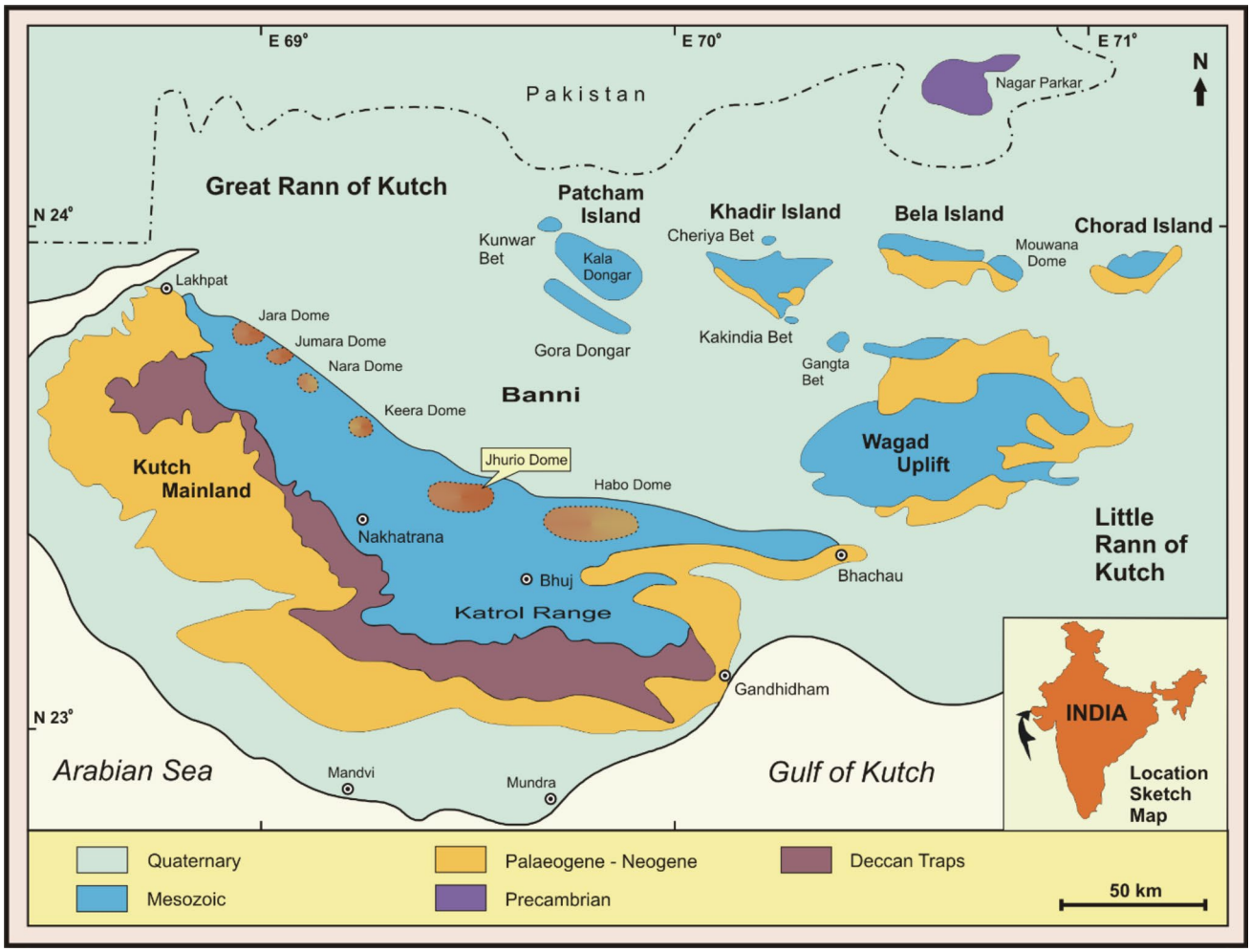

Fig. 1 Simplified geological map of Kutch, India showing study area (modified from Patel et al. 2012a)

interpretations regarding biostratigraphy and palaeoecology will be communicated in due course of time.

2 Geology and stratigraphy

Simplified geological map of Kutch is depicted in Fig. 1 which shows the distribution of Mesozoic, including Jurassic rocks of Kutch, India. Lying non-conformably over the Precambrian basement, the Jurassic rocks cover nearly half of the Kutch area (Biswas, 1993; Gaur & Talib, 2009). Due to the breakup of Gondwana the western continental-margin basins are formed in the Triassic/Jurassic age, forming horsts and grabens on local as well as regional scale (Biswas, 1991). At the western continental margin of India, the Kutch basin developed in the Early Jurassic (Jain et al., 2019; Rai & Jain, 2013). The horst and graben structure formed three parallel east–west-trending ridges with intervening valleys. The middle ridge is broken into many dome-like structures and the Jhurio Dome is one of the large domes exposed along this ridge. The Jhurio Dome exposes 302 m thick sediments, covers an extensive area, and categorised into Jhurio, Patcham, Jumara and Jhuran formations following the classification of Fürsich et al. (2020) who adapted the classification of Biswas (1993) with some modifications (Fig. 2).

3 Methodology and materials

A total of 67 samples were collected from exposed section belonging to Jhurio, Patcham, Jumara and Jhuran formations of Jhurio Dome, Kutch. However, samples of Jhuran Formation did not yield foraminifera and, therefore, excluded from the present study. Approximately 300–400 gm of field samples were crushed and boiled for three–four hours with washing soda then sieved with 35, 60 and 120 µm mesh and dried. From the dried material the microfauna is picked out followed by the arrangement on microfaunal slides for

