Swiss J Palaeontol (2017) 136:187–257
DOI 10.1007/s13358-017-0131-z

The planktonic foraminifera of the Jurassic. Part I: material and taxonomy

Felix Gradstein[1,2] · Andrew Gale[2] · Ludmila Kopaevich[3] · Anna Waskowska[4] · Algimantas Grigelis[5] · Larisa Glinskikh[6]

Received: 21 February 2017 / Accepted: 7 April 2017 / Published online: 30 May 2017

Abstract The taxonomy is modernized and updated for Jurassic planktonic foraminifera using all available literature and stratigraphic series of sediment samples from Canada, Portugal, France, Switzerland, Poland, Lithuania, Russia and Dagestan. The regional stratigraphy of all sampled sections is outlined. Many of the 65–200 μm sample residues yielded well-preserved free specimens, with local assemblages containing up to six species. Thin sections were studied also but do not allow detailed taxonomy. Two genera are described: *Globuligerin*a and *Conoglobigerin*a. *Globuligerina* probably appeared in the late Toarcian (late Early Jurassic) and *Conoglobigerina* first occurred in middle Oxfordian (early Late Jurassic). A principal difference between *Globuligerina* and *Conoglobigerina* is that the former has a smooth to pustulose wall surface texture and the latter a reticulate wall surface texture. Within the two genera, ten species are described, including from older to younger: *Globuligerina dagestanica* (Morozova), *G. avariformis* (Kasimova*)*, *G. balakhmatovae* (Morozova), *G. oxfordiana* (Grigelis), *G. bathoniana* (Pazdrowa), *G. jurassica* (Hofman), *G. oxfordiana* (Grigelis) *calloviensis* Kuznetsova emended*, G. tojeiraensis* Gradstein, *Conoglobigerina helvetojurassica* (Haeusler), *C. grigelisi* Gradstein and *C. gulekhensis* (Gorbachik and Poroshina). The coarsely perforate '*Globuligerina' stellapolaris* needs more investigation to establish its identity as a Jurassic or a Late Cenozoic taxon (Gradstein 2017a). *Globuligerina balakhmatovae, G. oxfordiana* and *G. bathoniana* occur from Bajocian through early Kimmeridgian, or even Tithonian. Subtle morphological trends may refine stratigraphic usage. Other taxa have shorter stratigraphic ranges. Nineteen plates and ten type species figures detail morphology of all taxa. For key taxa, both the types and specimens from other localities are illustrated.

Keywords Jurassic · Planktonic foraminifera · *Globuligerina* · *Conoglobigerina* · Europe · Canada · Russia · Dagestan

Introduction

This study attempts to update and synthesize the taxonomy of the Jurassic planktonic foraminifera and aims to be a modest monograph for users.

Evolution, stratigraphy and palaeobiogeography of Jurassic planktonic foraminifera are dealt with in a companion study to this one (Gradstein et al. 2017b).

Rich and diversified assemblages of these taxa from Eastern Canada, Portugal and Dagestan are central to our

---

Editorial handling: Daniel Marty.

This study is dedicated to the memory of Dr. Olga Pazdrowa (†), Poland (Photograph 1), who in 1969 presented the Earth Sciences with a fine description of a new and spectacular find of Jurassic planktonic foraminifera (*Globigerina bathoniana* sp. nov.) in her study entitled 'Bathonian Globigerina from Poland'.

✉ Felix Gradstein
felix.gradstein@gmail.com

[1] Natural History Museum, University of Oslo, 0318 Oslo, Norway

[2] SEES, University of Portsmouth, Portsmouth PO1 3QL, UK

[3] Geological Faculty, Lomonosov Moscow State University, Leninskie Gory, GSP-1, 119991 Moscow, Russian Federation

[4] AGH Akademia Górniczo-Hutnicza, al. Mickiewicza 30, 30-059 Kraków, Poland

[5] Academy of Sciences, Vilnius, Lithuania

[6] Trofimuk Institute, Ac. Koptyug av. 3, Novosibirsk 630090, Russia

Birkhäuser

understanding of morphological variability and biozonation. Type material was collected and examined from Eastern Canada, Portugal, France, Switzerland, Poland, Lithuania, Central Russia and Dagestan. Most samples yielded well-preserved free specimens. Thin sections were studied also but do not allow detailed taxonomy, but greatly assist with palaeobiogeography (Gradstein et al. 2017b).

Planktonic foraminifera are single-celled marine organisms with a calcareous and chambered test. The group first appeared during the late Early Jurassic (Toarcian) and developed over a time span of about 180 Ma. From Toarcian through Hauterivian time, species have a simple trochoid (globigeriniform) test with spherical, elongated or oval chamber shapes, and no keel. Their shells are microperforate, with an almost smooth, or pustulose to reticulate wall surface. The building material is considered to be high-magnesium carbonate (aragonite), (Gorbachik and Kuznetsova 1986; Simmons et al. 1997). Aperture is a simple opening at the base of the last chamber; a kummerform (bulla-like) last chamber with one or rarely two basal openings is often present. Bullae have a smoother wall surface than the overall test, and are in umbilical position, generally covering the primary aperture of the last chamber. Hemleben et al. (1989) report that bulla are grown as a function of gametogenesis.

Macro-perforate and keeled planktonic foraminifera only appeared in mid Cretaceous, and spinose forms in the early Cenozoic. These post-Jurassic taxa use low-magnesium carbonate (calcite) for test building. Reasons for this chemical–physical change in building material are not well understood, but may relate to the fact that seawater changed its Mg/Ca mole ratio during early Cretaceous from higher ratio values (2–4) to lower ratio (1–2) values. The idea is that aragonite and high-Mg calcite become the minerals of choice for many carbonate secreters when Mg/Ca in seawater is high (most or all of Jurassic), and calcite is the carbonate of choice when Mg/Ca of seawater is low (Cretaceous). Both changes in the rate of seafloor spreading/subduction and in land weathering directly influence the Mg/Ca ratio in seawater through time (J. McArthur personal communication to Gradstein in 2016; Stanley et al. 2002).

Photograph 1 Dr. Olga Pazdrowa (†) in her automobile in Poland

Note that calcitic particles generally preserve well, whereas aragonitic tests are easily lost due to dissolution on or below the seafloor, or later during deeper level (meteoric) diagenesis. The aragonitic tests of Jurassic planktonic foraminifera may be a factor in explaining their scattered stratigraphic–geographic record. More discussion on this issue is in the sections on stratigraphy and palaeoecology and palaeobiogeography (Gradstein et al. 2017b).

One living form (*Streptochilus globigerus*) has a benthic sibling—*Bolivina variabilis* (Darling et al. 2009), indicating that planktonic foraminifera may have derived from a benthic ancestor, and are likely polyphyletic (Leckie 2009).

There are about 50 living taxa, spread over all oceans, but not in marginal seas with lower salinity (for example North Sea or Baltic Sea). Some taxa have sunlight-dependent symbionts, whereas others, like keeled *Globorotalia truncatulinoides* (d’Orbigny), may live down to 2 km water depth. Two recent forms are microperforate (like the Jurassic ones), the subpolar to cold temperate *Globigerinita bradyi* Wiesner and the subpolar to tropical *G. glutinata* (Egger). These microperforate taxa are considered to have been derived from benthonic foraminifera in mid-Cenozoic time (Darling et al. 2009). To demonstrate morphological convergence, *G. bradyi* is illustrated on one of our plates together with Jurassic *Globuligerina bathoniana* (Pazdrowa; after Stam 1986). A strong morphological resemblance also exists between some Jurassic planktonic foraminifera and pioneering *Parvularugoglobigerina* taxa from Early Danian (Olsson et al. 1999), after the end-Cretaceous plankton extinctions. Whereas parvularugoglobigerinids are short lived, Jurassic ‘homeomorphs’ are mostly long ranging.

Planktonic foraminifera are a minor part of modern zooplankton, but a major producer of calcareous ooze on the seafloor together with calcareous nannofossils. This is a type of deposit that first appeared already in Middle Jurassic time on local highs above the seafloor (Colom 1955; Görög and Wernli 2003; Hudson et al. 2009).

Jurassic planktonic foraminifera have been studied since the second half of the nineteenth century with many scientific publications mainly by East and West European and Canadian micropalaeontologists. The annotated historical overview (Gradstein 2017c) records 29 publications in the period from 1881 to 1981, 26 studies from 1981 to 2001 and 16 from 2001 to 2015. Despite this effort, the knowledge on the origin, test morphology, geographic and stratigraphic distribution and speciation of taxa in the first

40 million years of their record is fragmentary, incomplete and taxonomic criteria applied are not consistent and conflicting.

The reasons for this unsatisfactory state of the art are several. As Görög and Wernli (2003) have expressed well: 'The tests of the Jurassic 'protoglobigerinids' have a rather simple morphology, with few discriminating characters. The intra-and inter-specific variability is great.' In theory, the latter feature should limit taxonomic splitting, but such unfortunately is not the case. As Dawkins (2008, p. 204) elegantly wrote: 'Minor variations are the stuff of evolution (not merely a set of accidental excursions around a created ideal type), but we recognize this only when we are prepared to sum small effects through long periods of time'. Or to phrase it in practical terms for Jurassic planktonic foraminifera: Taxonomy should clarify evolutionary and stratigraphic trends and not create new 'species' with few specimens from single localities without insight in correlative value of the taxon. Local ecophenotypic variation should not drive species taxonomy.

However, if all Jurassic planktonic foraminifera originally had an aragonitic test, non-fossilization may partly explain the fragmented distribution pattern dealt with in Gradstein et al. (2017b). As a result, it is difficult to obtain suitable material for study and taxonomic revision.

A third cumbersome situation relates to the fact that stratigraphic level has crept in taxonomic species differentiation, leading to circular reasoning. Prominent examples are: *Globuligerina bathoniana, G. oxfordiana and G. calloviensis*. Age is not and never should become a taxonomic character.

A fourth reason is that wall structure is becoming more and more important for generic taxonomy of planktonic foraminifera, which demands study with higher resolution using the scanning electron microscope. Many studies in the literature provide insufficient documentation of the wall texture. Acid treatment of samples tends to destroy test wall features, which severely limits taxonomic detail. Gradstein (2017c) lists ten or more, often original studies that used acid treatment for processing samples. Some other studies in this list analysed glauconitic or pyritic steinkerns, making taxonomy useless.

As a result of the above issues, the literature lacks insight in and agreement on morphologic variability in what might be palaeoecological and stratigraphically meaningful taxa.

Morphological features of Cenozoic and Cretaceous planktonic foraminiferal taxa that are within their ontogenetic variation in some Jurassic planktonic foraminifera were previously ranked at subspecies, species or even genus level. Such features include test size, aberrant coiling mode, shape of the aperture and slight shifts in the position of the aperture. Also, earlier studies did not effectively use wall surface patterns for taxonomy, as now applied in Cretaceous and Cenozoic planktonic foraminiferal systematics. Taxonomic splitting, instead of population-type taxonomy, makes it difficult to reproduce the stratigraphic ranges even in the same region, and hampers the understanding of the palaeoecology, palaeobiogeography and phylogeny of taxa.

Our taxonomic approach follows that employed for Cretaceous planktonic foraminifera (CPF; Petrizzo et al. in prep). Emphasis is placed on the overall test morphology, including type of coiling (trochospiral, planispiral, etc.), chamber shape, wall textures perforations (size of the pores) and wall surface ornamentation (pustules, pseudomuricae, ridges and networks of ridges). The shape of the aperture and its position on the last chamber are not considered a feature valid at generic level.

The latter was already observed by Pazdrowa (1969) and by Stam (1986), an observation that Banner and Desai (1988) and Simmons et al. (1997) did not heed in their genus taxonomic differentiation. Differences in shape and position of the aperture may be attributed to intraspecific variation. A typical aperture of *G. bathoniana* (Pazdrowa) is high, semi-circular, umbilical–extraumbilical, bordered with a narrow lip. But, individuals with a high and narrow, often looped aperture, or a low and broad aperture fall within the natural variation of this common and widespread taxon. Similar apertural variation is observed in assemblages of *Globuligerina dagestanica* and *G. oxfordiana* (see below under "Taxonomy").

In this study, we ignore *Globigerina gaurdakensis* Balakhmatova and Morozova (1961), *Globigerina spuriensis* Bars and Ohm 1968 and *Globuligerina geczyi* Görög 1994, as being benthonics or non-Jurassic taxa (see Stam 1986 and plate 2.10 in Simmons et al. 1997). We 'reject' all pre-Cretaceous taxa described as glauconitic casts (like *Globigerina conica*, *G. terquemi* and others without wall structure and often without clear aperture features), or pseudo-planktonic morphotypes from the Triassic and Jurassic of Austria (Fuchs 1975) and Crimea (Korchagin et al. 2002). Good documentation on problems with glauconitic cast typology or pseudo-planktonics is in Stam (1986, Chapter 5) and Simmons et al. (1997).

No attempt has been made either to reconcile taxonomy of Jurassic planktonic foraminifera in thin sections with the taxonomy using free specimens. The outstanding thin-section studies by Wernli (1987, 1988), Görög and Wernli (2003) and others are important for geographic distribution, palaeoceanography–palaeoecology and evolution of Jurassic planktonic foraminifera, but are difficult to reconcile taxonomically with studies using free specimens. If wall surface patterns can be preserved during acetolysis, such studies might help to extract free specimens on which taxonomy might be attempted (see for example the outstanding study with the classical CPF from Gubbio, Italy (Coccioni and Premoli Silva 2015).

In Gradstein et al. (2017b), we discuss what is currently surmised on the evolution of Jurassic planktonic foraminifera and its potential consequence for generic taxonomy. Gradstein (2017c) provides an annotated historic overview for this poorly understood group of microfossils, going back to 1881 when Haeusler described *Globigerina helvetojurassica* from the Birmenstorfer Schichten of Middle Oxfordian age in Canton Aargau, Switzerland.

Study

Felix Gradstein (FG) and Andrew Gale initiated the current research on the Jurassic planktonic foraminifera and FG wrote most of the text. Ludmila Kopaevich and Larisa Glinskikh kindly provided contacts, stratigraphic and micropalaeontologic information and important type material from Dagestan and Crimea. This greatly expanded the scope of our research. Algimantas Grigelis was contacted by us to update the documentation on taxa originally described from Lithuania and NW Russia; this has resulted in one new plate, a site location map of types, and direct study by us of existing type material in Lithuania and NW Russia. Anna Waskowska provided vital assistance with taxonomic differentiation, micropalaeontology–stratigraphy of Poland, new plates with superbly preserved Polish specimens, sample processing and specimen picking, and technical assistance leading to manuscript publication.

Materials

The large body of the published literature, annotated in Gradstein (2017c), is the library for our analysis. A key reference towards our taxonomy is Simmons et al. (1997) which focused on type descriptions and types deposited in musea. In order to create a good understanding of morphological variation of taxa in populations of Jurassic planktonic foraminifera, their palaeoecology, and their stratigraphic ranges a large number of topotype and other samples were analysed. The samples are from the Grand Banks of Newfoundland, Montejunto area, central Portugal, Galicia Bank off Portugal, NW France, Canton Aargau in Switzerland, Poland, Lithuania, Timano-Pechora (River Pizhma) and Rjasan (Shatrishche, River Oka) in Russia, and from the Khouroukra section, Dagestan.

Table 1 lists localities from which material has been analysed, either from the published literature or from our samples. Figure 1 shows the approximate stratigraphic distribution of samples, organized by localities. Among these, two localities (Grand Banks and Portugal) are particularly rich in specimens and in taxa. An X indicates that the locality contains type specimens.

Already Gorbachik and Kuznetsova (1983) pointed out that Jurassic planktonic foraminifera are rarely wholly distributed through an outcrop section, but are associated with individual beds. The authors observe that this fact is rarely stated in available publications and hampers Jurassic planktonic foraminiferal zones. This is one reason why we have made an effort to provide a detailed description of the record in the localities sampled.

Sample processing method

Outcrop and borehole samples analysed from Portugal and the Grand Banks have been conventionally processed according to the method described in Thomas and Murney (1985), and picked for the 65 μm and larger shelly microfossil fraction in an unbiased manner from split aliquots.

The Birmenstorfer samples were treated with peroxide water (H_2O_2) to obtain washed residues. Rock samples were broken into small fragments, placed in a beaker and covered with a solution of H_2O_2 (10%) and water (90%) until the maximum degree of disaggregation of the rock sample was reached. The samples were then washed under running water, sieved to obtain three size fractions (>38, >125 and >250 μm) and dried using a hot plate. This standard processing which was performed in the micropalaeontology laboratory of Dr. Maria Rose Petrizzo in Milano, Italy yielded almost a hundred well-preserved specimens of Jurassic planktonic foraminifera.

The Polish and Russian samples were washed with a conventional detergent and also 40 μm sieve.

Few harder limestone samples were studied, since acetolysis potentially modifies wall surface patterns. Also, in our study we do not describe specimens from casts and moulds. A few thin sections have been examined, mainly for Palaeoceanography, but also for selected information on local taxonomy.

Grand Banks of Newfoundland

Since 1965, and continuing today, hydrocarbon exploration wells are being drilled on the Grand Banks of Newfoundland. Between 1970 and about 1990, the Geological Survey of Canada had an active biostratigraphic research program on these wells in which the senior author of our study took part. Foraminifera, dinoflagellates, spore–pollen, ostracods, and occasionally also nannofossils, were routinely analysed at the Bedford Institute of Oceanography, Dartmouth, N.S., Canada. The purpose was to construct a stratigraphic and palaeo-environmental framework, and assist drilling and petroleum source- and reservoir rock analysis.

Table 1 Geographic distribution of Jurassic planktonic foraminifera studied from the literature, or in sample material

	E Canada, Grand Banks	NW Atlantic, DSDP SITE 534	Portugal, Galicia Bank	UK, Dorset	France	Switzerland, Italy	Hungary, Bulgaria	Poland, Germany	Baltic, S Sweden	W Russia	Crimea, Caucasus	Dagestan, Turkmenistan, Azerbijian	Turkey	NE Africa, Middle East	NW Australia, Exmouth Plateau
C.gulekhensis	?										X	X			
C.grigelisi	X		X		X										
G.tojeiraensis	X		X			X									
C.helvetojurassica			X		X	X									
G.oxfordiana calloviensis											X			X	
G.oxfordiana	X	X	X	X	X	X	X	X	X	X	X	X	?	X	X
G.bathoniana	X		X			X	X	X			X		?	X	X
G.dagestanica							X					X			
G.balakhmatovae	X		X		X			X				X			
G.avariformis			?			?						X	?		
G.jurassica	?		?			?					X				

The latter is documented in Fig. 1

The following summary of findings with respect to Jurassic planktonic foraminifera is based on the descriptions and figures by Gradstein (1975, 1976), Jansa et al. (1976) and Stam (1986). Figures 2 and 3 show the location map and a correlation chart of key exploration wells containing Jurassic planktonic foraminifera.

These wells are: Eider M-75, Murre G-67, Cormorant N-83, Bittern M-62 and Heron H-73. The Heron H 73 and Egret K-36 wells, with shallow marine Jurassic sediments, did not yield Jurassic planktonic foraminifera. Standard well sample abbreviations are: swc is side wall core sample; cts is ditch cuttings sample; core is the core sample.

Eider M-75 well

In the Eider M-75 well, Middle and Upper Jurassic sediments are present in the interval between ca. 2700 and 11,000 feet (Figs. 2, 3). Gradstein (1975, 1976) and Barss et al. (1979) described the local biostratigraphy and depositional environment. From 5960 to 8612 feet, the sediments consist of grey and dark grey shales, assigned to the Verrill Canyon Formation (Jansa and Wade 1975). These authors interpreted the palaeo waterdepth from deep neritic to upper bathyal, which is in agreement with our micropalaeontology interpretation. Lower down in the well, the shales are intercalated with limestones, and may represent a slightly shallower facies containing fewer Jurassic planktonic foraminifera.

Side wall cores and cuttings samples between 10,600 and 6230 feet in the *Garantella,'Globigerina' bathoniana* and *Epistomina regularis* Zones (Bajocian through Callovian, in agreement with palynostratigraphy of Barss et al. 1979) contain common to abundant specimens of Jurassic planktonic foraminifera. Specimens are light brownish in colour and well preserved. Taxa mainly include *Globuligerina bathoniana, G. oxfordiana* and *G. balakhmatovae*.

Stratigraphically upwards, from 7340 to approximately 5560 feet (Bathonian through Callovian), samples contain fewer foraminifera. Epistominids are still present, but Jurassic planktonic foraminifera are virtually absent,

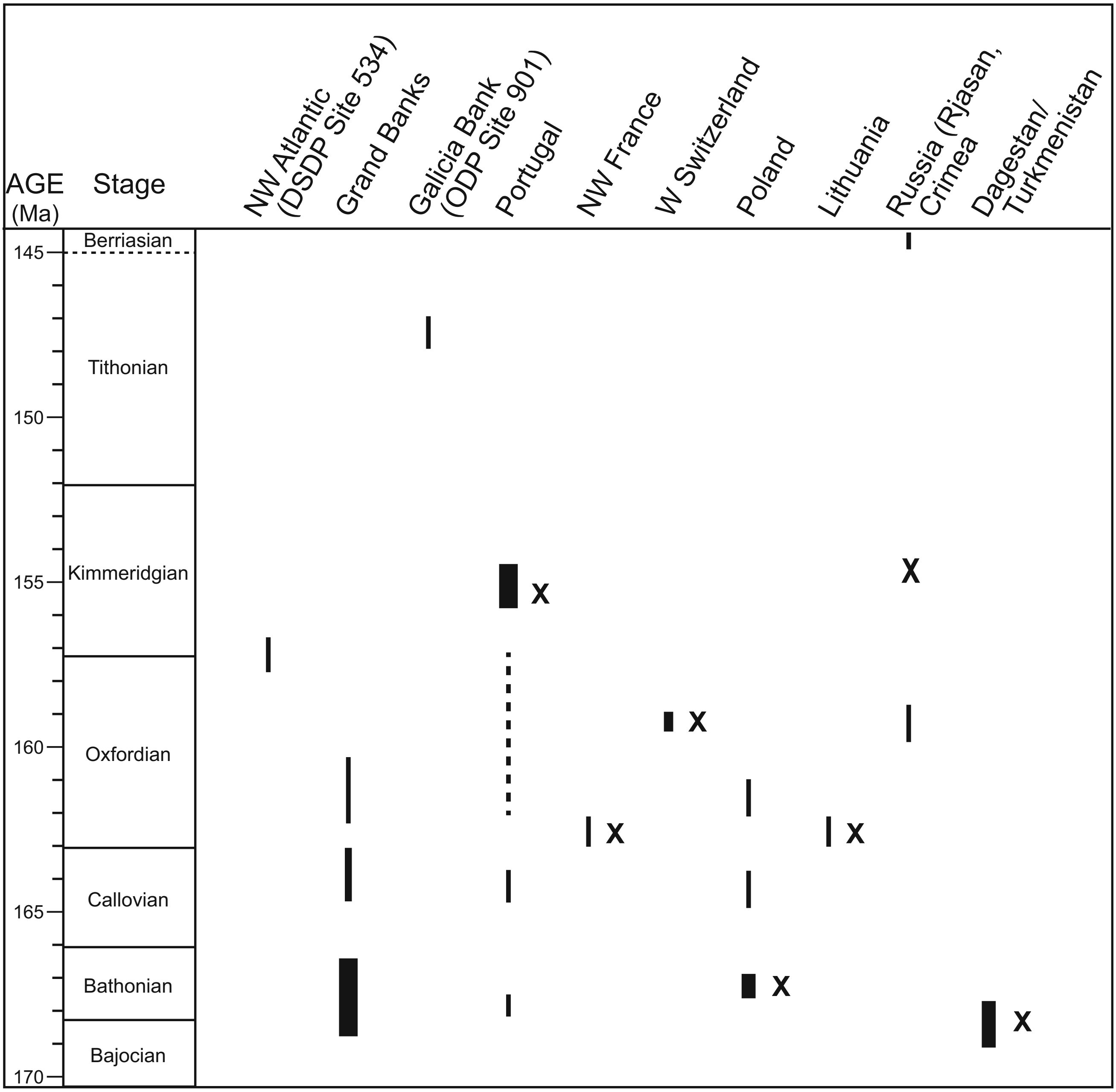


Fig. 1 Stratigraphic distribution of Jurassic planktonic foraminifera in the localities studied. A *thicker bar* means many specimens, and an *x* refers to species type locality

suggesting a shallower palaeo waterdepth. Shallowing continues in Early Oxfordian, above the highest occurrence of *Epistomina regularis* at 5560′, as indicated by the occurrence of *Chara* sporangia. Later in the Oxfordian and continuing during Kimmeridgian a palaeo waterdepth deepening is registered, as indicated by the presence of *Epistomina mosquensis, E. uhligi,* together with *Eogutulina meetensis, Lenticulina quenstedti, L. tricarinella* and *Ammobaculites coprolithiformis.* No Jurassic planktonic foraminifera were found. No Tithonian strata were encountered in the well.

Murre G-67 and Cormorant N-83 wells

Middle and Upper Jurassic sediments occur in the Murre G-67 well, in the interval between ca. 7000 and 3000 feet (Figs. 2, 3). The fossiliferous and deep neritic (to upper bathyal?) Verrill Canyon Formation was recognized between 5960 and 3740 feet. Bajocian through Callovian strata (from 6770 to 44,419 feet) contain a relatively rich and diversified microfossil assemblage with *Garantella, Pseudolamarckina* and *Epistomina*, together with planktonic foraminifera. The latter occur from 5800 to 4419 feet (Bathonian–Callovian, in agreement

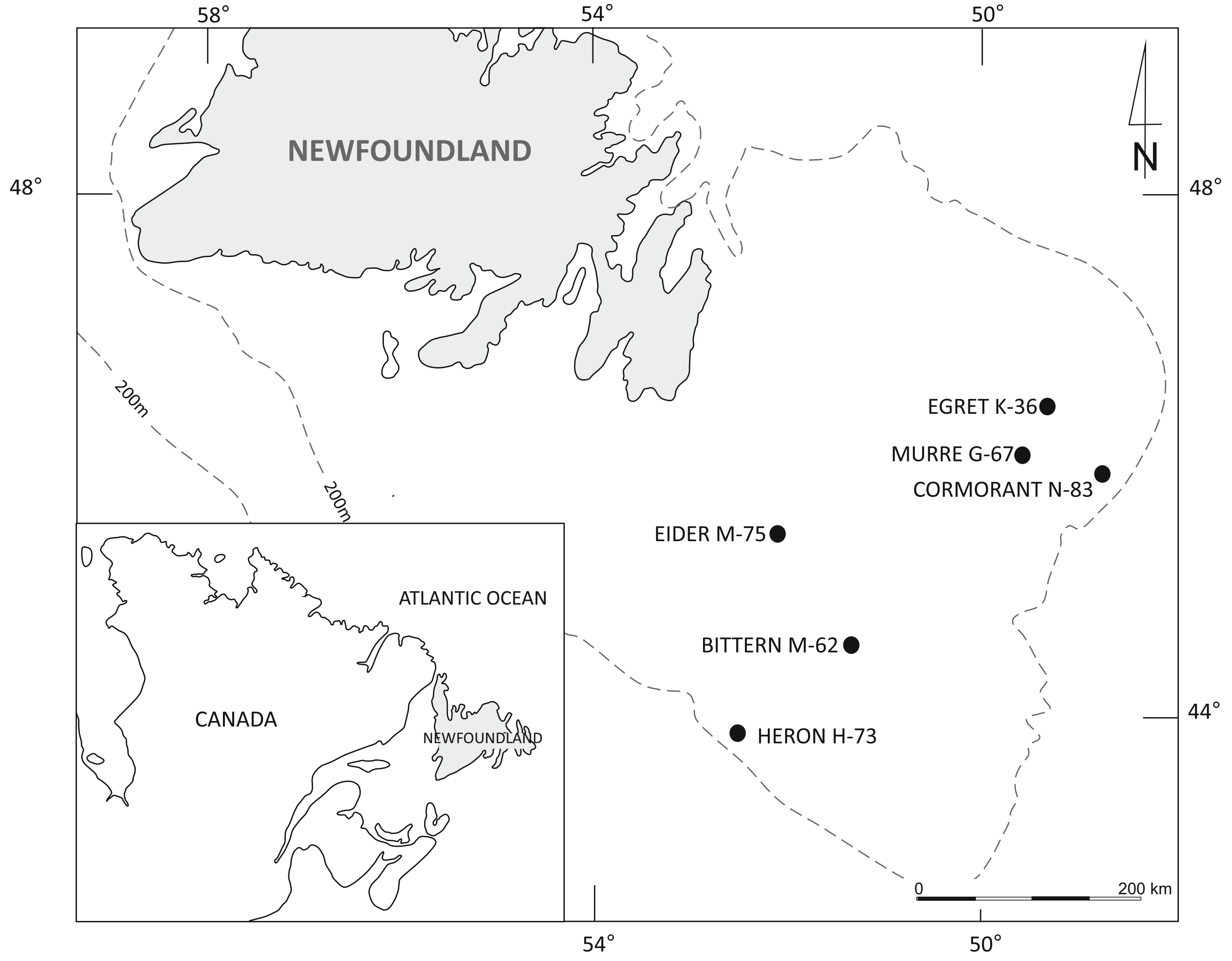


Fig. 2 Location of exploration wells on the Grand Banks of Newfoundland studied for Jurassic planktonic foraminifera (after Gradstein 1976 and Stam 1986). For details, see *text*

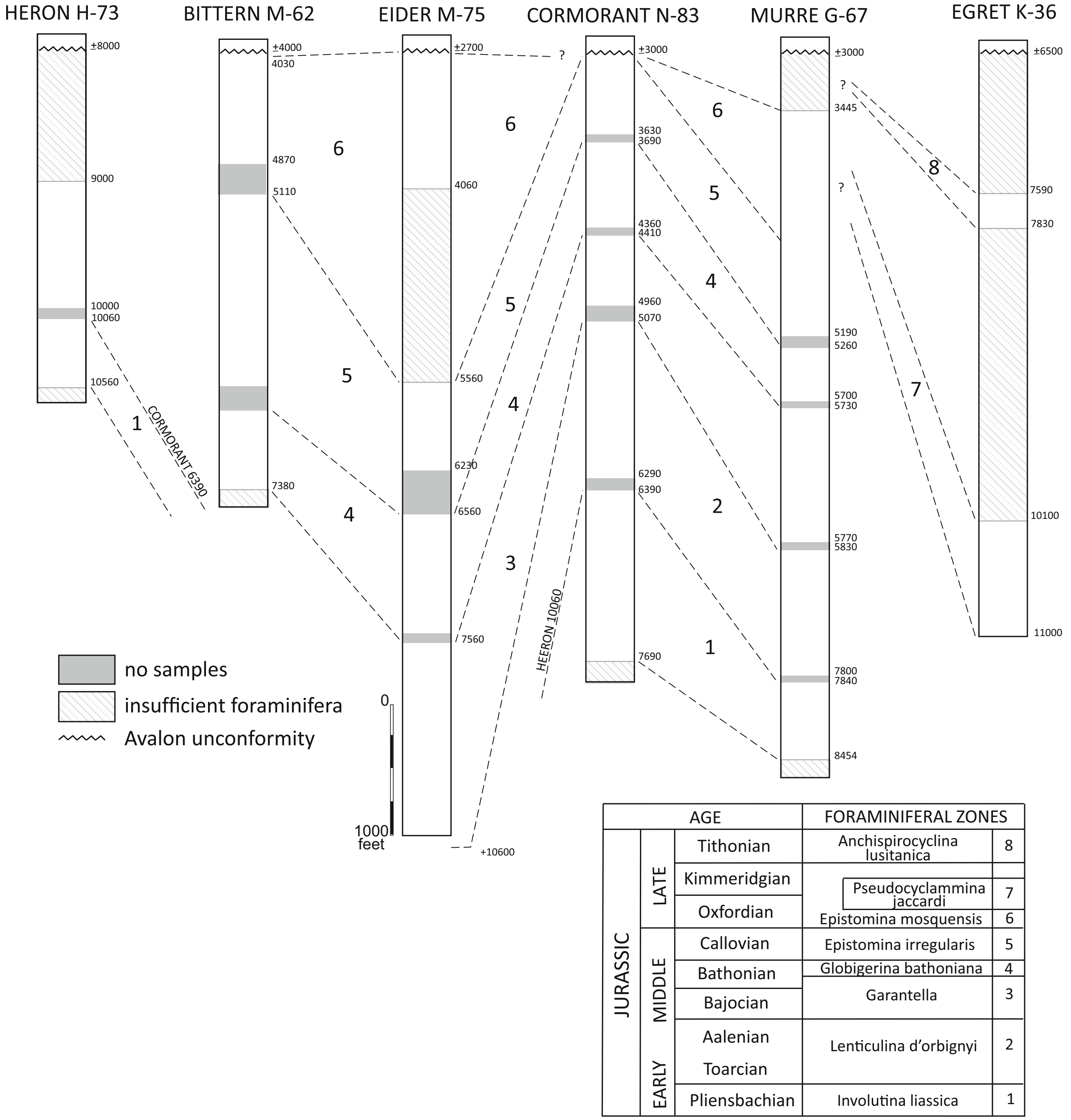
with palynostratigraphy in Barss et al. 1979) and contain *Globuligerina bathoniana* and *G. balakhmatovae*. The stratigraphic interval assigned to the Callovian yields specimens of *G. oxfordiana*. From about 4400–3400 feet, assigned to the *E. mosquensis* Zone, Oxfordian-Kimmeridgian, a decrease in species diversity and species abundance is observed, with only few specimens of *Epistomina mosquensis, E. uhligi* and *E. stellicostata*, *Lenticulina quenstedti* and *Patellina feifeli*, but no Jurassic planktonic foraminifera.

The Middle and Upper Jurassic of the Cormorant N-83 wells, between ca. 2700 and 5100 feet, micropalaeontologically and biostratigraphically are closely similar to that of the Murre G-67 well.

Bittern M-62 well

The Middle to Upper Jurassic sedimentary section in the Bittern M-62 well is present from ca. 3850 to 9000 feet (Figs. 2, 3). Sidewall cores from the upper part of this interval contain a relatively rich and diversified microfossil assemblage. Epistominids are abundant, with *E. mosquensis* and *E. uhligi* occurring throughout, whereas *E. regularis* is present in the lower part. Accompanying taxa include *Lenticulina muensteri, L. quenstedti*, agglutinants such as *Verneuilina minuta* and *Dorothia hechti*, *Ophtalmidium carinatum* and *Spirillina tenuissima*. Jurassic planktonic foraminifera are locally present in large numbers, like in the sidewall core at 5000 feet.

Globuligerina bathoniana (medium height) and *G. oxfordiana* commonly occur in swc at 5000 feet and swc at 5350 feet (*Epistomina regularis* Zone, Callovian; but assigned to the *C. costatum* subzone, Early Oxfordian according to the palynostratigraphy of Barss et al. 1979). At the same levels also occur rarely *G.balakhmatovae,* rarely *G.jurassica* (with an irregular trochospire), *G.tojeiraensis* and a small and compact *Conoglobigerina*



AGE			FORAMINIFERAL ZONES	
JURASSIC	LATE	Tithonian	Anchispirocyclina lusitanica	8
		Kimmeridgian	Pseudocyclammina jaccardi	7
		Oxfordian	Epistomina mosquensis	6
	MIDDLE	Callovian	Epistomina irregularis	5
		Bathonian	Globigerina bathoniana	4
		Bajocian	Garantella	3
		Aalenian	Lenticulina d'orbignyi	2
	EARLY	Toarcian		
		Pliensbachian	Involutina liassica	1

Fig. 3 Correlation of Jurassic strata in six Grand Banks wells, based on foraminifera. Zones *3*, *4* and *6* are locally rich in Jurassic planktonic foraminifera (after Gradstein 1976 and Stam 1986)

grigelisi. Deeper in the well (below 6000 feet) in the *G. bathoniana* Zone (Late Bathonian) occur rather flat *G. balakhmatovae* and high-spired *G. bathoniana*. A shallower palaeo waterdepth is inferred for the Upper Oxfordian–Kimmeridgian strata, based on abundant *S. tenuissima* and absence of Jurassic planktonic foraminifera. No Tithonian sediments occur in the well.

Portugal

Between 1978 and 1988, Gradstein with colleagues and students undertook stratigraphic surveys and sampling in road outcrops, mountain sections and beach cliffs with Jurassic marine strata in Central and South Portugal. The research was undertaken to complement the stratigraphy of the Grand Banks of Newfoundland. The Grand Banks and Portuguese basins were conjugate, prior to mid-Cretaceous oceanization of this segment of the North Atlantic.

R. Mouterde and C. Ruget Perrot (University of Lyon, France), M. M. Ramalho (Geological Survey, Lisbon), R. B. da Rocha (New University of Lisbon), C. Wilson (Open University, UK), T. P. Poulton (GSC, Calgary, Canada), and others generously provided ammonite stratigraphy guidance in the field, or assisted with analysis of ammonites collected.

The summary below focusses on those outcrops where Jurassic planktonic foraminifera were obtained from our samples (Stam 1986; Agterberg et al. 1989). Our new analysis updates the original observations on Jurassic planktonic foraminifera made in those studies.

