

Benthic foraminiferal assemblages from maximum flooding surface J30, Middle Jurassic Dhurma Formation, Central Saudi Arabia

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ABSTRACT: The benthic foraminiferal have been studied from mudstone-wackestones of the D5 Unit of the Dhurma Formation that represent the Middle Jurassic J30 maximum flooding surface of Sharland et al. (2001). The benthic assemblage consists of a mixture of smaller agglutinated species, *Haplophragmoides*, *Kutsevelia*, *Sculptobaculites*, *Trochammina*, and calcareous species (*Nautiloculina*, nodosariids, ophthalmidiids, polymorphinids, and spirillinids) without any larger foraminifera. The assemblage is indicative of open-marine midshelf conditions, and contains a number of cosmopolitan taxa that are known from the Middle Jurassic in other areas of the Tethys. The recovery of open-marine and cosmopolitan smaller benthic foraminifera in the D5 Unit of the Dhurma Formation provides a new tool for identifying the J30 maximum flooding surface and correlating the interval with other regions of the Tethys.

Keywords: Benthic Foraminifera, Sequence Stratigraphy, Paleobiogeography, Jurassic, Saudi Arabia

INTRODUCTION

The Middle Jurassic (Bajocian–Callovian) Dhurma Formation is the second oldest formation within the Jurassic Shaqra Group, and contains three hydrocarbon reservoirs, the Fraidah (equivalent of D4 Unit), Shahrar (in the D5 Unit), lower and upper Fadhili (in the D6 Unit) (Al-Husseini 1997; Hughes 2000; Cantrell et al. 2014). The formation is well exposed in central Saudi Arabia (text-figs 1a and 1b) and extends into the subsurface in the eastern region where most of the oilfields are located (text-fig. 1a). The Dhurma Formation is named after Dhurma town, located northwest of Riyadh city. The formation unconformably overlies the mixed carbonate-siliciclastic sediments of Lower Jurassic Marrat Formation and is in turn conformably overlain by the Tuwaiq Mountain Formation (text-fig. 2).

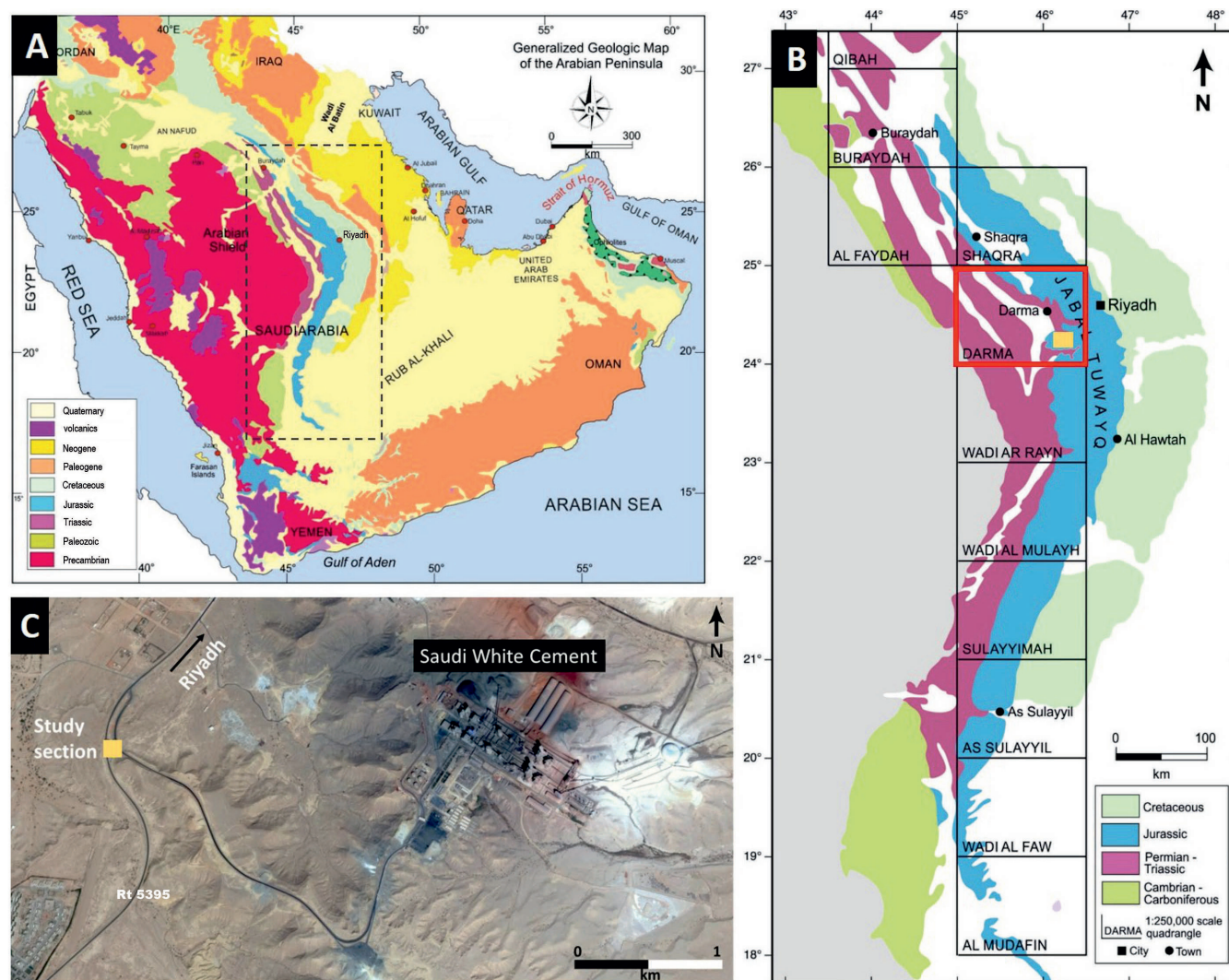
A number of recent studies conducted on the Dhurma Formation in central Saudi Arabia (Énay et al. 2009; Al-Hussaini et al. 2019; Ismanto et al. 2019) and Kuwait (Crespo de Cabrera et al. 2019, 2020) have mainly focused on the carbonate sedimentology and sequence stratigraphy. Studies of the foraminifera in the Dhurma Formation until now have been limited to the reservoir horizons in the subsurface, and were mainly conducted by Saudi Aramco micropaleontologists (Hughes 2009, 2018; Al-Dhubaib 2010) using thin sections. Foraminifera from the lateral equivalent of the Dhurma Formation in the subsurface of Kuwait have been recently studied by Kuwait Oil Co.

