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RESEARCH ARTICLE

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New insights into the taxonomy and evolution of Jurassic planktonic foraminifera

Felix Gradstein[1*] and Anna Waskowska[2]

Abstract

Globuligerina glinskikhae nov. sp. Gradstein & Waskowska and *Globuligerina waskowskae* nov. sp. Gradstein are new species of Jurassic planktonic foraminifera from the Middle Jurassic of Dagestan and Poland. *G. glinskikhae* nov. sp. with its remarkable 'protoglobigerine' test may be an early evolutionary offshoot of *Globuligerina oxfordiana* (Grigelis). It may be an index taxon for upper Bajocian through Bathonian strata in Eastern Europe and Southwest Asia, and might be recognizable also in thin sections. We consider *G. waskowskae* nov. sp. to be a possible forerunner of *Conoglobigerina helvetojurassica* (Haeusler), the first planktonic foraminiferal species with a reticulate wall texture. Currently, is only known from Poland. In some localities, specimens of *G. oxfordiana* and of *G. glinskikhae* nov. sp. posses an additional apertural opening, often lacking a rim; its function is enigmatic. The postulated lineage from Jurassic *Globuligerina balakhmatovae* (Morozova) to Cretaceous *Clavihedbergella eocretacea* Neagu is refined with the description of *Petaloglobigerina simmonsi* nov. gen., nov. sp. Gradstein from the Kimmeridgian of Portugal. The evolutionary transition from *G. balakhmatovae* to *P. simmonsi* occurs by means of the ontogenic development of a petaloid test, with a pronounced flattening of the whorl with ovate chambers, the last ones often offset and twisted. Jurassic planktonic foraminifera, now known to consist of three genera and 12+ species underwent long periods of stasis, interrupted by late Bajocian, mid-Oxfordian and early Kimmeridgian evolution. The three 'stasis and root' taxa *G. oxfordiana*, *G. bathoniana* and *G. balakhmat*ovae are geographically widespread in lower to mid palaeo-latitudes, and stratigraphically long ranging within the Middle and Late Jurassic. Modern digital microscopes, with co-axial and side LED lighting and excellent image stacking software are important tools in the study of Jurassic planktonic foraminifera, and fast and cost-effective communication tools in modern micropalaeontology.

Keywords: Jurassic, Planktonic foraminifera, Evolution, Biostratigraphy and palaeoecology

Introduction

This study reports on one new genus and three new species of Jurassic planktonic foraminifera. *Globuligerina glinskikhae* nov. sp. Gradstein & Waskowska and *Globuligerina waskowskae* nov. sp. Gradstein are new species of Jurassic planktonic foraminifera from the upper Bajocian–lower Bathonian strata of the Khouroukra section in central Dagestan and the middle Bathonian of the Gnaszyn section in the Częstochowa area of Poland. *Petaloglobigerina simmonsi* nov. gen., nov. sp. Gradstein occurs in the lower Kimmeridgian Tojeira Formation in the Montejunto area of central Portugal. All chronostratigraphic assignments are based on well-established local ammonite zonations (Stam 1986). The new taxa improve our understanding of the early evolution in this group of stratigraphically important microfossils.

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Material and methods

The Polish, Dagestan and Portuguese outcrop sections were described with great stratigraphic detail and with complete geographic notations in Gradstein et al. (2017a). Sample numbers used in the current study refer to the notations and stratigraphic sections in this literature reference.

In addition to standard Leica (M205C with PLANAPO 1.0× and 1.6× objectives) and Nikon (VL100POL) stereo microscopes, good use was made for wall texture determination of the Leica DM 750 M biological microscope with polarizer/analyser and Epi 10×/0.25 and N Plan L 20×/0.35 and Plan L 50×/0.50 objectives. Both objectives have long distances between objective and specimen and allow optimum incident light illumination. Digital optical images were obtained efficiently with the Deltapix M12ZS digital microscope with 1.25, 2.5 and 4.16 objectives and Insight stacking software. SEM images were obtained with the FEI QUANTA 200 FEG scanning microscope at the Laboratory of Phase, Structural, Textural and Geochemical Analyses of the Faculty Geology, Geophysics and Environmental Protection at AGH, Krakow, Poland.

Taxonomy

Globuligerina glinskikhae nov. sp., Gradstein and Waskowska

Figure 1, 1–7

Description

Test diameter generally in the 100–125 µm range, with 2–3 whorls in a compact trochoid shape. Relatively large, last whorl with three, globular chambers, slowly increasing in size, with the last globular chamber taking up about half of the final whorl. Coiling direction mostly dextral. Sutures depressed, umbilicus tight, aperture a low slit with rim at the base of the last chamber in the umbilical area. Test wall microperforate with numerous small pustules and scattered pore mounds.

The holotype and paratypes are from sample GN 6 in the lower part of the Gnaszyn section of the Częstochowa area of Poland (Gradstein et al. 2017a, Figures 12 and 13). The sample is placed in the *Morrisi* Ammonite Zone—Middle Bathonian; it is a grey and slightly sandy claystone with numerous bioclasts, mainly of mollusks shells. In the Gnaszyn section, the new species is relatively rare, but many paratype specimens occur in the marine clays of the Khouroukra section of central Dagestan (Gradstein et al. 2017a, Figure 9), particularly in sample 8 of Bed 19, assigned to the *Parkinsonii* Ammonite Zone, Upper Bajocian.

The new species is named in honour of Dr. Larisa Glinskikh, Novosibirsk, Russia, who supplied the sample material from Dagestan, and provided valuable stratigraphic information.

The type specimens are stored in the European Micropalaeontology Reference Centre of the MicroPress Europe Foundation at AGH, Krakow, Poland.