Brenha Road section

The Brenha section is located along the road from Figueira da Foz to Aveiro, close to the village of Brenha (fig. 4 in Stam 1986; just inland of Cape Mondego on insert map of our Fig. 4), and consists of an almost complete, ca. 700 m thick, sequence of Sinemurian through Oxfordian sediments. Tectonically, the section is a monocline. Stam (1986) provides a schematic litho- and chronostratigraphic framework. The marginal to shallow marine 'Couches de Coimbra' limestones of Sinemurian age (Schott and Staesche 1957), in Pliensbachian through early Bajocian time, change to a regular alternation of shale and (shaly) limestone. Middle and Upper Bajocian strata consist mainly of massive micritic limestones, whereas the Bathonian again shows a regular alternation of shales and well-bedded limestones. The Callovian strata are dominated by thick-bedded micritic-skeletal ammonite/brachiopod limestone with minor shale intercalations. The Middle Jurassic macrofauna includes belemnites, ammonites, brachiopods, some bivalves and crinoid stems. Ichnofossils are common with *Chondrites, Zoophycos and Planolites.* Degree of bioturbation differs from bed to bed; macrofauna is not abraded, likely indicative of in situ preservation.

The Middle Jurassic limestone-marl sequence is indicative of a below wave base, open marine and normal salinity setting, with aerobic bottom conditions. Some limestone mass-flow units occurred also (Wilson and Gradstein 1994).

Middle to Upper Oxfordian consists of oolithic limestones and sandy shales, indicative of shoaling in Late Jurassic time.

Sample 30–24 of Stam (1986) in Lower Bathonian well-bedded limestones yielded some Jurassic planktonic foraminifera specimens of medium height *Globuligerina bathoniana*. Future thin-section study of long series of closely spaced Brenha samples may assist to 'pin down' more levels with Jurassic planktonic foraminifera.

Microfauna associated with the Jurassic planktonic foraminifera mainly include *Spirillina* spp., *Lenticulin*a spp., *Nodosaria/Dentalina* spp., *Eoguttulina* spp., miliolids (*Ophtalmidium* spp.), and agglutinated taxa *Reophax, Trochammina* and *Verneuilinoides (*for details see Stam 1986, p. 22). No epistominids were observed, which may be due to the neritic, platform setting of the basin, and explain why Jurassic planktonic foraminifera are largely absent and occur in isolated samples only.

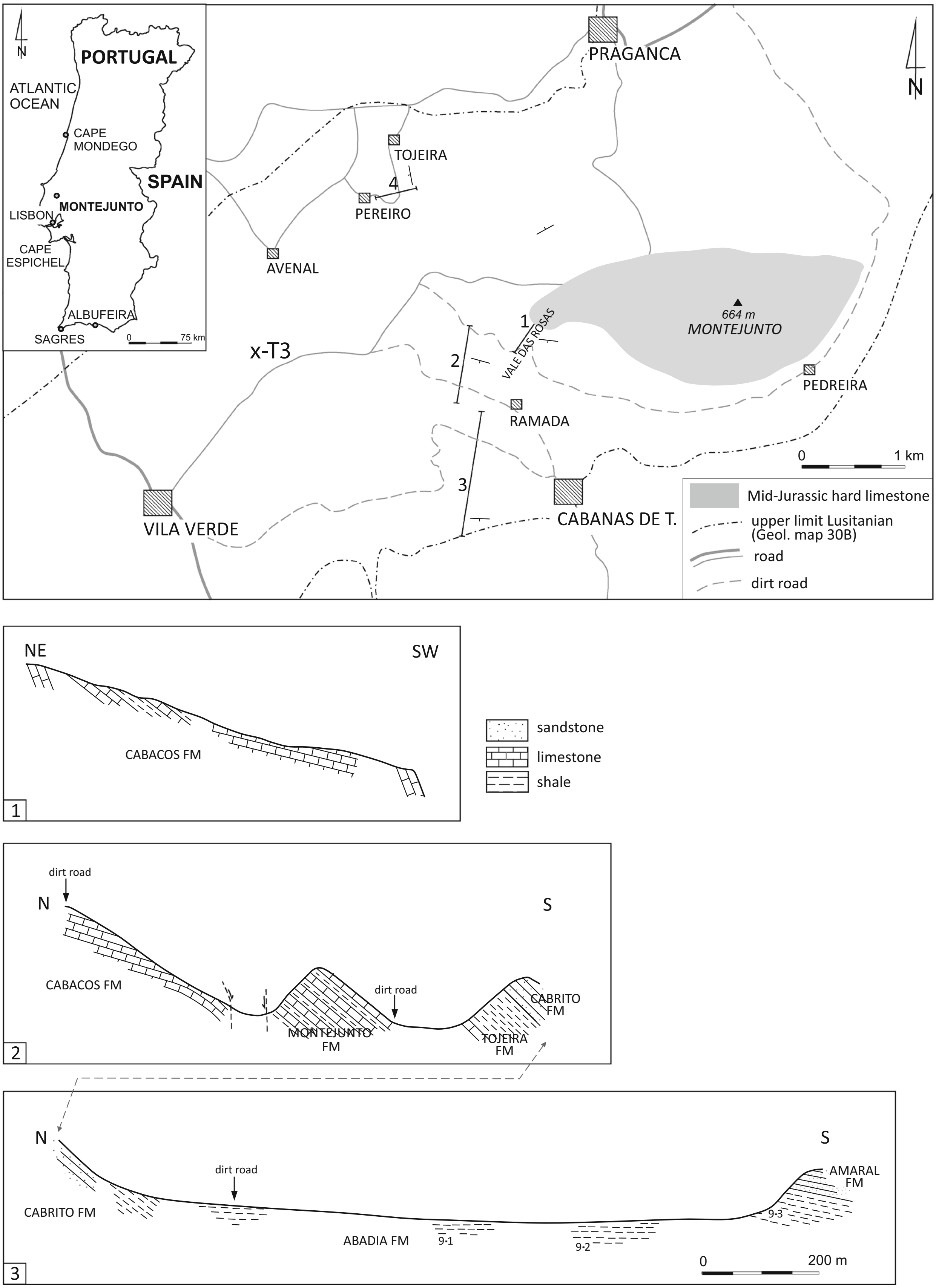
Note that the GSSP (Global Stratigraphic Section and Point) for the base of the Bajocian Stage is at the nearby Murtinheira Beach, along the coast of Cabo Mondego (see Ogg and Hinnov 2012, p. 741). The GSSP level coincides with the lowest occurrence of the ammonite *Hyperlioceras*. The few samples taken by Stam (1986) from this interval mainly in hard and laminated shaly limestone failed to obtain Jurassic planktonic foraminifera. Our re-sampling in 2016 of this beach outcrop also came up empty handed. Facies is likely neritic, with periodic watermass restriction to account for lamination.

Mareta Beach section

For the Mareta Beach section in Sagres, southern Portugal, the detailed study by Bordalo da Rocha (1976) is an excellent starting point to undertake a micropalaeontological investigation. Middle Jurassic foraminiferal palaeoecology and Jurassic planktonic foraminifera were investigated by Stam (1986).

The Mareta Beach section (figs. 32, 33 and 34 in Stam 1986; near Sagres on insert map of our Fig. 4) shows thick, well-bedded, calcareous shale with locally thin sand layers with ripple marks, load and flute casts, marls and upwards more limestones. The shales and marls have common *Bositria.* The lowermost section includes a coral bioherm, and the upper section has a spectacular syn-sedimentary slide, described in detail by Gibling and Stuart (1988). Bordalo da Rocha (1976) assigns a Callovian age to the whole lithological unit, using ammonite zonation.

In his sample 31 of Mareta Beach (*Coronatum* Zone, Middle Callovian), Stam recognized *Globuligerina bathoniana* (figs. 1–7 on plate 7 of Stam 1986). The unusual smooth tests are also discussed in the section on Taxonomy under the heading *G. oxfordiana calloviensis*. The neritic setting of the Callovian strata, with few epistominids, does not seem to lend itself to find common Jurassic planktonic foraminifera. A thin-section study might help to locate potential levels.


N
PORTUGAL
ATLANTIC OCEAN
CAPE MONDEGO
SPAIN
MONTEJUNTO
LISBON
CAPE ESPICHEL
ALBUFEIRA
SAGRES
0 75 km
PRAGANCA
N
TOJEIRA
4
PEREIRO
AVENAL
1
VALE DAS ROSAS
664 m
MONTEJUNTO
2
x-T3
PEDREIRA
RAMADA
0 1 km
3
VILA VERDE
CABANAS DE T.
Mid-Jurassic hard limestone
upper limit Lusitanian (Geol. map 30B)
road
dirt road
NE
SW
CABACOS FM
1
sandstone
limestone
shale
dirt road
N
S
CABACOS FM
dirt road
CABRITO FM
MONTEJUNTO FM
TOJEIRA FM
2
N
S
dirt road
AMARAL FM
CABRITO FM
9-3
ABADIA FM
9-1
9-2
0 200 m
3

◀**Fig. 4** Location map of the Montejunto area, with transects *1–4* and outcrop x-T3. The Tojeira Formation was the main target of study. Transect numbers are as used in Stam (1986) and Agterberg et al. (1989). The Tojeira Formation in transects 2 and 4 and locality x-T3 were (re-) sampled for this study in 2016

Montejunto sections

Rogerio Bordalo da Rocha (Lisbon) kindly guided Gradstein and his students in the late seventies of last century in the Montejunto (Estramadura) area of Portugal. Here, the Tojeira (shale) Formation, with common small ammonites of the *Planula–Platynota* Zones (Early Kimmeridgian), is rich in Jurassic planktonic foraminifera (Stam 1986; Agterberg et al. 1989). The Tojeira shales were sampled at several occasions in parallel outcrop sections, consistently demonstrating lateral continuity of local Jurassic planktonic foraminiferal acmes (see below).

An almost complete, but folded and faulted, sequence of Bathonian through Kimmeridgian marine sediments is exposed in the Montejunto area, ca. 50 km north of Lisbon. The strata are well visible on top, and on the flanks of Montejunto, a 664 m high mountain, ca. 7 km NE of Vila Verde (Fig. 4). Tectonically, Montejunto is a diapiric structure. Our stratigraphic account follows Stam (1986), Wilson and Gradstein (1994) and Wilson et al. (1990).

From Bathonian through Oxfordian time, a carbonate platform facies existed, locally lagoonal. A Kimmeridgian rifting event, which preceded the influx of over 1 km thick marine siliciclastics of the Abadia Formation, caused breaking-up of the carbonate platform. Reworking of limestones occurred in the deeper part of the basins. A palaeogeographic transect sketch (Fig. 5) shows the postulated tectonic-sedimentary setting, with the Tojeira unit being a local basin floor deposit.

The exposed sequence (Fig. 6) from older to younger starts with 50–100 m thick-bedded, micritic, sometimes oolithic/pisolithic limestones with rare crinoids and oysters. The presence of the larger foraminifera *Meyendorffina bathonica* is considered indicative of a Late Bathonian age. The overlying 100 m of sediments is composed of oolitic, algal and bioclast limestones with intercalated shale layers. Ammonites occur that are indicative of the *Macrocephalus* through *Athleta* Zones, Middle Callovian. Middle to Upper Oxfordian strata disconformably overly the Middle Callovian beds, with *Lamberti* and *Mariae* zones missing. Upper Jurassic strata include, from older to younger, the Cabacos, Montejunto, Tojeira, Cabrito, Abadia and Amaral Formations, with a total thickness of over 1500 m.

Above the Upper Callovian through Lower Oxfordian disconformity, the Cabacos Formation (*Cordatum–*

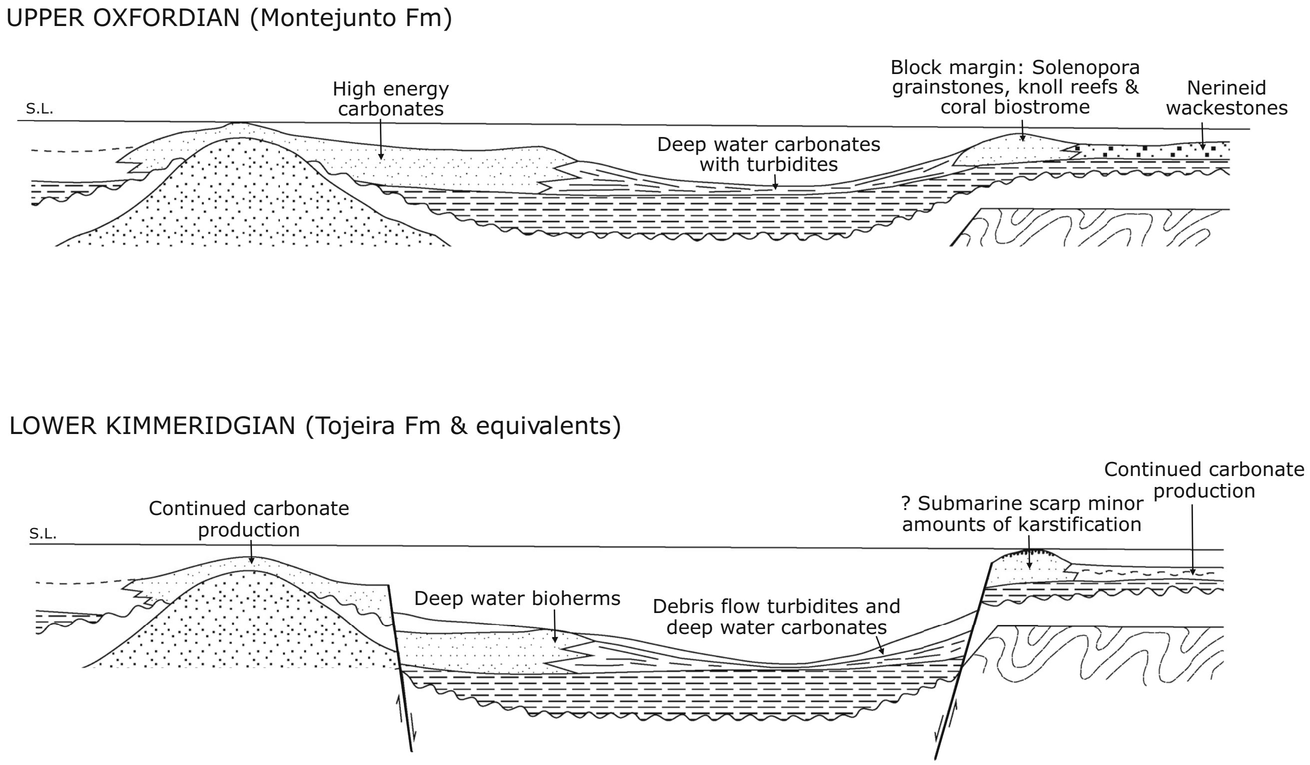


Fig. 5 Sketch section (not to scale) showing the tectonic settings of the Oxfordian carbonate build-ups and the onset of Kimmeridgian rifting. The sections are drawn from the southern end of the Caldas da Rainha diapir to the southeast end of the Montejunto anticline (after Wilson and Gradstein 1994)

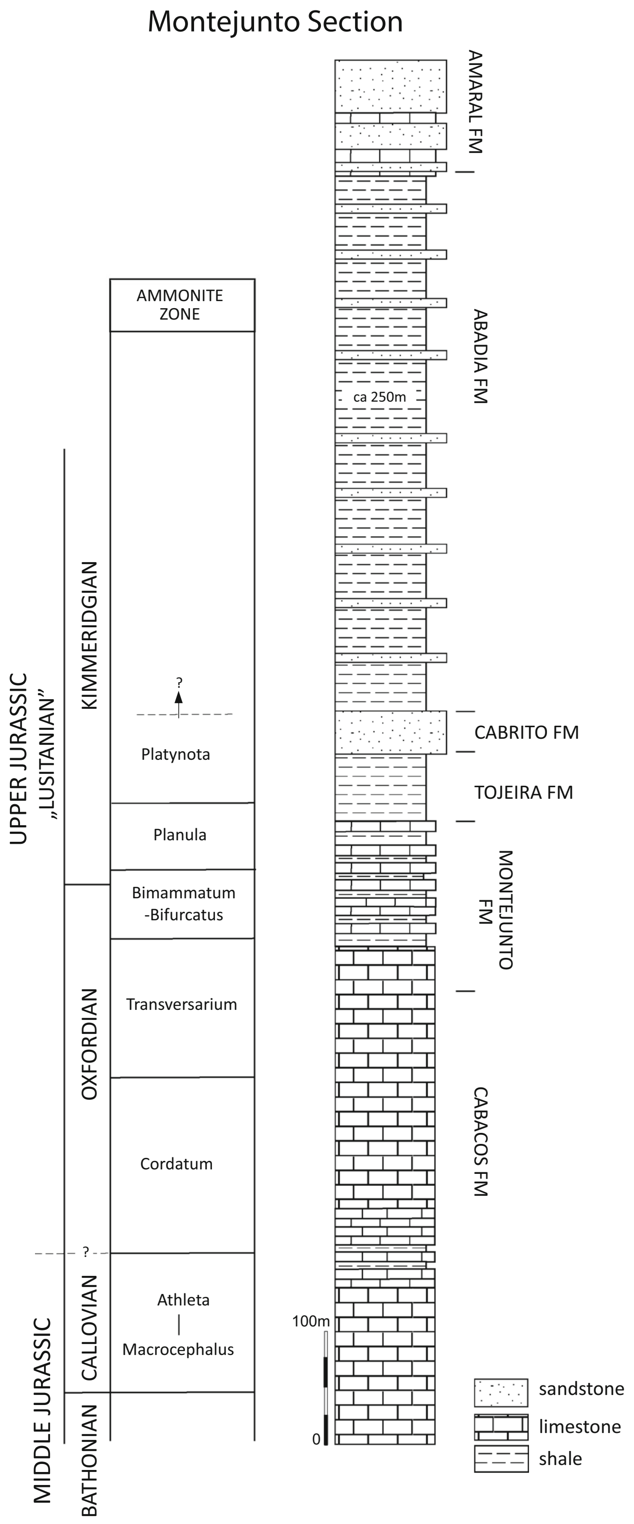


Fig. 6 Middle and Upper Jurassic stratigraphy of the Montejunto section, exposed along the flanks of the diapirically uplifted Middle Jurassic limestone massiv, about 50 km north of Lisbon, Portugal. The Tojeira Formation was the main target of study

Transversarium Zones) contains about 250 m of platy, thin-bedded grey limestones and shaly limestones, all very bituminous, micritic and locally oolithic; lumachelles and ammonites also occur.

The Montejunto Formation (*Transversarium–Planula* Zones) contains thick-bedded, white to grey micritic limestone, changing to alternating bluish-grey limestone and grey, hard shale, with thicker shales near the top. Several meters wide crinoid-brachiopod biostromes occur in the middle part of the unit. The Montejunto Formation is over 200 m thick; ammonites are common to frequent.

The Tojeira Formation (*Planula–Platynota* Zones), target of our micropalaeontologic study, is over 70 m thick and consists almost entirely of dark grey shales with limonitic concretions; it is brownish red in the middle part. Pyritized ammonites are common in the lower part of the unit, and silt content increases much near the top; belemnites are rare. TOC is less than 0.7% in all samples measured (personal communication 1985 of Snowdon, GSC, Calgary to Stam).

The overlying Cabrito, Abadia and Amaral units together are over 1 km thick with marine sands, silts, and conglomerates. Olistolithic limestone blocks and reworked coralline bodies occur, sand channel deposits with abundant ripple marks, and low-angle cross-bedding. Macrofossils have been found, but no foraminifera. Individual beds rapidly change thickness laterally.

The Tojeira Formation (*Planula–Platynota* Zones), with its rich foraminiferal assemblage, was the target of our investigation (Figs. 6, 7). The micropalaeontology of the Tojeira Formation, studied by Stam (1986) and Agterberg et al. (1989), revealed common to abundant Jurassic planktonic foraminifera, easily grouped in several taxa. Many samples, particularly in the middle part of the Tojeira unit, are rich in specimens using fractions of 65–125 µm and 125–180 µm of washed residues. Hundreds of well-preserved specimens may be picked out of the washed residues in a relatively short time. Micro-gastropods also are abundant, together with epistominids like *E. mosquensis*; both built tests of aragonite.

In the middle and upper part of the Tojeira Formation, several picked residues of the Stam (1986) and Agterberg et al. (1989) collections were re-studied in detail. This strategy was adopted to identify different morphotypes or known species of Jurassic planktonic foraminifera, prior to a more detailed taxonomic assessment. Based on the morphological variability observed, six or more Jurassic planktonic foraminiferal types, all microperforate were distinguished in the samples, described in the "Taxonomy" chapter.

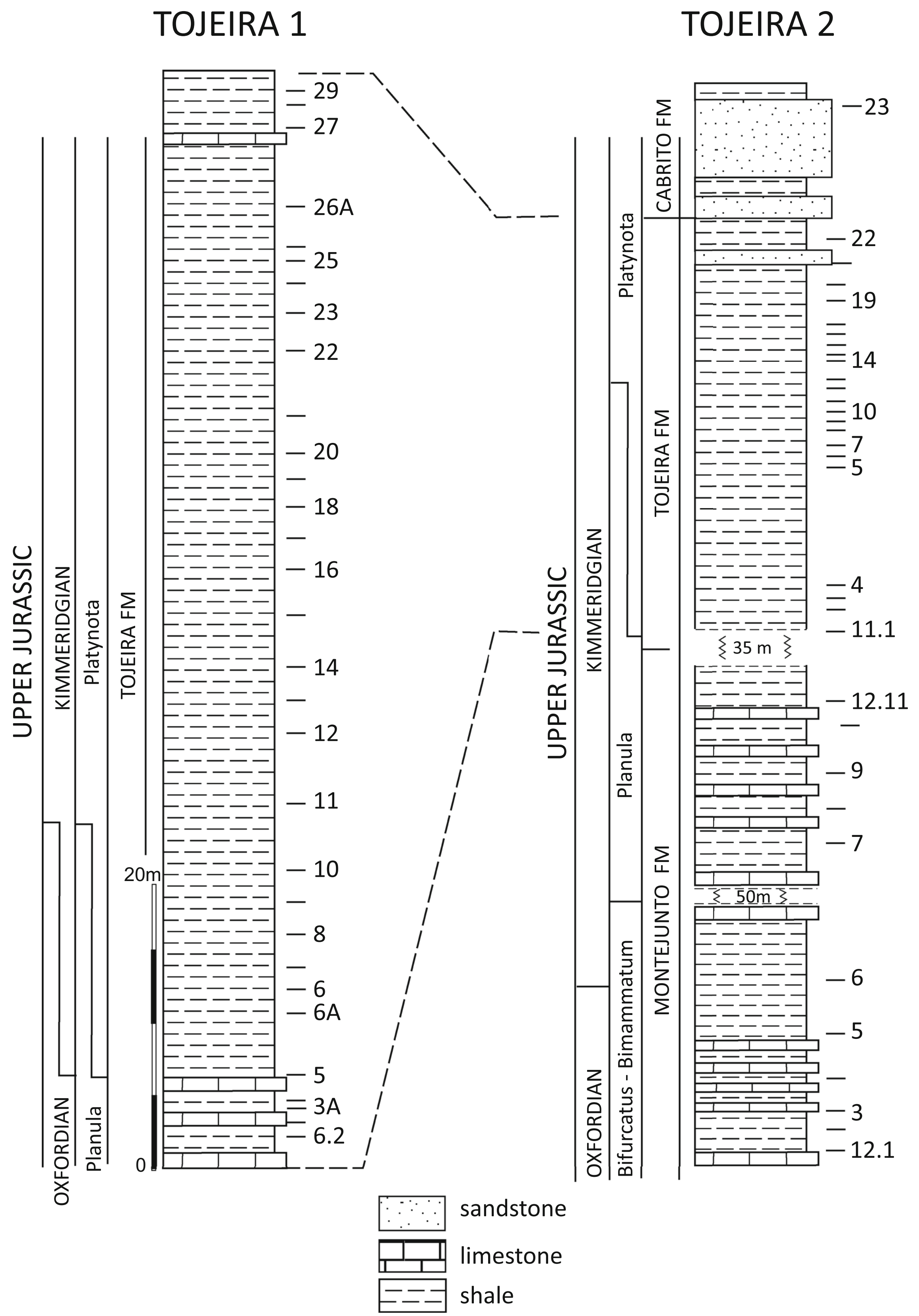


Fig. 7 Tojeira 1 section (on transect 2 in Fig. 4) and Tojeira 2 section (on transect 4 in Fig. 4) sections with sample numbers by Stam (1986). The sandy Cabrito Formation (poorly exposed) immediately overlies the upper shales in the Tojeira unit. Both the *Planula* and the *Platynota* ammonite zones are assigned an Early Kimmeridgian age

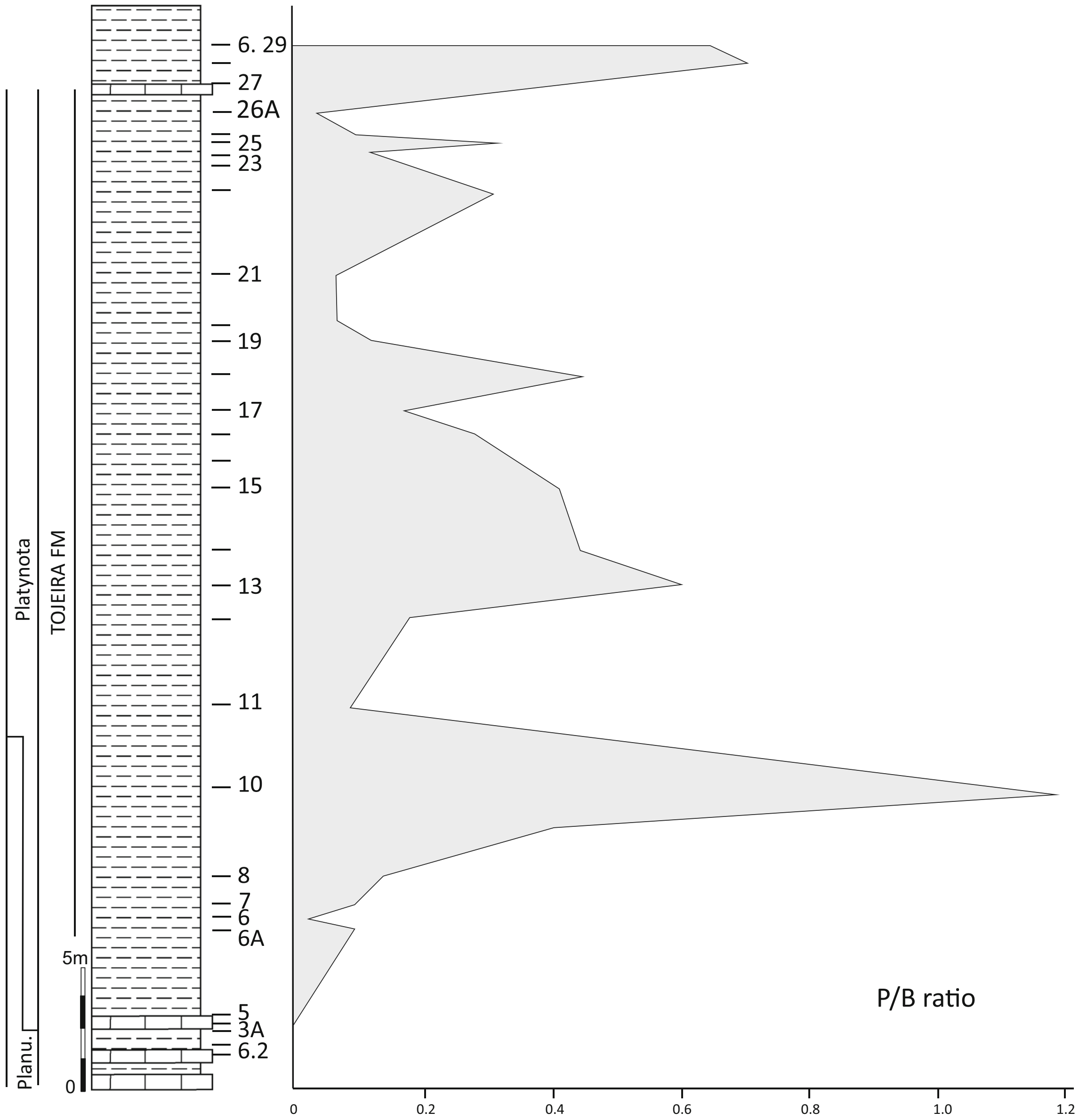


Fig. 8 Plankton-benthos ratio in the Tojeira 1 section (after Stam 1986)

The Portuguese Jurassic planktonic foraminifera occur together with a rich epistominid assemblage, also found in Grand Banks and other sections with *Pseudolamarckina rjasanensis*, *Epistomina mosquensis* and *E. uhligi.* Agglutinated foraminiferal taxa and micro-gastropods also are common. *Discorbis paraspis* and *D. scutiliformis* are rare. This benthic foraminiferal assemblage is only known from deeper neritic and bathyal settings (Stam 1986), in agreement with a deeper, basinal setting, sketched above.

Figure 8 shows probably the first documented example of periodic fluctuations in the Jurassic Plankton/Benthos (P/B) ratio in a local basin setting (Stam 1986; Agterberg et al. 1989). The deeper water benthic foraminifers *Epistomina mosquensis* and *Pseudolarmarkina rjasanensis* co-fluctuate in abundance with the planktonic taxa. Four such peaks were discerned for the planktonics largely consisting of *oxfordiana* and *tojeiraensis* type forms. The blooms were not seasonal, but incidental events of increased fertility in nutrient-rich water. Increase in plankton probably had less effect on total organic carbon content than plant debris deposition. Given the zonal assignment for the ~70 m thick Tojeira unit, blooms might have occurred once every half million years. Periods of exceptional deltaic (river) run-off in this local embayment setting (the basin was probably a few dozen km across, and open to the North Atlantic, westwards) dramatically increased watermass fertility. The increased calcareous planktonic sedimentation may have increased preservation potential of the epistominids (including *E. mosquensis*) tests in the now slightly pyritic shale.

Montejunto revisited

Since the Tojeira section of Montejunto in Portugal contains several taxa of Jurassic planktonic foraminifera as free specimens, some of them new to the literature (Gradstein 2017a), and shows remarkable specimen abundance, it was re-visited in May 2016. A party consisting of F. Gradstein, A. Gale, D. Watkins (Lincoln University, Nebraska, USA) and H. Turner (University of Portsmouth, UK) re-visited the Tojeira sections of Stam (1986) and Agterberg et al. (1989). The main purpose was to obtain fresh samples for taxonomy, study nannofossils and dinoflagellates and attempt carbon isotope stratigraphy. New data might increase stratigraphic resolution and might also reveal changes in biota abundance through time comparable to abundance changes observed in the planktonic foraminifera.

Our locality findings are as follows. The Tojeira 1 section in Transect 2 (Figs. 4, 7, left column) had grown over with shrub (Photograph 2a, b), but was successfully resampled. Our 2016 samples M1-1 through M1-3 in bluish marl and limestone with large *Perisphinctes* ammonites, but virtually devoid of planktonic foraminifera, are in the upper Montejunto Formation. Our 2016 sample T1-1 is in the basal Tojeira Formation, with hard bluish-grey marl inbetween thin limestone beds, approximately at base of the stratigraphic column in our Fig. 7 (left). This level is just above a small walnut tree plantation that obscures about 35–50 m of section. Photograph 2b shows the level of sample T1-1. The 2016 samples T1-2 through T1-5 span about 40 m of greyish Tojeira shale in the middle part of our Fig. 7 (left), which is bioturbated and shows only minor lamination. The 2016 sample T1-4 is in the goat path that runs across the outcrop, and corresponds approximately to sample 24/2P taken in the Tojeira Formation in 1978, and the source of type material for the new planktonic species described from this unit. The year 2016 sample T1-5 is about 10 m higher and slightly below the first of several 10 cm thick sandy intercalation with load casts. These sandy beds are gravity flows, heralding the onset of massive marine siliciclastic sedimentation (Abadia Formation). All T1 samples contain planktonic foraminifera with samples # 2, 3 and 5 being particularly rich with 5 or 6 taxa per sample. Hundreds of relatively well-preserved specimens may be picked out quickly.

Our investigations revealed that the Tojeira 2 section in transect 4 of Stam (1986) between the villages of Tojeira and Pereiro (Figs. 4, 7, right column) had largely vanished due to domestic construction and agriculture. Only a small outcrop of its upper Tojeira Formation level was still visible; this is the site of our sample T2-1, just below the onset of thin sand beds. This sample is rich in planktonic foraminifera.

A new outcrop section (x-T3 in Fig. 4) with about 20 m of greyish-brown silty shale is exposed, halfway along the road from Montejunto to Vila Verde dos Francos. The outcrop (Photograph 2c) is along a minor asphalt road (above the main asphalt road), which runs to the back of the convent gardens. Our 2016 samples T3-1 through T3-8 cover the Tojeira section, the upper part of which contains 5–15 cm thick fine-grained sand beds, with load coasts and upwards fining grain size. Small, brownish ammonite casts and small fulgerite concretions are also present throughout the shale. The sandy siliciclasts probably indicate upper Tojeira or lower Cabrito Formation. The T3 samples are poor in planktonic foraminifera, probably due to the high content of mica, fine grained and angular quartz and woody debris.

Dagestan

In 1961, V. G. Morozova and T. A. Moskalenko for the first time described a rich Jurassic ‘*Globigerina*’ biofacies, with abundant free specimens of several taxa. The assemblages are from Middle Jurassic fine-grained, deeper water (bathyal) shales near the villages of Gunib and Chokh, Central Dagestan, NE Caucasus (Fig. 9, left). The Gunib section has geographic coordinates 42°23′16N:46°57′40E, and the Chock section 42°19′18N:47°1′57E.

The publication by Morozova and Moskalenko (1961) indicates the presence of Jurassic planktonic foraminifera in lower Bathonian strata. The authors described several new taxa, including *Globigerina (Conoglobigerina) dagestanica* Morozova, *Globigerina (Eoglobigerina) balahkmatovae* Morozova, and *Globigerina (Conoglobigerina) avarica* Morozova. (Our note: The planktonic assemblage is associated with epistominids and discorbids, but no diversified *Garantella* and *Reinholdella* assemblage, as on the Grand Banks). Magomedov and Temirbekova (1974) provide evidence that planktonic foraminifera also occur in the lowermost of the so-called Mogokh deposits (=middle sub formation Tsudakhar Formation, *Parkinsoni* Zone, Upper Bajocian), i.e. lower in the section than described by Morozova and Moskalenko (1961).

Through the courtesy and cooperation of Temirbekova Umuhayabat Temirbekovna (Makhachkala, Dagestan), Jurassic planktonic specimens were obtained from the type sections near Gunib and Chokh in Central Dagestan. This allowed us to study topotype specimens of above three species of Morozova. Through the courtesy of co-author Ludmila Kopaevich, we also obtained micropalaeo slides

Photograph 2 **a** Tojeira Formation section 1 of Fig. 7 (left), Portugal; the basal limestone intercalations correspond to those drafted in Fig. 7 (left, base). In the foreground, a field with small walnut tree plantation, covering 35–50 m of unexposed section above the Montejunto Formation marls and limestones in section Tojeira 1 of transect 2 (Fig. 4); **b** Basal marls and single limestone bed of the Tojeira Member in Tojeira 1 section, also shown in Photograph a. **c** Minor outcrop of silty upper Tojeira shales in the Tojeira x-T3 section of Fig. 4, discovered in 2016 (with Turner waving and Watkins)

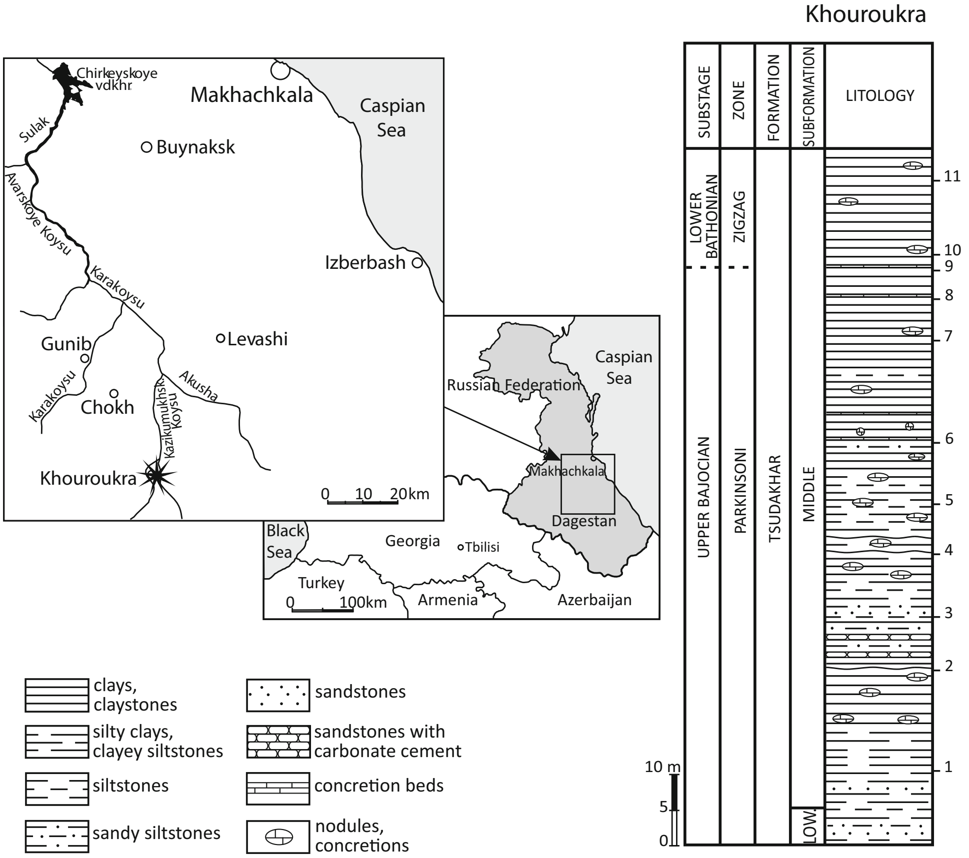


Fig. 9 *Left* Location map of the Khouroukra section, Central Dagestan. *Right* Litho-biostratigraphic framework for the Khouroukra section (Gulyaev et al. 2015, with changes). Sample numbers (*1–11*) to the *right of the column*

with planktonic foraminifera of the Gunib and Chokh sections from the Gorbachik collection in Moscow.