micropaleontologists (Crespo de Cabrera et al. 2020) using thin sections. Ghalandari et al. (2019) reported the Middle Jurassic foraminiferal biostratigraphy from an offshore field in the Iranian sector of the Gulf, using thin sections. Relatively few studies of the Middle Jurassic foraminifera have been carried out on outcrop sections (Al-Saad 2008; Kaminski et al. 2018a; Kaminski et al. 2018b; Ismanto et al. 2019). The marly units of the Dhurma Formation representing the maximum flooding horizons have never been investigated in detail, yet these horizons potentially hold microfossils that may be useful for stratigraphic correlation (Kaminski et al. 2018b). Therefore, the main objectives of this study are to document the benthic foraminifera from the marly unit of the D5 member corresponding to maximum flooding surface (MFS) J30 of Sharland et al. (2001) using disaggregated samples, interpret the paleoecological significance of the benthic foraminiferal assemblage, and evaluate their potential use as index fossils for correlation with other successions in the Tethys.

Study Area and Geological Framework

The exposure of D5 member of the Dhurma Formation is located within the Darma quadrangle (text-fig. 1b) in southwest Riyadh, central Saudi Arabia (N24°17'27", E46° 16'58"E). The exposure can be easily accessed via Highway 5395 which approximately 3 km from the Saudi white cement factory (text-fig. 1c) and 35 km from the main Riyadh – Makkah highway.

The Dhurma Formation is best exposed in the central part of Saudi Arabia (text-fig. 1a). Bramkamp and Steineke (1952) first