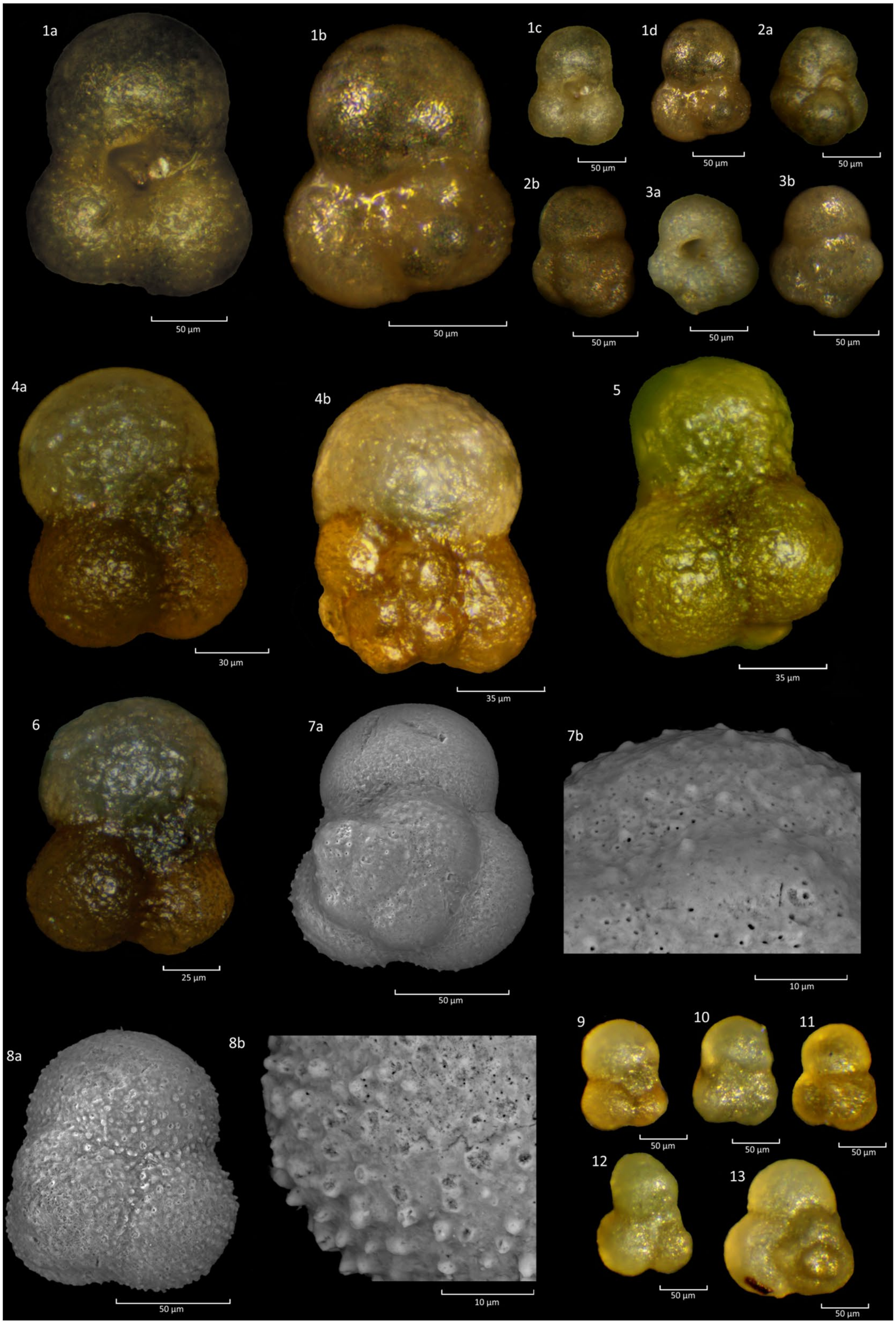
Discussion

Globuligerina glinskikhae nov. sp. may be readily distinguished from *Globuligerina oxfordiana* (Grigelis) because of its tight, three-chambered and highly globular last whorl (Fig. 1, no. 1). *G. oxfordiana* has four chambers (and only rarely 3.5 or 4.5) in the last whorl with the second chamber in the last whorl characteristically protruding (see Fig. 1, no. 1 and Fig. 1, nos. 2 and 3 for a comparison of the two test shapes). We have not observed morphological intermediates between the two taxa, but consider it likely that *G. glinskikhae* evolved from *G. oxfordiana*, perhaps during the Bajocian in Dagestan time and then spread to for example Poland, where it is rare in Bathonian strata. We have not observed the new taxon in clay-prone planktonic foraminiferal assemblages from the Middle Jurassic of Portugal or the Grand Banks of Newfoundland, but co-author AW had correspondence with palynology colleague Dr. Elahe Aarei (School of Earth Sciences, Damghan University, Iran) who showed pictures of Bathonian specimens closely resembling *G. glinskikhae*. We failed to obtain Iranian sample material.

Because of its prominent globular chambers, arranged in a large, three chambered last whorl, we consider it feasible to recognize this taxon in thin sections; it maybe a possible index for Upper Bajocian to Bathonian strata.

(See figure on next page.)

Fig. 1 *Globuligerina glinskikhae* Gradstein and Waskowska nov. sp. Nos. 1a, b—holotype, sample 6, *Morrisi* Ammonite Zone, Middle Bathonian, Gnaszyn, Poland; Nos. 1c, d—holotype. Nos. 2a, b, 3a, b—*Globuligerina oxfordiana* (Grigelis) in same sample 6; for details see text. Nos. 4a, 4b, 5, 6, 9, 10 and 11—paratypes, sample 8, *Parkinsoni* Zone, Upper Bajocian, Khouroukra, Dagestan. Nos. 7a, b and 8a, b—paratypes, sample 6, *Morrisi* Zone, Middle Bathonian, Poland; note the microperforate and pustulose wall with scattered pore mounds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Globuligerina waskowskae Gradstein nov. sp.

Figure 2, 1–8

Description

Test generally in the 100–150 µm range, with three whorls in a trochoid coil. The relatively small initial whorls stand in contrast to the large, final whorl with four chambers, regularly increasing in size. Our specimen photographs show the relatively flat spiral base of the last whorl. The axis of coiling tilts in the large penultimate chamber, resulting in progressive forward tilting over the umbilicus and culminating in crescentic shape of the other three chambers in the final whorl. Sutures depressed, aperture umbilical, a low and elongate arch to high arched, with a rim. Umbilicus closed. Wall microperforate, with many small pustules and scattered pore mounds.

The holotype and paratypes are from sample GN 6 in the lower part of the Gnaszyn section of the Częstochowa area of Poland (Gradstein et al. 2017a, Figures 12 and 13). The sample is placed in the *Morrisi* Ammonite Zone—Middle Bathonian; it is a grey and slightly sandy claystone with numerous bioclasts, mainly of mollusks shells. The new species is not common in the Gnaszyn section.

The new species is named in honour of Dr. Anna Waskowska, who did the fieldwork, the sampling and the micropalaeontologic analysis leading to the discovery of this new and distinctive species.

Type specimens are stored in the European Micropalaeontology Reference Centre of the MicroPress Europe Foundation at AGH, Krakow, Poland.

Discussion

We only have observed this taxon in samples from the Gnaszyn outcrop section. It is not clear if this single locality occurrence is because its stratigraphic range might be short, or that it is endemic to this shallow marine basin of Poland.