Co-author Larisa Glinskikh (Novosibirsk) participated in 2015 in a field trip that studied and sampled a nearby and stratigraphically identical section (42°9′23N:47°7′60E) to Gunib and Chokh. This means that the Jurassic planktonic foraminifera in it are essentially topotypes of those described first by Morozova and Moskalenko (1961). The stratigraphic levels in this new section ХУРУК̆РА (Khouroukra) were studied together with specialists in ammonite and belemnites, and described in Cherkashin et al. (2015, in Russian, where the Khouroukra section is described on p. 66–68 and shown in their photograph 24). The studied part of the Khouroukra section includes the lower and middle sub-formation of the Tsudakhar Formation (Fig. 9, right).

The lower subformation shows interbedded light grey siltstones and sandstones. The middle subformation is represented by a dark grey claystone, with interbeds of siltstones, rare sandstones, with siderite concretions. There are rare and thin (0.10–0.15 m) interbeds of calcareous rocks.

The Middle Jurassic macrofauna of the Khouroukra section includes belemnites, ammonites. Bajocian–Bathonian strata contain gastropodes, ostracodes and a relatively rich and diversified foraminifers assemblage with *Hyperammina, Trochammina, Reophax, Ophthalmidium, Ichthyolaria, Dentalina, Lenticulina, Oberhauserella* (including specimens resembling *O. parocula* Wernli and Görög 2007), *Epistomina* and *Discorbis* (*D. paraspis*), together with planktonic foraminifera.

Eleven samples were collected for Jurassic planktonic foraminifera of Late Bajocian and Early Bathonian age (Fig. 9, right). The samples were very well processed for foraminifera in the laboratory of Ludmila Kopaevich (Moscow). The strata contain more and better preserved specimens upwards in the section. Upper Bajocian samples 8 and 9 (Fig. 9) are particularly rich in planktonic foraminifera in the 65–125 μm size fractions. The shell preservation is good, and with its light brown colour reminds of the Bajocian–Bathonian planktonic foraminifera tests of the Grand Banks of Newfoundland. Over 150 specimens were picked and classified in at least four groups. Many specimens are high spired, trochospiral with 2–3 whorls and 4, rarely 3–4 or even 3 chambers in the last whorl. Chambers are globular, sutures incised and umbilicus small. Aperture is mostly a low arch, but loop-shape apertures also occur. The wall appears to be pustulose with an abundance of intertwining short ridges. The

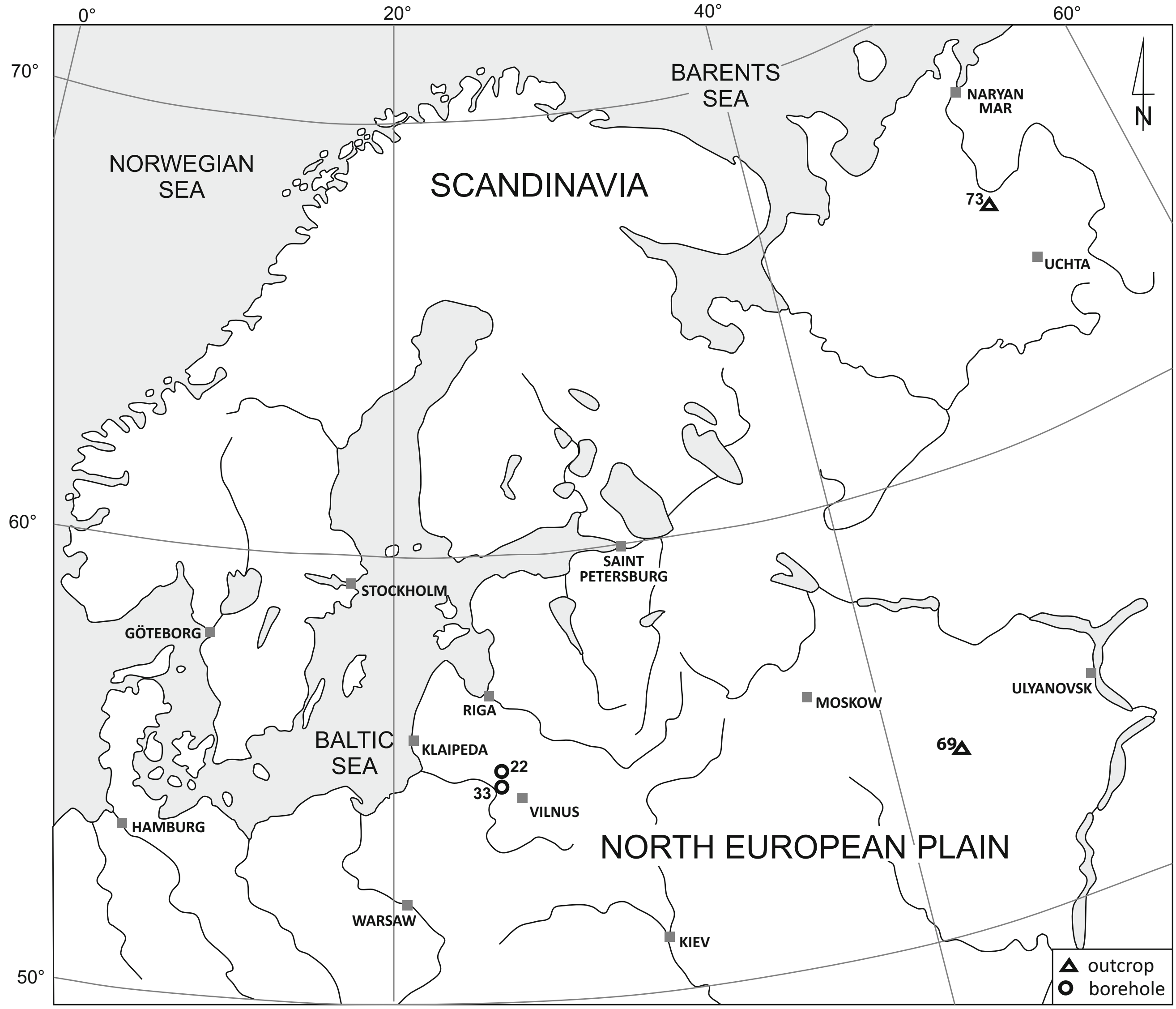


Fig. 10 Location of type localities of *Globuligerina oxfordiana* in Lithuanian shallow borehole 33. Auxiliary, well-preserved specimens of this taxon, as originally assigned by Grigelis, come from Lithuanian borehole 22, and outcrop 69, Nikitino region, Central Russia. Also shown is the location were '*Globigerina*' *stellapolaris* was originally described in the Timan-Pechora region of Northwest Russia. For details, see *text*

latter may be due in part from slight etching during processing. The higher spired specimens are assigned to *Globuligerina dagestanica* and overlap in variation with *G. bathoniana*.

A minor group of specimens is low spired, with 4 chambers in the last whorl. The last whorl is much larger than the previous one (s), and petaloid in shape. Aperture is a slit or low arch. The specimens are assigned to *Globuligerina balakhmatovae*. Some very high spired and slender trochospiral forms may belong to *Globuligerina avarica*, further discussed under *G. dagestanica* in the chapter on Taxonomy. Rare, lower spired and globose specimens with a comma-shaped aperture closely resemble *G. oxfordiana*. Details are in the chapter on Taxonomy.

Lithuania and Russia

Below a brief description is provided of the type localities of *Globuligerina oxfordiana* and '*Globuligerina*' *stellapolaris* based on the author's (A. Grigelis) notes made during field work in Lithuania on boreholes in 1956, in the Nikitino region, Central Russia in 1977, and in the Timan-Pechora region at River Pizhma of NW Russia in 1974. A geographic locality map with boreholes 22 and 33 and outcrop 69 (for *G. oxfordiana*) and outcrop 73 (for 'G'. *stellapolaris*) is in Fig. 10. No special analyses of lithology content of sedimentary rocks were made. Microfaunal remnants were picked by the author after standard sediment disintegration and hand-sieving procedure. The shallow

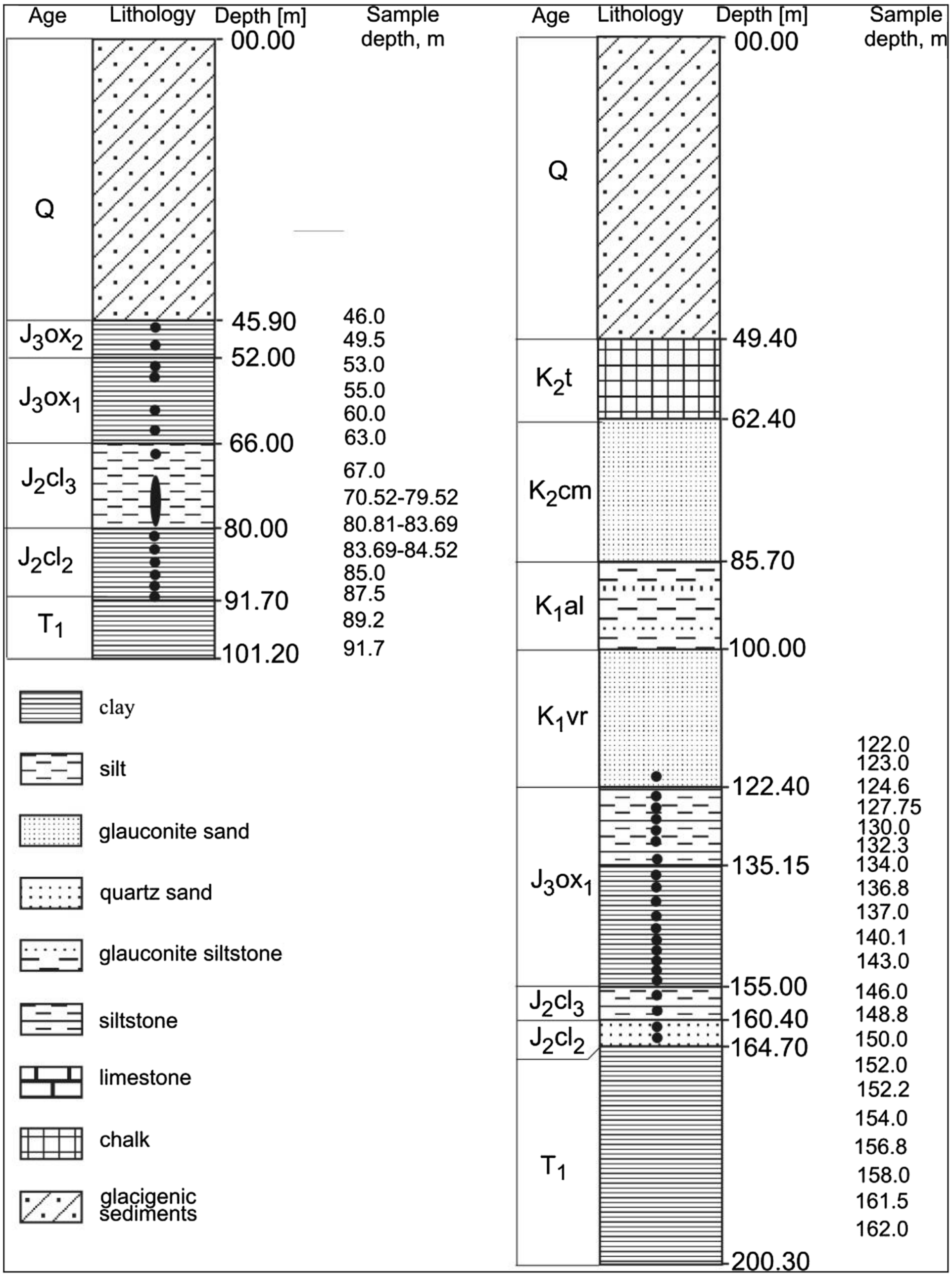


Fig. 11 Stratigraphy of the Lyduvenai (# 33 in Fig. 10) and Jotija (# 22 in Fig. 10) boreholes, Lithuania, from which *Globuligerina oxfordiana* was described originally

burial at the Oxfordian localities accounts for excellent preservation of the *G. oxfordiana* taxon.

Geologically, the Lithuanian area belongs to the Precambrian East European Craton. Relatively thin Mesozoic sedimentary strata underly Quaternary surface deposits. Marine Jurassic is distributed in the western–southwestern parts of Lithuania, with thickness changing from less than 30 m in the northwest to 250 m in the southwest, against the border with Poland.

Holo- and paratypes of *G. oxfordiana* come from dark claystone and dark siltstone in borehole Jotija (Jotija village), Sakiai District, Lithuania at 143 m below surface in sample 10, Lower Oxfordian (Fig. 10, # 33; Fig. 11, right column). In the original description, it is not indicated on which evidence geological age is assigned, but the foraminiferal assemblage contains *Spirophthalmidium birmenstorfense, Lenticulina brueckmanni, L. comptala, Vaginulina flabellata, Trocholina transversarii, Epistomina volgensis, E. brueckmanni* and *Epistominoides* sp. GPS coordinates of the borehole site are 55°02′17N:23°11′42E.

Well-preserved specimens of *Globuligerina oxfordiana* also occur in dark, micaceous silty clay in the interval of 55–66 m in borehole Lyduvenai, Raseiniai District, Lithuania (Fig. 10, # 22; Fig. 11, left column). GPS coordinates of this site are 55°30′ 29°N:23°04′ 59E. The type level contains the ammonite *Cardioceras tenuicostatum* Nikitin (Lower Oxfordian) and the foraminifera *Epistomina volgensis, E. intermedia* and *Lenticulina brueckmanni*.

In Central Russia, well-preserved specimens of this taxon (as assigned by Grigelis) also occur in sample 801 in the Shatriche-2 outcrop at the Nikitino settlement on the river Oka, Ryazan District. The actual outcrop is on high right bank of River Oka, ca 2.5 km below the confluence with River Pronya, in the outskirts of the village Shatriche, in a river washout called "Durnyanki". The sampled sediments are dated Middle to Late Oxfordian, but no specific fossil information is provided. A simple location map is shown in Fig. 10, # 69.

The types of '*Globuligerina' stellapolaris* Grigelis are from very thin Upper Jurassic strata outcropping along the banks of the Pizma and Ishma Rivers in the Pechora Basin (Fig. 10, # 73). Details are in Grigyalis et al. (1978) and Gradstein (2017a).

Crimea, Southwest Russia

For our study, Ludmila Kopaevich obtained one sample from the Tonas River Basin in E. Crimea, Russia. The hard marly sediment level is assigned to the 'Jacobi ammonite Zone, lower part of the Lower Berrisian, not far above the Jurassic-Cretaceous boundary. The Tonas River Basin is listed as co-locality from which Gorbachik and Poroshina (1979) described *Globuligerina caucasica* and *G. gulekhensis*. From our study, it appears that the sample contains a suite of small planktonic taxa, including rare forms resembling *Globuligerina gulekhensis* and some indeterminate specimens, one of which is almost planispiral like a *Praehedbergella* sp (not illustrated). All specimens are in the 65–125 μm fraction. Scanning electron microscope was undertaken for the study of wall texture (see section on "Taxonomy").

Micro-gastropods and benthic foraminifera are common; the latter include *Epistomina stellicostata*, *E. volgensis*, *E. ulighi*, *Neobulimina* sp., *Patellina* sp., *Lenticulina* spp. and several other nodosariids.

Poland

Ogrodzieniec

In 1969, Olga Pazdrowa published 'Bathonian Globigerina from Poland', (Pazdrowa 1969). The taxon *Globigerina bathoniana* was described from the ore-bearing clays of Ogrodzieniec, *Morrisi* Zone, middle Bathonian. The village of Ogrodzieniec is in the Zawiercie County, Southern Poland at 50°27′N and 19°31′E. Description of this new taxon was based on about 150 free, well-preserved specimens. Gradstein received from Olga Pazdrowa a foraminiferal assemblage from Ogrodzieniec, including the globigerinid taxon. Later, he also self undertook micropalaeontological sampling of the strata in the Ogrodzieniec claypit; these samples were used in the PhD. study by Stam (1986). Several, fairly low spired, topotype specimens of *Globuligerina bathoniana* are illustrated in the section on Taxonomy (see also plate 9, figs. 7–13 in Stam 1986).

The local foraminiferal assemblage is diverse, and from the list of taxa received from Olga Pazdrowa includes: *Garantella ornata, Reinholdella crebra, Epistomina regularis, E. costifera, E. nuda, Palaeomiliolina czestochowiensis, Ophtalmidium agglutinans, O. carinatum, Paalzowella pazdrowae, Spirillina radiata* and *Conorboides paulus*.

We note that as usual, epistominids are well represented together with Jurassic planktonic foraminifera. According to Pazdrowa (1969), the Jurassic planktonic foraminifera lived in a shallow marine basin with siliciclastic sedimentation. We interpret this palaeo environment as probably deep neritic, using the evidence from epistominids with Jurassic planktonic foraminifera from other basins (Stam 1986).

Krakow-Silesia

Since the Ogrodzieniec quarry discussed above has been partly filled in and made inaccessible, we collected *Globigerina bathoniana* (Pazdrowa) from the same *Morissi* ammonite Zone, and from the same formation in the southern part Kraków-Silesia. We consider our samples to correspond to the *locus typicus* of this taxon (see below).

The Jurassic planktonic foraminifera occur in the Mesozoic deposits of the Kraków-Silesia Monocline (south-central Poland), which records sedimentation in the epicontinental Middle Jurassic Polish Basin. This basin started with an early Aalenian transgression (Dayczak-Calikowska 1997). Our sampling focused on the Częstochowa Formation of Late Bajocian–Late Bathonian age (Fig. 12) (*Garantiana-Subarietis* to *Retrocostatum* ammonite zones; Matyja and Wierzbowski 2003). Thickness of the Czetochowa Formation changes from about 180 m in the north to a few meters eastward (Gedl and Kaim 2012). The formation consists of dark coloured clays, mudstones and subordinate sandstones with siderite.

Our samples were taken in the Gnaszyn (Gnaszyńscy) outcrop pit (Fig. 13; coordinates: N50°48′11.4″, E19°02′31.9″) located in the south-west Częstochowa city area of the Gnaszyn district. Its address is: Poland, 42-380 Częstochowa, ul. Tatrzańska 3 and is currently exploited by Wienerberger Ceramika Budowlana Sp. z o.o. The 25 m thick section of dark shales represents the higher part of the

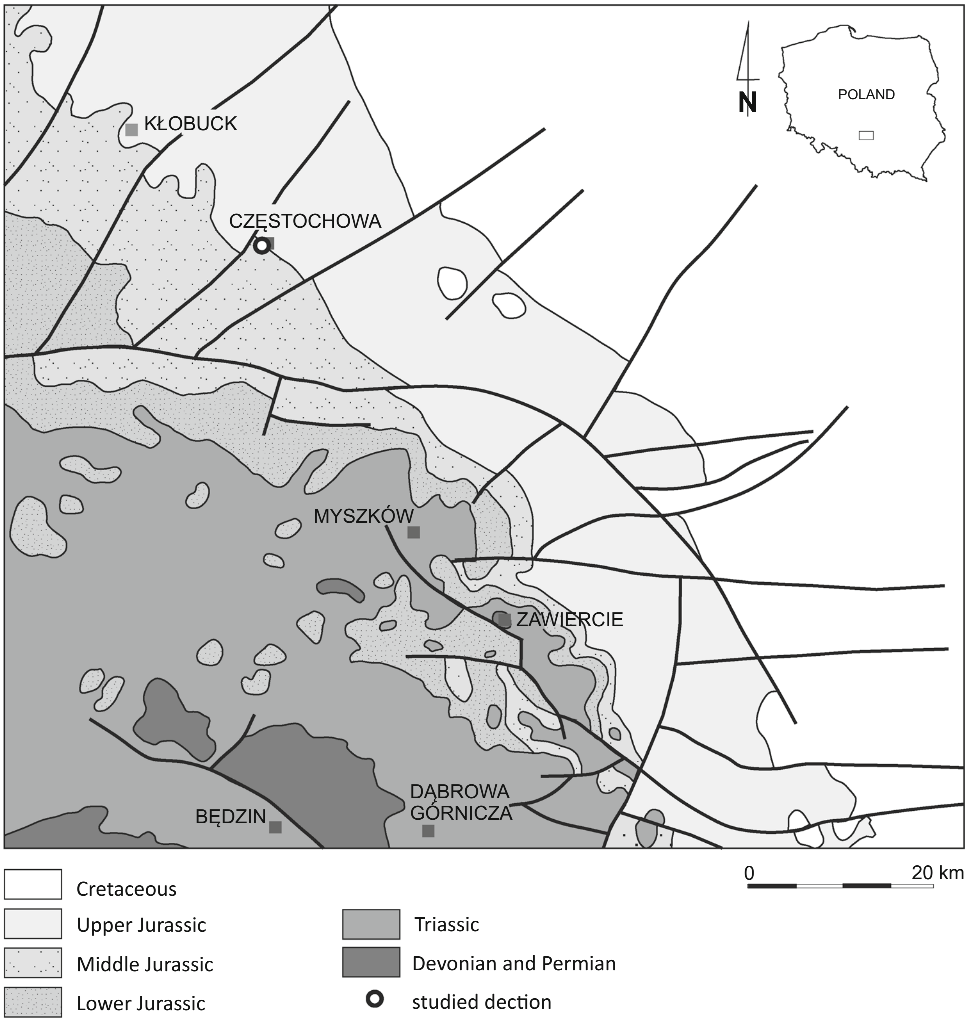


Fig. 12 Position of the Gnaszyn Quarry section (after Matyja and Wierzbowski 2006) with Middle Jurassic lithostratigraphical log of north part of the Kraków-Silesia Monocline (after Kopik 1997—simplified)

Częstochowa ore-bearing clay formation being locally 140 m thick (Fig. 12). The monotonous, strongly bioturbated black or dark greyish siltstones and claystones are rich in bioclasts, occasionally with different amount of sandy admixture. It contains 7 levels of sphaerosideritic concentrations (N-T horizons) (Matyja and Wierzbowski 2006; Fig. 12). There is a diverse and rich fossil fauna with ammonites, belemnites, bivalves, scaphopods, gastropods, foraminifers, echinoderms and shark teeths, as well as trace fossils, calcareous nannoplankton, pollen, sphoromorphs, dinoflagellates and driftwoods (Gedl et al. 2012 and references therein).

The Jurassic planktonic foraminifera bearing GN-6 sample was taken in the lower part of the Gnaszyn section (*Morrisi* Ammonite Zone–Middle Bathonian), 20 cm above the O sphaerosiderite horizon (Fig. 13). This is a grey and slightly sandy claystone with numerous bioclasts, mainly of mollusks shells (Photograph 4). Smoleń (2012) from this part of Gnaszyn section described foraminifera dominated by Ceratobuliminidae and Vaginulinidae calcareous benthonics and subordinate numbers of agglutinated taxa. Of planktonic foraminifera, only a single specimen of *Globuligerina bathoniana* was found (Smoleń 2012) from deposits below the O sphaerosiderite horizon. From our sample, we obtained numerous well-preserved *G. oxfordiana* and less well-preserved *G. bathoniana*. The specimens are relatively small and show good detail of wall texture (see section on "Taxonomy").

Pieniny Klippen Belt

A prominent *Globuligerina* limestone in Poland occurs in the Pieniny Klippen Belt (PKB) (location in Fig. 14). The following discussion is after Wierzbowski (1994) and Wierzbowski et al. (1999). The PKB is a part of the Carpathians mountain chain and forms a long and narrow (up to 20 km wide) structure, placed between Outer and Inner Carpathians. It extends over a distance of nearly 600 km from Viena (Austria) in the west, to Maramures

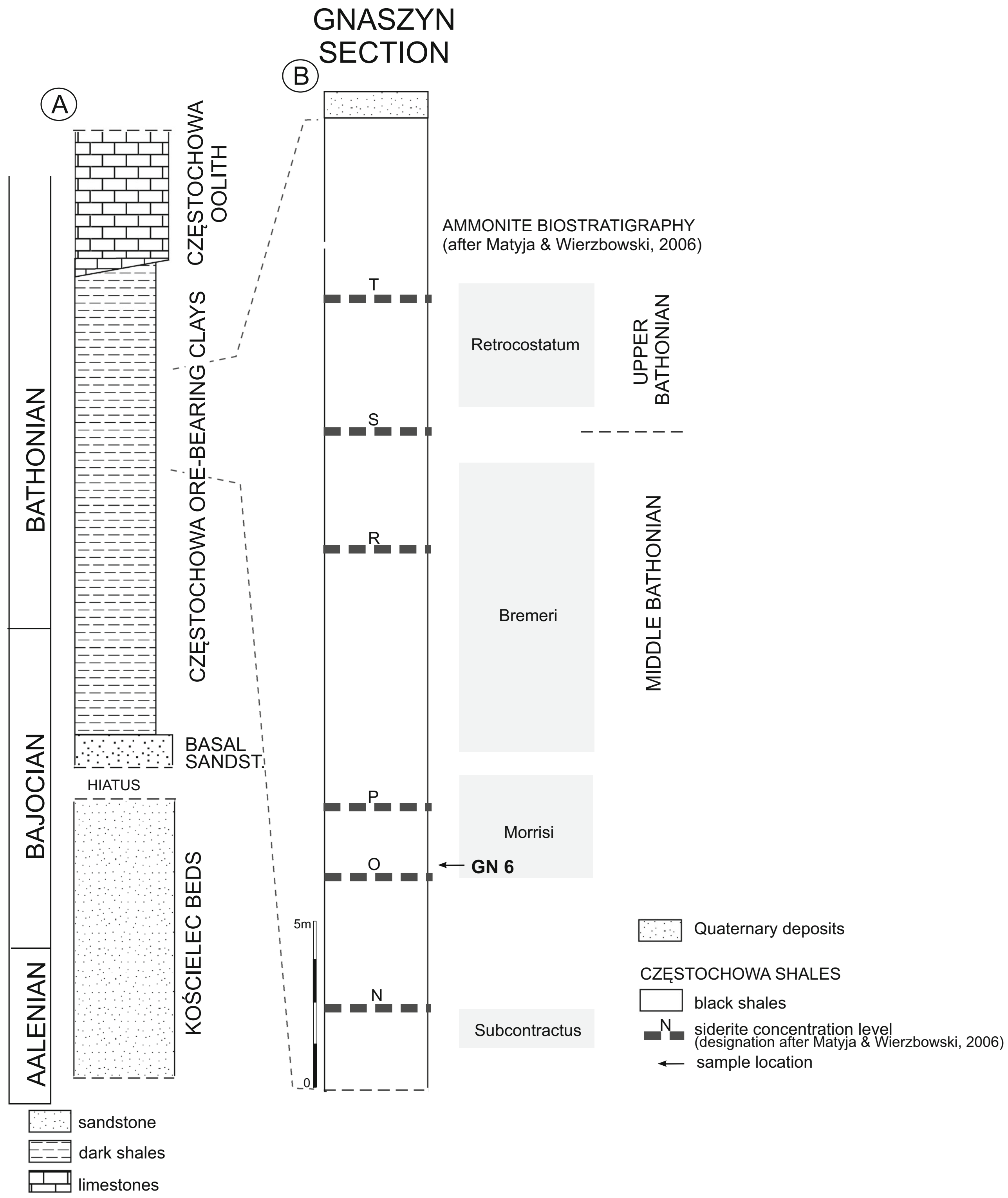
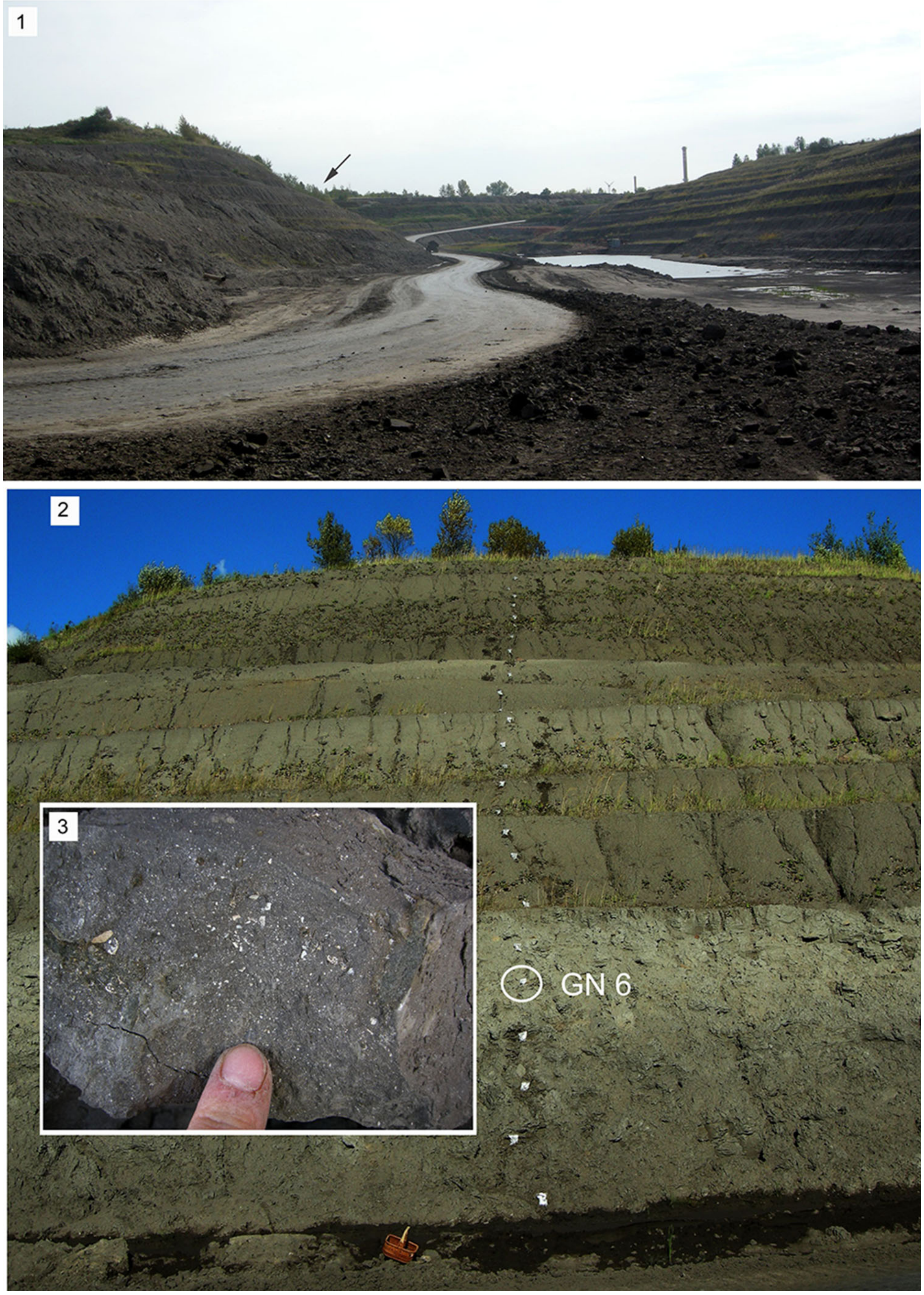


Fig. 13 Location of the Gnaszyn Quarry on the tectonic-sketch map of Częstochowa area (map after Dadlez et al. 2000—simplified)

(Romania) in the east. The PKB is built up of strongly tectonized strata that originated in the Western Alpine Tethyan Sea during Early Jurassic through Late Cretaceous. The rocks of the PKB are traditionally assigned to successions corresponding to deeper or shallower settings of the PKB. The *Globuligerina* limestone was identified and described from the Czorsztyn and Niedzica successions (e.G. Wierzbowski 1994; Wierzbowski et al. 1999; Hudson



Photograph 4 Gnaszyn quarry–Częstochowa area, Poland. *1* General view of the Gnaszyn Quarry with location of studied section, *2* position of Gn 6 sample, *3* the dark Bathonian shales of Częstochowa ore-baring clays

et al. 2005; Sidorczuk and Nejbert 2008; Hart et al. 2012 and papers cited therein).

In an attempt to obtain thin sections and also free specimens of the Jurassic plankton foraminifera in the hard limestones, one of us (Anna Waskowska) obtained samples from the isolated Obłazowa Klippe block in Nowa Biała village (coordinates: N49°25′42.4″, E 20°07′35.5″). The Jurassic limestones of the Czorsztyn succession built this klippe (Birkenmajer 1958, 1963, 1977; Wierzbowski et al. 1999), and are interpreted as deposits which originated from an elevated structure above the basin seafloor, known as Czorsztyn Ridge (e.G. Andrusov 1965; Birkenmajer 1977, 1986) (Fig. 15; Photograph 5).