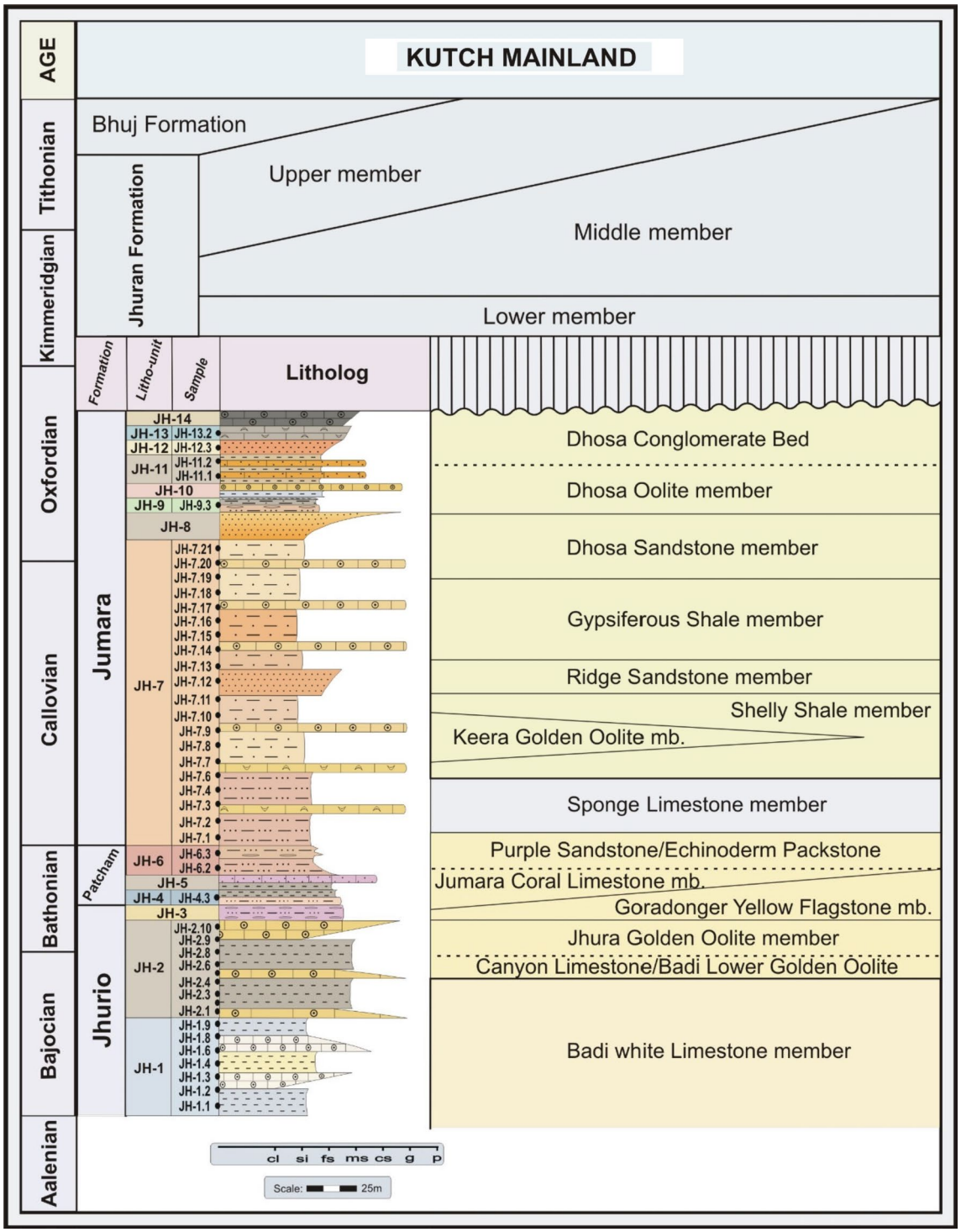

Fig. 2 Lithostratigraphic scheme for the Jurassic sedimentary sequence of Kutch (*after* Fürsich et al., 2020) showing the studied section with sample locations, Jhurio Dome, Kutch, India

identification. The genera and species are identified using generic classification by Loeblich and Tappan (1987) and Ellis & Messina catalogues, respectively. The SEM images are captured by JEOL—JSM-6510LV Scanning Electron

Microscope at USIF, Aligarh Muslim University, Aligarh, India.

4 Foraminiferal composition

The measured section of Jhurio Dome produced reasonably rich foraminiferal assemblages encompassing 87 species (Fig. 3) including 27 being reported for the first time from Indian Subcontinent (Fig. 4), pertaining to 26 genera and six suborders. Out of these, the Textulariina having six genera and 17 species and comprising 19.54% of total species, Spirillina with one genus, one species constituting 1.15%, Miliolina including one genus, one species constituting 1.15%, Lagenina having 14 genera, 58 species comprising 66.67%, Robertinina including three genera, nine species constituting 10.34% and Rotaliina with one genus and one species constituting 1.15%.

The present foraminiferal assemblages incorporate 14 families in which Vaginulinidae is dominant with 39 species (44.83%) followed by Nodosariidae having 16 species (18.39%); Epistominidae with eight species (9.20%); Eggerellidae containing six species (6.90%); Hormosinidae and Lituolidae having four species each (4.60%); Ammodiscidae and Robuloididae with two species each (2.30%), and Rzehakinidae, Spirillinidae, Cornuspiridae, Ichthyolariidae, Conorboididae and Turrilinidae having one species each (1.15%). Overall, present assemblages are dominated by calcareous forms at each level, generic (76.92%), species (80.46%), and specimen level (76.60%), rest of the forms are agglutinated. All calcareous species are perforate/hyaline in nature except a solitary imperforate/porcelaneous form.

Bhalla and Talib (1985, 1991) have earlier described and illustrated 53 species of foraminifera from Jhurio hill, Kutch, India including two species of genus *Epistomina*, an important genus for Jurassic biostratigraphy along with a brief account of paleoecology, age and Callovian–Oxfordian boundary as well as palaeobiogeographic interpretations. However, they assigned a Callovian to Oxfordian age to these sediments whereas current ammonite evidence favours a Bajocian as lower age limit for these sediments. Mandwal and Singh (1989, 1994) reported 95 foraminiferal species

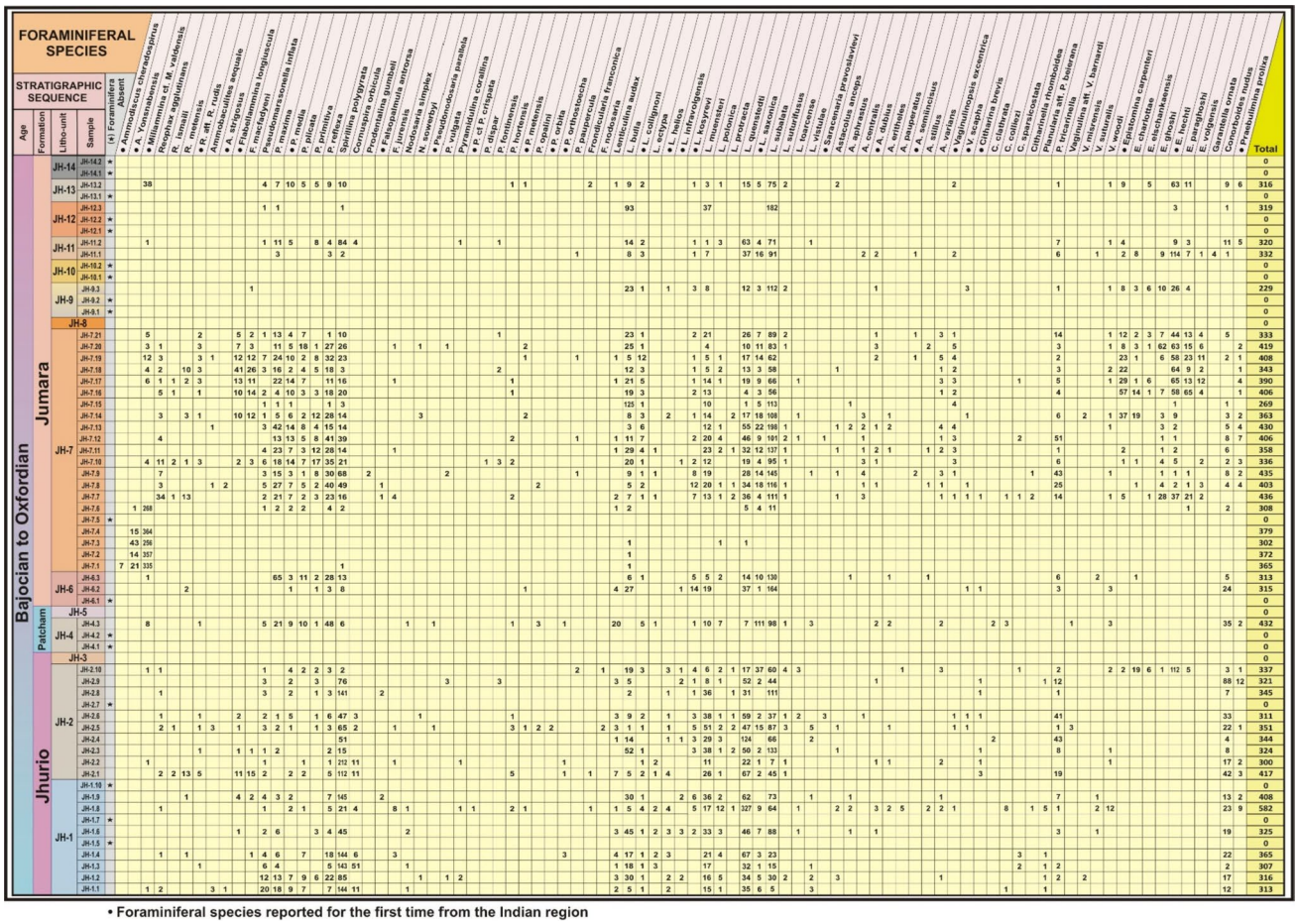

Fig. 3 Frequency Distribution of foraminiferal species, Jhurio Dome, Kutch, India

from Jhurio Dome without illustrating them and carried out biostratigraphic interpretations. They favoured Bathonian as the Lower age limit for the sediments exposed in Jhurio Dome.