Its distinctive test morphology points towards it as a potential forerunner of *Conoglobigerina helvetojurassica* (Haeusler) of the Middle Oxfordian of Switzerland and the Kimmeridgian of Portugal and France. The latter differs by its reticulate wall texture. Currently, we lack information on the occurrence of the new taxon in upper Bathonian through lower Oxfordian strata. As an example of morphological similarity, we show a picture on Fig. 2 nos. 9a, b of *C. helvetojurassica* from sample 24.2P from the lower Kimmeridgian Tojeira Formation, Montejunto Portugal. It is common in this sample, also rich in deeper marine epistominids such as *E. mosquensis* Uhlig. If it was without a reticulate wall texture, the Kimmeridgian specimens of *C. helvetojurassica* could readily be assigned to *G. waskowskae* nov. sp.

Globuligerina oxfordiana (Grigelis) 1985

Figure 3, 1–7

1958 ‘*Globigerina*’ *oxfordiana* Grigelis, Nauch.Dokl. Vyss.Shk., Geol.-Geogr. Nauki 3, pp. 110–111, text Fig. 1.

1966 *Globigerina oxfordiana* Grigelis. Bignot and Guyader 1966, pp. 105–107, plate 1, Figs. 1–11.

1971 *Globuligerina oxfordiana* (Grigelis). Bignot and Guyader 1971, p. 83, plate 1, Figs. 1–4; plate 2, Figs. 3, 4.

2017a. Globuligerina oxfordiana (Grigelis). Gradstein et al. 2017a, pp. 235–239, plates 9–14, all images.

Discussion

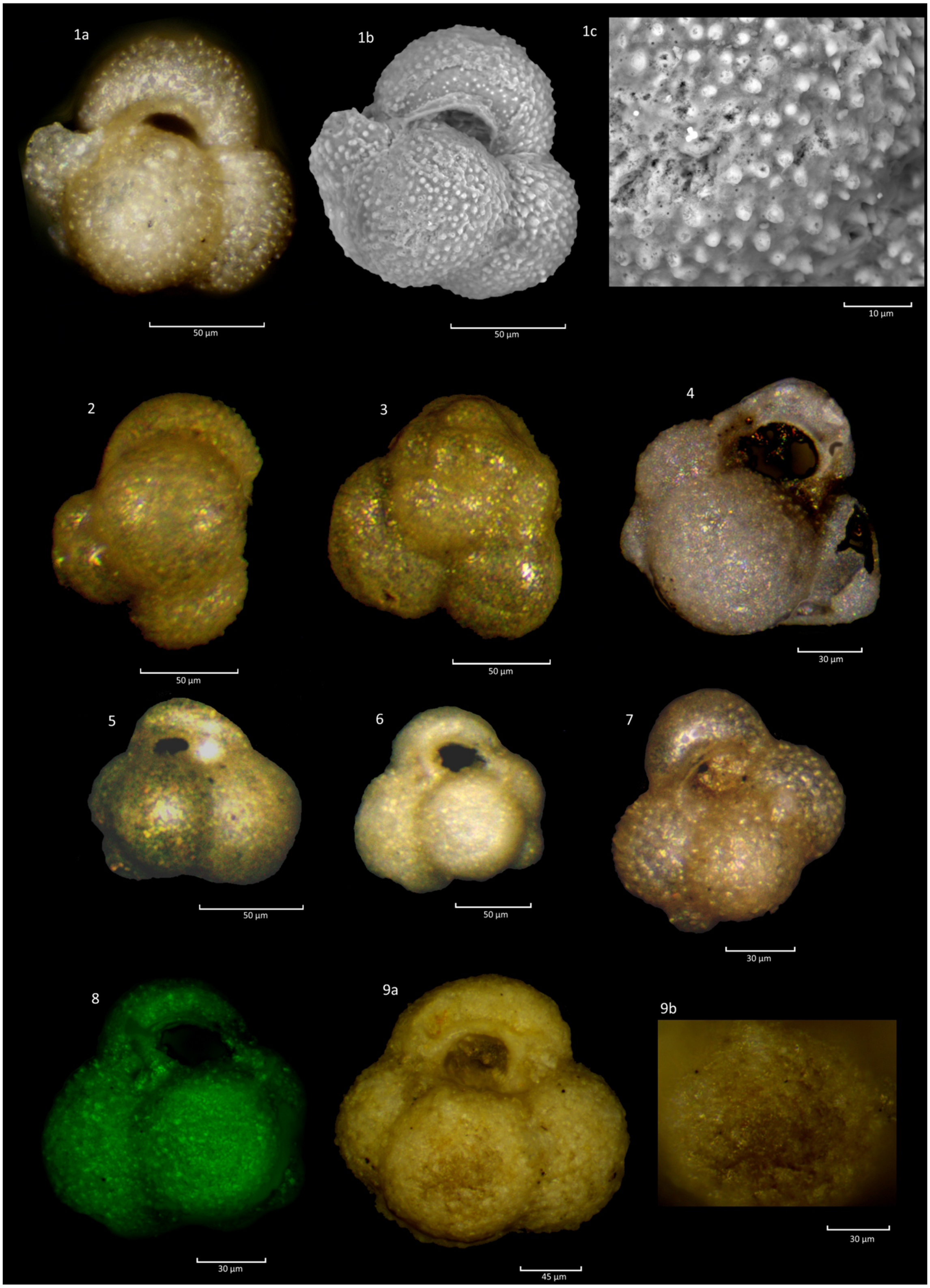
Globuligerina oxfordiana is common in many Middle-to-Late Jurassic open marine sedimentary successions, and is relatively well described. Aperture variable in shape, low-to-high arch, generally comma-shaped, with the posterior margin typically set forwards in the umbilicus. The aperture often has a thickened rim around it.

What is not reported in the literature is a peculiar apertural feature of *G. oxfordiana* with an additional opening such that the thickened wall of the apertural rim forms a pillar in the larger, total apertural opening. The feature was observed in specimens from the Middle Jurassic sections in Khouroukra, Dagestan and Gnaszyn, Poland, from the lower Oxfordian of NW France and the lower Kimmeridgian Tojeira Formation, Montejunto, Portugal. The feature is particularly common in the lower Oxfordian section in NW France. Figure 3, nos. 1–7 provides striking examples of this feature, clearly showing that the extra opening has no rim. A speculation is only that this feature of wall resorption leading to the extra apertural opening is linked to sexual reproduction.

Specimens of *G. glinskikhae* nov. sp. from Dagestan rarely show this peculiar feature too. This taxon commonly occurs with *G. oxfordiana* in the same Dagestani samples.

(See figure on next page.)