This Czorsztyn Formation consists of medium- and thick-bedded red and pink limestones with characteristic nodular structure—ammonitico rosso-type limestone. In the marly limestone matrix, hard limestone nodules occur. The macrofossils like ammonites, belemnites, crinoids, mollusks, brachiopods, echinoid spines, and aptichi are components of this limestone. For the Czorsztyn Limestone Formation, characteristic microfacies are:

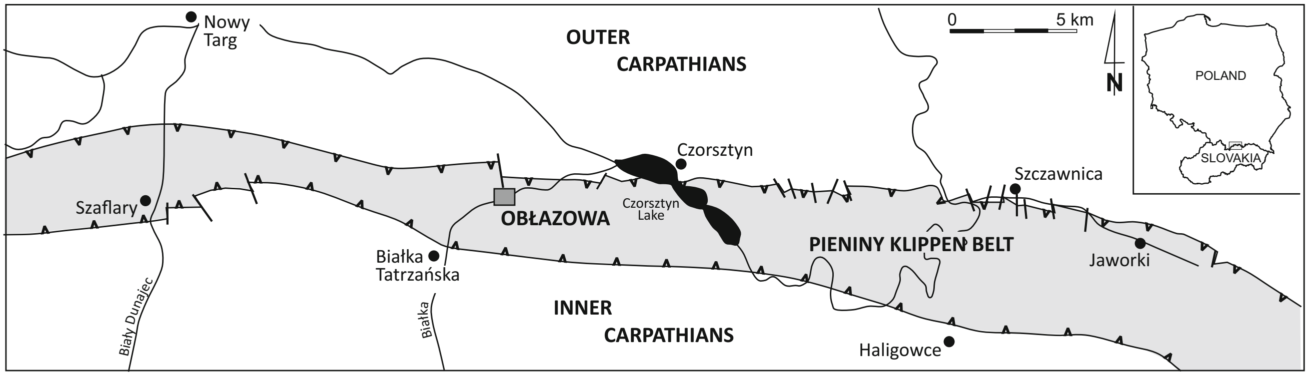


Fig. 14 Location of the Obłazowa Klippe block in Nowa Biała village, Poland within the Pienieny Klippen Belt (PKB) (map after Birkenmajer 1963—simplified)

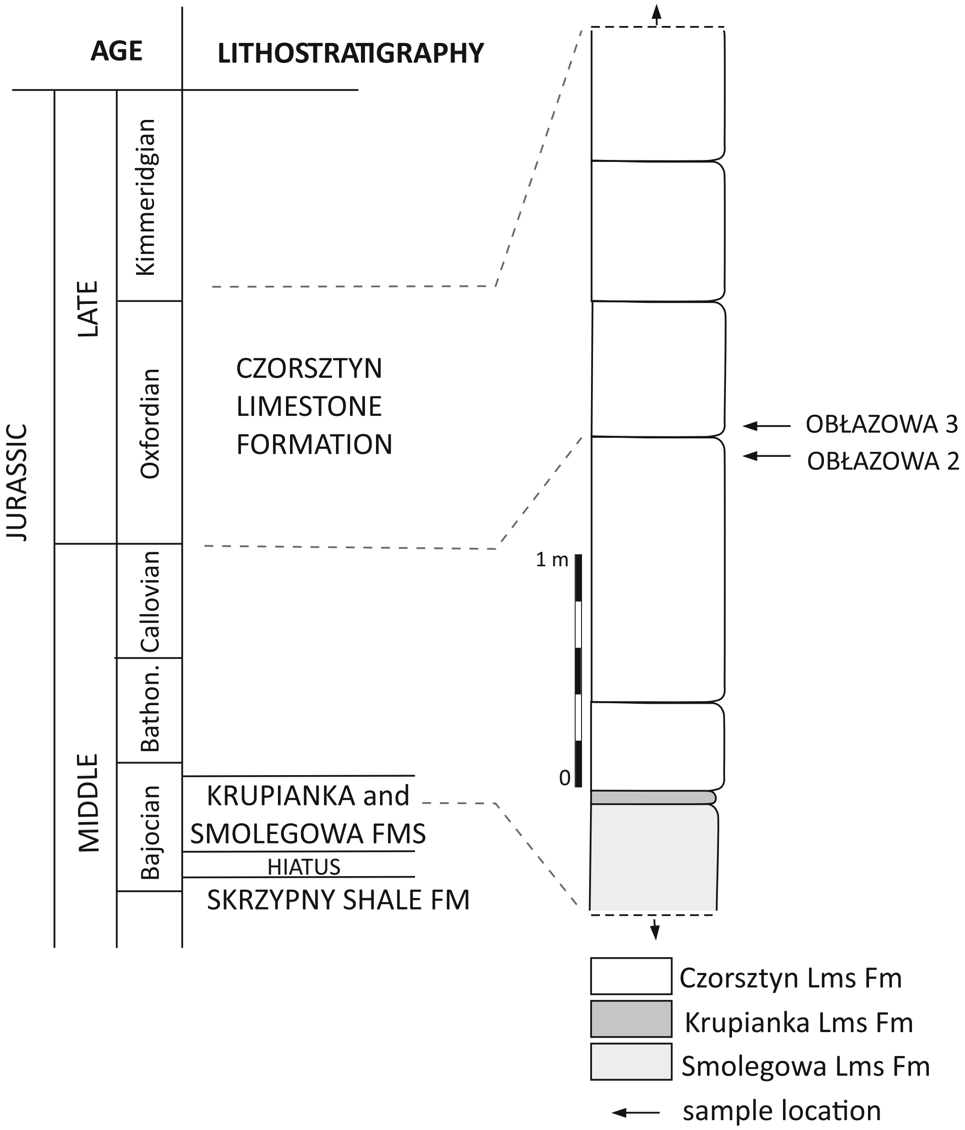
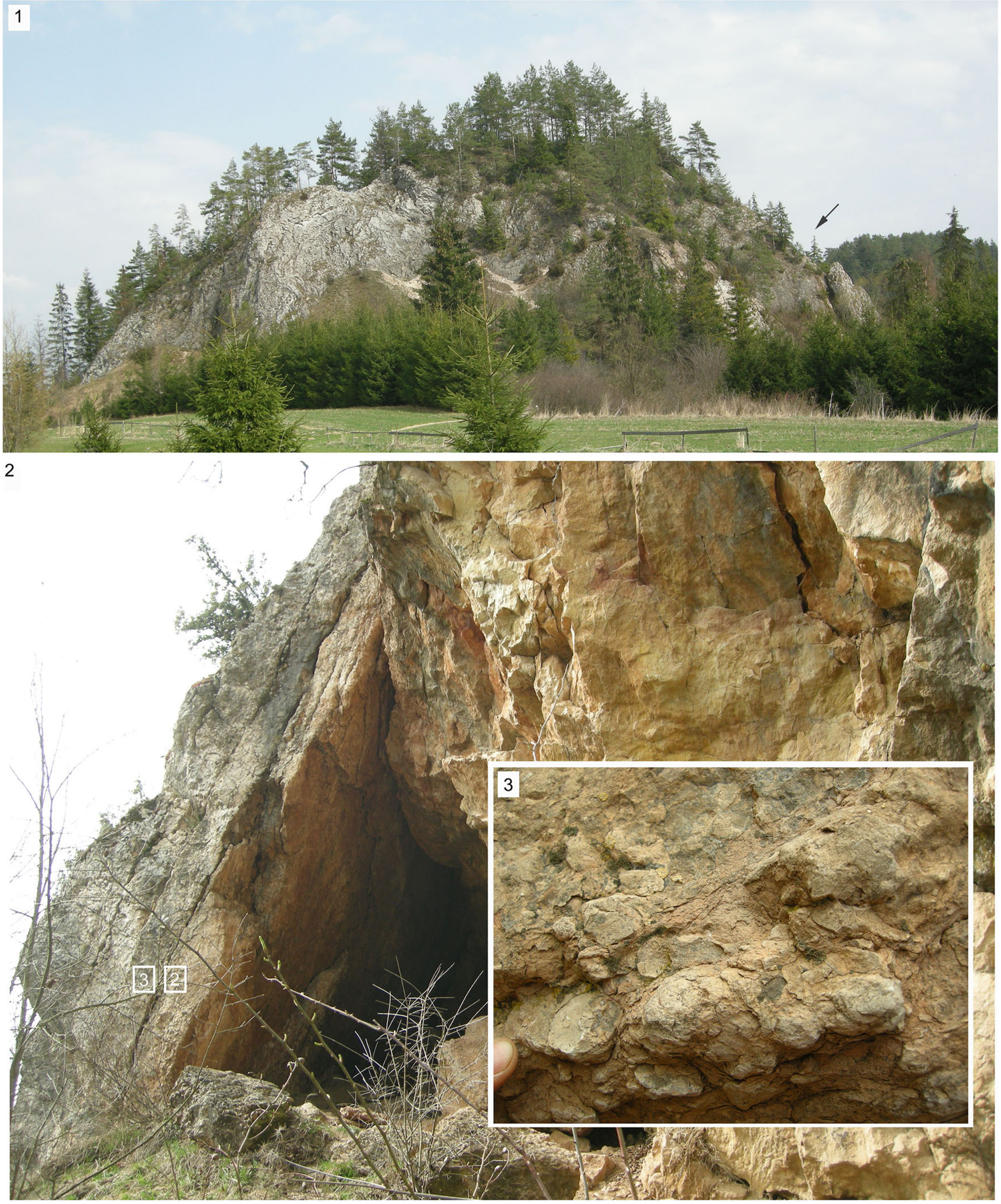


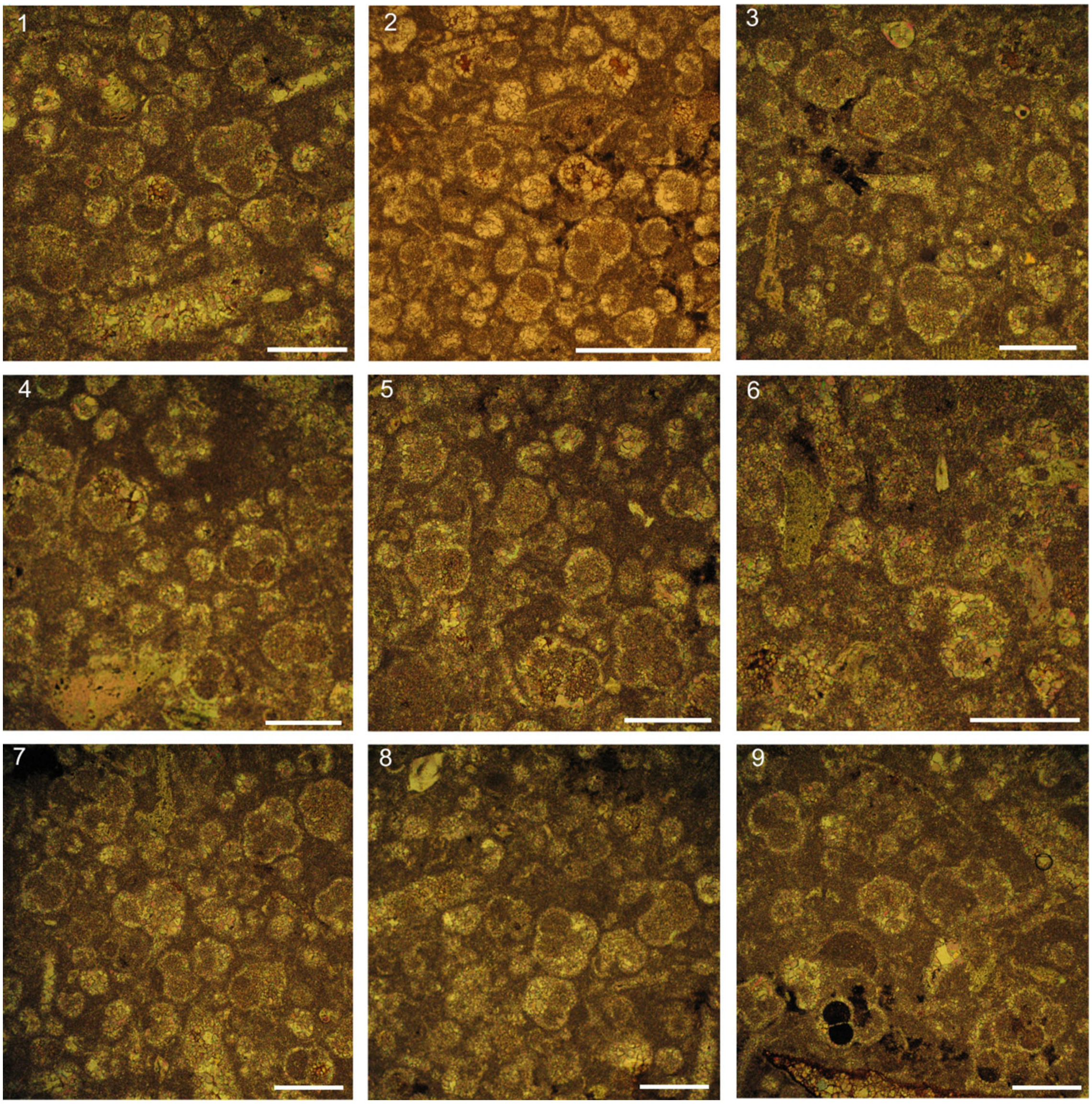
Fig. 15 Stratigraphy of the Jurassic Czorsztyn limestones in the Obłazowa Klippe block in Nowa Biała village, with position of the two samples studied for Jurassic planktonic foraminifera. For details, see *text*



Photograph 5 Obłazowa Klippe–Pieniny area, Poland. *1* Obłazowa Klippe with location of studied section, *2* position of Obłazowa 2 and Obłazowa 3 samples, *3* the red nodular limestone of the Czorsztyn Limestone Formation

(a) an uppermost Bajocian–Upper Callovian filament and juvenile gastropod microfacies,
(b) an uppermost Callovian–lowermost Kimmeridgian *Globuligerina* microfacies and
(c) a Kimmeridgian–Tithonian *Saccocoma* microfacies (e.G. Wierzbowski et al. 1999; Wierzbowski 1994; Krobicki et al. 2006 and paper cited therein).

Our Thin-section Plate 1 with *Globuligerina oxfordiana* ooze from the Obłazowa 3 sample is from a partly recrystallized packstone. It is rich in planktonic foraminifera, with rare component of mollusks shell and echinoderm fragments and some benthic calcareous foraminifera, occurring in a micritic matrix. The amount of planktonic foraminifera is estimated at 50% (Wierzbowski



Thin-section Plate 1 *Globuligerina oxfordiana* (Grigelis) ooze, Obłazowa 3 sample, Pieniny Klippen Belt, Poland—Oxfordian. *Scale bar* is 50 µm

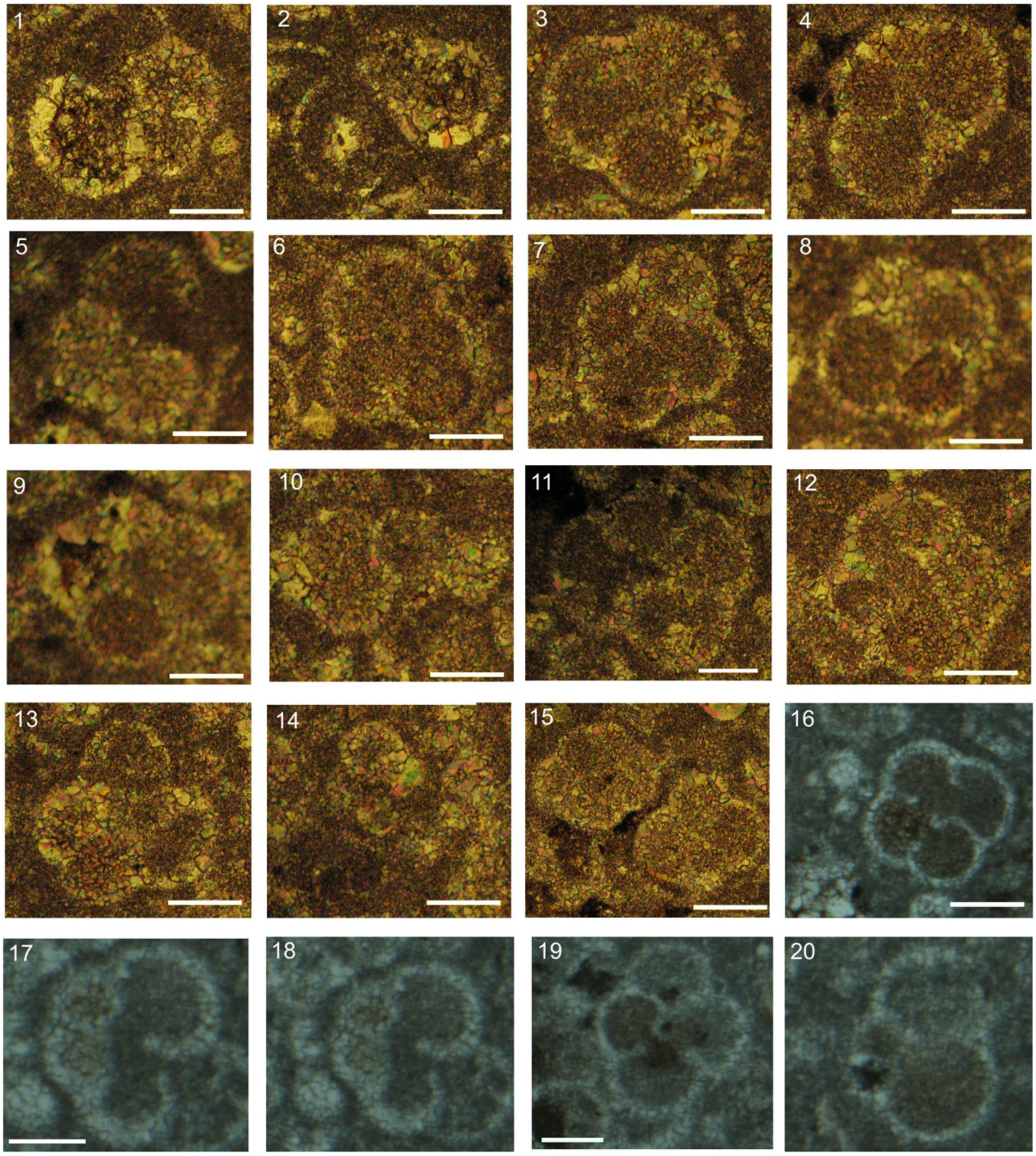
et al. 1999). According to the lithostratigraphical sketch by Wierzbowski et al. (1999), the sampled deposit is of Oxfordian age, as confirmed by ammonites, and lies about 10 cm above the lower Oxfordian boundary

Our Thin-section Plate 2 shows individual *Globuligerina oxfordiana*. Specimens in squares 1–15 are from Obłazowa 3 sample, Oxfordian. Specimens in squares 16–20 are from Obłazowa 2 sample, Callovian.

Our Thin-section Plate 3 shows cross-sections of *Globuligerina bathoniana*. Specimens in squares 1–5 are from Obłazowa 2 sample, Callovian. Specimens in squares 6–8 are from Obłazowa 3 sample, Oxfordian. Note wide open umbilicus in some specimens. *G. bathoniana* occurs with scattered specimens, and is clearly not rock forming with an ooze-like deposit.

France

Bignot and Guyader (1966) discovered several dozen small specimens of *Globuligerina oxfordiana* (Grigelis) in the clays of Villers, Le Havre, Normandy, Northwest France. The level is lower Oxfordian, *Mariae* Zone, about 6 m below the *Cordatum* zone with ferruginous oolites. Jurassic planktonic foraminifera are from a low energy, shallow marine embayment, connected to open sea. Using the palaeo waterdepth model of Stam (1986), the species lived



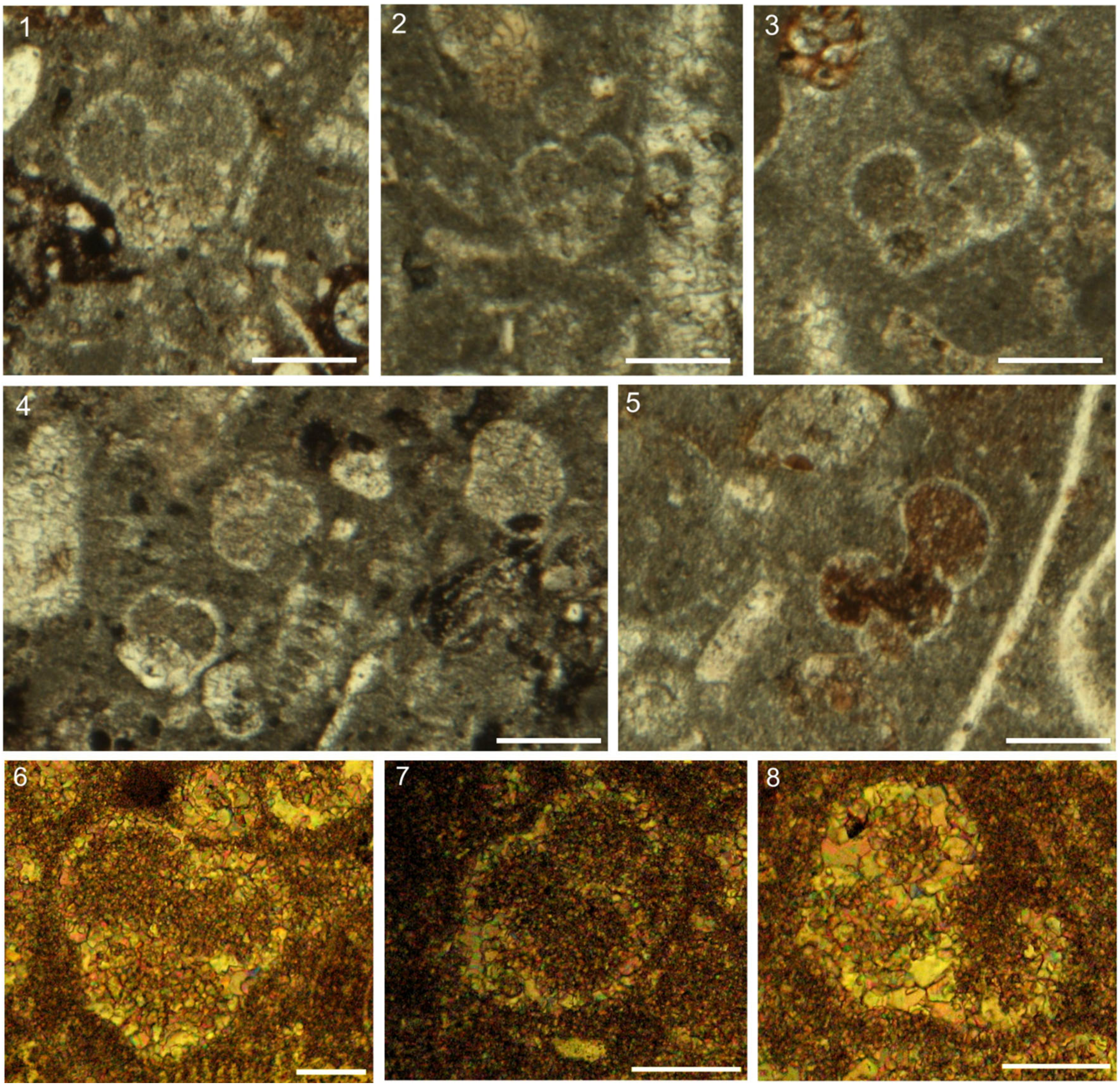
Thin-section Plate 2 Cross-sections of *Globuligerina oxfordiana* (Grigelis), Pieniny Klippen Belt, Poland. Specimens in squares *1–15* are from Obłazowa 3 sample, Oxfordian. Specimens in *squares 16–20* are from Obłazowa 2 sample, Callovian. *Scale bar* is 50 µm

in a shallow marine environment, not exceeding 150 m in palaeo waterdepth (Samson et al. 1992). G. Bignot kindly donated *G. oxfordiana* specimens to Gradstein. His topotype specimens are discussed and illustrated in the section on Taxonomy (see also plate 7, figs. 1–5 in Stam 1986).

Switzerland

The Eisengraben Section, ca 35 km NW of Zuerich in Canton Aargau, Switzerland is the type section of the Birmenstorfer Schichten, *Tranversarium* Zone, Middle Oxfordian. The section has coordinates 651,600/264,070 on Schweizerische Landeskarte 1:25,000, Blatt 1069, Frick (reference fig. 4 in Oesterle 1969; see our Fig. 16). It is in this section that Stam (1986), as advised and assisted by H. Bolli and R. Gygi, collected socalled topotype material of *Globigerina helvetojurassica* Haeusler. The few specimens collected by Stam were next used by Simmons et al. (1997) to describe and illustrate their *Haeuslerina helvetojurassica* (Haeusler).

In April 2016, Gradstein visited the Natural History Museum in Basel to study type slides listed to contain

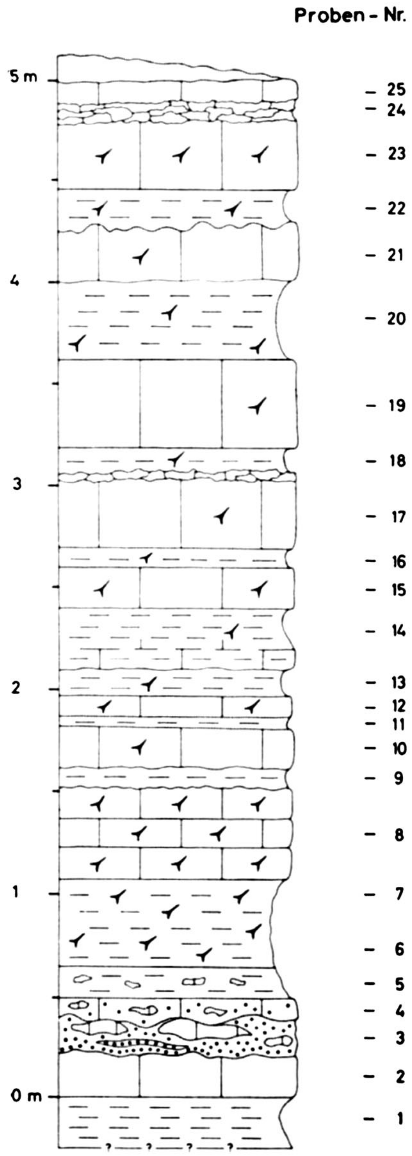


Thin-section Plate 3 Cross-sections of *Globuligerina bathoniana* (Pazdrowa), Pieniny Klippen Belt, Poland. Specimens in *squares 1–5* are from Obłazowa 2 sample, Callovian. Specimens in *squares 6–8* are from Obłazowa 3 sample, Oxfordian. Note wide open umbilicus in some specimens. *Scale bar* is 50 µm

Globigerina helvetojurassica Haeusler, and also sample the Eisengraben Section to obtain fresh material. The sampling was accomplished under the expert guidance of W. Etter and M. Knappertsbusch.

Photograph 3 shows the Eisengraben outcrop with levels 4 through 20 visible. These levels are listed in the original sample log of Oesterle (1968), (see Fig. 16). A duplicate set of samples were collected by us from each bed in the Eisengraben section, comprising alternating harder limestones and softer marls and clays. The sample levels correspond to the same sample levels investigated by Oesterle (1969). Limestone bed no. 19 can be easily identified due to its thickness. Also Bed no. 4 (presumably just above the level from which Stam collected his *G. helvetojurassica*) is easily recognizable in the outcrop, and both beds serve as key reference levels.

Our (rather surprising) findings are reported in Gradstein (2017a) and briefly also in the chapter on "Taxonomy". At this occasion, M. Knappertsbusch prepared nannofossil smear slides of three samples in the Eisengraben section. Nannofossils are rare, with the sub-coccolith fraction consisting of fine recrystallized micrite. Under the SEM, only one coccolith was found within 10 min of search, confirming low abundance. The taxon is *Watzenauria* sp., probably *W. brittannica* (Watkins, personal communication to Gradstein 2016).



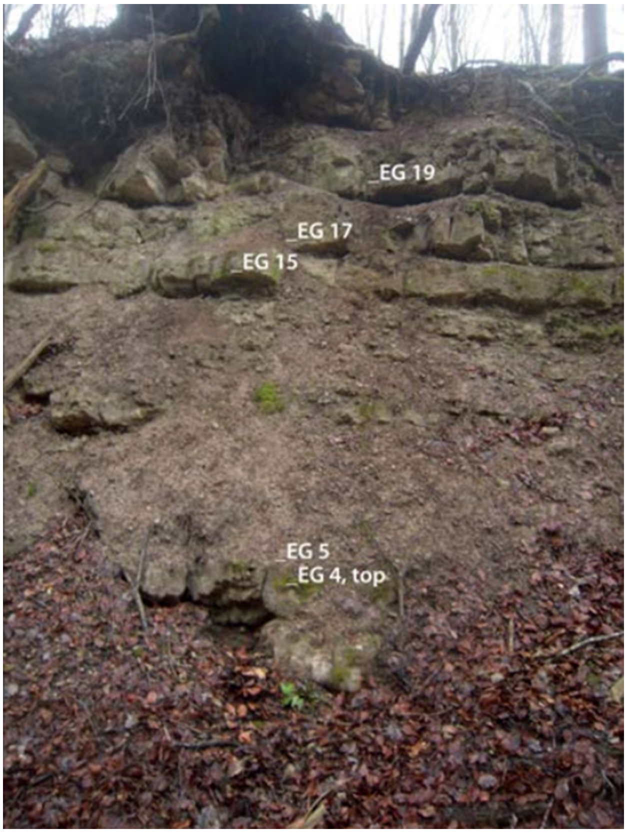
25 10 cm graubrauner Spongien-Biomikrit, limonitisiert, gegen oben in Humus übergehend
24 10 cm graubrauner Spongien-Biomikrit, stark korrodiert und limonitisiert
23 35 cm graubrauner spärlicher Spongien-Biomikrit, leicht limonitisiert
22 ca. 20 cm graubrauner Mergel mit Schwämmen
21 ca. 30 cm graubrauner, mergeliger Spongien-Biomikrit, limonitisiert, schlierig (Strömungsstruktur?)
20 40 cm graubrauner, verschwammter Mergel
19 50 cm graubrauner Spongien-Biomikrit, leicht limonitisiert
18 15 cm graubrauner Mergel mit vereinzelten Schwämmen
17 35 cm hellgraubrauner Spongien-Biomikrit, leicht limonitisiert, oberster Teil stark korrodiert
16 10 cm graubrauner Mergel
15 30 cm graubrauner Spongien-Biomikrit
14 30 cm graubrauner Spongien-Biointramikrit, limonitisiert, gegen oben in Mergel übergehend
13 15 cm graubrauner Mergel mit Tellerschwämmen
12 10 cm graubrauner Spongien-Biomikrit
11 5 cm bräunliche Mergel mit wenigen Schwämmen
10 20 cm grünlichgrauer, mergeliger Spongien-Biomikrit
9 10 cm graubrauner Mergel mit Spongien
8 45 cm graubrauner Spongien-Dismikrit
7
6 } 45 cm brauner Mergel mit Schwämmen
5 15 cm blaugrauer Mergel mit Quarz und Aufarbeitungen
4 10 cm grünlicher, glaukonitischer Spongien-Biomikrit mit Eisenooiden und Aufarbeitungen
3 ca. 20 cm rostbrauner Eisen-Oomikrit mit Aufarbeitungen und spärlichem Biodetritus, sehr stark limonitisiert und korrodiert
2 20 cm blaugrauer Echinodermen-Biomikrit, gegen oben zunehmend limonitisiert
1 dunkelgrauer Mergel ohne Fossilien

Fig. 16 Lithostratigraphic log of the Birmenstorfer Schichten, *Transversarius* Zone, Middle Oxfordian in Eisengraben, Canton Aargau, Switzerland (after Oesterle 1986). Also shown are the bed by bed positions of the samples taken by Oesterle (1986) and in 2016 by Knappertsbusch and Gradstein for study of '*Globigerina*' *helvetojurassica* Haeusler

North Atlantic Ocean

Several Deep Sea Drilling Project and Ocean Drilling Project sites have been drilled in deep marine (abyssal) Jurassic shales in the North Atlantic, and also the Pacific Ocean. None recovered in situ Jurassic planktonic foraminifera.

A good example is DSDP Site 534, on the landward side of marine Jurassic Magnetic Quiet Zone (JQZ), in the Blake-Bahama Basin. This Site established a Middle Jurassic (Bathonian-Callovian) age for the opening of the N. Atlantic Ocean (Sheridan, Gradstein 1983). The site cored abyssal (>2.7 km palaeo waterdepth, determined from backtracking ocean crust) Jurassic sediments with well preserved and common benthic foraminifera, nannofossils, radiolarians and dinoflagellates. It failed to find in situ Jurassic planktonic foraminifera. Rare, small and poorly preserved *G.* aff. *oxfordiana* specimens were obtained in Core 110 cc (Oxfordian-Kimmeridgian), interpreted as transported with gravity flows from shallower facies (Gradstein 1983). DSDP Leg 11, Site 105 in this region yielded similar observations (Luterbacher



Photograph 3 Birmenstorfer Schichten with selected sample levels in the Eisengraben Section, Canton Aargau, Switzerland

1972). Some tests are conspicuously coated with nannofossil tests.

ODP Site 901 on the Iberian Abyssal Plain, in 4718 m waterdepth, drilled a high basement block within the ocean/margin transition. The Jurassic interval is found from the top of Core 149-901A-3R to Core 149-901A-7R. Nannofossil biostratigraphy assigns this interval a Tithonian age (de Kaenel and Bergen 1996); the assemblage lacks some typical Tethyan markers, which could indicate some palaeogeographic watermass segregation from the Tethyan belt.

The Tithonian foraminifers in this site were studied by Collins et al. (1996), who failed to observe typical deep water foraminifer as found for example in DSDP Site 534 (Gradstein 1983; see above). The authors assigned the interval to a Tithonian age and neritic palaeo waterdepth in an oxygen minimum zone. Some epistominids were observed, and small and poorly preserved Jurassic planktonic foraminifera were found at several cored levels. A number of reasonably preserved individuals were assigned to *Globuligerina oxfordiana* and *G. bathoniana,* using the taxonomy of Stam (1986).

Courtesy of the ODP cores Repository in Bremen, Germany we obtained 3 new samples of this interval in Site 901 (149-901A, 3R1, 74–75.5 cm; 5R1, 142/144 cm and 6R1, 6/7.5 cm). The 5 and 6R samples suggest possible mass flow deposits with well-sorted angular quartz grains and abundant fibrous woody fragments. Sample 3R1 is a mudstone. Other than a few *Spirrilina*, *Frondicularia* and *Marginulina*, no foraminifera were observed. The assemblage is likely shallow marine.

In November 2016, Gradstein visited Dalhousie University, Halifax, N.S., Canada to study the microfossil slides with Jurassic planktonic foraminifera of Collins et al. (1996). No micropaleontology slides were located, only the small and washed residues of cores 3 and 5. The latter had been picked for the foraminifera reported, likely reason for the paucity of taxa obtained by us. *Globuligerina bathoniana* reported by Collins et al. (1996) was not found. In sample 5R1-142-144 cm, several poorly preserved and compact specimens were obtained of *G. oxfordiana* and two, poorly preserved specimens assigned to *Globuligerina tojeiraensis* Gradstein, with wide umbilicus and flaring, slender chambers in the last whorl. A dozen small, well-preserved and delicate specimens of a low trochospiral (?) benthic foraminifer are odd in this sample (not reported by Collins et al. 1969; ? contaminants).

Taxonomy

The species concept used in this study is an assemblage species concept. All specimens that form an entire, but gradual morphological range in a sample, are grouped together as one species. This provides a sound taxonomic base, since intergradational series are de-facto part of conspecificity (Mayer et al. 1953), and the concept has been widely applied in fossil and Recent foraminifera.

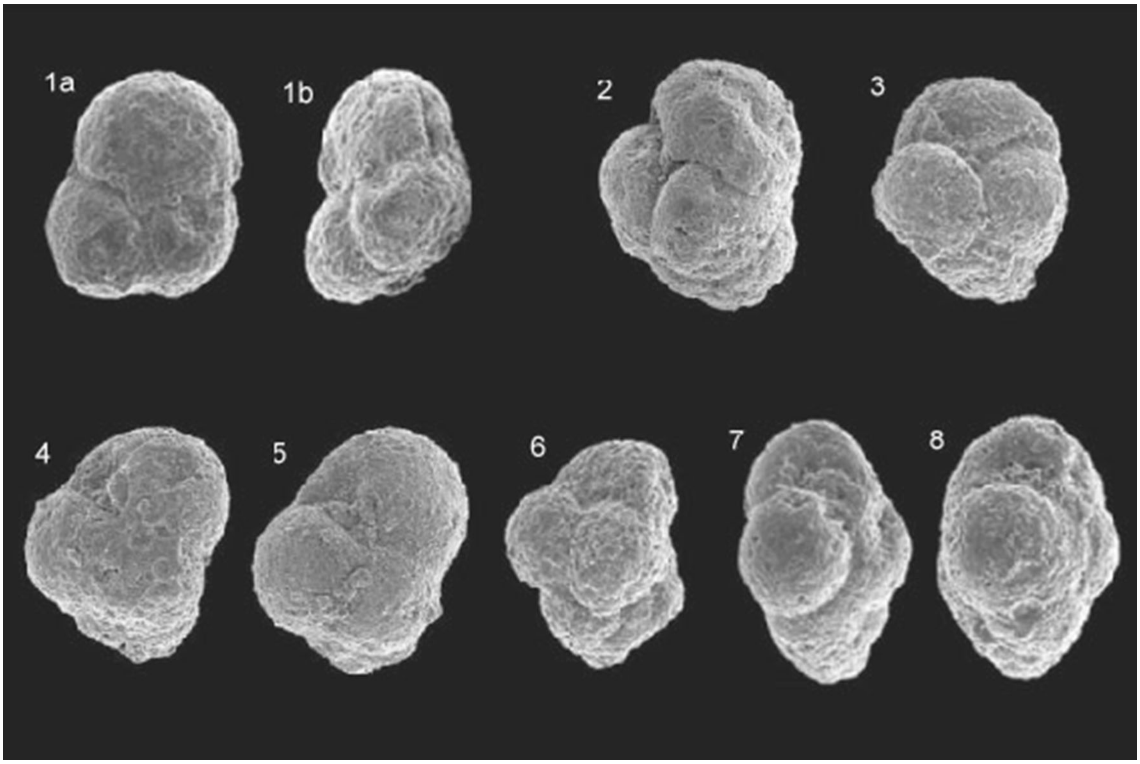
In our systematic treatment, we have tried to conform to the hierarchy of foraminiferal test features employed for Cretaceous planktonic foraminifera (CPF; Petrizzo et al. in prep). Emphasis is placed on overall building plan, chamber coiling, chamber shape, (micro-) perforation and wall surface ornamentation with pustules, pseudo murica (pointed pustules) and ridges, and network of ridges. The shape and position of the primary aperture vary within and between taxa; therefore, this feature is not ranked at a generic level. It was provided with generic rank in Simmons et al. (1979).

We refrain from more than simple use of biometric measurements, like height–diameter (*H*/*D*) ratio for taxonomy. A rigid framework of measurements is not the way to do taxonomy with this group of foraminifera having few distinguishing features.

In this study, we ignore *Globigerina gaurdakensis* Balakhmatova and Morozova and Moskalenko (1961), *Globigerina spuriensis* Bars and Ohm 1968 and *Globuligerina geczyi* Görög 1994 as being anomalously assigned to Jurassic planktonic foraminifera (see Stam 1986 and plate 2.10 in Simmons et al. 1997).

We also 'reject' as valid species all pre-Cretaceous taxa described from glauconitic casts, like *Globigerina conica*, *G. terquemi,* or recrystallized, and silicified or pyritized moulds (steinkerns). Such (pseudo-) types without original wall structure and often without clear apertural features cannot be used to describe and identify planktonic foraminifera. In the same vein, the pseudo-planktonic morphotypes from the Triassic and Jurassic of Austria (Fuchs 1975) and Crimea (Korchagin et al. 2002) are rejected. Good documentation on glauconitic cast types or pseudo-planktonics is in Stam (Stam 1986, Chapter 5) and Simmons et al. (1997). *Conoglobigerina meganomica* (Kuznetsova) 1980 and *Haeuslerina parva* (Kuznetsova) 1985 tentatively (!) dealt with in Simmons et al. (1997) are not included in our treatise. It is likely, that if good material was available these obscure taxa would be synonymized under better documented species.