5 Palaeoecological comments

Foraminifera are abundantly found in marine deposits, have excellent fossilisation potential, long geological history, very sensitive to environment and are frequently utilised as valuable and accurate palaeoenvironmental proxy (Jiang et al., 2020; Kaminski et al., 2020; Koho & Piña-Ochoa, 2012; Rita et al., 2016). The foraminiferal assemblages of Jhurio Dome, Kutch are categorised by the dominance of family Vaginulinidae followed by Nodosariidae, included in superfamily Nodosariacea. The dominancy of family Vaginulinidae demonstrates a shallow water, open marine shelf environs and due to near absence of porcelaneous form which indicates proximity to inner shelf, a middle to outer shelf environment is indicated (Bhat et al., 2016; Canales & Henriques, 2008; Farahani et al., 2018; Hjalmarsdottir et al., 2018; Reolid et al., 2019a, 2019b; Sevillano et al., 2020; Silva et al., 2017, 2020; Smoleń, 2012; Talib et al., 2014, 2016b; Talib et al., 2012a, 2012b; Wasim et al., 2021). Preponderance of hyaline species in the assemblages suggests normal salinity under well aerated vicinity (Amao et al., 2018; Bhalla & Abbas, 1984; Bhat et al., 2016; Canales & Henriques, 2008; Chan et al., 2017; Farahani et al., 2018; Gaur & Talib, 2009; Nagy & Johansen, 1991; Silva et al., 2017, 2020; Talib & Gaur, 2005; Talib et al., 2012a, 2016a; Valchev, 2003; Wasim et al., 2021; Zsiborás & Görög, 2020). Dominance of Nodosariidae suggests a distal and well-oxygenated tranquil environment (Bhat et al., 2016; Gaur & Talib, 2009; Silva et al., 2020; Talib et al., 2012a, 2014; Ziouit et al., 2021; Zsiborás & Görög, 2020).

In the present foraminiferal assemblages, *Lenticulina* is the most abundant genus at species and specimen levels, which shows the relatively deep open oceanic shelf environment with excessive quantity of dissolved O_2 (Bhat et al., 2016; Canales & Henriques, 2008; Reolid & Martínez-Ruiz, 2012; Reolid et al., 2008a, 2008b; Silva et al., 2017; Smoleń & Iwańczuk, 2018; Talib et al., 2012b, 2014, 2016a; Wasim et al., 2021). The dominance of shallow to deep infaunal genera like *Lenticulina, Nodosaria, Astacolus, Vaginulinopsis* and *Vaginulina,* shows normal O_2 values (Reolid & Martínez-Ruiz, 2012; Reolid et al., 2008a, 2008b; Talib et al., 2016b). Elongated flattened genera with active deposit-feeding and grazing omnivores feeding behaviour and belonging to shallow infaunal microhabitat like *Falsopalmula, Frondicularia, Saracenaria, Astacolus, Vaginulinopsis, Citharina, Citharinella* and *Planularia,* included in the submorphogroup J2 of the morphogroup scheme of Reolid et al. (2008a), is dominant in the present assemblages which suggests normal O_2 level, followed by elongated, subcylindrical uniserial forms characterising herbivores, bacterial scavengers and active deposit-feeders like *Prodentalina, Nodosaria, Pseudonodosaria, Pyramidulina, Vaginulina* and *Praebulimina* belong to submorphogroup J1 of Reolid et al. (2008a), shows open oceanic shelf environment (Colpaert et al., 2017; Oloriz et al., 2006; Reolid et al., 2008a, 2010, 2019b).

In this perspective, the foraminiferal assemblages of Jhurio Dome, Kutch emerge to be flourishing in a shallow water, open oceanic, deeper shelf environment ranging from mid to outer shelf with normal to high oxygen level and normal salinity.

6 Foraminiferal biochronology

Some researchers on Jurassic foraminifera have mentioned the scarcity of restricted vertical ranges in Middle to Late Jurassic sequences and according to them foraminifera are not credible for error-free age determination during this time span (Bhalla & Abbas, 1976; Talib & Faisal, 2006, 2007; Talib et al., 2007), whereas others have demonstrated their suitability in this regard (Herrero et al., 1996; Talib et al., 2007).

The Jhurio Dome assemblages are dominated by the species which are mostly long ranging and various authors emphasised the prospects of ammonites for age determination (Bhat et al., 2016; Gradstein et al., 2017; Kaminski et al., 2020; Sevillano et al., 2020; Silva et al., 2017, 2020; Smoleń & Iwańczuk, 2018; Talib & Gaur, 2008; Talib et al., 2012a, 2014, 2016a; Wasim et al., 2020). Therefore, precise age of this strata using foraminifera is not feasible. However, attempt has been made here to determine an equitable near precise age with the help of few short ranging species of the Jhurio, Patcham and Jumara formations exposed at Jhurio Dome, Kutch.

The Foraminiferal assemblages of Jhurio Dome include four species which are globally restricted to Bajocian age, viz., *Ammodiscus yonsnabensis, Reophax agglutinans, Pyramidulina opalini* and *Vaginulinopsis scapha.* Out of these, *Ammodiscus yonsnabensis* is restricted to Middle Bajocian of England (Nagy et al., 1983). *Reophax agglutinans* is originally reported from the Upper Bajocian of France by Terquem (1870). *Pyramidulina opalini* and *Vaginulinopsis scapha* are restricted to Bajocian of Portugal (Canales & Henriques, 2008, 2013).

A total of six species restricted to Bathonian in the Indian region are present in the studies assemblages. They are *Pseudomarssonella inflata, P. reflexa, Cornuspira orbicula, Pyramidulina orbita, Citharina sparsicostata* and *Conorboides nudus.* Out of these, *Pseudomarssonella inflata, P. reflexa,*

Cornuspira orbicula, Citharina sparsicostata and *Conorboides nudus* are restricted to Bathonian of Kutch, India (Mandwal & Singh, 1989; Talib et al., 2016a; Bhalla et al., 2019 and Wasim et al., 2021) and *Pyramidulina orbita* is restricted to Bathonian of Montana (Lalicker, 1950).