Fig. 2 *Globuligerina waskowskae* Gradstein nov. sp. Nos. 1a, b, c—holotype, sample 6, *Morrisi* Zone, Middle Bathonian, Gnaszyn, Poland; note microperforate wall with small, regularly distributed pustules, many with pore mounds. Nos. 2 and 3—paratypes, side and spiral views, same sample as holotype. No. 4 through 8—paratypes, same sample level as holotype. Nos. 9a, b—*Conoglobuligerina helvetojurassica* (Haeusler) with reticulate wall texture in sample 24—2, Tojeira Formation, Lower Kimmeridgian, Montejunto, Portugal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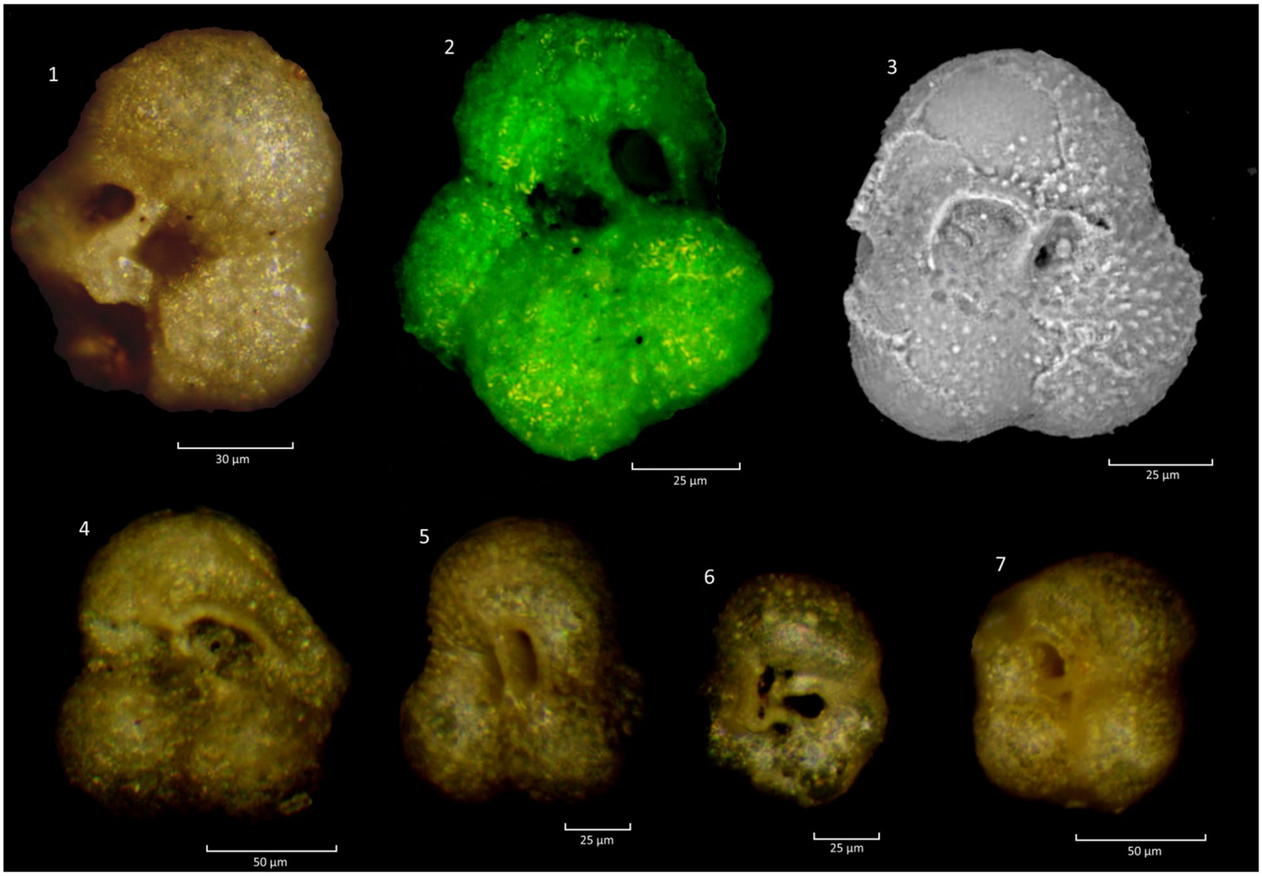

Fig. 3 *Globuligerina oxfordiana* (Grigelis). Nos. 1, 2, 3, 4, 5, 6 and 7 specimens with extra apertural opening (without rim or lip). Nos. 1 and 3—sample 6, *Morrisi* Zone, middle Bathonian, Gnaszyn, Poland. Nos. 2, 4, 5, 6 and 7—*Mariae* Zone, lower Oxfordian, Le Havre, France

Recently, Apthorpe (2020) showed a similar apertural feature in well-preserved specimens from the Bajocian of NW Australia. The specimens resemble *Globuligerina bathoniana* (Pazdrowa) and *G. oxfordiana.* The feature deserves further study.

Our specimens are stored in the European Micropalaeontology Reference Centre of the MicroPress Europe Foundation at AGH, Krakow, Poland.

Petaloglobigerina nov. gen. Gradstein

Test trochospiral, low spired, final whorl large and often flat with 3.5–4 petaloide and ovate chambers, rarely finger like; chamber periphery may become narrow and pointed, but not imperforate. In larger specimens, individual chambers in the last whorl may slightly twist from the axis of coiling; sutures strongly incised; umbilicus narrow or closed; aperture a narrow slit with rim at base of last chamber in umbilical position. A small and incomplete (half) bulla may be rarely present, covering the aperture. Wall microperforate and densely pustulose, with pustules fusing to form irregular ridges.

The new genus occurs abundantly in samples from the lower Kimmeridgian.

Tojeira Formation, Montejunto area (Estramadura), central Portugal.

Smaller, and likely mostly juvenile specimens in the assemblages have been previously referred to as *Globuligerina balakhmatovae* (Morozova) (Gradstein et al. 2017a, b) with its characteristic four chambers in the low concave last whorl, shaped in a clover-like pattern; aperture is slit and there is no bulla.

Globuligerina balakhmatovae represents a single taxon evolutionary branch of Jurassic planktonic foraminifera that has a low spired test and appears not to have changed test shape or wall texture from Bajocian through Kimmeridgian (Gradstein et al. 2018).

Characteristic specimens of *G. balakhmatovae* are illustrated in Fig. 4, nos. 4, 6–11 from the Khouroukra section in Dagestan (Upper Bajocian), which is the type section of the nominate species (Gradstein et al. 2017a).

Similar specimens occur in the Tojeira section (Fig. 4, 2) and in the Bajocian through Oxfordian of the conjugate Grand Banks of Newfoundland (Fig. 4, nos. 1, 3—5), (see also Stam 1986).

It might be tempting to transfer all specimens of this long-ranging species to the new genus *Petaloglobigerina*, but this awaits a more detailed evaluation of the original types as designated by Morozova and Moskalenko (1961) and re-illustrated in Simmons et al. (1997). For example, the holotype, (but not the paratypes) of *G. balakhmatovae* appears to fall outside the common *G. balakhmatovae* morphology as we observe it; the holotype test is more inflated and chambers are not petaloide or ovate.