'*Conglobigerina' trilocula, 'C'. biapertura, Conoglobigerina solaperta* and *C. pupa*, all new species by Wernli and Görög (2007) from the Bajocian-Bathonian of the Jura Mountains in France, need careful examination to establish their taxonomic affinity to the genus. Selected type species illustrations of these unusual species are on our Type species Fig. 1. '*Conoglobigerina' trilocula* is described as not having 'convincing' microperforation, although SEM illustrations suggest otherwise (see plate 2, fig. 10 of Wernli and Görög 2007). Its concavo-convex test with a depressed umbilical side is unusual for planktonics. '*Conoglobigerina' biapertura* as the name indicates has two apertures on the last chamber, with only 3 chambers in the last whorl; its three-chambered last whorl and possibly also its test wall surface pattern remind of *Globuligerina dagestanica* (Morozova). *Conoglobigerina solaperta* is often triserial and according to the authors the last chamber may have an apertural depression reminiscence of *Neobulimina atlantica* Gradstein. This taxon was first described from deep marine strata in the Upper Jurassic of the western North Atlantic Ocean. *Conoglobigerina pupa,* with its elongated chambers and what looks like twisted triserial coiling (?), reminds of buliminids, except for its arched shape aperture. It should be directly compared to the two small specimens described as



Type species Fig. 1 Selected taxa from the Upper Bajocian-Lower Bathonian of the French Jura Mountains. Specimens illustrated by Wernli and Görög (2007) on their plate 1 (figs. 16, 17), plate 1 (figs. 19, 22), plate 3 (figs. 1, 17, 22) and plate 4 (fig. 2). Republished with permission of the authors. Nos. *1a, b* Umbilical and side view of '*Conoglobigerina' trilocula* Wernli and Wernli (2007). Specimens in the population of this taxon are listed as being 100–130 µm high and 130–210 µm wide. Nos. *2, 3.* '*Conoglobigerina' biapertura* Wernli and Görög (2007). Specimens in the population of this taxon are listed as being 180–200 µm high and 150–180 µm wide. Nos. *4, 5, 6. Conoglobigerina solaperta* Wernli and Görög (2007). Specimens in the population of this taxon are listed as being 130–230 µm high and 130–210 µm wide. *7, 8. Conoglobigerina pupa* Wernli and Görög (2007). Specimens in the population of this taxon are listed as being 200–230 µm high and 130–150 µm wide

'Jurassic planktonic foraminifer sp.' in our study from the Oxfordian of Switzerland.

No attempt has been made to reconcile taxonomy of Jurassic planktonic foraminifera in thin sections with taxonomy using free specimens. The thin-section studies by Wernli and others (e.G. Wernli 1987, 1988) of the oldest Jurassic planktonic foraminifera are important, but should be re-attempted with modern limestone processing techniques to obtain free specimens (see for example Coccioni and Premoli Silva 2015). Only then should taxonomic classification applied, provided that wall surface patterns are preserved reasonably well.

Morphology features of tests and wall surface structures

Before we deal with the test morphology in adult specimen, it is instructive to briefly dwell on ontogentic development of tests in planktonic foraminifera. We assume that Jurassic planktonic foraminifera behave as modern foraminifera in their ontogentic development, and we have no reasons from observations of growth series to doubt that. Several recent studies look at this development in modern taxa, where Brummer et al. (1987), as enlarged upon by Caromel et al. (2016), define a five-stage model of growth in the globigerinids.

Growth begins with the prolocular stage, followed by the juvenile stage from the deuteroconch onwards, which is characterized by the addition of a number of chambers of uniform morphology. The neanic stage is initiated by abrupt overall morphological changes and represents a rapid, gradual transition towards the adult morphology, marked by changes in chamber shape, umbilical reduction and aperture position. These continue throughout the adult stage; maturity is signalled by the addition of minor but often distinct features, such as secondary apertures and further modifications in chamber shape and coiling. Growth is terminated by gametogenesis and the formation of one or two chambers highly variable in shape in the terminal stage.

The last sentence refers to the often observed kummerform last chamber with one or two apertures, often observed by us with all but one species of Jurassic planktonic foraminifera. The exception being *Globuligerina balakhmatovae*, as described below. An important consequence of the ontogenetic observations is that in pre-neanic stage tests of different species in a genus often look similar This fact is confirmed by trying to do taxonomy on Jurassic planktonic foraminifera in the less than 65 µm fraction. In our experience, the latter is a futile undertaking. This statement does not pertain to wall structure and wall texture analysis at 1–10 µm scale.

The morphology of the last whorl often is the most typical of species, particularly when the coiling axis of the last whorl or last two whorls is offset from that of the initial test stage. Late stage test wall features are often best developed over all but the last two chambers; the latter may still be rather smooth.

The morphological features of the adult tests to distinguish different fossil species are:

shape of the test
coiling mode and chamber arrangement
coiling direction
height/diameter (*H*/*D* ratio) measurement of test
shape of chambers
growth rate of the chambers
bulla and its aperture (s)
primary aperture
chamber margin
sutures
wall texture (perforation and pore mounds)
wall surface pattern (pustules, ridges, reticules, honeycomb patterns).

Jurassic planktonic foraminifera are globigeriniform trochospiral, with a high spire, medium high spire, or low spire. In *Globuligerina jurassica,* and occasionally also in *G. bathoniana*, a slightly irregular mode of coiling is observed, but no streptospiral mode. Triserial test building plans are virtually unknown (see Undetermined Planctonic Foraminifer sp.).

High spire means H/D is bigger than 1; medium high spire means H/D is approximately 1; low spired tests have an *H*/*D* ratio smaller than 1.

Both Pazdrowa (1969) and Stam (1986) made effective use of this ratio to differentiate higher and lower spired taxa; see also Grigelis (1985).

Successive chambers may grow slowly, medium rate or fast. The shape of the chambers may be:

(a) spherical with rather circular diameter,
(b) globular but a bit more irregular in shape,
(c) oval, meaning slightly elongated in a radial sense,
(d) oval and slightly flattened,
(e) reniform (kidney shaped),
(f) petaloid, meaning shaped like the individual petals in a flower,
(g) elongated in a radial sense, rounded or finger-like.

A kummerform last chamber (bulla) is common in most of the taxa. A bulla means a smaller than normal last chamber with one, or rarely two basal openings. Bullae have a smoother wall surface than the overall test, and are in umbilical position, generally covering the primary aperture of the last chamber. Hemleben et al. (1989) report that bullae are grown as a function of gametogenesis. This is in line with a lack of good evidence for megalospheric Jurassic planktonic foraminifera and of sexual–asexual dimorphism.

Sutures may be very depressed, or little depressed, and radial or (rarely) slightly curved in shape. No raised sutures were observed.

The margin of the test is almost always broadly rounded, but can be subacute, but not keeled. Tests with a weak imperforate peripheral margin have been observed, but are rare and confined to one taxon (*G. balakhmatovae*).

The aperture is umbilical or umbilical–extraumbilical in position. Apertural shape may be slit-like (rare), low arch, medium to high arch, or comma shaped. The comma-shaped aperture is asymmetrical, higher than wide and slightly bend sideways. This comma-shaped aperture is common in some taxa, but is not an exclusive feature at species level. It may have a rim surrounding it completely, or in part.

Apertural shape within one species assemblage is quite a plastic feature. Intraspecific apertural shape variation was already described by Pazdrowa (1969).

Bignot and Guyader (1971), followed by many authors, including Banner and Desai (1988) and Simmons et al. (1997), assigned a generic value to the shape and position of the aperture. In the generic classification of Banner and Desai (1988) and Simmons et al. (1997) *Conoglobigerina* has an intraumbilical, interiomarginal, low arch aperture, and *Globuligerina* an intraumbilical, interiomarginal comma-shaped and high aperture. This generic classification based on apertural shape and position is not followed in our study. As mentioned earlier, it would split natural assemblages (populations) of, for example *G. oxfordiana* and of *G. bathoniana,* into two genera.

To further clarify this observation, we quote M.R. Petrizzo and B. Huber, who in personal communication in 2016 to Gradstein stated that apertural shape and position are not criteria to be used at genus level. For example, *Guembelitria* is characterized by being triserial, and having a microperforate to maybe finely perforate wall texture, but a highly variable apertural shape. The aperture is a feature that might be used at species level, but is quite a plastic feature even in the same species.

The aperture generally has a thickened rim. As far can be observed, apertural shape does not change in (or vary) in immediately older chambers in the same test.

The wall texture (perforation) of planktonic foraminifera may be microperforate (pore diameter <1 μm), finely perforate (pore diameter 1–2.5 μm, normally spaced), or macroperforate (pore diameter >2.5 μm, closely spaced).

Jurassic planktonic foraminifera are exclusively described as being microperforate, meaning the outer wall of the test is characterized by having pores with a diameter of less than 1 μm to max 1.5 μm. Our observations, as far as possible, confirm the microperforate wall structure.

Although the wall of Jurassic planktonic foraminifera is almost always calcitic, this is widely described to be due to post-mortem change from aragonite to calcite. In this, we follow how Simmons et al. (1997) typify Jurassic planktonic foraminifera, whose authors succinctly write: ‘We consider them to belong to the Favusellacea, the aragonitic, microperforate, pseudomuricate superfamily, with an umbilical aperture, and all the adult chambers of all of these species are subglobular in shape. Although it has to be demonstrated if this superfamily is monophyletic, these features distinguish it from the globigerinids in the mid and late Cretaceous and Cenozoic that have tests of calcite and are medium to macroperforate, with or without spines’.

The character of the wall structure has been investigated for the ‘popular’ and widespread taxa *G. oxfordiana* and *G. bathoniana* (Pazdrowa 1969; Gorbachik 1983; Simmons et al. 1997). During the formation of chambers, the wall extends back over the older chambers; the wall itself is bilamellar, with a radial crystalline prismatic build-up; microcrystals are covered with an organic membrane.

The wall texture and wall surface patterns are not easy to study, since much of our material is not perfectly preserved, and may have secondary calcite overgrowth of tests. Simmons et al. (1997) illustrate well-preserved aragonitic tests, and their wall surface features are taken into account for our study.

Due to this post-mortem test calcification during fossilization, wall surface pattern is a more difficult feature to describe. We rarely observed a smooth pattern, like in some tests of *G. oxfordiana* and *G. balakhmatovae.* A rather smooth test is more common in smaller (ontogenetically younger) tests.

Wall surface pattern frequently consists of (densely) scattered smaller or larger irregular pustules (calcitic mounds of various shapes). These pustules may be blob-like blunt or pointed; pustules may grow in size in older chambers; pointed pustules are rare. Pustules may align to form discontinuous ridges (costae). These ridges again may align to form an irregular, reticulate pattern. Real honeycomb shaped, cancellate reticulation appears only with *Favosella hoterivica* (Subbotina) in earliest Cretaceous time.

The term muricate is often used in description of a wall surface that is densely studded with short rough points. Scanning electron microscope illustrations in our plate of type *G. oxfordiana* in the Jotija borehole, Lithuania and in Shatrishche, Central Russia suggest that these muricae are folds of the outer wall to form a conical structure. It is possible that, with very good preservation of tests, G. *oxfordiana* may be split in subspecies using different type of

Table 2 Listing of key Jurassic and one Early Cretaceous planktonic foraminiferal species, with their type locality and age (after original description)

Species	Type-locality	Zone or taxa	Age
C. gulekhensis (Gorbachik and Poroshina 1979)	Azerbaijan		Early Berriasian
C. grigelisi (Gradstein 2017a, b)	Montejunto region, Estramadura, Portugal	Planula to Platynota Zones	Early Kimmeridgian
G. tojeiraensis (Gradstein 2017a, b)	Montejunto region, Estramadura, Portugal	Planula to Platynota Zones	Early Kimmeridgian
C. helvetojurassica (Haeusler 1881), emended (Gradstein 2017a, b)	Birmensdorfer Schichten, Aargau, Switzerland	Transversarius Zone	Middle Oxfordian
G. oxfordiana (Grigelis 1958), emended (Bignot and Guyader 1971)	Lithuania + Normandy France	Mariae and Cordatum Zones	Early Oxfordian
G. calloviensis (Kuznetsova 1980)	Meganom Peninsula, Eastern Crimea (USSR)	Macrocephalites macrocephahis Zone	Early Callovian
G. bathoniana (Pazdrowa 1969)	Ogrodzieniec, Poland	Morissi Zone	Middle Bathonian
G. dagestanica (Morozova 1961)	Mogokh Beds, Chokh, Central Dagestan	C.dagestanica Zone	Bathonian
G. balakhmatovae (Morozova 1971)	Mogohk Beds, Chokh, Dagestan	C.dagestanica Zone	Early Bathonian
G. jurassica (Hofman 1958)	SE Crimea (USSR)		Bathonian–early Callovian
G. avariformis (Kasimova 1984)	Azerbaijan		Late Bajocian

wall structure ornamentation. These subspecies might be of stratigraphic use also.

The images of well-preserved *Globuligerina oxfordiana, G. bathoniana* and *G. tojeiraensis* (see section on Taxonomy) show pore mounds, a feature not observed in *Conoglobigerina.* Pore mounds are like 'volcanos' that surround the pores and are associated with microperforate *Guembelitriid* taxa. The feature is also found in some (but not all) Aptian hedbergellids. The function of the pore mounds is not clear (Petrizzo personal communication to Gradstein 2016), and it is not understood either if there is a relationship between the position or type of primary aperture and the distribution of the pore mounds.

In our free specimens material, it was not possible to distinguish thin- or thick-walled tests (Wernli 1987, 1988).

Genera and species

Two microperforate genera are distinguished: Medium high-spired *Conoglobigerina* with reticulate wall surface texture and low- to high-spired *Globuligerina* with almost smooth to pustulose wall. *Globuligerina* probably appeared in late Toarcian (late Early Jurassic) and *Conoglobigerina* first occurred in middle Oxfordian (early Late Jurassic). The generic description follows Gradstein (2017a).

There are 10 Jurassic species and one Berriasian, earliest Cretaceous species among these genera, listed in Table 2 with their type locality and relative age.

Genera

Conoglobigerina Morozova 1961, emended

Test trochospiral, low to medium high spired (H/D ratio 0.5–1, rarely over 1); final whorl may be compact or more open in shape. Chamber shape globular, rounded, rarely slightly irregular with 3.5–4 chambers in last whorl. Chambers of the last whorl strongly embrace previous whorls. Apertural shape variable, low arch or slit; mostly umbilical, but may be slightly extraumbilical in position. Wall microperforate, with small or larger, blunt pustules; pustules fuse to form ridges that are organized in broken cells that form an imperfect reticulate pattern.

In 1961, Morozova and Moskalenko defined the subgenus *Globigerina (Conoglobigerina)* with test diameter smaller than test height, and the subgenus *Globigerina (Eoglobigerina*) as small specimens with a very short spire. The latter subgenus has subsequently been abandoned. The genus *Eoglobigerina* Blow itself is a Cenozoic taxon; for taxonomic and phylogenetic reasons

This genus name cannot be used in the Jurassic.

Simmons et al. (1997) restricted the genus *Conoglobigerina* to forms having an intraumbilical, interiomarginal and low arch aperture, like *C. dagestanica* and *C. balakhmatovae* and *C. gulekhensis*. In the latter, pustules have fused to form short ridges that are organized in a broken cell pattern, close to a reticulate cancellate pattern. In this, *C. gulekhensis* is considered an intermediate between non-reticulate Jurassic taxa and the Cretaceous favusellids with a honeycomb, cancellate wall pattern, like *Favusella hoteriva* and *F. washitensis*.

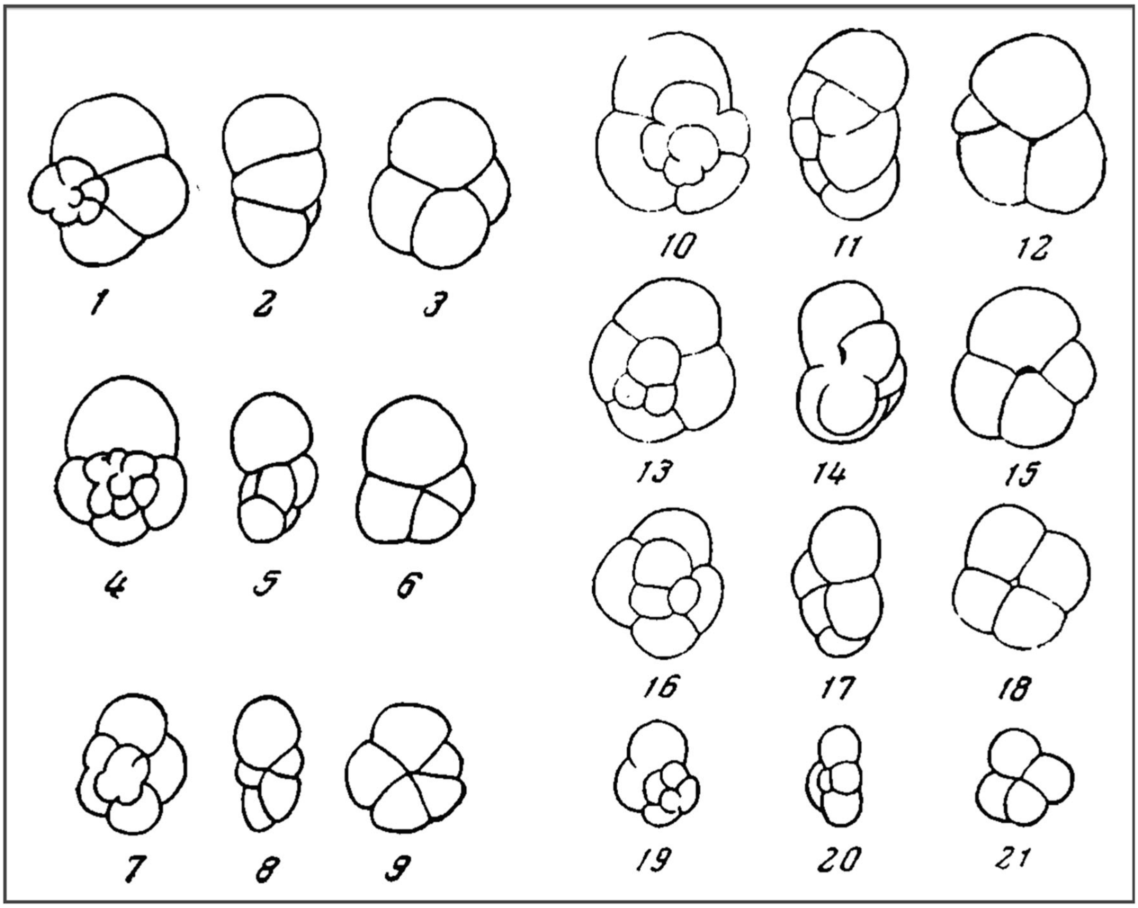
In our study, weight on a genus level is given to wall surface pattern and whorl embracement. *Conoglobigerina* is medium trochospiral, with an irregularly reticulate wall surface pattern. In our material, the genus includes three species: *C. helvetojurassica*, *C. grigelisi* and *C. gulekhensis*, with the first two occurring in Late Jurassic and the latter (as far as known) in earliest Cretaceous time. *C. helvetojurassica* has a large last whorl with four big, globular chambers; *C. grigelisi* has a strongly embracing last whorl. The wall surface pattern in both taxa is reticulate. From wall surface patterns, some specimens of *Globuligerina oxfordiana* may be intermediate between non-reticulate *Globuligerina* and reticulate *Conoglobigerina.*

The rather compressed and cancellate tests described by Görög and Wernli (2013) from the Early Kimmeridgian of the French Jura, possibly assigned to *Favusella hoterivica*, fit in our description of *C. helvetojurassica.*

Globuligerina **Bignot and Guyader 1971, emended**
Test trochospiral, low to medium to high spired (*H*/*D* ratio varies between 0.5 and 1.5). Mostly 4 and rarely 3–4 or only 3 chambers in the last whorl. Chamber shape globular or somewhat flattened, or may be oblong, elongated in a radial sense. Chambers rarely show an equatorial imperforate band. Apertural shape variable; often a medium to high arch; the arch may be an asymmetrical arch or comma shaped; aperture rarely a slit; aperture position mostly umbilical, but may be slightly extraumbilical. The aperture has a thickened and imperforate rim (lip) that may circle the aperture (as observed in well-preserved *G. oxfordiana*). Wall microperforate, smooth to pustulose; pustules may be pointed (pseudomuricae), or blunt; pustules may have pore mounds; pustules may fuse to form ridges.

Taxa include G. dagestanica, *G. avariformis*, *G. balakhmatovae, G. oxfordiana subspecies calloviensis, G. oxfordiana, G. tojeiraensis*, *G. bathoniana and G. jurassica*. *Globuligerina oxfordiana* first described from Lithuania by Grigelis (1958) is the type species of the genus.

A special case is the species *Globuligerina calloviensis* Kuznetsova, (placed as subspecies under *G. oxfordiana*) with an almost smooth wall. It is tentatively included in this genus pending more study of its wall structure and



Type species Fig. 2 Original drawings in Morozova and Moskalenko (1961) of *Globigerina balakhmatovae* Morozova from Upper Bajocian of Turkmenia (nos. *1–3*) and Lower Bathonian from Central Daghestan (nos. *4–12*); holotype in nos. *4–6*. All drawings magnification ×100 (absence of) wall sculpture. The smooth tests suggest that the outer shell is almost not preserved. At present, it is only known from the Callovian of the Crimea.

Although only thin-sectioned tests and no free specimens have been described from the Toarcian through Aalenian interval, we assume the literature from that stratigraphic interval is dealing with the genus *Globuligerina*.

The genus name *Globuligerina* was proposed in 1971. In that year, G. Bignot and J. Guyader (reprinted in the Proceedings of the II Planktonic Conference in 1970 in Rome), using their French specimens, erected the subgenus *Globuligerina* under the genus *Globigerina* with a slightly loop-shaped (bulimine) aperture with a little lip. *Globigerina oxfordiana* Grigelis 1958 (Note: Not 1956 as Bignot and Guyader write) emended is named type species.

This was the beginning of the use of apertural shape for generic definition in Jurassic planktonic foraminifera (Grigelis and Gorbatchik 1980; Banner and Desai 1988), despite the fact that already Pazdrowa (1969) reported that in *G. bathoniana* the apertural shape varies from symmetrical low arch to symmetrical high arch to comma shaped (looped or bulimine or comma shaped). Grigelis (1974) and types of the species in the section on Taxonomy clearly show a comma-shaped aperture for *G. oxfordiana,* but arched apertures are common also.

Species

Globuligerina balakhmatovae (Morozova) 1961

Type species Fig. 2. Plate 1, nos. 7–16; Plate 2, nos. 1–8; Plate 3, nos. 1–6.

1961 *Globigerina (Eoglobigerina) balakhmatovae* Morozova. Vopros.

Mikropal 5, p. 23; fig. 5, 1–21; plate 1, figs. 1–9, 11 and 12.

1971 '*Globigerina' balakhmatovae* Morozova. Brönnimann and Wernli, p. 121; plate 1, figs. 1–4; plate 4, figs. 1, 2.

1986 *Globuligerina balakhmatovae* (Morozova). Stam, p. 112; plate 11, figs. 11, 12; plate 12, figs. 1–8.

1997 *Conoglobigerina balakhmatovae* (Morozova). Simmons et al., p. 23–24; plate 24, figs. 7–12, 16.

Description Test small, less than 150 μm. Low spiral test, consisting of two whorls, the first small one with 4, rarely 3–5 chambers and the final, much larger and wider one with 4 chambers; *H/D* ratio about 0.5. Chambers mostly globular, rounded, but in the last whorl may become slightly compressed along their height (flattened), giving an ovate chamber shape (Plates 2, 3). Last whorl chambers wide in an equatorial sense, petaloid and resembling a 'flower'. Umbilicus slightly open. Sutures between the chambers weakly depressed, straight in the last whorl. Specimens have no bulla. In Grand Banks and Portuguese samples, rare specimens occur with an imperforate peripheral band (Plate 2); aperture small, a half circle arch or low arch, with narrow rim; wall surface shiny or matte, smooth to finely pustulose in Middle Jurassic strata and may become coarse pustulose with fused ridges in Kimmeridgian sediments (see Plate 3).

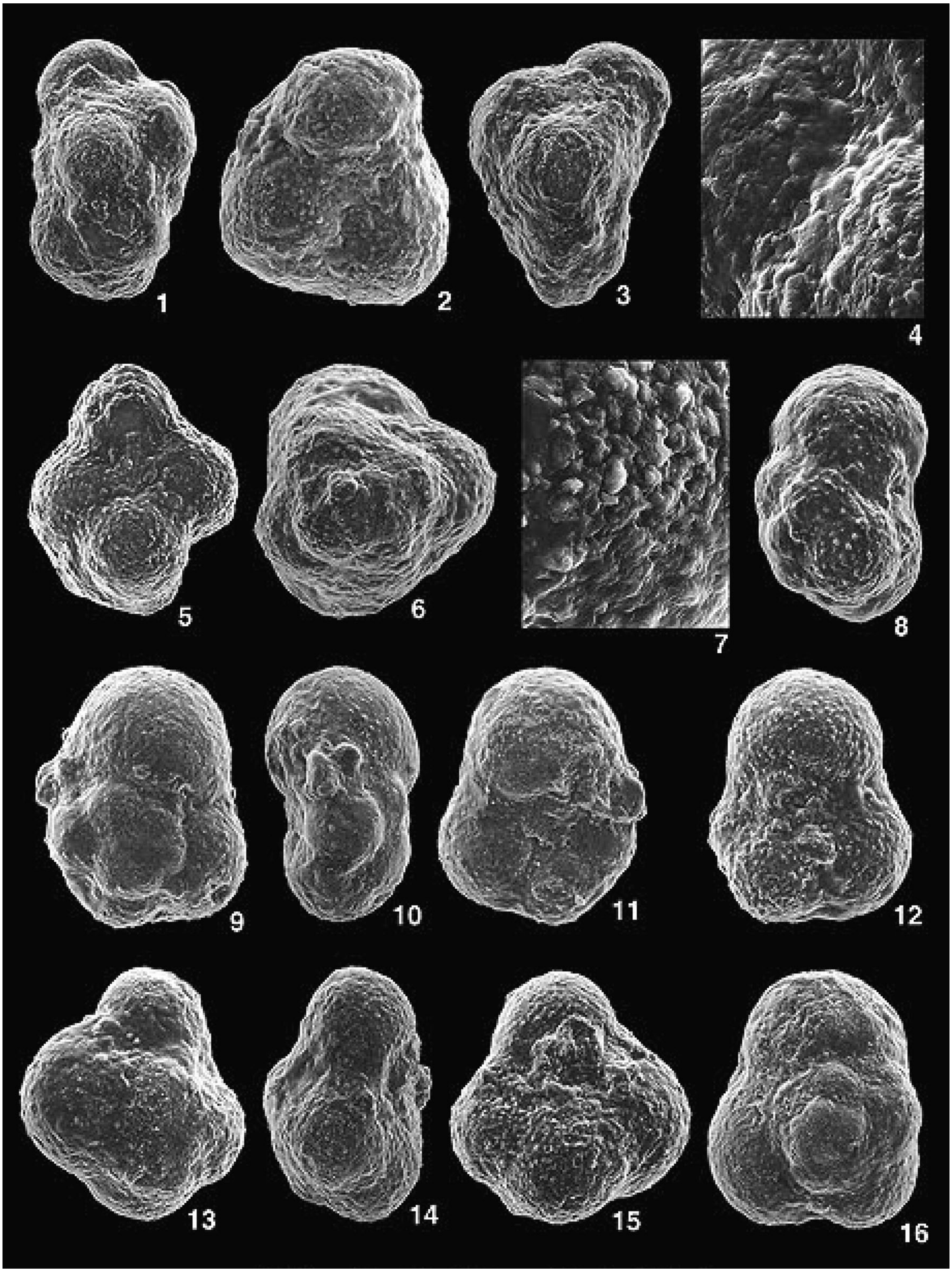
Discussion This is the only species and morphotype with a low spire and globular rounded to ovate chamber shape, a small, rounded aperture, and no bulla. The test surface in stratigraphically older material is smoother than in other Jurassic planktonic foraminiferal taxa. Flattening of the chambers is observed both in the Grand Banks and in the Portugal material. It was also mentioned in the description by Morozova and Moskalenko (1961) and by Bignot and Guyader (1966) for the Middle Jurassic type specimens in Dagestan. Flattening of the test is not the result of post-mortem compaction.

Comparison of the Bathonian type assemblage from Dagestan and the Grand Banks and particularly the Kimmeridgian specimens of this taxon suggests either an evolutionary trend to more ovate chambers and more flaring and lobate, flatter last whorl, or a geographic morphological differentiation. The Dagestan specimens often have more rounded chambers. Wall surface texture shows a trend to coarser pustulose texture in stratigraphically younger specimens (Plate 3). A more quantitative study of test variation, counting specimens with specific characters, is warranted to clarify these morphological trends.

In the Tojeira shales of Central Portugal (Early Kimmeridgian), morphological transitions occur between *G. balakhmatovae* and *G. tojeira*ensis. Such specimens have a slightly more open umbilicus, the last whorl is less petaloid and chambers more spherical globular and stretched out than in *G. balakmatovae* sensu strictu.

Plate 1 (=Plate 2.4 in Simmons et al. 1997). Nos. *1–6*, *Globuligerina dagestanica* (Morozova) 1961 (originally published as *Conoglobigerina avarica* Morozova 1961), Early Bathonian, central Dagestan. Specimens deposited in the Geological Institute of the Academy of Sciences of Russia, Moscow. No. *1* (no. 3513/3) height of spire 170 μm, ×235. Nos. *2*, *3*, height of spire 150 μm, ×265. No. *4* (no. 3513/24) enlargement of the wall surface, ×1100. No. *5*, umbilical view, ×285. No. *6* (no. 3513/19) specimen diameter 180 μm, spiral view, ×220. Nos. *7–16*, *Globuligerina balakhmatovae* (Morozova) 1961 (published originally as *Conoglobigerina balakhmatovae*), Early Bathonian, central Dagestan, holotype and paratypes in the Geological Institute of the Academy of Sciences, Russia, Moscow. No. *7*, paratype (no. 3514) enlargement of the surface showing microperforations and pustules, ×1500. Nos. *8*, *12*, paratype (no. 3513/19) specimen diameter 120 μm, ×335. Nos. *9–11*, holotype (no. 3513/1), specimen diameter 180 μm, ×285. Nos. *13–15*, paratype with slightly ovate chamber shape, specimen diameter 140 μm, ×265. No. *16*, spiral view of paratype showing two whorls with rapidly enlarging chambers, ×220

▶


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

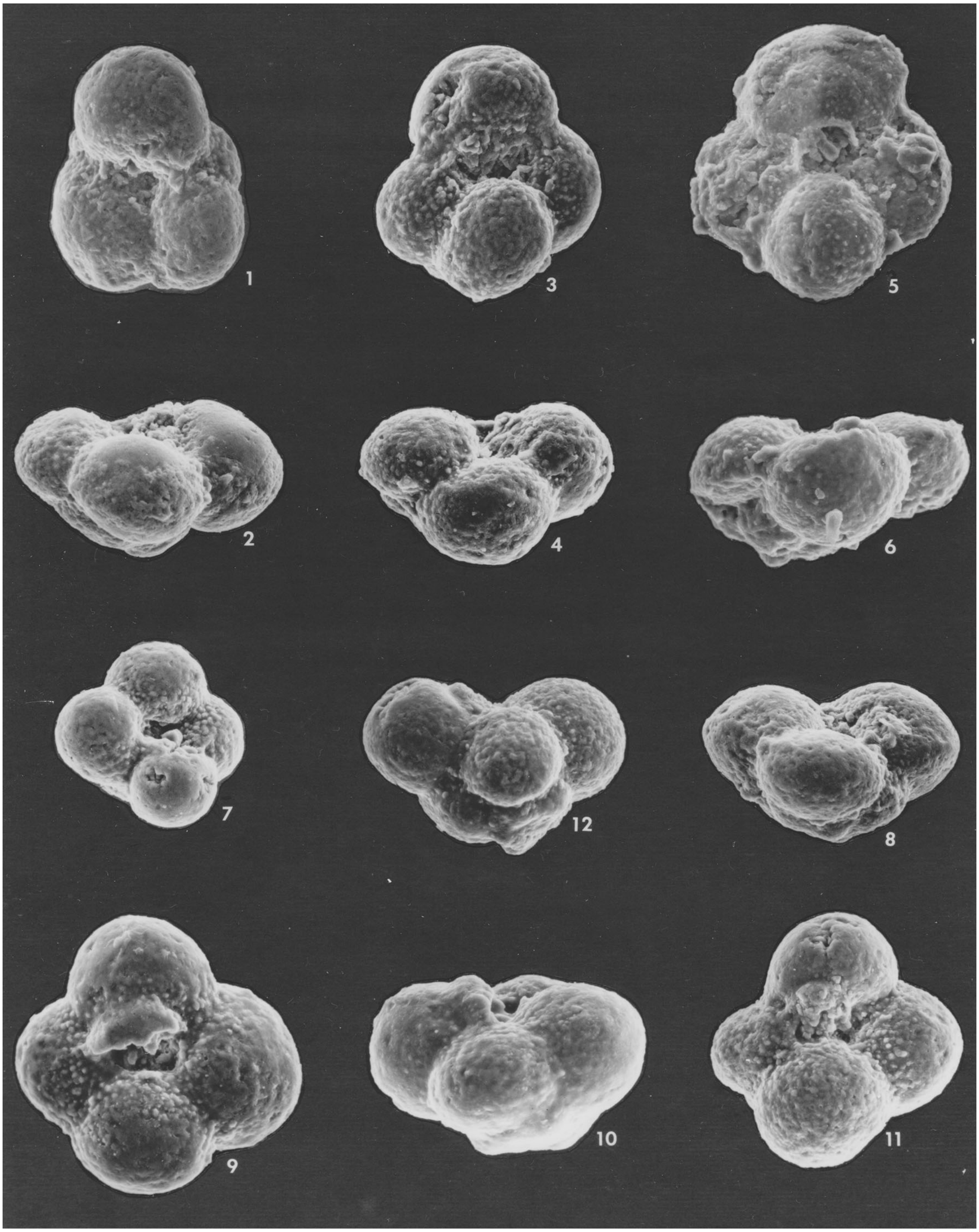


Plate 2 (=Plate 12 in Stam, 1986). Nos. *1*, *2*, *8*, *G. balakhmatovae*, Murre G-67 well, swc. 5230′, *Reinholdella* spp. Zone, Late Bathonian, ×200. No. *8* shows an almost keeled specimen with imperforate equatorial band. Nos. *3–7*. Eider M-75 well, cts. 8260–8290′, *Garantella* spp. Zone, Bajocian-Bathonian, ×200. Nos. *9–12*, *Globuligerina bathoniana* (Pazdrowa), Eider M-75, cts. 8260–8290′, *Garantella* Zone, Bajocian-Bathonian. Nos. *9*, *10*, ×240; Nos. *11*, *12*, ×200; note a partial bulla-like structure on both specimens

Stam (1986) observed that *G. balakhmatovae* resembles *G. oxfordiana*, from which it differs in having less inflated chambers, a subglobular to ovate outline in sideview, and occasionally an imperforate band. The latter feature appears unique to the Grand Banks and Portugal.

The holo- and some paratypes (Nos. 7–16 on Plate 1) are from shales in the upper ‘band’ of the Mogokh beds, Lower Bathonian, near the village of Chokh, Dagestan. The foraminiferal assemblage is also rich in epistominids and discorbids. The specimens are rather globular in chamber shape, which does not reflect the variation in chamber shape observed in the type samples from Khouroukra, Dagestan. In the latter also rather flat specimens occur with more ovate chambers. Brönnimann and Wernli (1971) also illustrate the variation from more globular to more ovate chambers shape in the same assemblage.

More data are needed to decide if the change from smooth to finely pustulose wall texture to coarser pustulose with fused ridges is an evolutionary trend or a local ontogenetic feature (see Plate 3).

Wernli and Görög (2007) provide an excellent description and illustrations of specimens referred to *G. balakhmatovae* from the Upper Bajocian through Upper Bathonian of the French Jura Mountains. The reason that this remarkable finding is not taken up in the formal taxonomic references under this taxon above is due to several unique morphological features. Firstly, specimens occur (but not all) with a looped aperture, never observed in any of our well-preserved material of *G. balakhmatovae*, including the types. Secondly, the test is weakly concavo-convex, with the umbilical face depressed, a feature virtually absent in typical *G. balakhmatovae*. Thirdly, the equatorial outline of the last whorls is rather rounded and not lobate and petaloid, but we agree that this feature may vary regionally. The authors propose a morphological transition from *Oberhauserella* aff. *parocula* Wernli and Görög (see Type species Fig. 3) to *Globuligerina balakhmatovae.*

Palaeoecology Stam (1986) postulated that higher spired forms like *G. bathoniana* occur in shallower marine sections than *G. balakhmatovae*. None of the rich and diverse Jurassic planktonic foraminifera assemblages from Portugal or Grand Banks are from deep marine settings, like middle bathyal or deeper.