◂**Fig. 4** Foraminiferal species reported for the first time from India, Jhurio Dome, Kutch. 1. *Ammodiscus cheradospirus* Loeblich and Tappan; 2. *A. yonsnabensis* Nagy et al.; 3. *Miliammina* cf. *valdensis* Bartenstein and Brand; 4. *Reophax* aff. *R. rudis* Terquem; 5. *Ammobaculites strigosus* Gerke and Sosipatrova; 6. *Flabellammina longiuscula* Alexander and Smith; 7. *Pseudomarssonella media* Redmond; 8. *Falsopalmula antrorsa* Loeblich and Tappan; 9. *Pseudonodosaria parallela* Marsson; 10. *Pyramidulina* cf. *P. crispata* Terquem; 11. *P. metensis* Terquem; 12. *P. orbita* Lalicker; 13. *P. orthostoecha* Loeblich and Tappan; 14. *Lenticulina collignoni* Epistalie and Sigal; 15. *L. helios* Terquem; 16. *L. infravolgensis* Furssenko; 17. *L. kosyrevi* Kuznetsova; 18. *L. saxonica* Bartenstein and Brand; 19. *Saracenaria pravoslavlevi* Furssenko and Polenova; 20. *Astacolus dubius* Franke; 21. *A. semiincisus* Terquem and Berthelin; 22. *Vaginulinopsis excentrica* Cornuel; 23. *V. scapha* Lalicker; 24. *Citharina brevis* Furssenko and Polenova; 25. *Epistomina carpenteri* Reuss; 26. *E. hechti* Bartenstein et al. and 27. *Praebulimina prolixa* Cushman and Parker

Callovian age is represented by Indian and global occurrence of eight species, viz., *Reophax metensis, Falsopalmula jurensis, Pyramidulina dispar, Frondicularia franconica, F. nodosaria, Lenticulina polonica, Astacolus stillus* and *Epistomina elschankaensis.* Whereas, *Reophax metensis* is restricted to Callovian of Egypt (Said & Barakat, 1958) and Kutch, India (Alhussein, 2014; Bhalla et al., 2019; Bhat et al., 2016; Talib et al., 2016b), *Falsopalmula jurensis* is restricted to Callovian of Kutch, India (Bhalla et al., 2019). *Pyramidulina dispar* occurs in Callovian of Rajasthan, India, (Kalia & Chowdhury, 1983) and Kutch, India (Bhalla et al., 2019). *Frondicularia franconica* and *F. nodosaria* are restricted to Callovian of Kutch, India (Bhalla et al., 2019), whereas, *Frondicularia franconica* is restricted to Callovian of Scotland (Gordon, 1967) and England (Hart et al., 2019), *Frondicularia nodosaria* is restricted to Callovian of Scotland (Gordon, 1967). *Lenticulina polonica* occurs in Callovian of Kutch, India (Bhalla et al., 2019) and restricted to Upper Callovian of Poland (Wisniowski, 1890). *Astacolus stillus* is restricted to Callovian of Kutch in India (Bhalla et al., 2019; Bhat et al., 2016). *Epistomina elschankaensis* occurs in Callovian of Kutch, India (Pandey & Dave, 1993; Talib et al., 2016b and Bhalla et al., 2019) and this species is also restricted to Callovian of erstwhile USSR (Myatlyuk, 1953) and Russia (Colpaert et al., 2017).

Species restricted within Oxfordian age are represented by the following eight species from Jhurio Dome of Kutch, viz., *Ammodiscus cheradospirus, Falsopalmula antrorsa, Pyramidulina metensis, Lenticulina toarcense, L. vistulae, Epistomina charlottae, E. paraghoshi* and *E. volgensis.* Out of these, *Ammodiscus cheradospirus* is restricted to Oxfordian of Canada (Tingley & Sawyer, 2015). *Falsopalmula antrorsa* is restricted to Oxfordian of South Dakota, United States (Loeblich & Tappan, 1950). *Pyramidulina metensis* is restricted to Oxfordian of England (Gordon, 1965). *Lenticulina toarcense* is a globally long ranging species but in India it is restricted to Oxfordian of Kutch (Bhalla et al., 2019), *L. vistulae* and *Epistomina charlottae* are restricted to Oxfordian of Kutch, India (Bhalla et al., 2019). *E. paraghoshi* is restricted to Oxfordian of Kutch, India (Bhalla et al., 2019; Pandey & Dave, 1993) and *E. volgensis* is restricted to Oxfordian of Kutch, India (Bhalla et al., 2019 and Wasim et al., 2021).

The present six species, viz., *Pseudomarssonella media, P. primitiva, Spirillina polygyrata, Pyramidulina fontinensis, Lenticulina helios* and *Garantella ornata* are represent Bajocian to Bathonian globally including India. Out of these, *Pseudomarssonella media* is restricted to Bajocian to Bathonian of Saudi Arabia (Malik et al., 2020). *P. primitiva* is globally restricted to Bajocian to Bathonian of Saudi Arabia (Redmond, 1965 and Malik et al., 2020). *Spirillina polygyrata* is a globally long ranging species but restricted to Bajocian to Bathonian of Saudi Arabia (Malik et al., 2020). *Pyramidulina fontinensis* is also globally long ranging species but restricted to Bajocian to Bathonian of Saudi Arabia and Iran (Malik et al., 2020 and Farahani et al., 2018). *Lenticulina helios* occurs in Bajocian to Bathonian of Iran (Farahani et al., 2018). *Garantella ornata* is restricted to Bajocian to Bathonian of Canada (Gradstein, 1978).

Two foraminiferal species have restricted vertical range from Bathonian to Callovian in the present assemblages, these are *Lenticulina bulla* and *Epistomina ghoshi. Lenticulina bulla* is restricted to Bathonian and Callovian of Kutch, India (Wasim et al., 2021) whereas, *Epistomina ghoshi* is described by Pandey and Dave (1993) from the Bathonian of Kutch, India and later reported by Talib et al. (2016b) from the Callovian of Kutch.

In the present assemblages, 15 species are restricted to vertical range from Callovian to Oxfordian, viz., *Flabellammina macfadyeni, Prodentalina gumbeli, Pyramidulina hortensis, P. orthostoecha, Lenticulina ectypa, L. subalata, L. suturifusus, Astacolus anceps, A. aphrastus, A. eritheles, A. pauperatus, Citharina clathrata, C. colliezi, Citharinella rhomboidea* and *Vaginulina* aff. *V. barnardi.* Out of these, *Flabellammina macfadyeni* and *Lenticulina ectypa* are restricted to the Callovian to Oxfordian sequence of Kutch, India (Bhalla et al., 2019), *A. pauperatus* to Kutch, India (Bhalla & Talib, 1991; Talib et al., 2012b and Bhalla et al., 2019), *Citharinella rhomboidea* to Kutch, India (Bhalla & Talib, 1991; Gaur & Talib, 2009; Bhat et al., 2016; and Wasim et al., 2021) and Jaisalmer, India (Kalia & Chowdhury, 1983). *Prodentalina gumbeli* and *L. suturifusus* to Kutch, India (Bhalla & Abbas, 1978; Talib et al., 2012b) and to Jaisalmer, India (Kalia & Chowdhury, 1983), *Pyramidulina hortensis, Astacolus anceps, A. aphrastus, A. eritheles, Citharina clathrata, C. colliezi and Vaginulina* aff. *V. barnardi* to Kutch, India (Bhalla & Abbas, 1978; Bhalla & Talib, 1991; Talib et al., 2016b and Wasim et al., 2020, 2021). *L. subalata* is a globally long ranging species but in India it ranges from Callovian to Oxfordian (Gaur & Talib, 2009; Talib et al., 2012b; Wasim et al., 2020). *Pyramidulina*

orthostoecha is globally restricted to Callovian to Oxfordian, as this species is originally described from Callovian of Montana by Loeblich and Tappan (1950) and later by Tingley and Sawyer (2015) from Oxfordian of Canada.