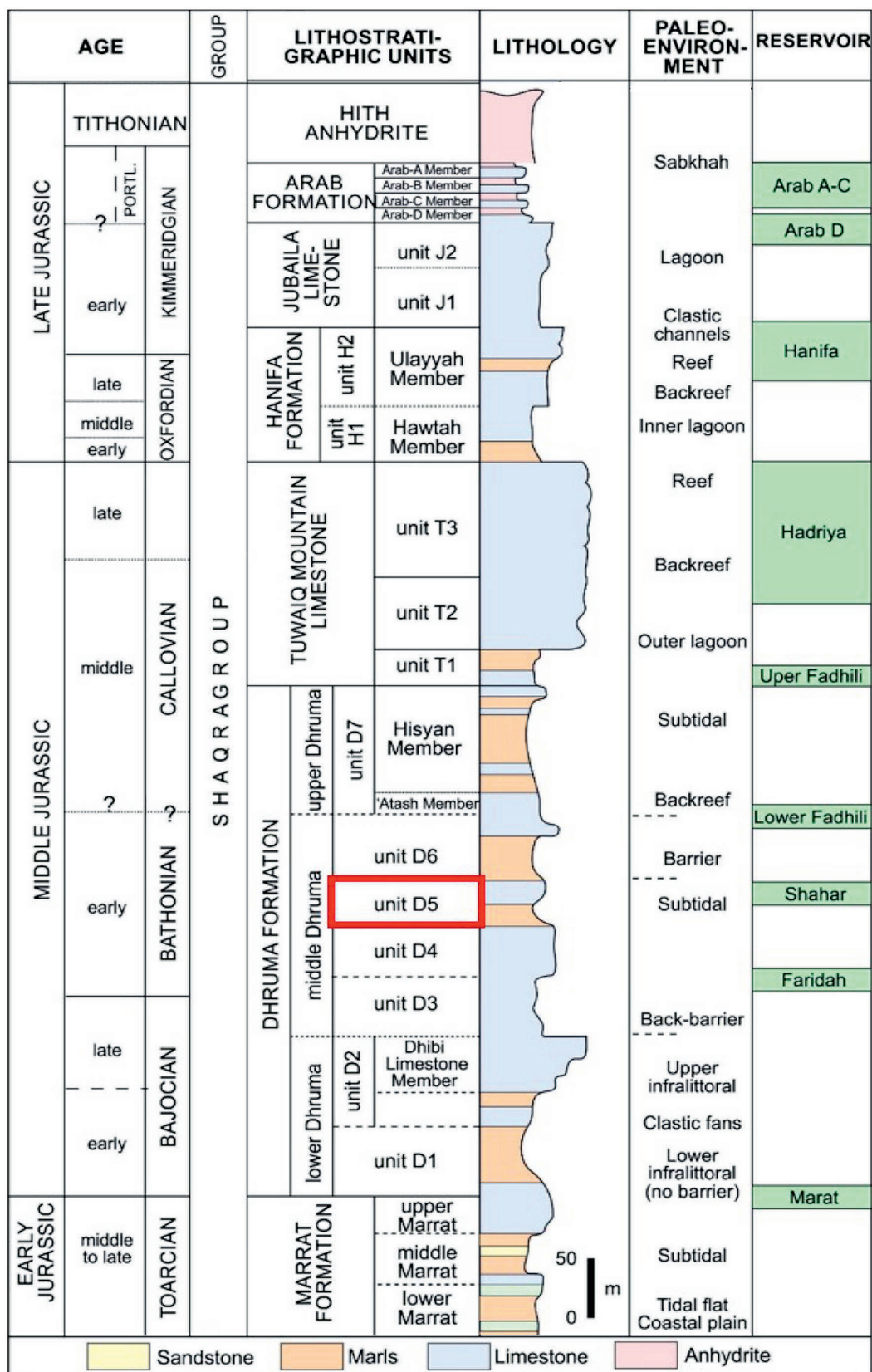
TEXT-FIGURE 1

Location of the sampled section. a. Geological map of Saudi Arabia showing the Phanerozoic sedimentary outcrop belt in Saudi Arabia (after Le Nindre et al. 2003). b. An enlarged part of the sedimentary succession showing the Mesozoic outcrop belt in central Saudi Arabia (after Fischer et al. 2001). c. A satellite image showing the study locality, Hafra Nisah, near Riyadh (from Google Earth).

subdivided the Dhurma formation into three units; lower, middle, and upper unit respectively. Later, Powers et al. (1966) subdivided the formation into three members, and named them the Dhibi limestone (lower), Atash (middle), and Hisyan (upper) at the type section. Detailed lithostratigraphic and biostratigraphic studies by Vaslet et al. (1983) and Manivit et al. (1985, 1986) revised previous members and subdivided the Dhurma Formation into seven informal units, D1–D7. The lower Dhurma was subdivided into the D1 and D2 units, the middle Dhurma comprises the D3 to D6 units, while the upper Dhurma was designated as D7. Énay et al. (1987), formalized the seven units and named them the Balum (D1), Dibi (D2), Jufrayr (D3), Uwaynid (D4), Barrah (D5), Mishraq (D6) and Atash with Hisyan (D7). On the basis of its genetic relationship with the muddy carbonates in the lower part of the overlying Tuwaiq Mountains, the D7 Unit of the Dhurma Formation was re-assigned to the basal

part of the Tuwaiq Mountain Formation (Hughes 2004; 2008; 2009).

Based on biostratigraphic zonations using ammonites, nautiloids, brachiopods, and more recently foraminifera (e.g., Arkell 1952; Powers et al. 1966; Cooper 1989; Hughes 2009, 2018; Ismanto et al. 2019), the D1 to D6 members were dated as early Bajocian to middle Callovian. The D5 Unit contains the J30 maximum flooding surface of Sharland et al. (2001). This assignment is also supported by the recent study of Kaminski et al. (2018b), based on the presence of planktonic foraminifera within the marly lithofacies of the upper part of the D5 unit. In addition, this unit has been correlated to the lower Bathonian *Clydocromphalus* ammonite Zone by Énay et al. (2009) (= the *Procerites aurigerus* Zone in the global scale). Our investigation of calcareous nannofossils in the studied samples revealed the



TEXT-FIGURE 2

Lithostratigraphic succession of the Jurassic Shaqra Group overlying the Upper Triassic–Lower Jurassic Minjur Sandstone in central Saudi Arabia (after Sharland et al. 2001). The group is comprised of seven carbonate formations. The Middle Jurassic Dhruma Formation investigated in this study is the second oldest formation within the group.



TEXT-FIGURE 3

A view of the studied outcrop section with interpreted sequence stratigraphy, with sample positions indicated. The outcrop is 19.5 m in height. Red triangle indicates the highstand systems tract.

presence of *Watznaueria britannica* (Stradner 1963) Reinhardt 1964, *Watznaueria manivitiiae* Bukry 1973, *Watznaueria barnesiae* (Black 1959) Perch-Nielsen 1968, *Discorhabdus striatus* Moshkovitz and Ehrlich 1976 and *Lotharingius* sp., Noël 1973 (Kaminski et al. 2018b). Based on the known ranges of the identified calcareous nannofossil species, the age of the upper part of the D5 Unit of the Dhurma Formation can be constrained as not older than Bathonian (First Occurrence of *Watznaueria barnesiae*) and not younger than Oxfordian (Last Occurrence of *Discorhabdus striatus*).

The investigated outcrop section represents the upper part of the D5 unit of the Dhurma Formation. It is predominantly composed of marly limestone and marl. The basal 16 m of the outcrop is comprised of cyclic deposition of bioclastic mudstone and peloidal-bioclastic wackestone. The sequences commenced with the deposition of a 2 m thick nodular, clayey and friable mudstone with thin shelled bivalves, ostracodes, and sponge spicules. The facies is repeated from the 6 m to 12.5 m interval of the outcrop section. Iron staining is commonly observed in some of the intervals. The wackestone facies with thickness ranging from 1.5 to ~3 m, contains peloids, with bivalve and echinoid shell fragments, and its intervals are partially burrowed. The sequence is capped by a 1.5 m thick interval of cross-bedded peloidal skeletal packstone and grainstone beds. The topmost 15 cm grainstone interval contains vertical burrows (tiggilites).