Range Late Bajocian of Turkmenistan and Early Bathonian of Dagestan; Bathonian through Callovian (or Early Oxfordian) of Grand Banks; Late Bajocian–Late Bathonian in the French Jura and Early Kimmeridgian of Portugal.

Globuligerina dagestanica **(Morozova) 1961**

Type species Fig. 4. Plate 1, nos. 1–6; Plate 4, nos. 1–10; Plate 5, nos. 1–13.

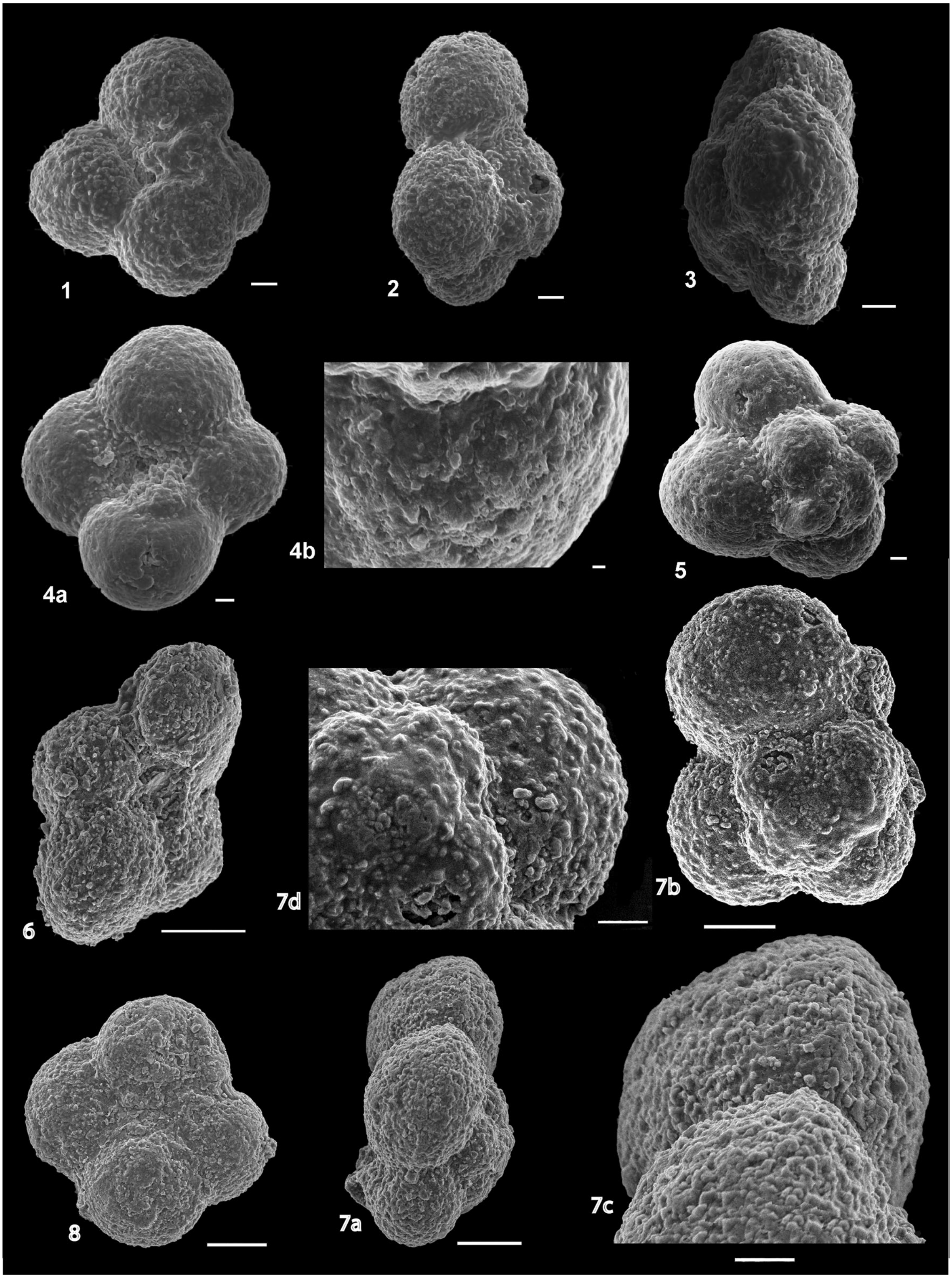
1961 *Globigerina dagestanica* Morozova. Voprosy Mikropal. (french translation), p. 24–26; fig. 7; plate 1, figs. 10, 13,15; plate 2, figs. 14–19.
1961 *Globigerina (Conoglobigerina) avarica* Morozova, p. 26, 27; plate 2, figs. 1–13; p. 21, fig. 8.
1984 *Globuligerina araksi* Kasimova. Kasimova and Ayileva, pp. 12–13, fig. 10a–c.
1997 *Conoglobigerina dagestanica* Morozova. Simmons et al., p. 20, 22, plate 2.3, figs. 1–13; plate 2.4, figs. 5, 13–15.
1997 *Conoglobigerina avarica* Morozova. Simmons et al., p. 22, 23, plate 2.4, figs. 1–4.

Description The original description by Morozova and Moskalenko (1961) mentions a highly variable morphology regarding the number of chambers in the last whorl, height of test and shape of the trochospire. Typically, the diameter of the test is about the same as the height, or the test is higher than wide. As seen from the apex (first chambers) upwards to the third and last whorl, the test may be slightly triangular in outline. Up to 5 chambers in the initial (often very small) whorls and 3–4 in the final (third whorl) which increases rapidly in width and height; chambers subglobular in shape with straight sutures; the intraumbilical aperture is a low to medium high symmetrical arch. Type species Fig. 4 shows the original drawings of the species by Morozova, with drawings 1–3 referred to as holotype, showing 3 chambers in the last whorl. Topotypes illustrated here (Plate 4) also show a medium high test, with rapidly expanding last whorl containing 3 or 4 chambers.

Simmons et al. (1977) mention that the surface of the test wall is covered with pseudomuricae, which often fuse laterally into very short ridges, and that the aperture is a low, intraumbilical arch, without lip. Our Plate 5 shows the original types as re-illustrated by these authors; the holotype in Nos. 5–7 on this plate has 4 and not 3 chambers in the last whorl, stated above.

In our topotypic material of the Khouroukra Section, collected by Larisa Glinskikh, a majority of specimens is also about as high as wide, but higher or wider specimens also occur. The test shape may be quite variable, with many specimens having a rather irregular, deformed test. There are specimens with 3, 3–4 and 4 chambers in the last whorl; aperture is generally a low arch, and rarely a bit higher, and sometimes looped. Apertures have a thickened rim around it, above the umbilicus. A small bulla may be present. Plate 4 illustrates test shape variation; it also shows the wall surface to be intricately covered with criss-cross ridges. The criss-cross ridges effect may in part be due to slight etching. SEM illustrations of topotype *G. dagestanica* provided by L. Kopaevich show mostly a pustulose wall surface pattern, with few ‘etched’ areas on some specimens. Both Kopaevich and Glinskikh consider the etching to be a natural phenomenon and not due to the standard and gentle laboratory washing of the samples.

Morozova and Moskalenko (1961) mention that its morphological variability is an essential and distinctive characteristic of *G. dagestanica*. This is in agreement with what we observe in the Khouroukra section. Despite this observation, specimens with height larger than diameter are referred by Morozova and Moskalenko (1961) and Simmons et al. (1997) to the species *Conoglobigerina avarica* Morozova (1961), with 3 or 3–4 chambers in the final


1
2
3
4a
4b
5
6
7d
7b
8
7a
7c

◀**Plate 3** *Globuligerina balakhmatovae* (Morozova) in Middle and Late Jurassic strata. Nos. *1*, *4a*, *4b* and *5*, cuttings sample 8360 ft. Eider well, Grand Banks, Bajocian-Bathonian; umbilical view and spiral views with 10 µm *scale bar* and wall texture image with 2 µm *scale bar*. Wall texture varies from relatively smooth to densely pustulose, with pustules merging into short ridges. No. *2*, sample 24/2P, Tojeira Fm. Montejunto, Portugal, early Kimmeridgian; *scale bar* 20 µm; 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. *6–8*, Tojeira Formation, Montejunto, Portugal, early Kimmeridgian. No. *6*, oblique umbilical view with low arch aperture with lip, sample T1/4 Gradstein sampled 2016. Nos. *7a*, *c*, side view with ovate last two chambers becoming almost pointed and coarse pustulose to irregularly reticulate wall on umbilical face; sample 24/2P; nos. *7b*, *d*, spiral view and enlarged, coarse pustulose wall texture

whorl. In our rich topotype material from Khouroukra, such specimens are also present, and form part of an ontogenetic series that grades from lower spire to higher spire, and than show a simultaneous decrease in the number of chambers in the final whorl. Hence, we prefer to lump *G. avari*ca in with *G. dagestanica. G. araksi* Kasimova is also lumped in with the latter.

Morozova and Moskalenko (1961) also refer to the Recent *Globigerinita bradyi* (Wiesner) as a morphologically similar, albeit smaller size species. *Globigerinita bradyi* (see our Plate 8, nos. 13–16) in the modern oceans sometimes displays a long test (Herb 1968, p. 479, figs. 7, 8), with a last whorl with fewer chambers than in earlier whorls. Herb (1968) mentions such a gerontic shape for about half of the many specimens encountered in Drake Passage, Southern Ocean.

The 20 or so specimens described by Wernli and Görög (2007) under *Globuligerina* aff. *dagestanica* (Morozova) from the Upper Bajocian through Lower Bathonian of the Southern Jura Mountains in France are more triangular in outline and have less globose chambers. More comparative study is warranted to ascertain whether or not *G. dagestanica* also occurs in France.

Range Late Bajocian through Bathonian, possibly already occurring in Early Bajocian (Wernli and Görög 1999, 2000). Morozova and Moskalenko (1961) reported it from Dagestan and Turkmenia, and Kasimova and Ayileva (1984) from Azerbaijan. Given the overlap in test morphology of *G. bathoniana* and *G. dagestanica*, it is well possible to find *dagestanic*a-type specimens over a much wider stratigraphic and geographic range than provided in the literature (for example in the Kimmeridgian Tojeira Formation of Portugal). This fact underlines the problem in creating a stratigraphically meaningful species concept for Jurassic planktonic foraminifera.

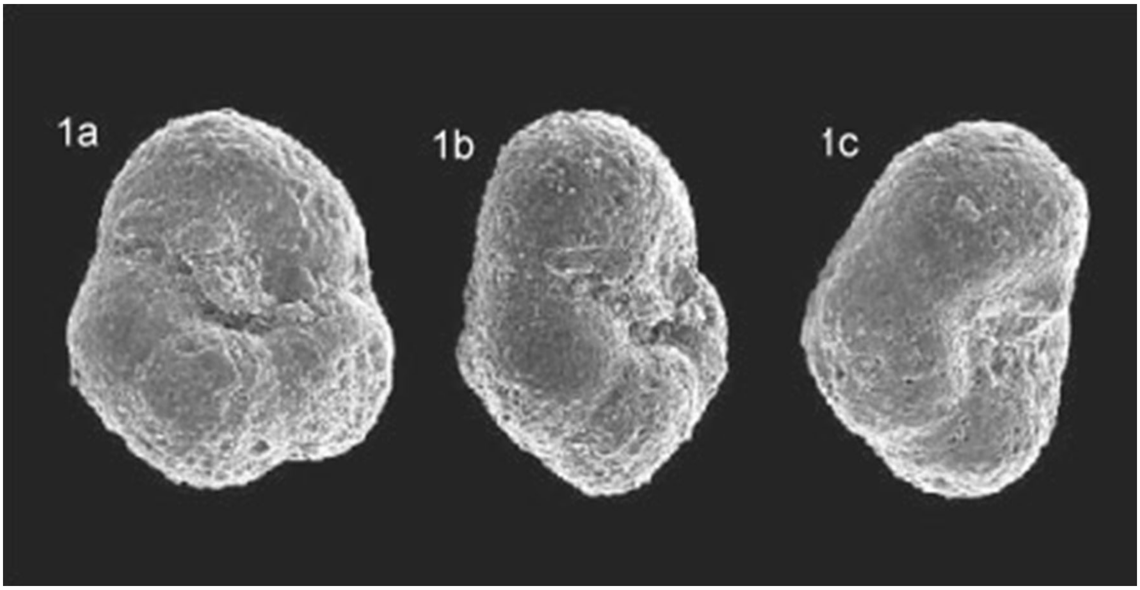
***Globuligerina jurassica* (Hofman) 1958**

Plate 6, nos. 10–13

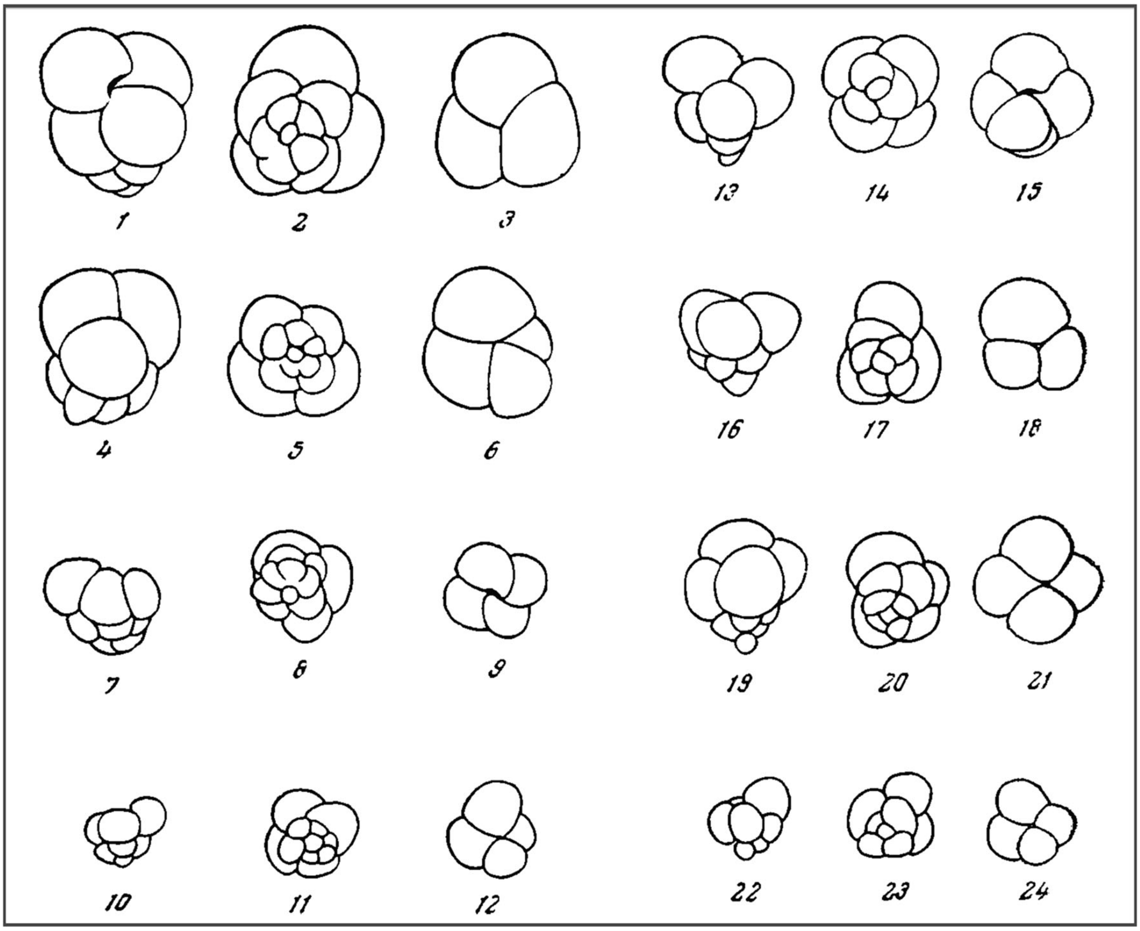
1958 *Globigerina jurassica* Hofman. p. 125, 126, text-figs. a–c.

1997 *Conoglobigerina jurassica* (Hofman). Simmons et al., p. 25, plate 2.7, figs. 11–14; plate 2.8, fig. 3.

Description The original description by Hofman refers to a small test of 3 whorls, chambers regularly enlarging in younger whorls, and 3–4 chambers in the last whorl.



Type species Fig. 3 Three views of same specimen. *Oberhauserella* aff. *parocula* Wernli and Görög (2007) from the Upper Bajocian-Lower Bathonian of the French Jura Mountains. Specimen illustrated by Wernli and Görög (2007) on their plate 2 (nos. *7–8*). Specimens diameter in the small population of this taxon is listed around 200 µm. Re-published with permission of the authors



Type species Fig. 4 Original drawings of *Globigerina dagestanica* Morozova (1961). Specimens from the lower Bathonian of Central Daghestan. Holotype in nos. *1–3*, with 5 chambers in whorl one, 4 chambers in whorl two, and 3 chambers in the final whorl. Specimen nos. *13–15* has an initial triloculine whorl, specimen nos. *16–18* is triloculine, and specimens nos. *19–24* totally quadriloculine. All drawings magnification ×100

Chambers may be arranged somewhat irregularly in the trochoid coil. Sutures are straight, aperture is a small and elongated slit; wall microporous. Dimensions are a height of about 100 µm and a diameter of 120 µm. The original illustration does not differ much from some specimens described as *G. dagestanica* by Morozova (1961). This is confirmed by the SEM illustration of the neotype (the holotype is lost) selected for this taxon by Simmons et al. (1997). The latter reports: the neotype is high spired with four chambers in the last whorl. The aperture is intraumbilical, covered by a bulla, with two accessory openings. The wall surface is covered with pseudomuricae, which occasionally fuse into very short, disconnected ridges.

None of the above features would make it clear that *G. jurassica* differs from some irregularly coiled or slightly aberrant specimens assigned to *G. dagestani*ca, or even to *G. bathoniana*. Hence, a more detailed study of the original material of Hofman and topotype material from Crimea is desirable to confirm this taxon as an independent entity. The test dimensions reported of the neo- and paratype by Simmons et al. (1997) are almost double that of specimens described by Hofman (1958). Such large specimens are unusual in Jurassic planktonic foraminifera; maybe this large test size is in error (a possibility acknowledged by Simmons, personal communication to Gradstein 2016).

Range Decribed originally from the Bathonian-Early Callovian of SE Crimea. Rare specimens resembling *G. jurassica* have been observed by us in the Oxfordian of the Birmenstorfer Schichten, Switzerland, the Kimmeridgian of Portugal and the Bathonian of the Grand Banks. A lack of large assemblages with characteristic morphological data precludes firm taxonomic assessment.

Globuligerina bathoniana (Pazdrowa) 1969

Type species Figs. 5 and 6; almost specimens on Plates 7, 8, 9 and 10.

1969 *Globigerina bathoniana* Pazdrowa. Ann. Soc. Geol. Pologne 39 (1–3), p. 45–52, text figs. 1–16, plates 2–4.

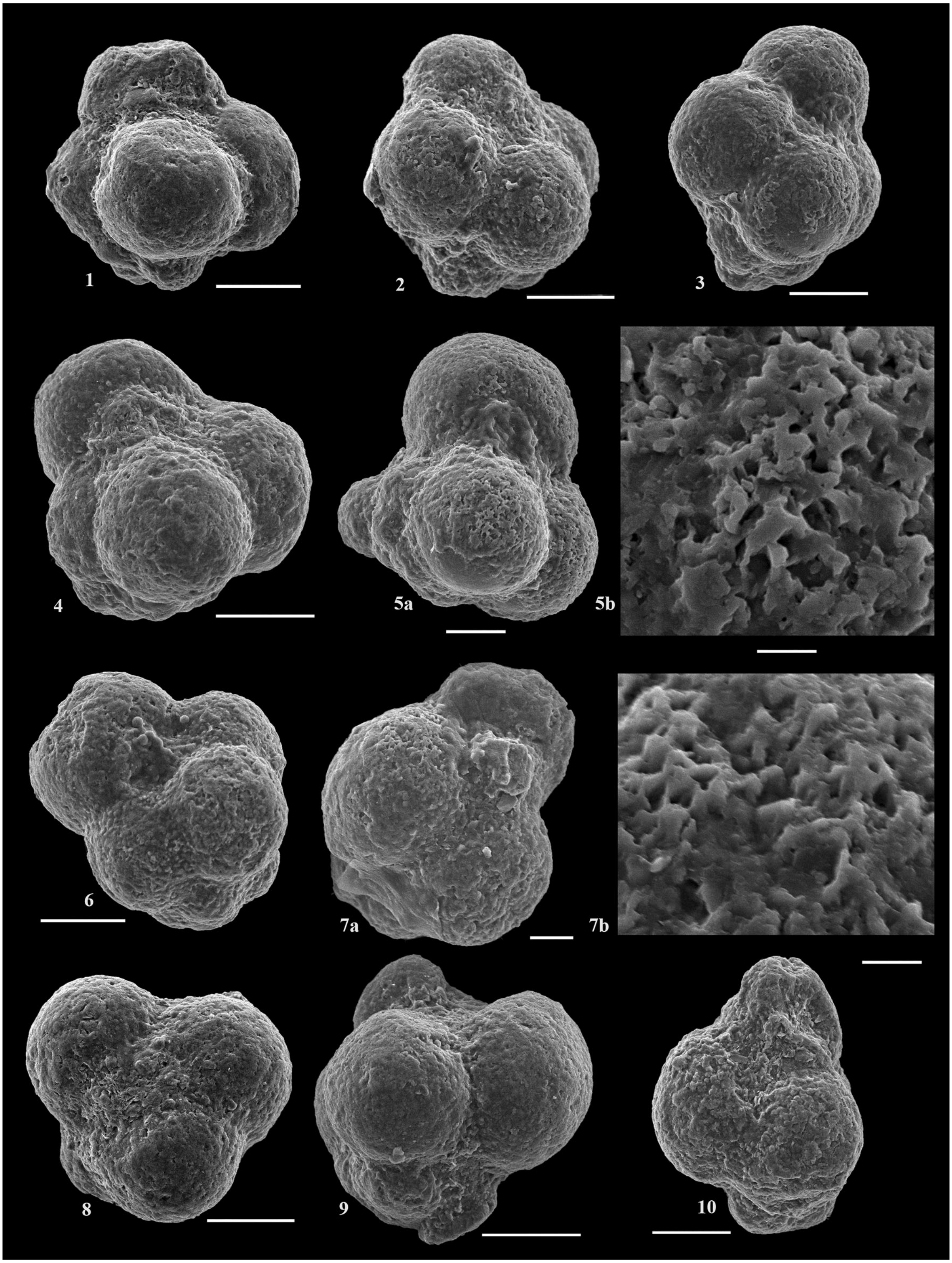


Plate 4 Topotype *Globuligerina dagestanica* (Morozova), 1961 from samples *8* and *9* (see our Fig. 9), Khouroukra section, Late Bajocian, Dagestan. Specimens nos. *7a, 8, 9* and *10* have 3 to 3.5 chambers in the last whorl; the other specimens have 4 chambers in the last whorl. The aperture, where visible, is either a medium high arch or loop shaped. Wall texture is pustulose and from nos. *5b* and *7b* appears to be slightly etched (see *text*)

1986 *Globuligerina bathoniana* (Pazdrowa). Stam, p. 108, 109; plates 9, figs. 6–13; plate 10, figs. 1–12; plate 11, figs. 1–10; plate 12, figs. 9–12, plate 13, figs. 1–12; plate 14, figs. 1–2, 5–7.

1997 *Globuligerina bathoniana* (Pazdrowa). Simmons et al. p. 27, plate 2.8, figs. 4–12.

1999 *Globuligerina bathoniana gigantea* Wernli and Görög, p. 422, p l. 1, figs. 15–23.

Description Medium to high trochospiral, with an *H/D* ratio ranging from 0.6 to 1.3. Test in 2–3 whorls of 7–13, mostly 9 chambers, 3.5–4 chambers in the last whorl; whorls not much increasing in width. Chambers rounded, spherical. Sutures depressed, mostly straight; umbilicus narrow. Aperture variable in shape, low to high arch (semicircular), generally comma shaped, with the posterior margin typically set forward in the umbilicus. Aperture with thickened rim (lip). Test calcareous, densely microperforate; the bilamellar wall shows a dense and irregular network of slightly blunt tubercles, between which the micropores are situated. Calcite crystals are aligned perpendicular to the wall surface. No preferred coiling direction of tests. A smooth to slightly pustulose bulla, with one or two apertures, is often present, obscuring the primary aperture. Pazdrowa (1969) reports that the proloculus often measures between 0.01 and 0.02 mm (max.), rarely down to 0.005 mm. Both specimens with pointed apex (initial whorl) or a blunt one occur, which we confirm from the observations with Grand Banks material (see Plate 8). Pazdrowa (1969) described this species using about 150 well-preserved specimens from the ore-bearing *Morrisi* Zone clays of Ogrodzieniec, Poland; the age of the strata is Middle Bathonian.

Discussion Pazdrowa (1969) states that *Globigerina dagestanica* from the Bathonian of Dagestan differs from *Globuligerina bathoniana* by a much less distinct aperture, which also is much smaller and has no lip. *Globuligerina oxfordiana* is also similar in shape, aperture and chamber arrangement, but has a much lower spire. Also, in *G. oxfordiana* the second chamber and final chamber in last whorl typically 'stick up', relatively to the first and third chambers in the last whorl.

Globigerina jurassica Hofman 1958, from the Bathonian to Lower Callovian of Crimea has irregularly arranged chambers, and the aperture is much less distinct, smaller and lower than in *Globuligerina bathoniana*. Pazdrowa (1969) notes that some specimens in her *G. bathoniana* assemblage closely resemble *G. jurassica*, which she refers to be aberrant, pathological forms. In our diversified material from Grand Banks and Portugal, such specimens also are present, which confirms morphological overlap between the two taxa.

Study of our topotypic material of *G. dagestanica* from Khouroukra, Dagestan, shows overlap in morphology between *G. dagestanica* and *G. bathoniana*. In contrast to what Pazdrowa (1969) observed, comma-shaped apertures also occur in *G. dagestanica.* Rare specimens of the latter with a fairly high and regular trochospire, four chambers in the last whorl and medium high arch or looped aperture with a rim, cannot be distinguished from 'average' *G. bathoniana*. Our observations do confirm that *G. bathoniana* does not have 3 chambers in the last whorl; hence, this might be characteristic to assign specimens to *G. dagestanica*.

There is considerable variation in size of *G. bathoniana* specimens within and between localities. *G. bathoniana gigantea* Wernli and Görög are included in the synonymy of the nominate taxon.

Plate 8 illustrates a number of well-preserved specimens of *G. bathoniana* from the Middle Jurassic of the Grand Banks, Eastern Canada. The lower row of this plate shows 4 specimens of the microperforate *Globigerinita bradyi* (Wiesner) from a plankton tow on the inner shelf, offshore Nova Scotia, Eastern Canada. The morphological similarity is remarkable, demonstrating limited variation around a common and evolutionary successful building plan of completely unrelated taxa. Deformed and aberrant morphotypes, not unlike deformed *Globuligerina bathoniana,* are known from this recent species, which also often has a bulla.

Some specimens of Stam (1986) from the Bathonian of the Grand Banks with a much expanded and embracing last whorl (Plate 8, no. 7 and Plate 9, no. 11) bear resemblance to *Conoglobigerina helvetojurassica*. Overlap in test shape variation between *G. bathoniana* and *C.helvetojurassica* is suggested, but the test surface textures are different, the latter being reticulate.

Globuligerina bathoniana from Gnaszyn 6 sample (see Fig. 13, Plate 10) in the Middle Bathonian of the Częstochowa area shows excellent test preservation with distinctive pustulose wall surface texture; also note occasional pore mounds on no. 12 of Plate 10.

Pore mounds are structures-like volcanos that surround the pores and are always associated with microperforate taxa like *Guembelitria* and are quite common in some Aptian hedbergellids, but Aptian hedbergellids without pore mounds also occur. The function of the pore mounds is not clear, and it is not clear if there is a relationship between the position or type of primary aperture and the distribution of the pore mounds (Petrizzo, personal communication to Gradstein 2016).

G. bathoniana specimens from Callovian marls and limestones in the Algarve, southern Portugal show an unusual preservation of tests (Stam 1986). Specimens seemingly are internal moulds (Plate 8, nos. 1, 2 and 5–7),

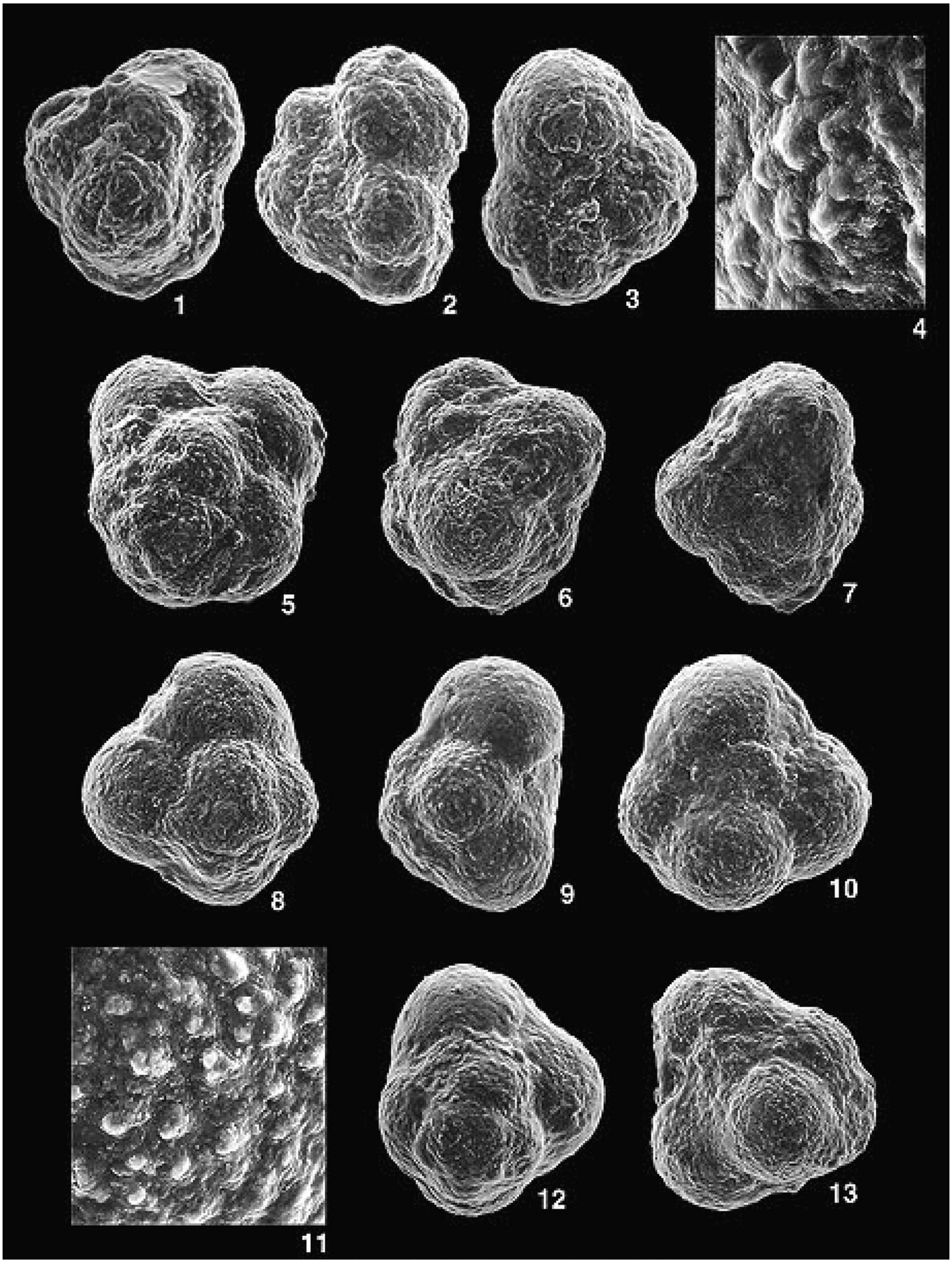


Plate 5 (=Plate 2.3 in Simmons et al. 1997). G*lobuligerina dagestanica* (Morozova) 1961 (published originally as *Globuligerina araksi* Kasimova 1984), Late Bajocian, Negramskoye, Aras River, Azerbaijan, deposited in the Azerbaijan Academy of Sciences. Nos. *1–3*, metatype of *G. araksi*, specimen diameter 130 μm, spiral, peripheral and umbilical views, ×310; no. *4* enlargement of the wall surface to show pustules often fusing laterally to form short ridges, ×1500. Nos. *5–13*, holotype and paratypes of *Globuligerina dagestanica* (Morozova) 1961 (published originally as *Conoglobigerina dagestanica* Morozova 1961). Bathonian, near the villages of Chokh and Gunib, central Dagestan, deposited in the Geological Institute of the Academy of Sciences of Russia, Moscow; nos. *5–7*, holotype (no. 3513/2) specimen diameter 190 μm, spiral, peripheral and umbilical views, ×210; nos. *8–10*, paratype, specimen diameter 150 μm, spiral, peripheral and umbilical views, ×265; Nos. *11*, *12*, paratype, specimen diameter 190 μm, enlargement of the surface showing micro perforations and pustules, ×1250 and spiral view, ×210; no. *13*, paratype (no. 3513) specimen diameter 210 μm, peripheral view of medium height spire, ×190

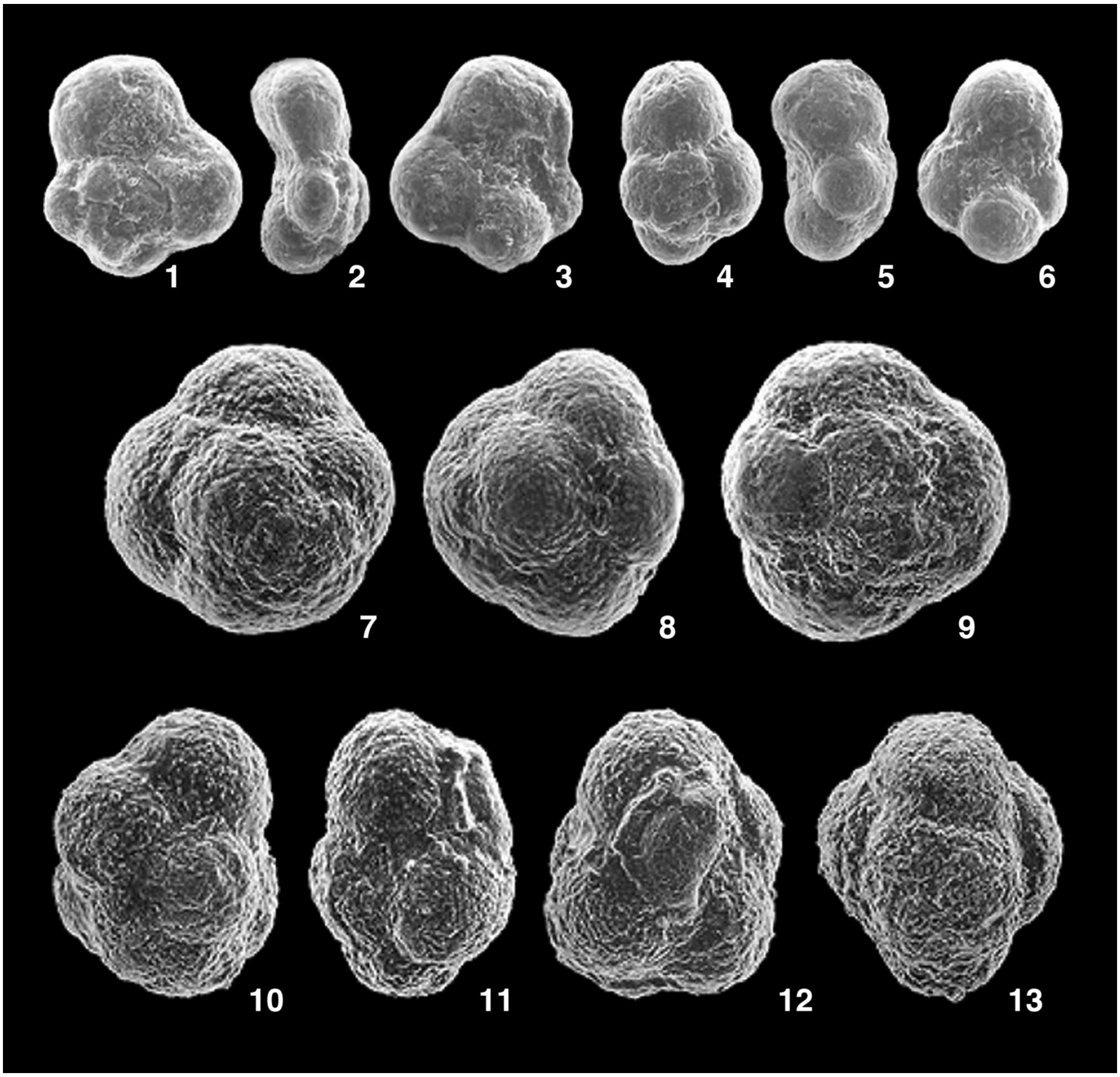


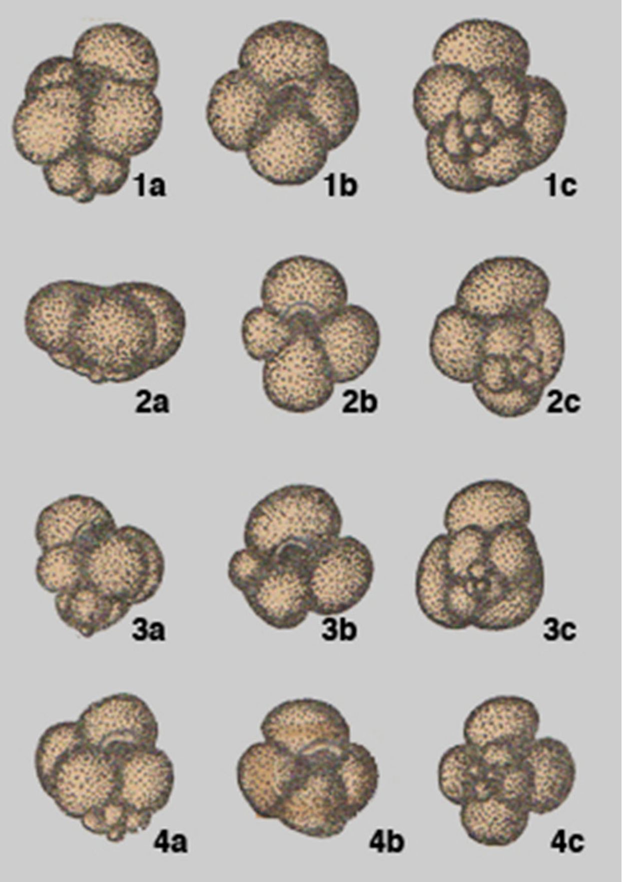
Plate 6 (=Plate 2.5, figs. 5–10 and plate 2.7, figs. 8–14 of Simmons et al. 1997). Nos. *1–6*. *Globuligerina oxfordiana* (Grigelis) subspecies *calloviensis* Kuznetsova emended, Early to Middle Callovian, Crimea, USSR. Two metatypes deposited in the Geological Institute, Academy of Sciences, Moscow, USSR. Nos. *1–3*, 110 µm diameter; nos. *4–6*, 180 µm diameter. Figures 8, 9, 10. *Globuligerina avariformis* (Kasimova) 1984. Upper Bajocian, Negramkoye Gorge, Aras River, Nakhichevan, Azerbaijan, donated by G. K. Kasimova to the Natural History Museum, London, metatype. Unusually large specimen diameter of 320 µm, as reported by Simmons et al. (1997) may be an error; spiral, side and umbilical views (×125). *Globuligerina jurassica* (Hofman 1958). Bathonian–Early Callovian, southern Crimea, deposited in the Geological Faculty, Moscow State University, Russia. Nos. *11–13*, neotype, specimen diameter 270 µm; spiral, side and umbilical views; umbilicus with partial bulla, ×150; no. *14*, paratype, specimen diameter 260 µm, spiral view, ×155. Test sizes may be quoted too large (see *text*)

but also show faint ridge patterns, unlikely to be features on internal moulds. It reminds of the unusual preservation of slim *oxfordiana*-like specimens from the Callovian of Crimea and Ukraine, described here as *G. oxfordiana calloviensis*. A detailed study of Callovian Algarve samples might shed light on the preservation issue.