Petaloglobigerina simmonsi Gradstein nov. sp.

Figure 5, nos. 1–8

Description

Test generally in the 100–150 μm range, trochospiral, low spired. Final whorl large and often almost flat with 3.5–4 petaloide and ovate chambers, rarely finger-like; chamber periphery may become narrow and even pseudo-keeled, but us not imperforate. In larger specimens, individual chambers in the last whorl may slightly twist from the coiling axis; sutures strongly incised; umbilicus narrow or closed; aperture a narrow slit with rim at base of last chamber in umbilical position. A small and incomplete (half) bulla may be rarely present, shielding the aperture. Wall microperforate and densely pustulose, with pustules fusing to form irregular ridges.

The new species name is in honour of Dr. Mike Simmons, who made major contribution to the understanding of this group of microfossils with his taxonomic study published in 1997 (Simmons et al. 1997).

The type specimens are stored in the European Micropalaeontology Reference Centre of the MicroPress Europe Foundation at AGH, Krakow, Poland.

Discussion

The species is abundantly in samples from the lower Kimmeridgian.

Tojeira Formation, Montejunto area (Estramadura), central Portugal.

Smaller and likely mostly juvenile specimens in the assemblages have been assigned to *G. balakhmatovae* (Stam 1986; Gradstein et al. 2017a, b) with its characteristic four chambers in the low concave last whorl, shaped in a clover-like pattern; aperture is a slit, and there is no bulla.

We postulate that *P. simmonsi* nov. gen., nov. sp. shows a morphological transition in its ontogeny from *G. balakhmatovae*, the latter being its evolutionary ancestor.

There is no stratigraphic record of the *P. simmonsi* nov. gen., nov. sp. in post (early) Kimmeridgian strata for which we lack sample material with free specimens. Gradstein et al. (2018) proposed the change from specimens, now assigned to *P. simmonsi* nov. gen., nov. sp. to *Clavihedbergella eocretacea* Neagu 1975 in the early Berriasian, but more information is essential. In *C. eocretacea* (http://www.mikrotax.org/pforams/), chambers in the last whorl expand more in size and the apertural position is umbilical extra-umbilical or interiomarginal, not umbilical as in *P. simmonsi* nov. gen., nov. sp. Aperture is a low arch or slit with a narrow rim in both taxa. Chambers in both taxa may become somewhat elongated and rather flat, and may twist relative to the plane of coiling. In both taxa, four chambers are commonly found in the last whorl. Both taxa also have an ovate chamber shape, with a tendency to a narrow periphery and a rugulose wall texture.

Evolution

Integrating the work of Gradstein et al. (2017b, 2018) with the new taxa described herein provides new insights into the evolution of early planktonic foraminifera.

The study of Wernli (1988) on thin sections from Toarcian limestone samples from the Domuz Dag mountain chain of SE Turkey provided by Poisson (Paris) documents the oldest known occurrence of true planktonic foraminifera. Curiously, this is the only record of this oldest known assemblage. Hence, planktonic foraminifera appeared in the Toarcian around 180 Ma ago. The youngest Jurassic occurrence of this group is documented by Görög and Wernli (2004) describing a single taxon of planktonic foraminifera (extracted with acetic acid) in Tithonian age samples from Hungary. Hence, Jurassic planktonic foraminifera range from Late Toarcian (*Bifrons-Variabilis* ammonite Zones) through Late Tithonian (*C. alpina* calpionellid Zone).

(See figure on next page.)

Fig. 4 *Globuligerina balakhmatovae* (Morozova). Nos. 1, 4a, b and 5, cuttings sample 8360 ft., Eider well, Grand Banks, Bajocian-Bathonian; wall texture varies from relatively smooth to densely pustulose, with pustules merging into short ridges. No. 2, sample 24/2P, Tojeira Formation, Montejunto, Portugal, lower Kimmeridgian; wall texture coarsely pustulose. No. 3, swc sample 5000 ft., Bittern well, Grand Banks, Callovian—early Oxfordian; note the coarse pustulose test and oblong chambers, final one becoming pointed. Nos. 6, 7, 8, 9, 10 and 11 side, umbilical and spiral views of co-types of *Globuligerina balakhmatovae* (Morozova) in the type section for this taxon from sample 8, *Parkinsonii* Zone, Upper Bajocian, Khouroukra, Dagestan.

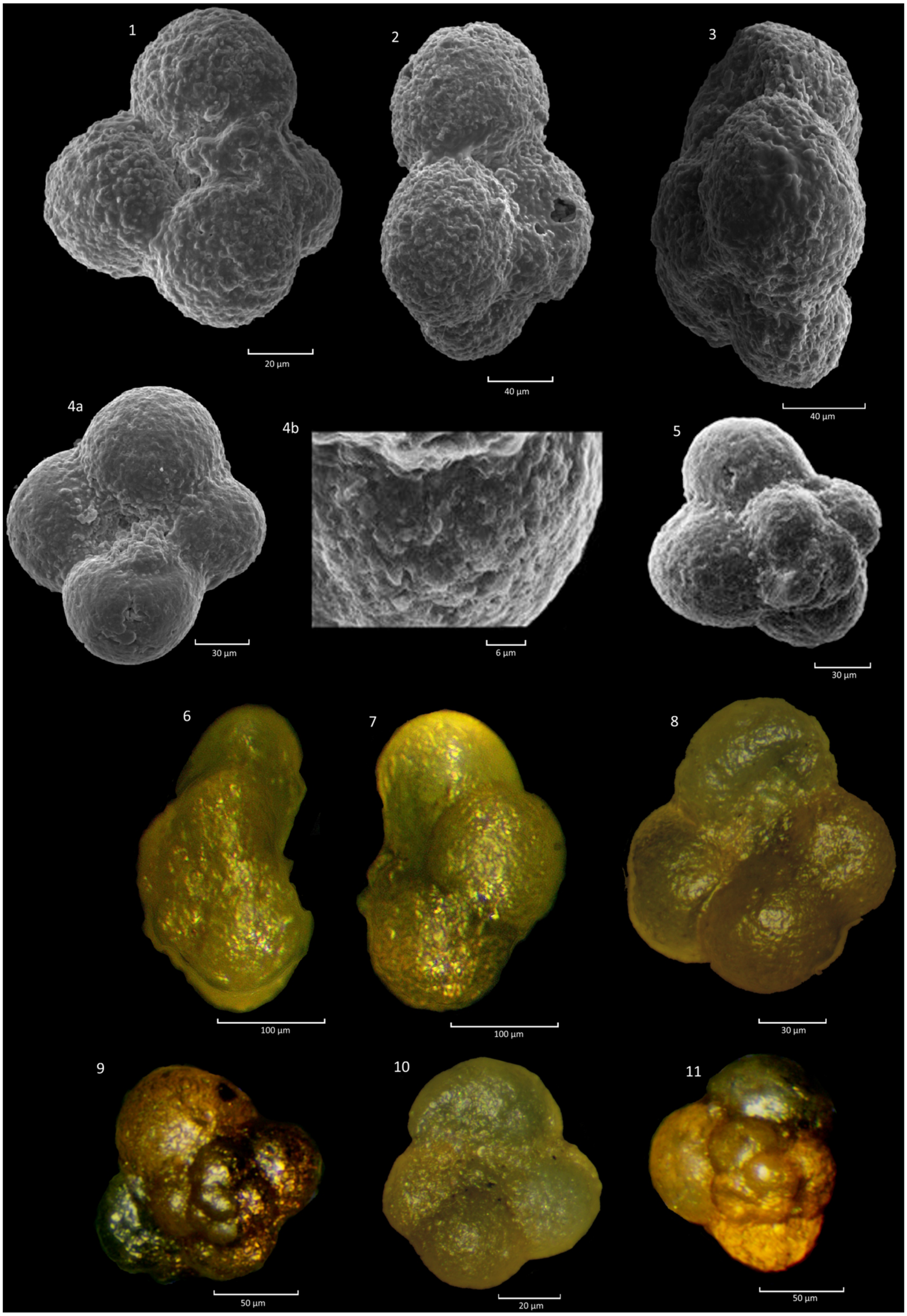
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Figure 6 depicts this history in a simple stratigraphic column, a figure updated from Gradstein et al. (2017b, 2018).