MATERIALS AND METHODS

In total, 16 samples from a ~19-m thick outcrop section representing the marly sediments of the D5 member (text-fig. 3) of the Dhurma Formation were collected, processed and analyzed for their microfaunal contents. The marl and claystone samples were disaggregated using standard micropaleontological technique by boiling in water with a soap solution and washed over a 63 micron stainless steel sieve. The lithified carbonate samples were processed using the acetolysis method to liberate the microfossils (Lirer 2000). The acetic acid disaggregation method is routinely used to extract microfossils from carbonate rock without having an adverse effect on the preservation of the microfossils (Chan et al. 2017; Kaminski et al. 2018b).

The foraminiferal specimens were sorted from the washed and dried residues into micropaleontological slides and examined using a stereomicroscope. Well-preserved specimens were imaged using a JSM-5900LV Scanning Electron Microscope and a digital camera mounted on a Nikon-1500 stereo-microscope in the Geosciences Department, King Fahd University Petroleum Minerals (KFUPM).

RESULTS

The samples from the J30 MFS in the studied section contain an assemblage of smaller benthic foraminifera consisting of 23 species belonging to 14 genera (Table 1; Appendix 1). The re-

covered assemblage contains a mixture of agglutinated and calcareous benthic taxa. The agglutinated assemblage consists of *Haplophragmoides*, *Kutsevelia*, *Trochammina*, and *Riyadhella*, whereas the calcareous assemblage is dominated by *Nautiloculina* (the agglutinated nature of its test wall is questionable – see Brönnimann 1968), small nodosariids, vaginulinids, polymorphinids, and small miliolids. The genera *Spirillina* and *Ophthalmium* are abundant at some horizons (see Appendix). The foraminiferal specimens are smaller in size than those reported at other Tethyan localities, and many of the nodosariids consist of only a few chambers. No larger benthic foraminifera were recovered from the studied samples, although such forms have been reported from both the underlying and overlying reservoir units of the Dhurma Formation (Hughes 2018). The planktonic foraminifera comprise approximately 5–10% of the assemblage at the studied locality, and were described in detail by Kaminski et al. (2018b).

DISCUSSION

The recovery of cosmopolitan benthic foraminiferal assemblages in the D5 Unit of the Dhurma Formation provides a new tool for identifying the J30 maximum flooding surface and interpreting its paleoecology. This assemblage of smaller benthic foraminifera has not been previously reported by industry micropaleontologists, who have concentrated their efforts on the overlying reservoir units of the Dhurma Formation using petrographic thin sections (e.g., Al-Dhubaib 2010; Hughes 2018; Crespo de Cabrera et al. 2019, 2020). In this study, we have the advantage of being able to disaggregate the marly sediments of the upper part of the D5 Unit using normal micropaleontological methods, enabling us to examine the microfossils in three dimensions. Hughes (2018) placed the D5 Unit in his DM-5 biozone. The biozone is defined as the stratigraphic interval above the last occurrence of *Riyadhoides mcclurei* and *Placopsina* sp., but below the first occurrence of an assemblage containing *Protopenneroplis striata*, *Coscinoconus limognensis*, *Pseudocyclammina lituus*, *Satorina apuliensis*, *Mesoendothyra croatica*, *Praekurnubia crusei* and encrusting stromatoporoids. The biozone is characterized by the lack of distinctive foraminiferal index species (Hughes 2018). This study confirms the absence of these larger agglutinated foraminifera in the muddy sediments of the D5 Unit, which contains only smaller agglutinated taxa (*Haplophragmoides* spp. *Kutsevelia* spp., *Trochammina* spp. and *Riyadhella* spp.) that are mostly undescribed.

The marine invertebrate assemblages of the Central Arabian Basin have been known to contain numerous endemic species, which make correlation with other areas of the Tethys a difficult task. Arkell (1952) pointed out the endemic nature of the ammonites, and remarked that many of the familiar cosmopolitan species are missing in central Saudi Arabia. Kier (1972) described the echinoids from the Jurassic of Saudi Arabia and found that 24 out of 27 taxa were new to science. Brachiopods described from the Dhurma Formation by Cooper (1989) are also largely endemic. Benthic foraminifera reflect the same trend: Redmond (1964, 1965) described several new genera and species of benthic foraminifera from the Dhurma Formation, and these forms dominate the assemblage in the reservoir units. Al Saad (2008) reported 100 species of benthic foraminifera in the composite section of the Dhurma formation west of Riyadh, of which 35 are only known from Saudi Arabia. The presence of endemic species among different fossil groups, and the lack or rarity of cosmopolitan species argues for restricted marine

TABLE 1

Counts of foraminifera in the studied samples.