We obtained two small specimens resembling *G. bathoniana* from our sample EG 4 mid from the Birmenstorfer Schichten, Canton Aargau, Switzerland. Coiling is somewhat irregularly trochoid and the aperture is arch shaped.

Range The distinctive taxon *G. bathoniana* was originally described by Pazdrowa (1969) from the middle Bathonian of Poland. It has been found in sediments ranging from Bajocian through Early Kimmeridgian, and even Tithonian. Localities with observations are Poland, Grand Banks of Newfoundland, Portugal, France, Germany, Switzerland, Balkan, Azerbaijan, Crimea and NW Australia.

Phylogenetic trend No clear evolutionary trend was observed in stratigraphically successive samples. Between localities there are marked differences in the percentage of specimens with longer tests or more aberrant tests. More



Type species Fig. 5 Re-illustration of original copies of figs. 1–9 in Pazdrowa (1969). Provided by Olga Pazdrowa to Gradstein of *Globigerina* (now *Globuligerina*) *bathoniana* Pazdrowa. Specimen no. *1a–c* is the holotype. Note the variability in test height, chamber shape, shape of aperture (low arch, or low to high looped) and coiling direction. Specimen height between 140 and 180 µm, specimen diameter between 130 and 170 µm

study may reveal if there is a stratigraphic trend to longer tests.

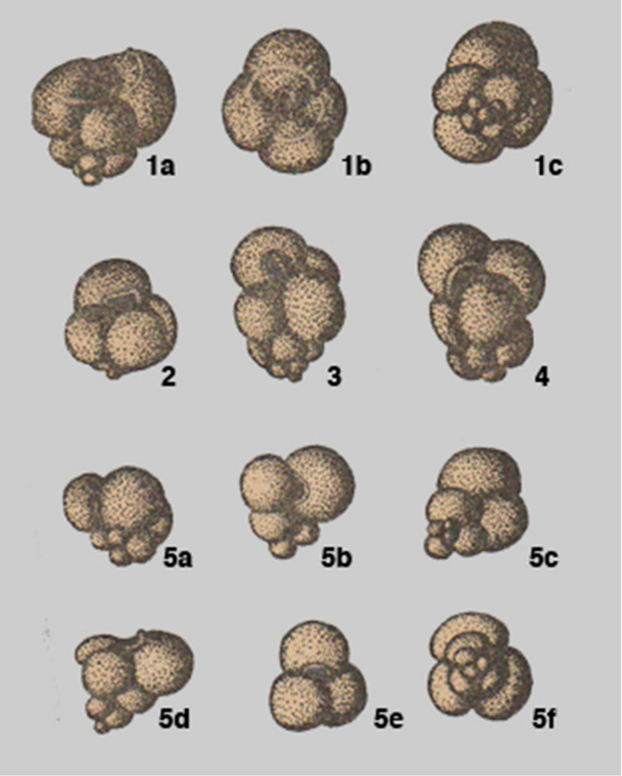
Globuligerina avariformis (Kasimova) 1984

Plate 6, nos. 7–9

1984 *Conoglobigerina avariformis* Kasimova. Kasimova and Aliyeva, p. 2, p l.1, figs. 1–4.
1997 *Conoglobigerina avariformis* Kasimova. Simmons et al., p. 23, plate 2.7, figs. 8–10, plate 2.8, fig. 2.
Non 2013 Conoglobigerina? avariformis Kasimova, Görög & Wernli, p. 285, figs. 4.8–4.13.

Description The original hand-drawings of the species leave no doubt that there is morphological overlap in test features and building plan of *G. avariformis* and *G. dagestanica*; the test also often has a bulla.

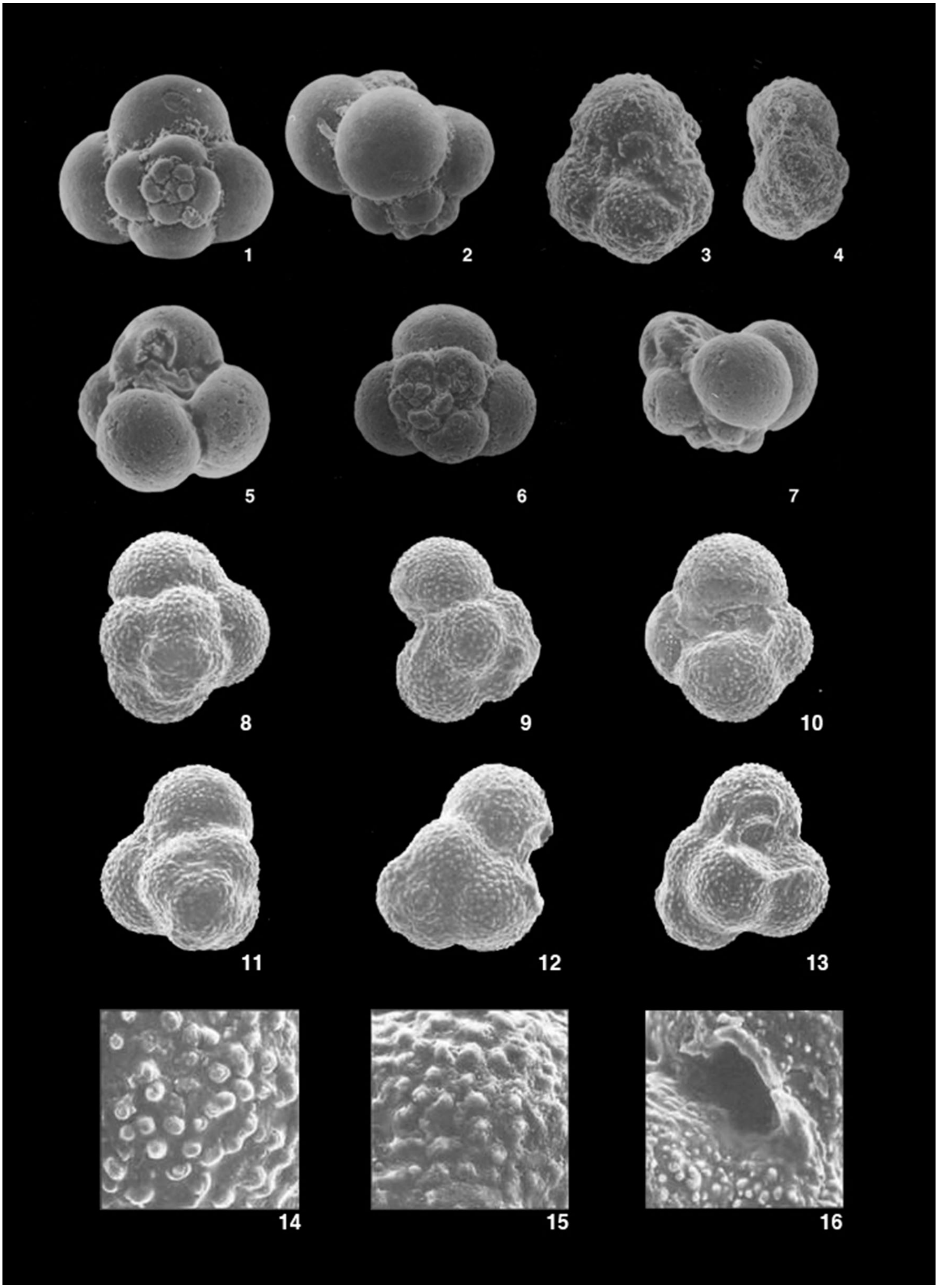
Simmons provides a good image of a metatype (our Plate 6, nos. 7–9), which emphasizes a feature readily observable in suitable material, namely a compact test with a strongly embracing last whorl consisting of 4 chambers. The latter may vary from 3 to 4. The pseudomuricae of the test surface may fuse into short, discontinuous ridges also observed in *G. dagestanica*.



Type species Fig. 6 Re-illustration of original copies of figs. 1–9 in Pazdrowa (1969). Provided by Olga Pazdrowa to Gradstein of *Globigerina* (now *Globuligerina*) *bathoniana* Pazdrowa. Specimen no. *1a–c* is the holotype. Note the variability in test height, chamber shape, shape of aperture (low arch, or low to high looped) and coiling direction. Specimen height between 140 and 180 µm, specimen diameter between 130 and 170 µm

Wernli and Görög (1999) report unusually large *C. avariformis* from the Bajocian Ammonitico Rosso limestones of Som Hill, Bakony Mountains in Hungary. The specimens were extracted using acetolysis.

Stratigraphic range The species is originally known from the Late Bajocian of Azerbijan. The specimens referred to by Görög and Wernli (2013) as *Conoglobigerina ? avariformis* Kasimova from the Kimmeridgian of the French Alps are assigned by us to *Conoglobigerina grigelisi*. These specimens show a semi-reticulate wall structure. Görög and Wernli (op. cit.) list the original *C. avariformis* type as long ranging (Bajocian-Tithonian) and widespread in Europe. This important observation should be corroborated with the new insight in the wall structure. Namely, we propose that the original *C. avariformis* of the Middle Jurassic of


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

◀**Plate 7** (=selected plate figures from Stam 1986 and Simmons et al. 1997) Nos. *1*, *2*, *5–7*, *Globuligerina bathoniana* (Pazdrowa) from sample 31 of Stam (1986), *Coronatum* Zone, Middle Callovian, Mareta Beach, Portugal; nos. *1*, *2*, two views of same specimen, ×200; nos. *5–7*, three views of same specimen, ×240; specimens are decalcified (see *text*). Note that the two tests each contain 3 whorls and loop-shaped aperture with lip in no. *5*. Nos. *3*, *4*. *Globuligerina oxfordiana* (Grigelis) from sample 6.16 of Stam (1986), *Platynota* Zone, Early Kimmeridgian, Tojeira Formation, Montejunto, Portugal; two views of same specimen, ×175. Nos. *8–16*. *Globuligerina bathoniana* (Pazdrowa) 1969, Middle Bathonian, Ogrodzieniec, Poland; two metatypes deposited in the Geological Faculty, Moscow State University, Russia (specimens diameter ~160 μm). Nos. *8–10*, spiral, side and umbilical views, ×250; nos. *14–15*, same specimen, two views of surface detail showing pseudomuricae usually separated but some adjacent pairs fusing into very short and discontinuous ridges (×1250 and ×1100, respectively). Nos. *11–13*, spiral, side and umbilical views, metatype donated by B. Masters to The Natural History Museum, London (specimen diameter 170 μm), spiral, side and oblique umbilical views (×235). No. *16*, topotype showing enlargement of the apertural face with a low loop-shaped aperture (×750). Traces of a bulla can be seen on nos. *10* and *11*

Europe evolved into *C. grigelisi* by acquiring a more reticulate wall surface ornamentation.

Globuligerina oxfordiana (Grigelis) 1958

Type species Fig. 8. Plates 11, 12, 13, 14, all figures

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, p. 105–107, plate 1, figs. 1–11.
1971 *Globuligerina oxfordiana* (Grigelis). Bignot and Guyader, p. 83, plate 1, figs. 1–4; plate 2, figs. 3–4.
1983 *Globuligerina oxfordiana* (Grigelis). Gorbachik, Akad.Nauk. SSSR, 26, p. 48–51 + 6 plates.
1986 *Globuligerina oxfordiana* (Grigelis). Stam, p. 110–112; plate 7, figs. 1–5 (not 6–12); plate 8, figs. 4–7, (not 8–12); plate 9, figs. 1–5; plate 14, figs. 3–4, 8–15.
1997 *Globuligerina oxfordiana* (Grigelis). Simmons et al. p. 26–27; plate 1.1, figure 1; plate 1.2, figs. 1–5; plate 2.9, figs. 1–15.

Description Relatively low trochospiral, with an *H*/*D* ratio of 0.3 to 0.8 or even 1; spherical chambers, 3.5–4 in the last whorl. Equatorial periphery varies from fairly lobulated circular to fairly lobulated oval. Last whorl only slightly elevated above previous whorl. Second chamber and final chamber in last whorl typically ‘stick up’, relatively to the first and third chambers in the last whorl. Sutures depressed, mostly straight. 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. In exceptionally well-preserved specimens, a small triangular flap may be seen to extend from the lower lip into the umbilicus. A smooth to slightly pustulose bulla, with one aperture, is frequently present, obscuring the primary aperture.

The test wall is microperforate with pores of ca 1 μm in diameter. Wall surface is densely sculptured with different modes:

1. by cone-like blunt pustules (pseudomuricae) with diameter of 1–4 μm pointed in centre by a small raise with micro-pore (pore mound).
2. by porous pustules joining into short irregular ridges.
3. by ridges joining in a reticulate pattern.

Already Gorbachik (1983) showed the onset of reticulation on older chamber of a specimen of this species; this is clearly an ontogenetic feature in specimens of some assemblages. In our material, reticulation is visible on specimens in Plates 12 and 13. On our Plate 12, it is shown as a strong external feature on the wall in some older chambers, whereas on Plate 13 it is shown as an underlying and more subtle, but persuasive texture pattern on the chamber wall. If ontogeny recapitulates evolution, the local wall texture change may be seen to strengthen our postulate that *G. oxfordiana* is ancestor to *C. helvetojurassica* (see discussion under this taxon). But interestingly, the specimens from four, widely different localities of Late Bajocian through Early Kimmeridgian age show pustulose wall texture only. More study is required to understand the wall texture development through time and places.

The type specimens of *G. oxfordiana* are from borehole Jotija (Jotija village), at 143 m below surface in sample 10, Early Oxfordian (Figs. 10, 11). Other specimens assigned by Grigelis to this species come from sample 801 at Shatriche-2 outcrop of Middle to Late Oxfordian age in the Rjasan District, Central Russia (Fig. 10).

Type species Fig. 8 shows the holotype (redrafted) from the Early Oxfordian of Lithuania.

The types are stored in the collections of the Department of Geology, Vilnius State University, Lithuania, and in Palaeozoology Institute, Stockholm University, Sweden.

Well-preserved specimens of this taxon also come from dark, micaceous clay in the interval of 55–66 m in borehole Lyduvenai, Raseiniai District, Lithuania (Figs. 10, 11). GPS coordinates of the site are 55°30′29N:23°04′59E. The type level also contains the ammonite *Cardioceras tenuicostatum* Nikitin (Early Oxfordian) and the foraminifera *Epistomina volgensis, E. intermedia* and *Lenticulina brueckmanni.*

The specimens on Plate 11 are reproduced from Simmons et al. (1997) and come from the Oxfordian of the Volga Basin, Russia, from the Oxfordian near Moscow, and from the Lower Oxfordian, Le Havre, Normandy, France. Tests are well preserved and reported by these authors to be aragonitic, testifying to minimal effect of diagenesis.

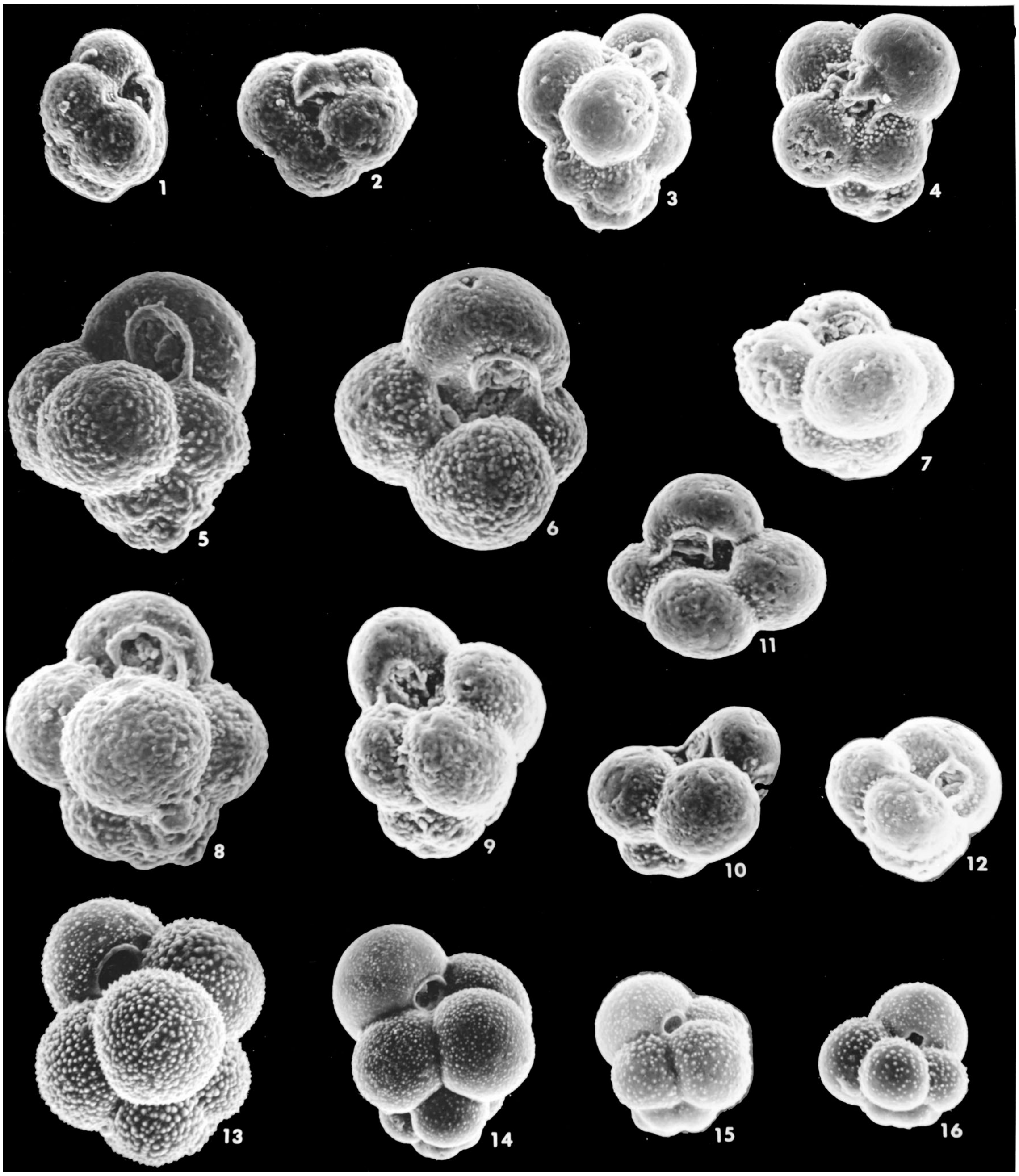


Plate 8 *Globuligerina bathoniana* (Pazdrowa) and *Globigerinita bradyi* (Wiesner). Plate re-illustrated from Stam (1986). Both species are microperforate. Nos. *1–12*, *Globuligerina bathoniana* (Pazdrowa), Eider M-75 well, cts. 8260–8290′, *Garantella* spp. Zone, Bajocian-Bathonian, Grand Banks, Canada, ×200; nos. *1–4* with partial bulla on last chamber. Nos. *13–16*, *Globigerinita bradyi (Wiesner)*, Recent, inner shelf, offshore Nova Scotia, Canada, ×220

Pristine specimens have been collected by us from the Middle Bathonian of Gnaszyn, Częstochowa area, Poland. Note microperforation and pustules with pore mounds on specimens in Plate 13. Both the Lithuanian and Rjasan specimens also show pore mounds.

A small apertural flap and the pore mounds described for *G. oxfordiana* in well-preserved specimens may be a local feature, not widely reported.

The specimens obtained by Wernli and Kindler (1986) from the Callovian-Oxfordian of Switzerland agree with the test morphology of *G. oxfordiana*.

Range This taxon is widely recorded and has a long stratigraphic range. The oldest occurrence (determined from free specimens) may be in the *Humphriesianum* Zone, Early Bajocian of France (Bignot and Janin,

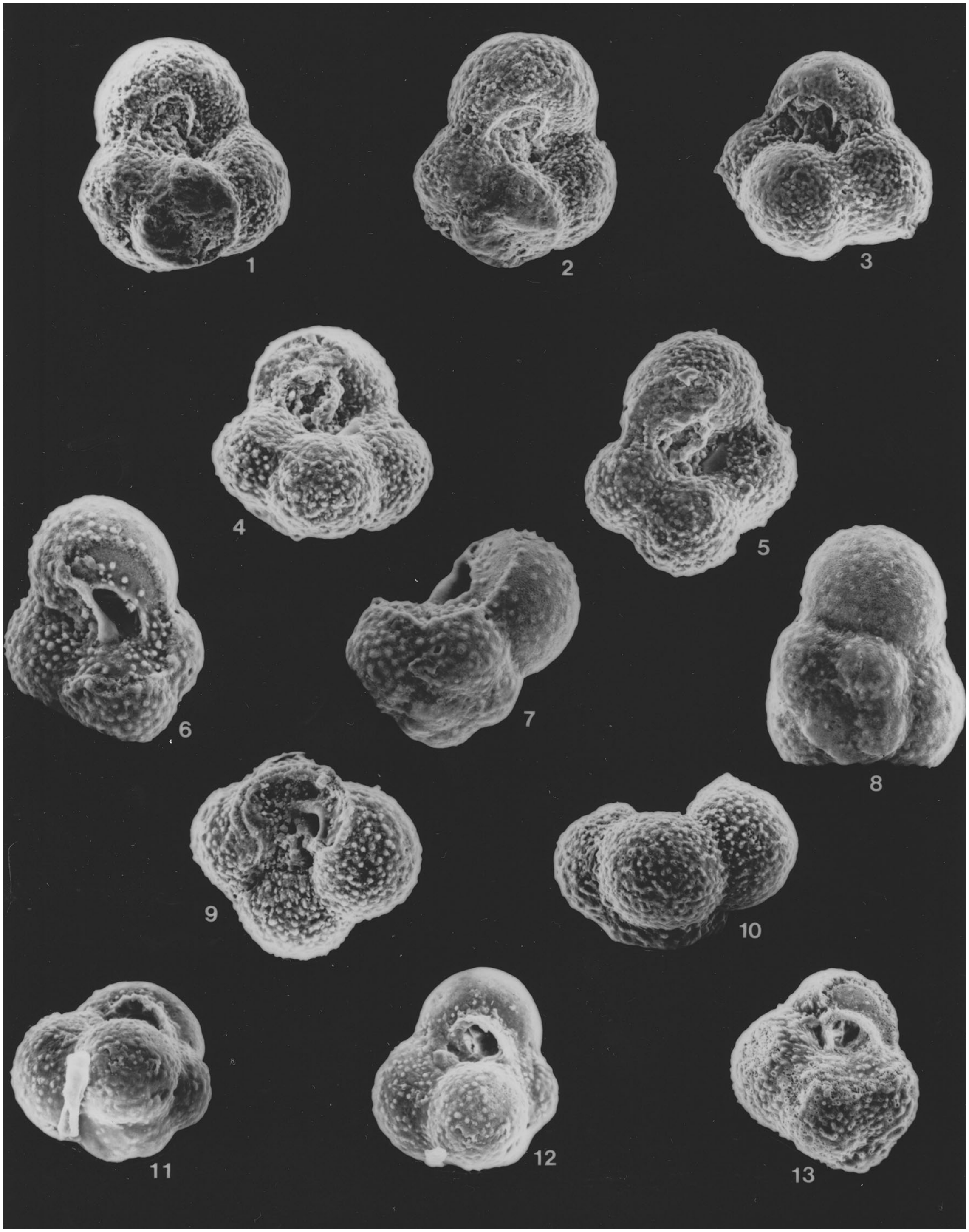


Plate 9 *Globuligerina oxfordiana* (Grigelis) and *Globuligerina bathoniana* (Pazdrowa). Re-illustrated from Stam (1986), Plate 9. Nos. *1–5*, *Globuligerina oxfordiana* (Grigelis), Eider well, Grand Banks, cts. 7560–7590′, X160 (nos. *1, 2*); cts. 7960–7990′, X220 (no. *3*); cts 7760–7790′, X235 (nos. *4, 5*). Well cuttings samples from the *Garantella* spp. Zone (Bajocian–Bathonian). Nos. *6–13*, *Globuligerina bathoniana* (Pazdrowa), topotypes, Ogrodzieniec, Poland, *Morrisi* Zone (Middle Bathonian), X385 (nos. *6–8*), X275 (nos. *9, 10*), X530 (nos. *11–13*)

1984), and the Bajocian and Bathonian of the Balkan (several studies by Wernli and Görög), and the Bajocian-Bathonian of offshore Eastern Canada. We observed that well-preserved specimens occur in the Upper Bajocian–Lower Bathonian of Dagestan (Khouroukra Section) and in the Bathonian (Czestochowa area, sample Gnaszyn 6)

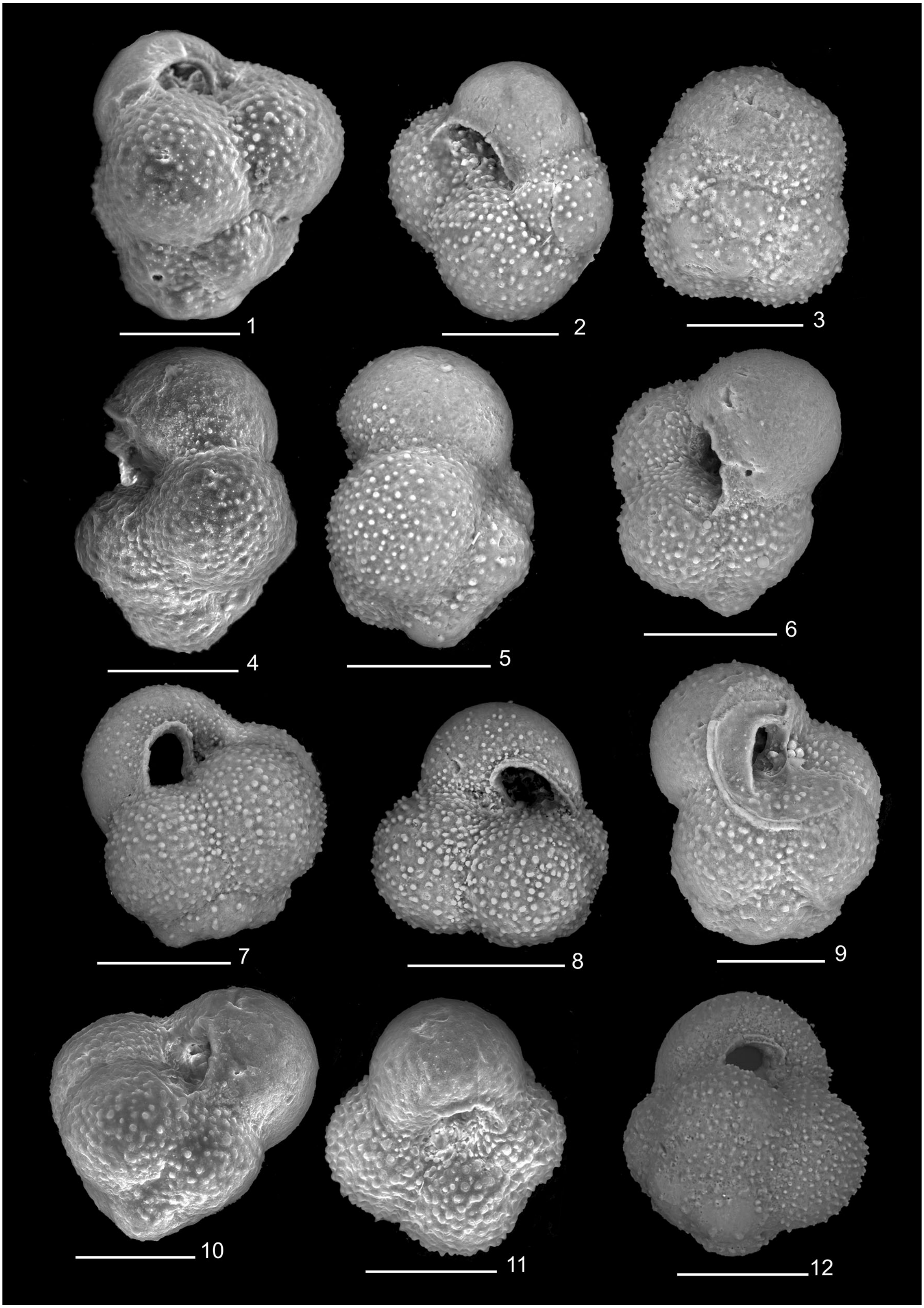
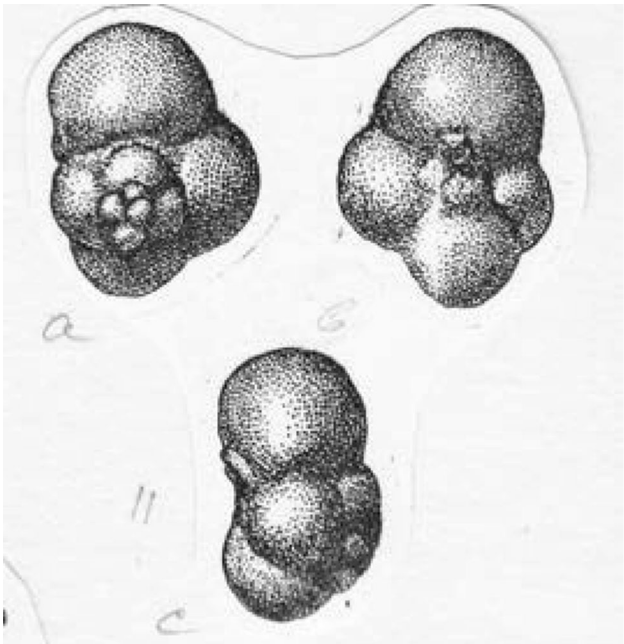


Plate 10 *Globuligerina bathoniana* (Pazdrowa) from Gnaszyn 6 sample (see our Fig. 13), Middle Bathonian, Częstochowa area, Poland. Nos. *1, 4, 5, 7, 9, 10* and *12* side views; nos. *2, 6, 8, 11* umbilical views; no. *3* spiral view of small specimen. Note the excellent preservation with distinctive pustulose wall surface texture; also note pore mounds in no. *12*. The *scale bar* is 50 µm



Type species Fig. 8 Holotype of *Globuligerina oxfordiana* (Grigelis), Jotija borehole, 143 m, sample 10, Lower Oxfordian, SW. Lithuania, test diameter 200 µm. Drawing in 1980 by micropalaeontology graphic artist Sergei Nikolayev, St. Petersburg (Grigelis 1985)

of Poland. Apthorpe (2003, unpublished) reports it from the Bajocian of NW Australia. The youngest well-established record is from the Lower Kimmeridgian of Portugal (see under "Materials") and the French Jura. It may even occur in the Tithonian of Hungary, in forms transitional to *Favosella hoterivica* [Görög and Wernli 2003; see our discussion under *Conoglobigerina helvetojurassica* (Haeusler)]. We also observed poorly preserved specimens in the Tithonian of ODP Site 901A, core 5R1-142-144 cm. It is widely known from Europe, like NW France, Germany, as far north as southern Sweden and Baltic (type areas), and to the south in the Mediterranean, Russia near Moscow and the Upper Volga Basin, and in the Middle East. Simmons et al. (1997) report it from the Oxfordian of Ethiopia and the taxon was also observed in the well samples from Somalia (personal communication 1986 from H. Leffingwell, Unocal to F. Gradstein).

Globuligerina oxfordiana (Grigelis) subspecies ***calloviensis*** Kuznetsova 1980 emended

Plate 6, nos. 1–6.

1980 *Globuligerina calloviensis* Kuznetsova. Kuznetsova and Uspenskaya, p. 750, plate 2, figs. 1–4.
1986 *Globuligerina calloviensis* Kuznetsova. Gorbachik, plate 5, fig. 3; plate 6, figs. 1–2.
2017 *Globuligerina oxfordiana* (Grigelis) subspecies *calloviensis* Kuznetsova emended. Gradstein (2017a), p. 21, plate 1, figs. 11–16.

Description Based on more than 200 specimens in Lower Callovian strata from the Meganom Peninsula, Eastern Crimea, K. Kuznetsova in Kuznetsova & Uspenskaya (1980) described *Globuligerina calloviensis*. It has a low spiral side and a slightly concave umbilical side, with a wide umbilicus, narrowly arched aperture with thin lip and tuberous and cellular wall sculpture. The illustration of the holotype indicates sculpture with broken ridges, forming an incomplete thin and broken network over the test.

Stam (1986) included *G. calloviensis* in *G. oxfordiana*. Simmons et al. (1997) also argued that *G. calloviensis* is morphologically very close to *G. oxfordiana* and might be considered a subspecies of the latter. Despite limited data on definition and restricted distribution, this species of Jurassic planktonic foraminifera was retained by Simmons et al. (1997), who illustrated metatypes (see our Plate 1, nos. 1–6). These specimens clearly show the comma-shaped aperture and overall test shape like *G. oxfordiana*. The remarkable feature is the lack of ridges (pseudomuricae) on the test surface, which appears almost smooth. This is in contrast to the original description by Kuznetsova. The tests are not internal moulds. We conclude that there is wide variation in sculpturing and preservation of the type specimens, which should be investigated.

We assign the type, which has not been reliably recorded outside the Callovian of the Crimea and Ukraine, subspecies status, as suggested by Simmons et al. (1997). Stam (1986), on his plate 14, figs. 8–14, shows specimens of *G. oxfordiana* from the Tojeira Formation, Montejunto in Portugal that well resemble the type illustration by Kuznetsova and the metatypes of *G. calloviensis* illustrated by Simmons et al. (1997). Note that in Gradstein (2017a, b) this subspecies was listed as *Globuligerina oxfordiana* (Grigelis) subspecies *calloviensis* ssp. nov. Gradstein. The correct notation is at the top heading of the text on this new subspecies.

We take the opportunity to mention the possible similar preservation of some Callovian specimens of *G. bathoniana*, in Stam (1986) from Algarve, Southern Portugal. Although some of these Algarve specimens appear to be internal moulds, some others appear to be thin-shelled, as if Callovian Jurassic planktonic foraminifera underwent an unusual change in wall structure. The issue is taken up under the discussion of the taxonomy of *G. bathoniana*.