The Toarcian through Aalenian record is only known from thin sections, and it appears that an often larger and higher spired form similar to *G. bathoniana* and a smaller, lower spired form similar to *G. oxfordiana* occur in these thin sections. This needs better documentation with well-preserved free specimens. Test size difference in itself may not be a taxonomic feature, and often has more to do with growth conditions in optimal or sub-optimal environments, selective sediment sorting, water masses and vertical biota distribution, and other hard to evaluate factors in fossil material.

As outlined in Fig. 6, we consider that within the Jurassic and earliest Cretaceous four lineages of planktonic foraminifera occur, which for graphic clarity are indicated with green, brown, blue and red stratigraphic lines. Two key taxa, *P. simmonsi* nov. gen., nov. sp. and *G. oxfordiana* are postulated to be ancestral links to Cretaceous taxa.

The 'green group' is monotypic and consists of *G. balakhmatovae* evolving in Kimmeridgian time in *P. simmonsi* nov. gen., nov. sp.

The ancestry of G. *balakhmatovae* is not clear. A possible morphological transition exists to *Oberhauserella* aff. *parocula* described by Wernli and Görög (2007) from SE France, but this requires refinement of our knowledge on the stratigraphic appearance and test morphology of both taxa. A detailed study of wall textures should be undertaken, including other taxa in the genera *Globuligerina* and *Oberhauserella*.

There is no stratigraphic record of the low-spired *P.simmonsi* nov. gen., nov. sp. in post (early) Kimmeridgian strata. Based on a general similarity in test morphology, Gradstein et al. (2018) proposed that this taxon might have evolved in *C. eocretacea* in early Berriasian time.

The 'brown group' includes *Globuligerina dagestanica* (Morozova), the common species *G. bathonian*a and rare *G. jurassica* (Hofman), all higher spired trochoid morphotypes with an arch to looped aperture and commonly a bulla. Essentially, we can distinguish one taxon with a more symmetrical and regular trochospire with four chambers in the last whorl (*bathoniana* type), and another taxon with more irregular (or sometimes triangular) trochospire with 3, 3–4 or 4 chambers in the last whorl (*dagestanica* type). In our opinion, *G. jurassica* might be a local and often aberrant variant of *G. dagestanica;* it is not illustrated in Fig. 6.

The 'blue group' consists of *Globuligerina avariformis* (Kasimova) and *Conoglobigerina grigelisi* (Gradstein), both of which do not have a geographically widespread record. The taxa typically have a last whorl that strongly embraces earlier ones, such that the test almost appears involute. An evolutionary line age is postulated from the compact *G. avariformis* into the equally, or even more compact *C. grigelisi.* The latter acquires a reticulate wall sculpture. Its youngest record is Kimmeridgian. We refrain to speculate on the ancestry of *G. avariformis*, our stratigraphic and taxonomic data are insufficient.