Genus / sample	S1	S2	S4	S5	S6	S7	S8	S10	S12
<i>Haplophragmoides</i>	10	2	4	3	8	10	2	10	3
<i>Recurvoides</i>					2				
<i>Kutsevelia</i>	1							2	3
<i>Trochammina</i>	4		2	3					4
<i>Riyadhella</i>						4			
<i>Ophthalmidium</i>	82	16	46	64	19	134	115	277	215
<i>Spirillina</i>	1	99	41	2	1				
<i>Laevidentalina</i>	23	35	15	33	23	7	17	18	55
<i>Nodosaria</i>		27	1	7	4	4	13	5	7
<i>Fronicularia</i>		3				1			
<i>Lingulina</i>		2	1		2	1	1		
<i>Planularia</i>	42	7		3	4	6	3	27	30
<i>Eoguttulina</i>	12	63	2	24	9	12		18	55
<i>Epistomina</i>			5			4	9		
<i>Nautiloculina</i>	19	33	8	1	9	63	68	9	
<i>Lenticulina</i>	3		4		4	3		27	4
<i>Ramulina</i>		15							
<i>Globuligerina</i>	3	3	2	26	5	1	10	15	18
<i>Conoglobigerina</i>	2	4	3	12	18	26	75	25	28

connections between the Central Arabian Basin and the Tethys Ocean.

The benthic foraminiferal assemblage recovered from the D5 Unit represents open-marine midshelf conditions based on the predominance of smaller nodosariids, vaginulinids and miliolids.

Al-Dhubaib (2010) interpreted the nodosariid-dominated biofacies in the D7 Unit of the upper Dhurma Formation / lower Tuwaiq Mountain Formation to represent deeper depositional conditions, in an intrashelf basin below storm wave base. The lack of larger benthic foraminifera and the presence of rare planktonics in our samples suggest relatively deeper-water conditions, possibly below the photic zone. Specimens are small, with many nodosariids consisting of few chambers, suggesting oligotrophic conditions prevailed within the Central Arabian Basin during the deposition of the upper part of the D5 unit. Central Saudi Arabia was situated astride the equator during the Middle Jurassic, and the presence of common miliolids suggests hypersaline conditions within the basin.

Our main purpose in studying the foraminiferal assemblages from the maximum flooding surfaces in the Central Arabian basin was to test the hypothesis that some cosmopolitan species may have entered the basin during sea level highstands, and therefore may provide a better correlation to the Tethyan faunal province. The presence of planktonic foraminifera in the upper D5 unit gives one such opportunity (Kaminski et al. 2018b) and provides a direct correlation with the Dhurma Formation in Kuwait (Crespo de Cabrera et al. 2020). The Kuwait Oil Co. micropaleontologists reported a smaller benthic foraminiferal assemblage consisting mainly of nodosariids and *Lenticulina* spp. (Crespo de Cabrera et al. 2020; table 3), but because the study was carried out using only thin sections, they were not able to identify the benthic foraminifera to the species level. In terms of the benthic foraminiferal assemblage recovered from the upper D5 unit, species identification proves difficult because many of the recovered specimens in our samples are either stunted or appear to be juveniles. Nevertheless, several of the nodosariid species found in the

D5 unit are identifiable (Table 1), and a number of these have been described from the Middle Jurassic of Western Europe by Roemer (1839), Strickland (1846), Bornemann (1854), Gümbel (1862), Terquem (1866, 1870), and by Terquem and Berthelin (1875). Several taxa are found in common with the Middle Jurassic of Gujarat, India (Alhussain 2014), which in plate tectonic reconstructions was situated geographically just south of the Arabian plate at the time (Golonka et al. 2006). For example, the species *Fronicularia longiscata* was reported from the Middle–Upper Jurassic Jhurio and Chari formations of India (Alhussain 2014). Jain et al. (2019) have reported *Lenticulina muensteri*, *Lenticulina varians*, and *Laevidentalina guembeli* in the Middle Jurassic of the Kachchh Basin in India. *Nautiloculina oolithica* was first described from the Oxfordian of Switzerland (Mohler 1938). It has also been reported from the Kimmeridgian of Cuba (Brönnimann 1968), the Middle Jurassic of the former Yugoslavia (Velić 2007), and more recently from southern Iran (Ghalandari et al. 2019) and Kuwait (Crespo de Cabrera 2020). Equally important is the observation that many common and cosmopolitan Middle Jurassic foraminifera are rare or absent in our section. In India, Alhussain (2014) reported diverse *Lenticulina*, *Citharina*, *Marginulina* and *Epistomina* species in the Middle Jurassic of India, but in the Central Arabian Basin these forms are extremely rare. Nevertheless, the presence of several cosmopolitan taxa in the sediments of the D5 Unit representing the J30 maximum flooding event indicate better connections between the Arabian Basin and the Tethys during times of higher sea level.

CONCLUSIONS

We recovered 23 species of smaller foraminifers in the upper D5 Unit of the Dhurma Formation corresponding to the J30 maximum flooding surface. The assemblage is dominated by smaller nodosariids, polymorphinids, and miliolids with an admixture of smaller agglutinated forms. No larger agglutinated foraminifera were found, suggesting deposition in deeper water, beneath the photic zone. The nodosariid assemblage consists of small specimens that appear to be juveniles, indicating oligotrophic conditions prevailed in the Central Arabian basin at the time. The benthic foraminiferal assemblage is partially endemic, but the finding of several cosmopolitan species in the J30 maximum flooding horizon offers the possibility for correlation with other areas of the Tethys.