Eight foraminiferal species having a restricted vertical range from Bajocian to Callovian of different parts of the world are present in the Jhurio Dome assemblages. These are *Pseudomarssonella maxima, P. plicata, Nodosaria simplex, N. sowerbyi, Pseudonodosaria vulgata, Astacolus varians, Planularia* aff. *P. beierana* and *Vaginulina suturalis*. Out of these, *Pseudomarssonella maxima* is restricted to the Bajocian to Callovian in Saudi Arabia (Redmond, 1965; Saad, 2008 and Malik et al., 2020). *P. plicata* is restricted to Bajocian to Callovian of Saudi Arabia (Saad, 2008) and Kutch, India (Talib et al., 2016a). *Nodosaria simplex* and *N. sowerbyi* are restricted to Bajocian to Callovian of Middle-East (Saad, 2008). *Pseudonodosaria vulgata* is a globally long ranging species but restricted to Bajocian to Callovian sequence of India and Saudi Arabia (Bhalla et al., 2019; Malik et al., 2020). *Astacolus varians* occurs in the Bajocian to Callovian of Saudi Arabia (Kaminski et al., 2020). *Planularia* aff. *P. beierana* and *Vaginulina suturalis* are globally long ranging species but they are restricted to the Bajocian to Callovian of Saudi Arabia (Kaminski et al., 2020).

Seven species ranging from Bathonian to Oxfordian found in the present foraminiferal assemblages are *Reophax ismaili, Pyramidulina corallina, Lenticulina audax, L. quenstedti, Astacolus centralis, Vaginulina misrensis* and *V. woodi.* Out of these, *Reophax ismaili* and *Pyramidulina corallina* occur in the Bathonian to Oxfordian of Kutch, India (Bhalla et al., 2019; Talib et al., 2016a, 2016b). *Lenticulina audax* and *L. quenstedti* are globally long ranging species but range from Bathonian to Oxfordian of Kutch, India (Wasim et al., 2020, 2021). *Astacolus centralis* was originally described from the Bathonian of France (Terquem, 1870) and later reported by Talib et al. (2016a) and Wasim et al. (2021) from Bathonian of Kutch, India. Bhalla et al. (2019) suggest that this species occurs in Callovian to Oxfordian of Kutch, India, therefore this species is considered as Bathonian to Oxfordian in age. *Vaginulina misrensis* and *V. woodi* are described from Bathonian to Oxfordian of Kutch, India (Wasim et al., 2021).

In the view of above discussion, it is evident that a fair number of relatively short ranging foraminiferal species are present in the Jhurio Dome which are used for dating of these sediments. They include species restricted to a single stage, represented by four species of Bajocian, six of Bathonian, eight of Callovian and eight of Oxfordian; species restricted to two stages represented by six species ranging from the Bajocian to Bathonian, two from the Bathonian to Callovian and 15 from the Callovian to Oxfordian; and species restricted to three stages represented by eight ranging from Bajocian to Callovian and seven from Bathonian to Oxfordian (Fig. 5). Therefore, on the basis of these species, a Bajocian to Oxfordian age is assigned to the studied section of the Jhurio to Jumara formations exposed at Jhurio Dome, Kutch. This age is in conformity with the age assigned on the basis of ammonites.

7 Conclusions

1. The Middle to Late Jurassic sequence exposed at Jhurio Dome, Kutch, yielded benthic foraminiferal assemblages comprising 87 species. A total of 27 species are reported for the first time from the Indian Subcontinent. The foraminiferal assemblages are dominated by the family Vaginulinidae. The calcareous and agglutinated forms are present but the calcareous forms are dominant representing 80.46% of the total species. Hyaline forms are dominant in the calcareous constituent except for a single porcelaneous species.
2. To interpret the palaeoecology and palaeoenvironment of the sediments exposed at Jhurio Dome, Kutch, the foraminiferal assemblages are analysed using various contemporary techniques. On the basis of the dominance of suborder Lagenina, family Vaginulinidae, calcareous hyaline forms, genus *Lenticulina,* submorphogroup J1 and J2, shallow to deep infaunal group, detritivores and bacterial scavengers group, elongated flattened forms, and elongated uniserial group, the present assemblages are regarded to be flourishing in a shallow water, open oceanic, deeper shelf environment ranging from mid to outer shelf with normal to high oxygen level and normal salinity.
3. Most of the species of Jurassic foraminifera investigated are rather long ranging. However, on the basis of a fairly large number of species representing Bajocian, Bathonian, Callovian and Oxfordian either globally or in the Indian Subcontinent, a Bajocian to Oxfordian age has been assigned to the studied section exposed at Jhurio Dome, Kutch.

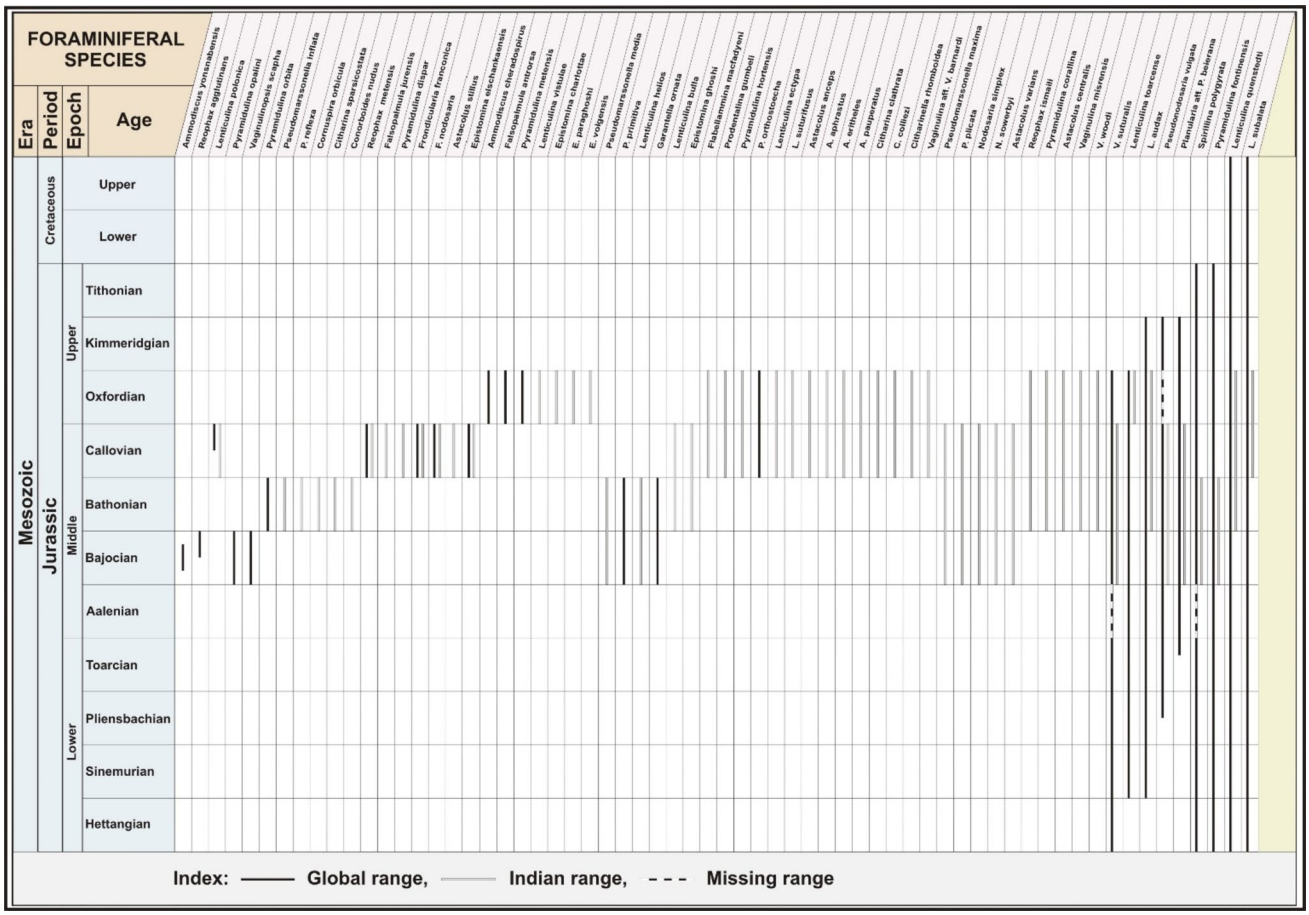

Fig. 5 Known global and Indian ranges of foraminifera from Jhurio Dome, Kutch, India