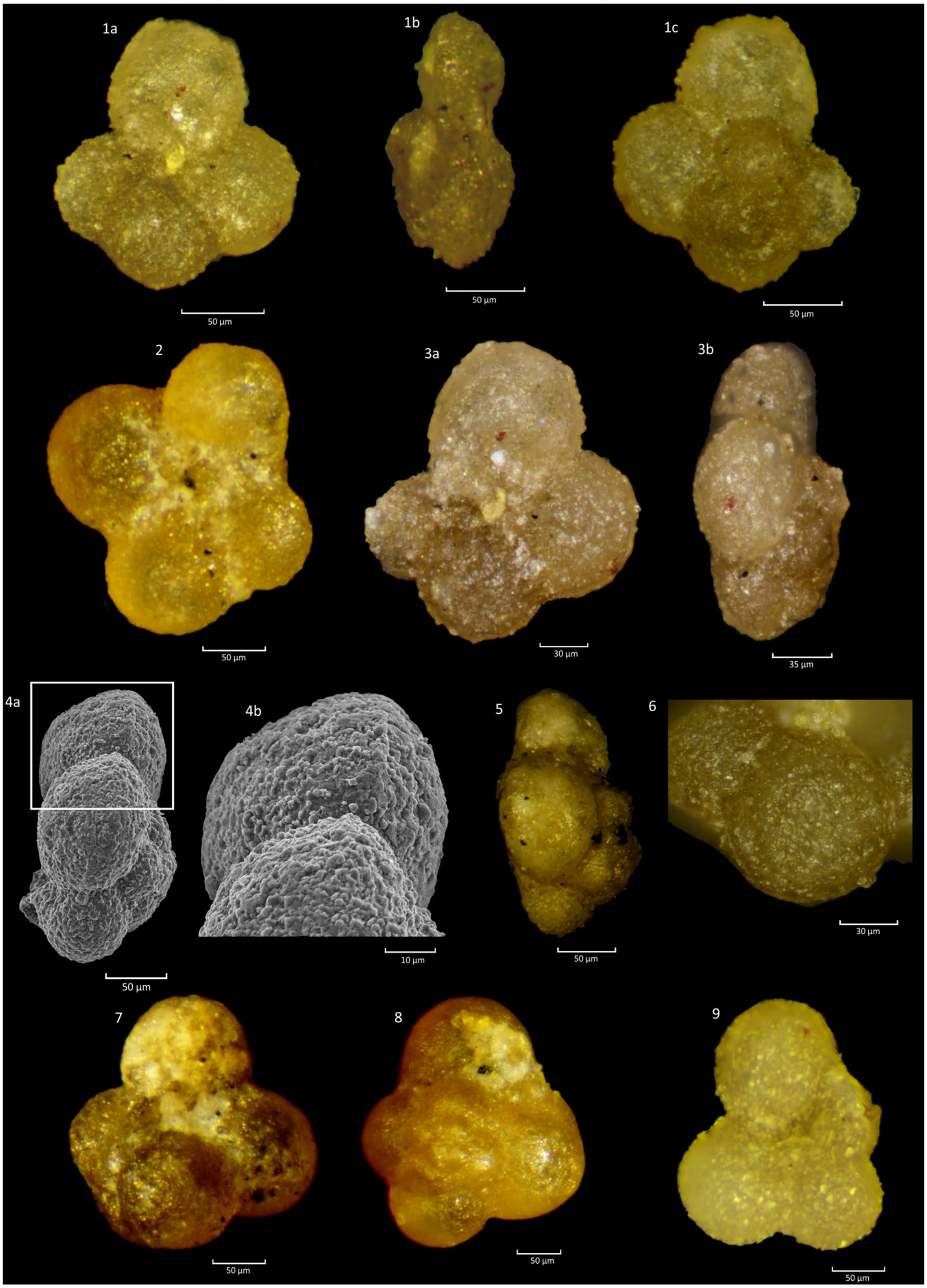
The 'red group' includes *G. xfordiana*, *G. glinskikhae* nov. sp., *G. tojeiraensis* Gradstein and the inferred lineage from *G. waskowskae* nov. sp. to *C. helvetojurassica*. These are low-to-medium high-spired morphotypes, with spherical-globular or radially somewhat elongated chambers, narrow to wide umbilicus, large last whorl and arch to looped aperture with lip. In well-preserved and typical *G. oxfordiana*, the looped aperture is very slightly offset from the umbilicus. A stratigraphic trend exists in this taxon to a more reticulate wall texture with the umbilicus opening up.

Gorbachik (1983) showed the onset of reticulation on older chamber of a specimen of this species; this is clearly an ontogenetic feature in rare specimens of some assemblages. If ontogeny recapitulates evolution, this wall texture change may be seen to strengthen our postulation that *G. oxford*iana is ancestral to *Favusella hoterivica* (Subbotina). But interestingly, specimens from our four other, widely different localities of Late Bajocian through Early Kimmeridgian age (Grand Banks, Portugal, Poland and Dagestan) show pustulose wall texture only. The close morphological comparison and overlap in wall texture features, makes it viable to consider *G. oxfordiana* to be the ancestor of *F. hoterivica.* In Fig. 6, both taxa are illustrated. To demonstrate that this evolution took place in Tithonian time, as postulated in Fig. 6, wall texture analysis of well-preserved, free specimens is required.

The species *G. tojeiraensis*, with elongated chambers and wide-open umbilicus is known from the Bajocian–Bathonian of Dagestan, the Callovian–Oxfordian of the

(See figure on next page.)

Fig. 5 *Petaloglobigerina simmonsi* Gradstein nov. gen, nov. sp. Nos. 1a–c, holotype, sample 10, section 1, Tojeira Formation, lower Kimmeridgian, Montejunto, Portugal. Note the offset first chamber in the last whorl of the spire and the oval and pointed last chamber. Nos. 2 and 3a, b, paratypes, same sample as holotype; note last chamber offset from spiral whorl and low arch aperture. Nos. 4a, b, paratype from sample 6–28 in the upper Tojeira Fm., lower Kimmeridgian, Montejunto, Portugal; note the four chambered last whorl with pointed periphery and the densely pustule wall texture. No. 5, paratype side view from sample T1–3, Tojeira Formation, lower Kimmeridgian, Montejunto, Portugal. No. 6—densely pustulose test wall in paratype in same sample as holotype. Nos. 7 and 8 paratypes from sample 6–28 in upper Tojeira Formation, lower Kimmeridgian, Montejunto, Portugal. 9—paratype in same sample as holotype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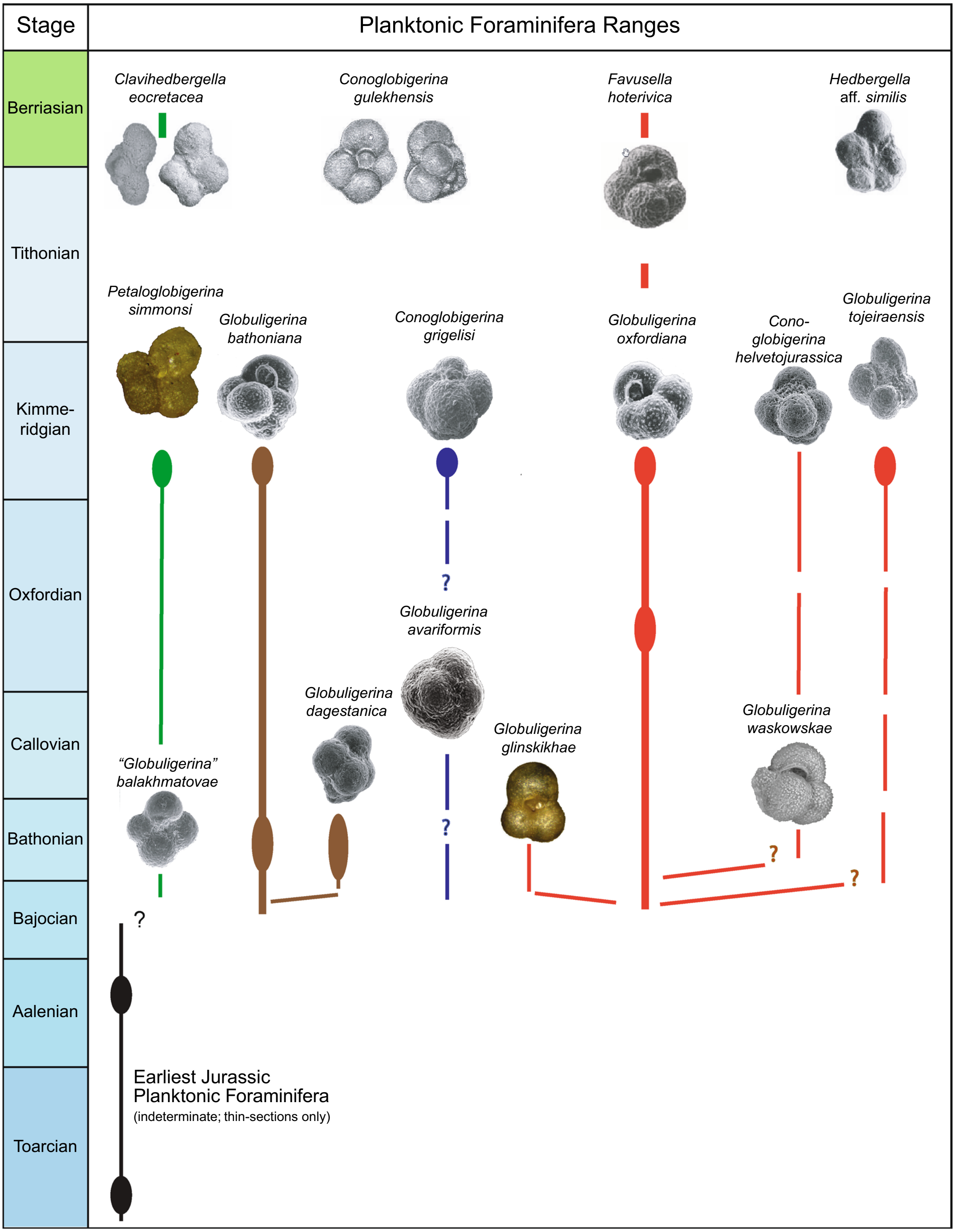