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PLATE 1

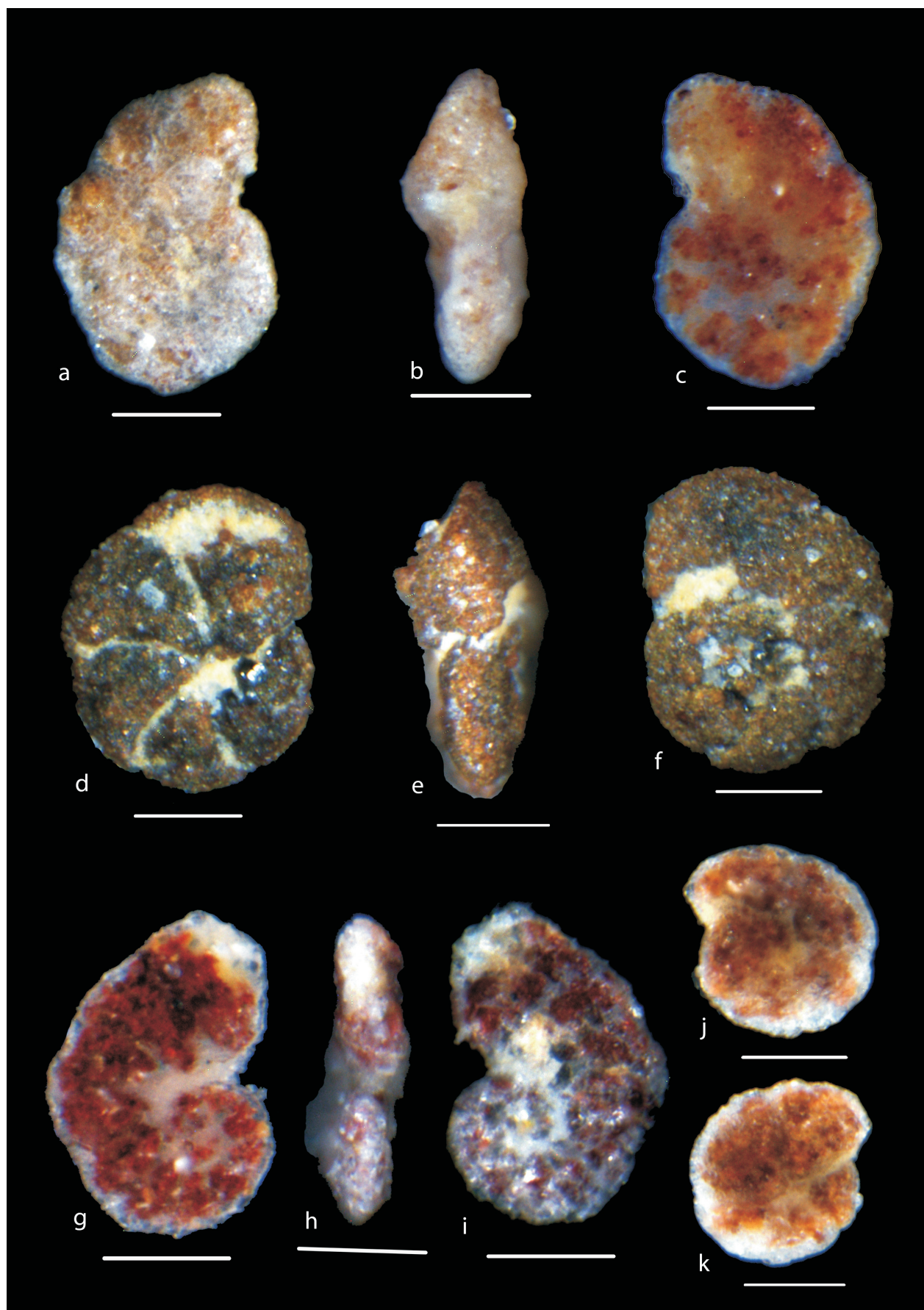
Scale bars = 100 microns.