Acknowledgements We are grateful to the Chairperson, Department of Geology, Aligarh Muslim University, Aligarh, India for providing laboratory facilities and Dr. Adnan Quasim, Assistant Professor in the same department, for encouragement during the course of the present investigations. Critical reviews and constructive suggestions provided by two anonymous reviewers are gratefully acknowledged which substantially improved the manuscript. Financial assistance for the present study was utilised by Maulana Azad National Fellowship (MANF) granted by University Grant Commission (UGC), India, which is gratefully acknowledged.

Author contributions All the authors contributed equal efforts in the field work, laboratory work and drafting the manuscript. AHA finalised all laboratory work (identification of microfaunal species, interpretations, etc.). All the authors have read and confirmed the final version of manuscript for the submission.

Declarations

Conflict of interest All the authors including corresponding author declare that they have no competing interest.

References

Alhussein, M. (2014). Taxonomy of the middle Jurassic benthic foraminifera of the Kachchh Basin, Western India. *Beringeria, 44*, 51–105.

Amao, A. O., Kaminski, M. A., & Babalola, L. (2018). Benthic foraminifera in hypersaline Salwa Bay (Saudi Arabia): an insight into future climate change in the gulf region? *Journal of Foraminiferal Research, 48*(1), 29–40.

Bhalla, S., & Abbas, S. M. (1976). The Age and Palaeographical significance of Jurassic Foraminifera from Kutch, India. 1st International Symposium on Benthic Foraminifera of Continental Margins, Canada. *Maritime Sediments, Special Publications*, 1 (B), 537–544

Bhalla, S. N., & Abbas, S. M. (1978). Jurassic foraminifera from Kutch India. *Micropaleontology, 24*(2), 160–209.

Bhalla, S. N., & Abbas, S. M. (1984). Depositional environment of the Jurassic rocks of Habo hills, Kutch, India. *Bulletin Des Centres De Recherches Exploration-Production Elf-Aquitaine Mémoire, 6*, 55–60.

Bhalla, S. N., & Talib, A. (1985). On the occurrence or foraminifera in the Jurassic rocks of Jhurio Hill, Central Kutch. *Journal of the Palaeontological Society of India, 30*, 54–56.

Bhalla, S. N., & Talib, A. (1991). Callovian-Oxfordian foraminifera from Jhurio hill, Kutch, Western India. *Revue De Paléobiologie, 10*(1), 85–114.

Bhalla, S. N., Talib, A., Gaur, K. N., Wasim, S. M., & Singh, Y. P. (2019). A synthesis of Foraminiferal researches on Jurassic sediments of Kutch Basin, India. *Journal of the Palaeontological Society of India, 64*(1), 127–139.

Bhat, B. A., Talib, A., & Wasim, S. M. (2016). Systematics, age, paleoecology and paleobiogeography of Jurassic foraminifera from Fakirwari Dome, Kutch, Gujarat, India. *Micropaleontology, 62*(2), 171–194.

Biswas, S. K. (1991). Stratigraphy and sedimentary evolution of the Mesozoic basin of Kutch, western India. In S. K. Tandon, C. C. Pant, S. M. Casshyap (Eds), *Sedimentary basins of India: tectonic context. Gyanodaya Prakashan, Nainital, 1(p),* 74–103

Biswas, S. K. (1993). Geology of Kutch. *K. d. Malaviya Institute of Petroleum Exploration, Dehradun, 1*, 450.

Canales, M. L., & Henriques, M. H. (2008). Foraminifera from the Aalenian and the Bajocian GSSP (Middle Jurassic) of Murtinheira section (Cabo Mondego, West Portugal): biostratigraphy and paleoenvironmental implications. *Marine Micropaleontology, 67*(1–2), 155–179.

Canales, M. L., & Henriques, M. H. (2013). Foraminiferal assemblages from the Bajocian global stratotype section and point (GSSP) at Cape Mondego (Portugal). *Journal of Foraminiferal Research, 43*(2), 182–206.

Chan, S. A., Kaminski, M. A., Al-Ramadan, K., & Babalola, L. O. (2017). Foraminiferal biofacies and depositional environments of the Burdigalian mixed carbonate and siliciclastic Dam Formation, Al-Lidam area, Eastern Province of Saudi Arabia. *Palaeogeography, Palaeoclimatology, Palaeoecology, 469*, 122–137.

Colpaert, C., Nikitenko, B. L., & Khafaeva, S. N. (2017). Stratigraphy and Eco-stratigraphic distribution of foraminiferal morphogroups from the Upper Jurassic of the Makar'yev section (Unzha River, Volga River basin). *Russian Geology and Geophysics, 58*(1), 70–86.

Farahani, T. S., Reolid, M., Yazdi, M., & Majidifard, M. R. (2018). Benthic foraminiferal assemblages of the Middle and Upper Jurassic sediments from the northeastern Alborz and western Koppeh Dagh, Iran: systematic palaeontology and palaeoecology. *Annales De Paléontologie, 104*(4), 249–265.

Fürsich, F. T., Pandey, D. K., Alberti, M., Mukherjee, D., & Chauhan, G. (2020). Stratigraphic architecture and palaeoenvironments in the Kachchh rift basin during the Jurassic. In *36th International Geological Congress, Field Trip Guide*, 2, 143.

Fürsich, F. T., Pandey, D. K., Callomon, J. H., Jaitly, A. K., & Singh, I. B. (2001). Marker beds in the Jurassic of the Kachchh Basin, western India: their depositional environment and sequence-stratigraphic significance. *Journal of the Palaeontological Society of India, 46*, 173–198.

Gaur, K. N., & Talib, A. (2009). Middle-Upper Jurassic Foraminifera from Jumara Hills, Kutch, India. *Revue De Micropaléontologie, 52*(3), 227–248.

Gordon, W. A. (1965). Foraminifera from the Corallian beds, upper Jurassic, of Dorset, England. *Journal of Paleontology, 39*(5), 828–863.

Gordon, W. A. (1967). Foraminifera from the Callovian (Middle Jurassic) of Brora, Scotland. *Micropaleontology, 13*(4), 445–464.

Gradstein, F., Gale, A., Kopaevich, L., Waskowska, A., Grigelis, A., Glinskikh, L., & Görög, Á. (2017). The planktonic foraminifera of the Jurassic. Part II: stratigraphy, palaeoecology and palaeobiogeography. *Swiss Journal of Palaeontology, 136*(2), 259–271.

Gradstein, M. (1978). Jurassic grand banks of foraminifera. *Journal of Foraminiferal Research, 8*(2), 97–109.