Fig. 6 Stratigraphic ranges and evolution of Jurassic planktonic foraminifera. For details, see text

Grand Banks of Newfoundland and the Lower Kimmeridgian of Portugal. Its overlap in morphology with *G. oxfordiana* suggests the latter to be ancestral. The origin of *G. oxfordiana* itself is shrouded in mystery.

The discovery and description in this study of well-preserved *G. waskowskae* nov. sp. (Fig. 2), with a test morphology much alike *C. helvetojurassica* makes it attractive to consider the former taxon to be ancestral. The principal new feature in this evolution is the distinctive reticulate wall texture of *C. helvetojurassica*, appearing in Middle Oxfordian.

In summary, and as illustrated in Fig. 6, the planktonic foraminifera occurred in Toarcian-Aalenian time (but no free specimens record) and with at least eight taxa in Bajocian–Bathonian. With the subsequent disappearance of two taxa and appearance of four new taxa, the Oxfordian–Kimmeridgian planktonic foraminiferal record consists of six taxa. Giving weight to the acmes of taxa in Portugal, the Kimmeridgian is the time Jurassic planktonic foraminifera flowered. A dramatic faunal change-over, which is not well documented, and not well understood led to the survival of only one taxon, most likely *G. oxfordiana*, during Tithonian time. During Berriasian time, several new taxa appeared.

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Authors' contributions
Both FG and AW performed the detailed micropalentologic analysis; FG wrote most of the manuscript and AW made the plate figures. Both authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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References

Apthorpe, M. (2020). Middle Jurassic (Bajocian) planktonic foraminifera from the northwest Australian margin. *Journal of Micropalaeontology, 39,* 93–115. https://doi.org/10.5194/jm-39-93-2020
Bignot, G., & Guyader, J. (1966). Découverte de foraminifères planctoniques dans l'Oxfordien du Havre (Seine-Martitime). *Revue de Micropaléntologie, 2,* 104–110.
Bignot, G., & Guyader, J. (1971). Observations nouvelles sur *Globigerina oxfordiana* Grigelis. In: A. Farenacci (Ed). *Proc. II Planktonic Conference, Roma* (pp. 79–83).
Gorbachik, T. N. (1983). *Globuligerina oxfordiana* (Grigelis)—a typical species of the genus *Globuligerina* in electron microscope. *Akad Nauk SSSR, 26,* 48–51. **(+6 plates)**.
Görög, A., & Wernli, R. (2004). A rare protoglobigerinid association (Foraminifera) from the Tithonian of Gerecse Mts, Hungary. *Hantkeniana, 4,* 37–45.
Gradstein, F. M. (2017a). New and emended species of Jurassic planktonic foraminifera. *Swiss Journal of Palaeontology, 136,* 161–185.
Gradstein, F. M. (2017b). The planktonic foraminifera of the Jurassic. Part III: Annotated historical review and references. *Swiss Jouranl of Palaeontology, 136,* 273–285.
Gradstein, F., Gale, A., Kopaevich, L., Waskowska, A., Grigelis, A., & Glinskikh, L. (2017a). The Planktonic foraminifera of the Jurassic. Part 1: Material and taxonomy. *Swiss Journal of Palaeontology, 136,* 187–257.
Gradstein, F., Gale, A., Kopaevich, L., Waskowska, A., Grigelis, A., Glinskikh, L., & Görög, A. (2017b). The planktonic foraminifera of the Jurassic. Part II: Stratigraphy, palaeocology and palaeobiogeography. *Swiss Journal of Palaeontology, 136,* 259–271.
Gradstein, F. M., Waskowska, A., Kopaevich, L., Watkins, D. K., Friis, H., & Panera, J. P. (2018). Berriasian planktonic foraminifera and calcareous nannofossils from Crimea Mountains, with reference to microfossil evolution. *Swiss Journal of Palaeontology, 138*(2), 213–236. https://doi.org/10.1007/s13358-018-0175-8.
Morozova, V. G., & Moskalenko, T. A. (1961). Foraminiferes planktoniques des depots limitrophes du Bajocien et du Bathonien du Daghestan central (Nord-East du Caucase). *Voprosy Mikdropalaeontol SSSR, 5,* 3–30.
Simmons, M. D., Boudagher-Fadel, M. K., Banner, F. T., & Whittaker, J. E. (1997). The Jurassic Favusellacea, the earliest Globigerina. British Micropalaeontological Society Publication Series. In M. K. Boudagher-Fadel, F. T. Banner, & J. E. Whittaker (Eds.), *The early evolutionary history of planktonic Foraminifer* (pp. 17–53). London: Chapman & Hall.
Stam, B. (1986). Quantitative analysis of Middle and Late Jurassic Foraminifera from Portugal, and its implications for the Grand Banks of Newfoundland Utrecht Micropal. *Bull, 34,* 167.
Wernli, R. (1988). Les protoglobigerines (foraminifers) du Toarcien et de L'Aalenien du Domuz Dag (Taurus Occidental, Turquie). *Eclogae Geologicae Helvetiae, 81*(3), 661–668.
Wernli, R., & Görög, A. (2007). Protoglobigérines et Oberhauserellidae (Foraminifères) du Bajocien-Bathonien du Jura méridional, France. *Revue de micropaléontologie, 50,* 185–205.

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