a-c *Kutsevelia* sp., Sample 1

d-f *Trochammina* sp., Sample 1

g-i *Kutsevelia* sp., Sample 12

j,k *Haplophragmoides* sp., Sample 1



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PLATE 2

Scale bars = 100 microns

a-c *Lenticulina* sp., internal moulds, Sample 6

d-i *Nautiloculina oolithica* Mohler 1938, internal moulds, Sample 2

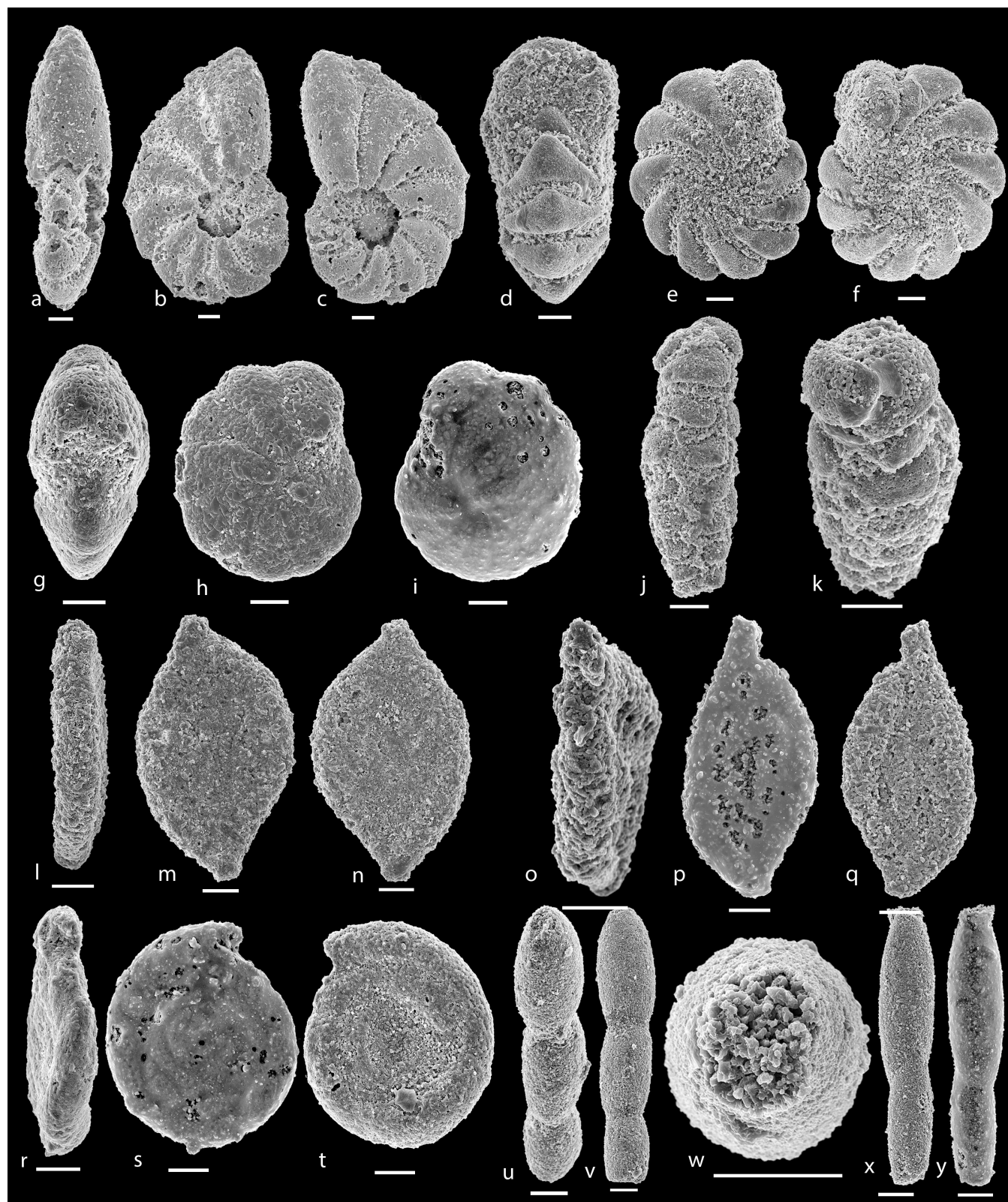
j,k *Riyadhella regularis* Redmond 1965, internal moulds, Sample 6

l-q *Ophthalmidium aspera* Terquem and Berthelin 1875, l-n. Sample 1, o-q. Sample 2

r-t *Spirillina* sp., Sample 2

u,v *Laevidentalina* sp. 1, Sample 2

w-y *Laevidentalina* sp. 2, Sample 5



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PLATE 3

Scale bars = 100 microns

a-f *Laevidentalina guembeli* (Schwager 1865), a-c internal molds, Sample 1.

g-i *Nodosaria* cf. *geniculata* (Terquem and Berthelin 1875) (see Riegraf et al. 1984), Sample 2