Hart, M. B., Page, K. N., Price, G. D., & Smart, C. W. (2019). Reconstructing the Christian Malford ecosystem in the Oxford Clay Formation (Callovian, Jurassic) of Wiltshire: exceptional preservation, taphonomy, burial and compaction. *Journal of Micropalaeontology, 38*(2), 133–142.

Herrero, C., Copestake, P., & Johnson, B. (1996). Saracenella mochrasensis sp. nov. (Foraminiferida), a regional biostratigraphic marker species for the upper Toarcian (Jurassic) of Europe. *Journal of Foraminiferal Research, 26*(3), 187–192.

Hjalmarsdottir, H. R., Nakrem, H. A., & Nagy, J. (2018). Environmental significance and taxonomy of well-preserved foraminifera from Upper Jurassic-Lower Cretaceous hydrocarbon seep carbonates, central Spitsbergen. *Micropaleontology, 64*(5–6), 435–438.

Jain, S., Abdelhady, A. A., & Alhussein, M. (2019). Responses of benthic foraminifera to environmental variability: a case from the Middle Jurassic of the Kachchh Basin (Western India). *Marine Micropaleontology, 151*, 1–21.

Jiang, S., Song, H., Kemp, D. B., Dai, X., & Liu, X. (2020). Two pulses of extinction of larger benthic foraminifera during the Pliensbachian-Toarcian and early Toarcian environmental crises. *Palaeogeography, Palaeoclimatology, Palaeoecology, 560*, 1–16.

Kalia, P., & Chowdhury, S. (1983). Foraminiferal biostratigraphy, biogeography, and environment of the Callovian sequence, Rajasthan, north-western India. *Micropaleontology, 29*(3), 223–254.

Kaminski, M. A., Amao, A. O., Babalola, L. O., Balc, R., Chan, S. A., Gull, H. M., & Malik, M. H. (2020). Benthic foraminiferal assemblages from maximum flooding surface J30, Middle Jurassic Dhruma Formation, Central Saudi Arabia. *Stratigraphy, 17*(4), 279–292.

Koho, K. A., Piña-Ochoa, E. (2012). Benthic foraminifera: inhabitants of low-oxygen environments. In *Anoxia*, 21, 249-285

Lalicker, C. G. (1950). Foraminifera of the Ellis Group, Jurassic, at the type locality. *The Paleontological Institute, the University of Kansas, 2*, 3–20.

Loeblich, A. R., Jr., & Tappan, H. (1950). North American Jurassic Foraminifera: I. The type red water Shale (Oxfordian) of South Dakota. *Journal of Paleontology, 24*(1), 39–60.

Loeblich, A. R., Jr., & Tappan, H. (1987). *Foraminiferal genera and their classification* (pp. 1–2). Van Nostrand Reinhold Company. 1-970, 1-847.

Malik, M. H., Babalola, L. O., Al-Ramadan, K., & Kaminski, M. A. (2020). Integrated micropaleontology, sedimentology and sequence stratigraphy of the Middle Jurassic D5–D6 Members of the Dhruma Formation, Central Saudi Arabia. *Micropaleontology, 66*(6), 519–547.

Mandwal, N., & Singh, S. K. (1989). Bathonian age for the sediments in Jhurio Hill, Kachchh, foraminiferal evidence. *Journal of the Palaeontological Society of India, 34*, 41–54.

Mandwal, N., & Singh, S. K. (1994). The Jurassic foraminifera from the Patcham-Chari formations of Jhurio hill (Jhura dome), Kachchh, Western India. *Journal of the Geological Society of India, 44*(6), 675–680.

Myatlyuk, E. V. (1953). Iskopaemye foraminifery SSSR: Spirillinidy, Rotaliidy, Epistominidy I Asterigerinidy. Gos. naučno-techničeskoe izd-vo neftjanoj i gorno-toplivnoj literatury. *Mr. Scientific and Technical Publishing House of Oil and Mining Fuel Literature, 71*, 1–274.

Nagy, J., & Johansen, H. O. (1991). Delta-influenced foraminiferal assemblages from the Jurassic (Toarcian-Bajocian) of the northern North Sea. *Micropaleontology, 37*(1), 1–40.

Nagy, J., Løfaldli, M., & Bomstad, K. (1983). Marginal marine microfaunas of the Jurassic (Bajocian) Yons Nab Beds of the Yorkshire coast. *Department of Continental Shelf Surveys Publication, 108*, 111–127.

Olóriz, F., Reolid, M., & Rodríguez-Tovar, F. J. (2006). Approaching trophic structure in Late Jurassic neritic shelves: a western Tethys example from southern Iberia. *Earth-Science Reviews, 79*(1–2), 101–139.

Pandey, J., & Dave, A. (1993). Studies in Mesozoic foraminifera and chronostratigraphy of Western Kutch, Gujarat. *Geoscience*

Research Group, KD Malaviya Institute of Petroleum Exploration, Oil & Natural Gas Commission, 1, 1–221.

Patel, S. J., Joshi, P. N., & Joseph, J. K. (2012). Ammonite zonation of the Jurassic rocks of the Gangta Bet area, Wagad region, eastern Kachchh, India. *Journal of the Palaeontological Society of India, 57*(2), 35–39.

Rai, J. (2003). Early Callovian nannofossils from Jara Dome, Kachchh, western India. *Journal of the Palaeontological Society of India, 61*(3), 283–294.

Rai, J., & Jain, S. (2012). Early Jurassic Gondwanaland break up–A nannofossil story. In *DST Sponsored Field Workshop and Brainstorming Session on 'Geology of Kachchh Basin, Western India: Present Status and Future Perspectives', 26th to 29th January*

Rai, J., & Jain, S. (2013). Pliensbachian nannofossils from Kachchh: implications on the earliest Jurassic transgressive event on the western Indian margin. *Zitteliana, 53*, 105–120.

Redmond, C. D. (1965). Three new genera of foraminifera from the Jurassic of Saudi Arabia. *Micropaleontology, 11*(2), 133–140.

Reolid, M., Copestake, P., & Johnson, B. (2019a). Foraminiferal assemblages, extinctions and appearances associated with the Early Toarcian Oceanic Anoxic Event in the Llanbedr (Mochras Farm) Borehole, Cardigan Bay Basin, United Kingdom. *Palaeogeography, Palaeoclimatology, Palaeoecology, 532*, 109277.

Reolid, M., Duarte, L. V., & Rita, P. (2019b). Changes in foraminiferal assemblages and environmental conditions during the T-OAE (Early Jurassic) in the northern Lusitanian Basin, Portugal. *Palaeogeography, Palaeoclimatology, Palaeoecology, 520*, 30–43.

Reolid, M., & Martínez-Ruiz, F. (2012). Comparison of benthic foraminifera and geochemical proxies in shelf deposits from the Upper Jurassic of the Prebetic (southern Spain). *Journal of Iberian Geology, 38*(2), 449–465.

Reolid, M., Nagy, J., & Rodríguez-Tovar, F. J. (2010). Ecostratigraphic trends of Jurassic agglutinated foraminiferal assemblages as a response to sea-level changes in shelf deposits of Svalbard (Norway). *Palaeogeography, Palaeoclimatology, Palaeoecology, 293*(1–2), 184–196.

Reolid, M., Nagy, J., Rodríguez-Tovar, F. J., & Olóriz, F. (2008a). Foraminiferal assemblages as palaeoenvironmental bioindicators in Late Jurassic epicontinental platforms: relation with trophic conditions. *Acta Palaeontologica Polonica, 53*(4), 705–722.

Reolid, M., Rodríguez-Tovar, F. J., Nagy, J., & Olóriz, F. (2008b). Benthic foraminiferal morphogroups of mid to outer shelf environments of the Late Jurassic (Prebetic Zone, southern Spain): characterization of biofacies and environmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology, 261*(3–4), 280–299.

Rita, P., Reolid, M., & Duarte, L. V. (2016). Benthic foraminiferal assemblages record major environmental perturbations during the Late Pliensbachian-Early Toarcian interval in the Peniche GSSP, Portugal. *Palaeogeography, Palaeoclimatology, Palaeoecology, 454*, 267–281.

Saad, H. A. (2008). Stratigraphic distribution of the Middle Jurassic foraminifera in the Middle East. *Revue De Paléobiologie, Genéve, 27*(1), 1–13.

Said, R., & Barakat, M. G. (1958). Jurassic microfossils from Gebel Maghara, Sinai, Egypt. *Micropaleontology, 4*(3), 231–272.

Sevillano, A., Septfontaine, M., Rosales, I., Barnolas, A., Bádenas, B., & López-García, J. M. (2020). Lower Jurassic benthic foraminiferal assemblages from shallow-marine platform carbonates of Mallorca (Spain): stratigraphic implications. *Journal of Iberian Geology, 46*(1), 77–94.

Silva, S. C., Canales, M. L., Henriques, M. H., & Ureta, S. (2020). Benthic foraminiferal assemblages across the Aalenian-Bajocian boundary in the Iberian and Basque-Cantabrian basins (North Spain). *Palaeobiodiversity and Palaeoenvironments, 100*(1), 51–78.

Silva, S. C., Canales, M. L., Sandoval, J., & Henriques, M. H. (2017). Paleoecological quantitative analysis based on benthic foraminifera of the Aalenian-Bajocian boundary (upper Bradfordensis–lower Discites) in the Barranco de Agua Larga section (Betic Cordillera, Southern Spain). *Journal of Iberian Geology, 43*(1), 75–96.

Smoleń, J. (2012). Faunal dynamics of foraminiferal assemblages in the Bathonian (Middle Jurassic) ore-bearing clays at Gnaszyn, Kraków-Silesia Homocline, Poland. *Acta Geologica Polonica, 62*, 403–419.

Smoleń, J., & Iwańczuk, J. (2018). Foraminiferal biostratigraphy of the Middle and Upper Jurassic of the Polish Lowlands: the state of the art. *Geological Quarterly, 62*(2), 257–286.

Talib, A., & Faisal, S. M. (2006). A preliminary note on the occurrence of foraminifera in the Middle to Upper Jurassic sediments of Fakirwari, Kutch Mainland, Gujarat. *Journal-Geological Society of India, 68*(6), 963.

Talib, A., & Faisal, S. M. (2007). On the occurrence of microfossils (Foraminiferida) in the Jurassic rocks of Ler Dome, Kutch Mainland and Gujarat. *Current Science, 92*(5), 595–596.

Talib, A., & Gaur, K. N. (2005). Foraminiferal palaeoecology, microfacies and palaeoenvironment of middle-upper Jurassic sequence, Jumara Hills, Western Kutch, Gujarat. *Indian Journal of Petroleum Geology, 14*(2), 9.

Talib, A., & Gaur, K. N. (2008). Affinities and palaeobiogeographic implications of middle to late Jurassic foraminifera from Jumara Hill, Kutch, India. *Neues Jahrbuch Für Geologie Und Paläontologie-Abhandlungen, 247*(3), 313–323.

Talib, A., Gaur, K. N., & Bhalla, S. N. (2007). Callovian-Oxfordian boundary in Kutch Mainland, India-a foraminiferal approach. *Revue De Paléobiologie, 26*(2), 625.

Talib, A., Gaur, K. N., Singh, Y. P., Wasim, S. M., & Anjum, S. (2012a). Some foraminiferal taxa in the middle to Late Jurassic sediments of Kaiya Dome, Kutch. *Journal of the Geological Society of India, 79*(2), 161–168.

Talib, A., Gaur, K. N., Sisodia, A. K., Bhat, B. A., & Irshad, R. (2012b). Foraminifera from Jurassic sediments of Keera Dome, Kutch. *Journal of the Geological Society of India, 80*(5), 667–675.

Talib, A., Upadhyay, G., & Haseen, M. (2014). Jurassic foraminifera from Jajiya Member, Jaisalmer Formation, Western Rajasthan. *Journal of the Geological Society of India, 83*(1), 38–46.

Talib, A., Wasim, S. M., Sabeeha, & Arkan, M. (2016a). Jurassic Foraminifera from the Dharang Member, Habo Formation, Habo Dome, Kutch, India: systematics, age, palaeoecology and palaeobiogeography. *Journal of Systematic Palaeontology, 15*(5), 403–426.

Talib, A., Wasim, S. M., & Sharma, B. (2016b). Benthic foraminifera from Black Limestone Member, Habo Formation, Habo Dome, Kutch, India: age and palaeoecologic implications. *Arabian Journal of Geosciences, 9*(4), 263.

Terquem, O. (1870). Dissertation on foraminifera of the Oolithic System, including the genera *Frondicularia, Flabellina, Nodosaria, Dentalina,* etc. of the Ammonites parkinsoni zone of Fontoy (Moselle). *Mémoires De l'académie Impérial Des Sciences, 5*, 299–380.

Tingley, L. M., & Sawyer, M. (2015). A study of Jurassic paleoenvironment and paleoclimate in the Western Canadian Sedimentary Basin using foraminiferal assemblages. *Geo Convention, Calgary, New Horizons Geoscience, 1*, 1–3.

Valchev, B. (2003). On the potential of small benthic foraminifera as palaeoecological indicators: recent advances. 50 years University of Mining and Geology "St. Ivan Rilski", Annual. *Geology and Geophysics, Sofia, 46*(1), 51–56.

Wasim, S. M., Reolid, M., Talib, A., & Alvi, S. H. (2020). Callovian to Oxfordian benthic foraminifera from Ler Dome, Kutch Basin

(Gujarat, India): Systematic, ecostratigraphy and palaeoenvironmental reconstruction. *Rivista Italiana Di Paleontologia e Stratigraphia, 126*(2), 315–362.

Wasim, S. M., Talib, A., & Alvi, S. H. (2021). Systematics, age, paleoecology and paleobiogeography of Middle to Late Jurassic benthic foraminiferal assemblages from Jumara Dome, Kutch, Gujarat India. *Micropalaeontology, 67*(1), 73–104.

Wisniowski, T. (1890). Microfauna of the Ornatus Clay in the vicinity of Krakow, Part 1: foraminifera of the Upper Callovian of Grojec. *Pamietnik Akademii Umiejętności w Krakowie, Wydzia3 Matematyczno Przyrodniczy, 17*, 181–242.

Ziouit, K., Sebane, A., Sebane, A. T., & Mahrouk, L. (2021). Benthic Foraminifera from the Saïda clay formation (Djebel Brame, northwestern Algeria) biostratigraphy and paleoecology. *Arabian Journal of Geosciences, 14*(1), 1–10.

Zsiborás, G., & Görög, Á. (2020). Aalenian–lower Bajocian foraminiferal fauna from the Ammonitico Rosso series of Bakonycsernye (Hungary). Part 2: palaeoecological and palaeobiogeographical aspects. *Journal of Foraminiferal Research, 50*(1), 73–88.