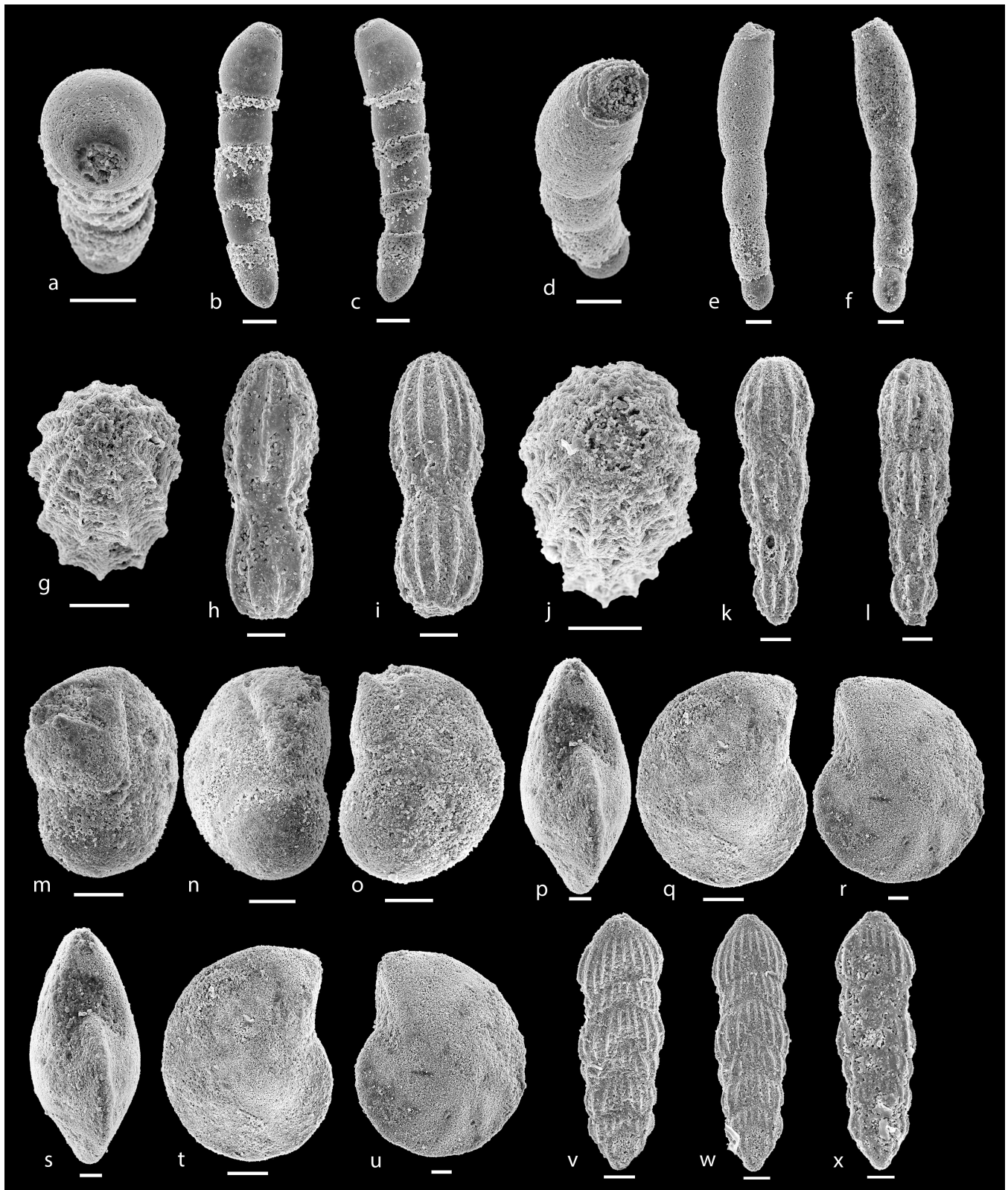
j-l *Marginulina interrupta* Terquem 1866, Sample 6

m-o *Lenticulinaspp.* (juvenile?), Sample 10

p-r *Lenticulina muensteri* (Roemer 1839), Sample 10

s-u *Lenticulina varians* (Bornemann 1854), Sample 10

v-w *Fronicularia longiscata* Terquem 1870, Sample 2



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PLATE 4

Scale bars = 100 microns

a-c *Fronicularia longiscata* Terquem 1870, Sample 2
d-f *Planularia* aff. *beierana* (Gümbel 1862), Sample 1
g,h *Planularia listi* (Bornemann 1854), Sample 1
i *Planularia suturalis* (Terquem 1858), Sample 1

j-l *Eoguttulina angustata* (Terquem 1858), Sample 1
m-o *Eoguttulina* cf. *liassica* (Strickland 1846), Sample 12
p-r *Eoguttulina* sp. Sample 12



APPENDIX 1

Benthic foraminifera recovered from maximum flooding surface J30.

Agglutinated foraminifera:

Trochammina sp. Plate 1, fig. 2a-c.
Kutsevella sp. Plate 1, fig. 3a-c.
Haplophragmoides sp. Plate 1, fig. 4a,b.
Recurvoides sp. (not figured)
Riyadhella regularis Redmond 1965. Plate 2, fig. j,k.

Calcareous foraminifera:

Ophthalmidium aspera Terquem & Berthelin 1875. Plate 2, fig. l-q.
Spirillina sp. Plate 2, fig. r-t.
Laevidentalina sp. 1. Plate 2, fig. u,v.
Laevidentalina sp. 2 Plate 2, fig. w-y.
Laevidentalina guembeli (Schwager 1865) = *Dentalina guembeli* Schwager 1865. Plate 3, fig. a-f.
Nautiloculina oolithica Mohler 1938. Plate 2, fig. d-i.
Nodosaria cf. *geniculata* (Terquem and Berthelin 1875) (see Riegraf et al. 1984). Plate 3, fig. g-i.
Marginulina interrupta Terquem 1866. Plate 3, fig. j-l. (see Tappan 1955).
Lenticulina sp. (juvenile). Plate 3, fig. m-o.
Lenticulina muensteri (Roemer 1839) = *Robulina münsteri* Roemer 1839. Plate 3, fig. p-r.
Lenticulina varians (Bornemann 1854) = *Cristellaria varians* Bornemann 1854. Plate 3, fig. s-u.
Fronicularia longiscata Terquem 1870. Plate 3, fig. v-w; Plate 4, fig. a-c.
Planularia aff. *beierana* (Gümbel 1862) = *Marginulina beierana* Gümbel 1862. Plate 4, fig. d-f.
Planularia listi (Bornemann 1854) = *Cristellaria listi* Bornemann 1854. Plate 4, fig. g,h
Planularia suturalis (Terquem 1858) = *Cristellaria suturalis* Terquem 1858. Plate 4, fig. i.
Eoguttulina angustata (Terquem 1858) = *Polymorphina angustata* Terquem 1858. Plate 4, fig. j-l =
Eoguttulina cf. *liassica* (Strickland 1846) = *Polymorphina liassica* Strickland 1846. Plate 4, fig. m-o.
Eoguttulina sp. Plate 4, fig. p-r.