Globuligerina tojeiraensis **Gradstein 2017**

Plate 15, nos. 1–10.

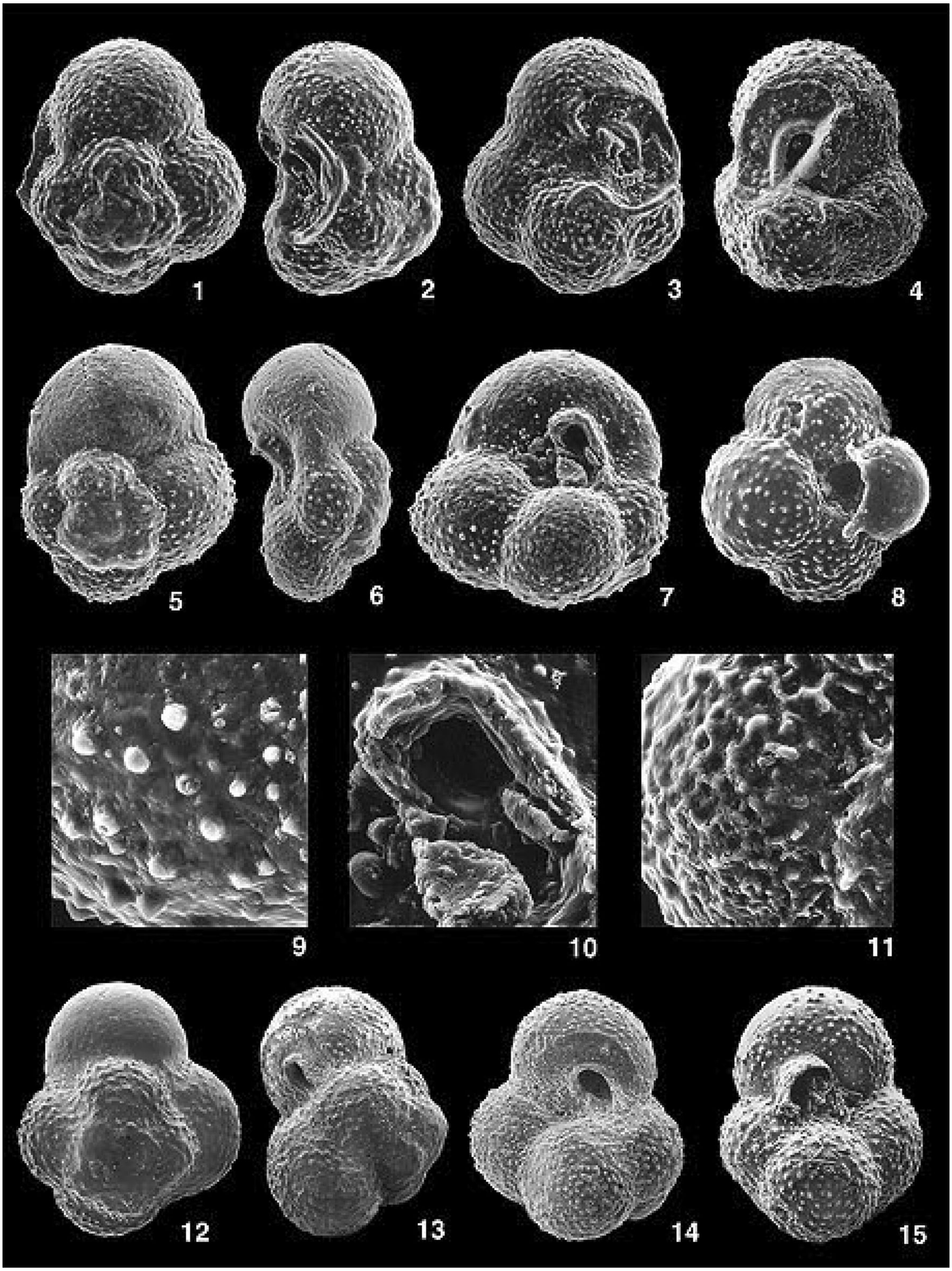


Plate 11 *Globuligerina oxfordiana* (Grigelis). Plate re-illustrated from Simmons et al. (1997), plate 2.9. Nos. *1–3*, Oxfordian of Upper Volga Basin, Russia, deposited in the Geological Faculty of Moscow State University; spiral, side and umbilical views; clear trace of bulla; specimen diameter 150 µm. Nos. *4* and *8*, Oxfordian near Moscow, Russia, deposited in the Geological Faculty of Moscow State University; umbilical view, specimens diameter 140 µm; specimen no. *8* with partial bulla (×300) Nos. *5–7, 9* and *10*, Oxfordian near Le Havre, N. France; donated by G. Bignot to The Natural History Museum, London; spiral, side and umbilical views (approx. ×300); detail of surface (×1500) and loop-shaped aperture (×1250). Another specimen in no. *11* with pseudomuricae fusing into short ridges and onset of reticulation (×1000). Nos. *12–15*, Oxfordian of Upper Volga Basin, Russia; 2 specimens donated by T. Gorbachik to The Natural History Museum, London; spiral and side views, specimen diameter 170 µm (×235); umbilical view, specimen diameter 140 µm (×285)

2017 *Globuligerina tojeiraensis* Gradstein. Gradstein (2017a), p. 22, Fig. 10, nos. 1–10.

Description Relatively low to medium high trochospiral, with an *H*/*D* ratio of 0.3–05, rarely larger. Test consists of 2–3 whorls with a tiny initial chamber (where visible). No preferred coiling direction observed. Last whorl with 4 chambers that strongly increase in width, flaring out. Chambers are rounded with deeply incised sutures; chambers in the last whorl often radially elongate and higher than broad; last chamber often pointing slightly left or right in the equatorial plane. The test has a sunk-in umbilical region; umbilicus small to large (wide open). *G. tojeiraensis* has this peculiar knack (depressed umbilicus) with surrounding chambers often sticking up two by two. The chambers 2 and 4 of the last whorl stick more up than chambers 1 and 3.

Aperture a low to rarely high arch; it may be slightly asymmetrical in shape, like shown on Plate 15, nos. 3 and 5a. Aperture generally umbilical in position, rarely umbilical–extraumbilical. A small bulla occurs rarely; it obscures the aperture of the final chamber. Wall pustulose; pustules may fuse to form broken ridges; poremounds are visible on some tests (Plate 15, no. 1).

Differential diagnosis G. tojeiraensis differs from *G. oxfordiana* in its elongated (stretched) chambers in the last whorl, often oblique last chamber (pointing left or right), and often wide open umbilicicus. The wall sculpture is densely pustulose, with pustules forming broken ridges; a trend not normally seen in *G. oxfordiana*. *G. tojeiraensis* is generally higher spired than *G. balakhmatovae* and *G. oxfordiana* and lower spired than *G. bathoniana;* none of which has elongated chambers, or a wide umbilicus.

Range and occurrence The type level is the Tojeira Formation, Montejunto Formation, central Portugal of Early Kimmeridgian Age (Planula–Platynota Zones). The species is common in the Portuguese outcrops.

A number of small, compact specimens with limited umbilical opening, but typical oblique last chamber occur in swc 5000′, Bittern M-62 well, Grand Banks. The sample is of Late Callovian to Early Oxfordian age.

The species probably also occurs in the Birmenstorfer Schichten (Oxfordian), Canton Aargau, Switzerland. Rare specimens assigned to this species occur in Tithonian samples on Galicia Bank, offshore Portugal.

Specimens assigned to *Conoglobigerina caucasica* by Gorbachik and Poroshina (1979) and by Simmons et al. (1997), which latter authors show the wall surface to be pustulose/pseudomuricate, may belong in *Globuligerina tojeiraensis* (see Plate 19, nos. 7, 8 and taxonomy text on *C. gulekhensis*). This potential taxonomic emendation requires study with an assemblage of many specimens of typical *C. caucasica.*

Phylogeny In Bittern M-62 well, compact specimens with a ‘sideways leaning’ last chamber assigned to *G. tojeiraensis* have the second chamber of the last whorl typically ‘sticking up’, as in *G. oxfordiana.* In the Portuguese material, where the taxon is common, morphological transitions occur to *G. oxfordiana.* Hence, this indicates that the latter is a possible ancestor to *G. tojeiraensis*.

Conoglobigerina helvetojurassica (Haeusler) 1881

Type species Fig. 7; Plate 16, nos. 1–9; Plate 17, nos. 1a–e.

1881 *Globigerina helvetojurassica* Haeusler. p. 36, plate 2, figs. 44, 44a.

1890 *Globigerina bulloides* d’Orbigny var. *helveto-jurassica* Haeusler, p.118, plate 15, fig. 46.

1968 ‘*Globigerina’ helvetojurassica* Haeusler, Oesterle, p. 774–777, fig. 50 (3 specimens with 9 illustrations).

2013 *Favusella hoterivi*ca (Subbotina). Görög and Wernli, p. 286–287, plate 5, figs. 1–8.

Non 1986 *Globuligerina oxfordiana* (Grigelis), Stam, p. 110–112, plate 7, figs. 6–12, plate 8, figs. 1–3. (Note: Stam, 1986 lumped his *G. helvetojurassica* in *G. oxfordiana*).

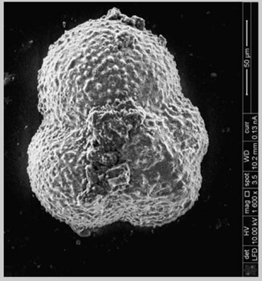
Non 1997 *Haeuslerina helvetojurassica* (Haeusler), Simmons et al., p. 28, 29, plate 2.6, figs. 1–8.

2017 *Conoglobigerina helvetojurassica* (Haeusler), Gradstein (2017a), p. 10, 11, plate 3, figs. 1–9; plate 4, fig. 1.

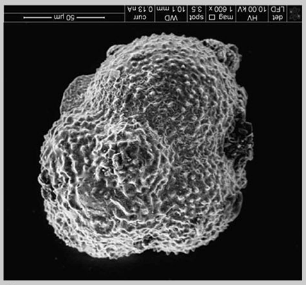
Description Low to medium high trochospiral, with an *H*/*D* ratio of 0.5–1; The trochospire axis may be slightly curved, such that the chambers of the final whorl sit oblique of the chambers of the previous whorl. No preferred coiling direction observed. Last whorl flaring out and much larger than previous (2) whorls. Spherical–circular chambers (nicely ball shaped), four in the last whorl; chambers in the last whorl not much increasing in size. Umbilicus generally open and wide, rarely narrow. Sutures depressed, mostly straight. Aperture variable in shape, low to medium high arch, umbilical to slightly extraumbilical; a looped aperture was rarely observed also. The aperture often has a thickened rim around it. A bulla is observed in some specimens. Wall pustulose and reticulate to strongly reticulate.

Type locality and stratigraphic level Birmenstorfer Schichten, Eisengraben Section, Canton Aargau, Switzerland; *Transversarium* Zone, Middle Oxfordian.

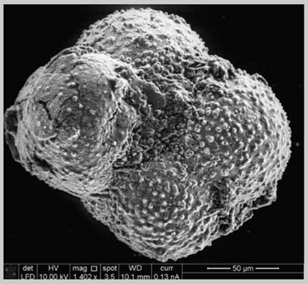
Discussion Lower spired and smaller specimens of *C. helvetojurassica* resemble *Globuligerina oxfordiana*. *C. helvetojurassica* typically has a large last whorl, flaring out and nicely ball-shaped chambers that little increase in size



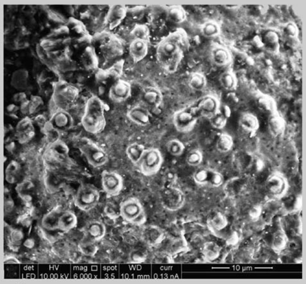
1



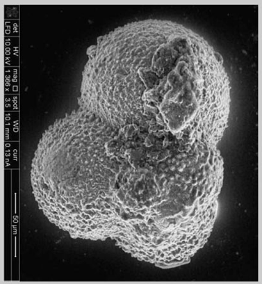
2



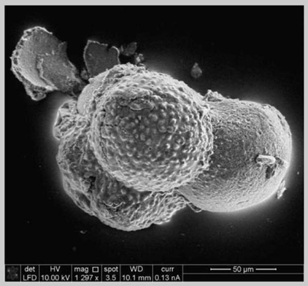
3



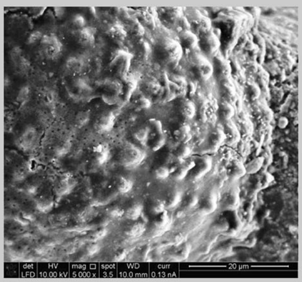
4



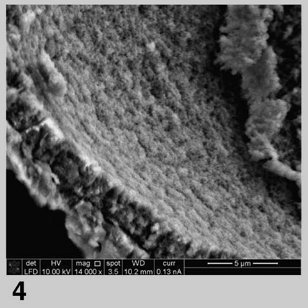
1



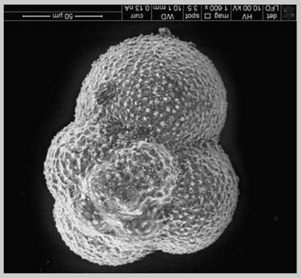
2



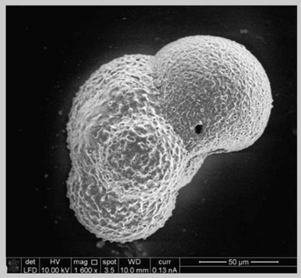
3



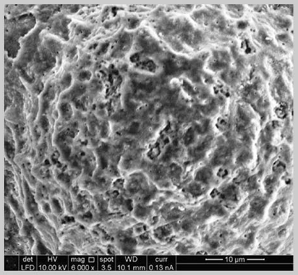
4



1



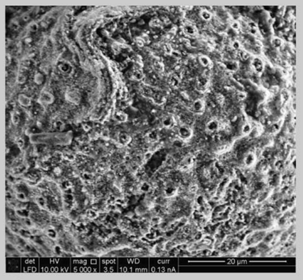
2



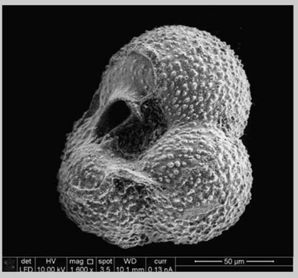
3

4

1



2



3

4

◀**Plate 12** *Globuligerina oxfordiana* (Grigelis) 1958, para- and topotypes. *Top row* Topotypes, Jotija borehole, 143 m, sample 10, Early Oxfordian, SW. Lithuania. No. *1*, spiral view, dextral coiling, diameter 160 µm; no. *2*, spiral view, sinistral coiling, diameter 155 µm; no. *3*, umbilical, diameter 174 µm and detail of microperforate and pustule wall surface with filled pore mounds; mounds up to 3 µm in diameter. *Second row from top* Topotypes, J otija borehole, 143 m, sample 10, Early Oxfordian, SW. Lithuania. No. *1*, spiral view, dextral coiling, diameter 184 µm; no. *2*, side view and detail of pustule wall surface, rarely joining in short ridges, diameter of pustulae up to 4 µm; the thickness of the bilamellar and microperforate wall in the far right picture exceeds 5 µm. *Second row from bottom* Paratypes, Shatrishche-2, sample 801, Middle to Late Oxfordian, Rjasan' District, Central Russia. No. *1*, spiral view, sinistral, diameter 160 µm; no. *2*, side view, reticulate wall surface with detail in no. *3*; no. *4*, peripheral view of specimen with pustule wall surface and fragment of bulla wall above aperture. *Bottom row* Paratypes, Shatrishche-2, sample 801, Middle to Late Oxfordian, Rjasan' District, Central Russia. No. *1*, spiral view, pustulose wall, loop-shaped aperture with narrow rim and remnant of bulla; test diameter 170 µm; no. *2*, detail of pustule wall surface with pore mounds and minor wall surface reticulation; no. *3*, slightly oblique umbilical view with pustulose wall in last chamber and tendency to reticulation in older chambers, looped aperture and bulla remnant, test diameter 150 µm; no. *4*, umbilical view, pustulose last chamber and more reticulate older chambers, looped aperture with strong lip, test diameter 150 µm

in the last whorl and a semi-reticulate to strongly reticulate wall. Such is not known from *G. oxfordiana*, *G. bathoniana* or from *G. dagestanica.*

The specimens from the lower Kimmeridgian of Les Bouchoux, France described by Görög and Wernli (2013) as *Favusella hoterivica* (Subbotina) fall in the variation of *C.helvetojurassica* and confirm the taxon ranging upwards from Oxfordian into Kimmeridgian. The Kimmeridgian occurrence of *C. helvetojurassica* is now also known from Portugal (Tojeira Formation).

We postulate *Globuligerina oxfordiana* to be the ancestor of *Conoglobigerina helvetojurassica*. The two taxa may be morphologically exchanged if no detail of the wall texture is available. For the latter a good binocular or low magnitude (magnification 200×) petrographic microscope will do, but SEM visualization is a must for detail. As reported under *G. oxfordiana*, some Oxfordian specimens of this taxon show onset of reticulation.

Conoglobigerina grigelisi is more compact than *C. helvetojurassica*, with less globular and more oblong chambers in the last whorl. The last whorl strongly embraces previous whorls down to the apex, a feature not seen in *C. helvetojurassica.* The umbilicus in *C. grigelisi* is narrow and the sculpture of the wall surface texture is often (but not always) less perfectly reticulate.

Gradstein (2017a) reported on the historical background of the taxonomy for this taxon, and new findings in the Basel Museum. The study also contains a discussion of the mistaken identity of *Globuligerina helvetojurassica* (Haeusler) by Stam (1986) and of *Haeuslerina helvetojurassica* (Haeusler) by Simmons (1997). Specimens of *Globuligerina helvetojurassica* that we obtained in 2016 from the type level in the Birmenstorfer Schichten vary in size from ~100 to ~180 µm and are well preserved.

Plate 17, nos 1a–e shows SEM digital images of an unusual specimen in the Birmenstorfer assemblage assigned to *Conoglobigerina helvetojurassica*. Only one specimen was obtained after picking five trays with washed sample residues, but its features are clear enough. The overall test shape, wall structure and wall texture indicate that it most likely belongs to this taxon.

The planoconvex and involute test is relatively large (150–200 µm in diameter) with four chambers in the last whorl, with chambers slightly increasing in size. Aperture is not preserved. The wall is microperforate and wall texture is reticulate.

Normally, *C. helvetojurassica* has a medium high trochospiral test, but a seen on Plate 17, no. 1c, the spiral side is concave and involute and not trochoid and evolute. Concave spiral sides maybe observed with sessile foraminifera that are attached to a hard surface. Such attachment surfaces maybe somewhat irregular in shape and the foraminiferal test may accommodate such a surface; hence, a concave test shape might occur if the attachment surface is convex. The actual surface attachment spots on the specimen of *C. helvetojurassica* are clearly shown as darker coloured, rather smooth surfaces on chambers 1 and 3 of the last whorl.

A peculiarity is the small test with 5 (?) globular chambers in a flat coil that under higher magnification appears to be microperforate and pustulose or semi-reticulate. It is attached to the larger specimen, but seems to be a separate individual. More specimens are required to assemble a thorough description and interpretation. At this stage, the large specimen is considered a possible benthic, attached life cycle individual of the nominate taxon.

Range and occurrence Middle Oxfordian of Switzerland (sample EG4 mid, Birmenstorfer Schichten) and Lower Kimmeridgian of Central Portugal (samples 24/2P and T2/12, respectively, in the middle and upper part of the Tojeira Formation) and SE France. *C. helvetojurassica* ranges from Middle Oxfordian through Early Kimmeridgian. Tithonian–Berrisian limestones in Hungary may harbour this taxon if wall structure studies confirm its identity.

Jurassic planktonic foraminifer sp.

Plate 17, nos. 2, 3

At the sample level 4 mid (Fig. 2) with *Conoglobigerina helvetojurassica* (Haeusler) in the Eisengraben Section of the Birmenstorfer Schichten, 4 small (less than 125 µm)

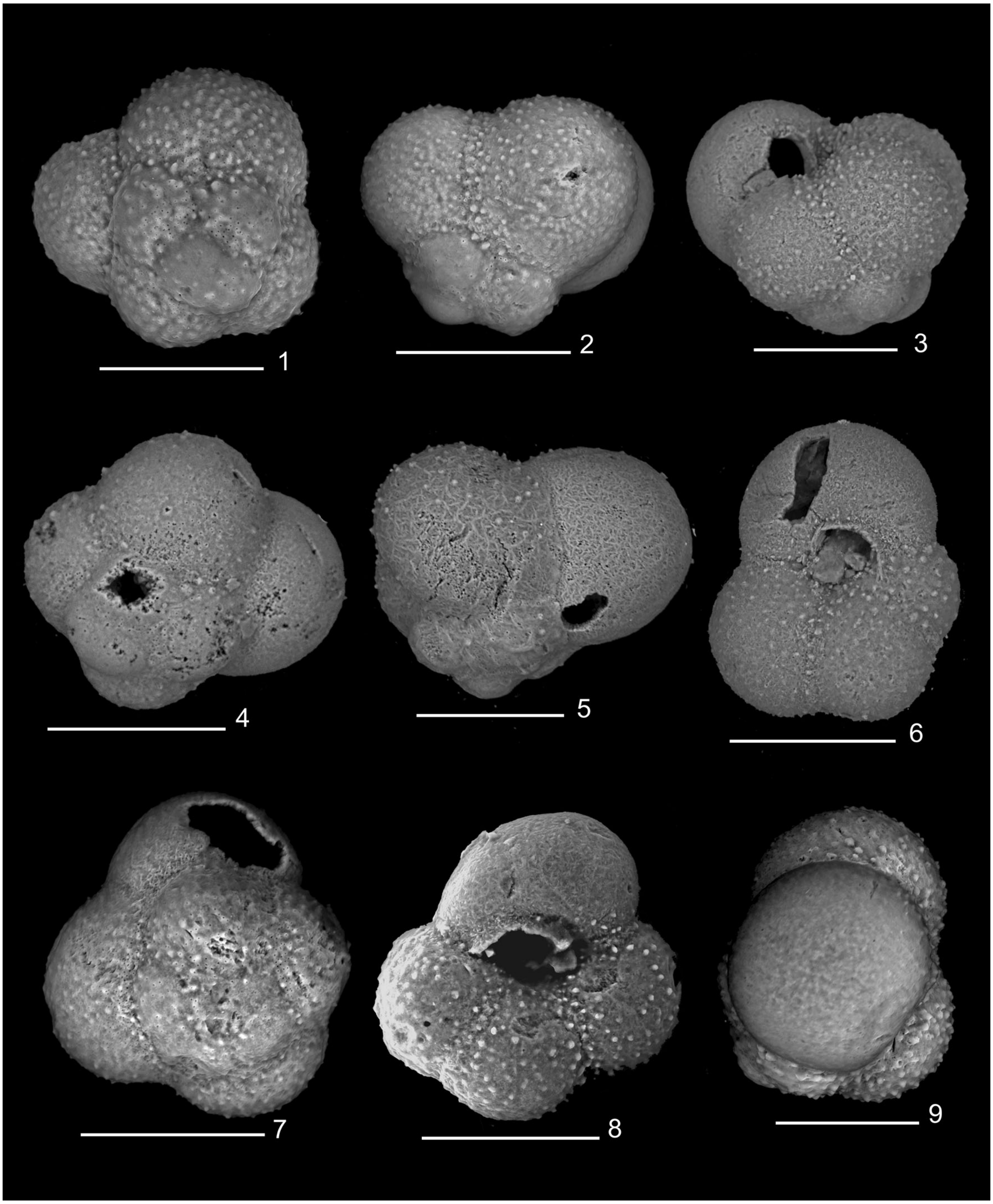


Plate 13 *Globuligerina oxfordiana* (Grigelis) from Gnaszyn 6 sample, Częstochowa area, Poland, Middle Bathonian. Note micro perforation and pustules with pore mounds. Nos. *1, 4, 7* spiral view; nos, *2, 3, 5* side view; nos. *6, 8* umbilical view; no. *9* umbilical view with large bulla; the *scale bar* is 50 μm

specimens were found, two of which may be assigned to *Globuligerina bathoniana* (Pazdrowa). Two other ones appear to be a new taxon, not described earlier.

The test is triserial or slightly trochoid coiled, with 3 whorls; test chambers regularly increase in size. Last chamber markedly sticking up. Aperture not preserved. Test wall is microperforate and reticulate and shows many low and longitudinal ribs, crossing chamber sutures. Until more and better preserved specimens are located, it is refrained from formally describing this taxon. *Conoglobigerina pupa* Wernli and Görög 2007 (their plate 4, figs. 1, 2) bears resemblance, including what looks like faint striation on these specimens from the Middle Jurassic of France.

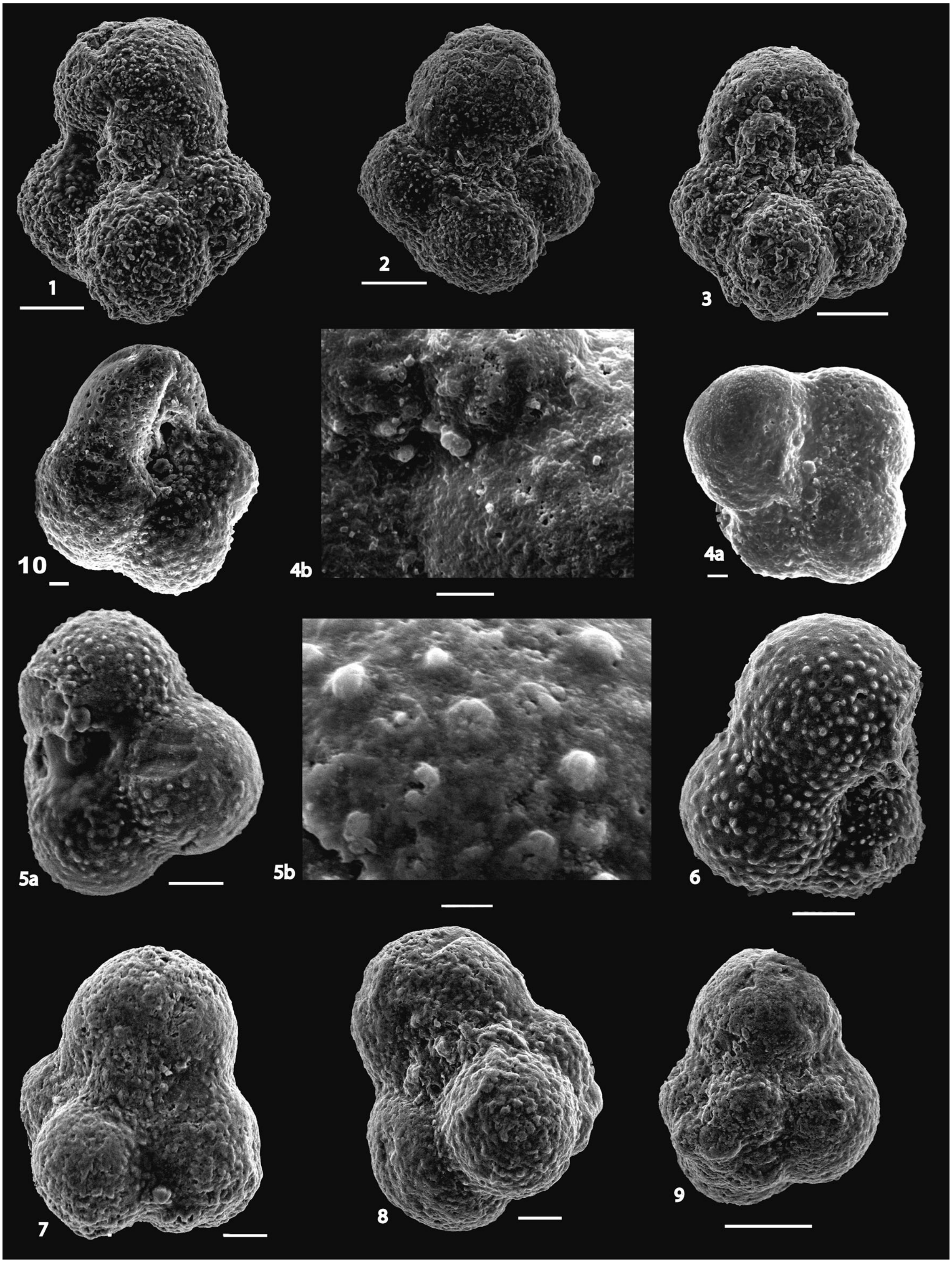


Plate 14 *Globuligerina oxfordiana* (Grigelis) from late Bajocian through early Kimmeridgian. Note that in these, well preserved, specimens there is no clear change in wall surface texture from Bajocian through Kimmeridgian. Nos. *1, 2* and *3*, sample T2/8, Tojeira Fm., Montejunto, Portugal, Early Kimmeridgian, *scale bars* 50 µm. Nos. *10, 4a* and *4b*, borehole GdF 496, Le Havre, France, Early Oxfordian, *scale bars* 10 µm (donation G. Bignot, France). Nos. *5a, 5b* and *6*, Gnaszyn 6 sample, Częstochowa, Poland, Middle Bathonian, specimens *scale bars* 20 µm, wall texture *scale bar* 5 µm. Nos. *7, 8* and *9*, sample *8*, roof bed 19, Khouroukra, Dagestan, Late Bajocian, *scale bars* 20 µm for specimens *7* and *8*, and 50 µm for specimen *9* with spiral view

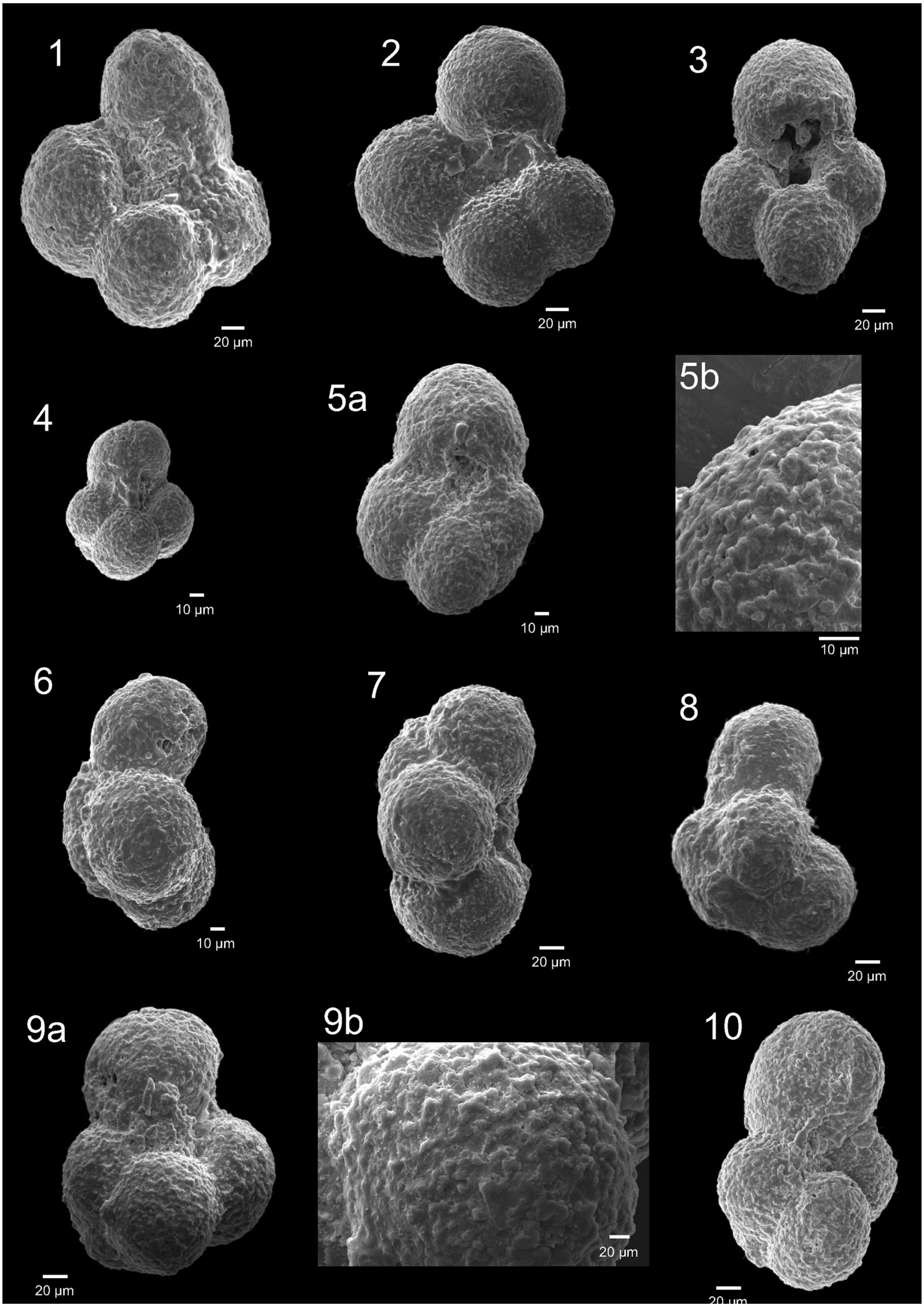
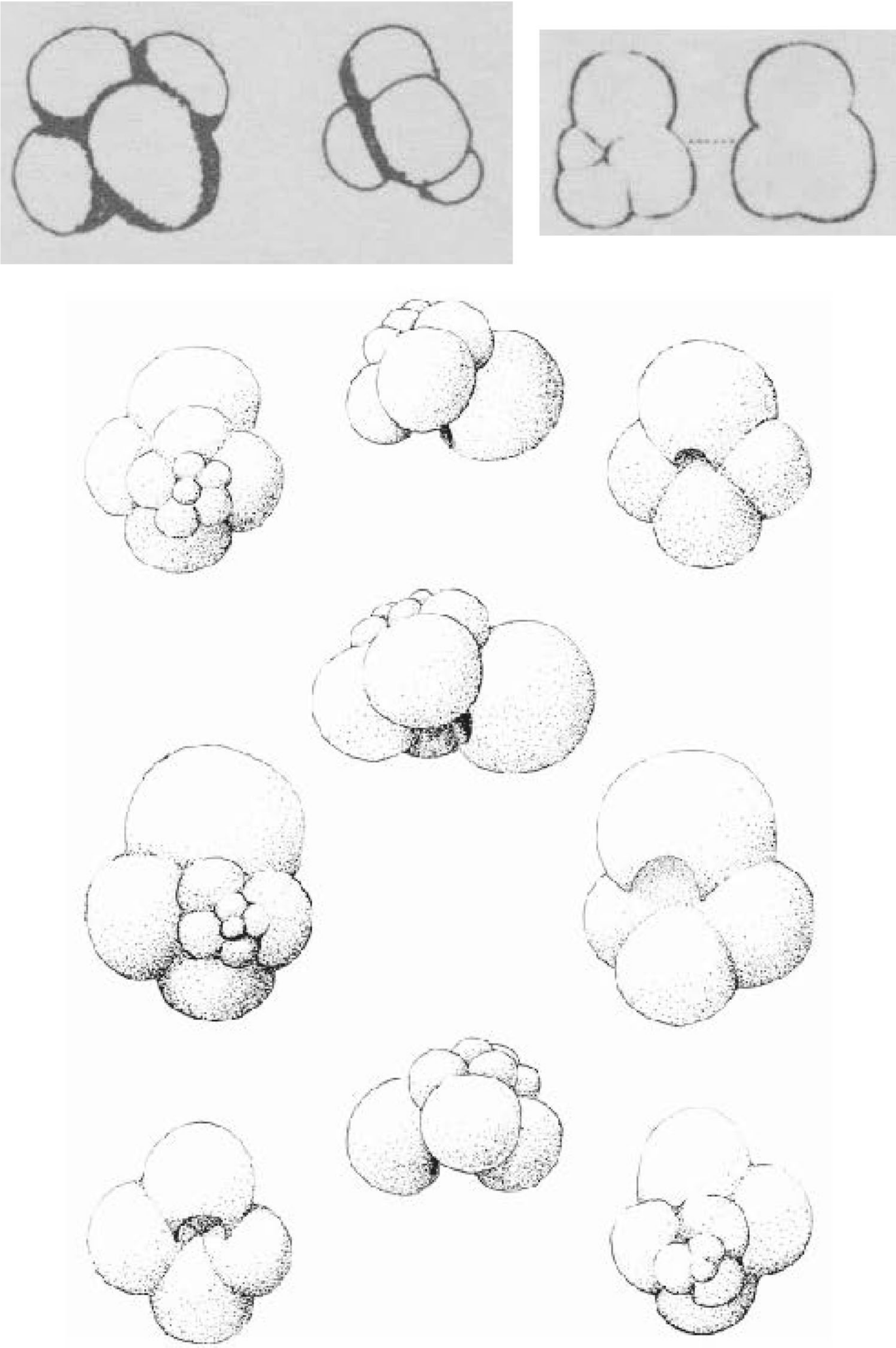


Plate 15 *Globuligerina tojeiraensis* Gradstein, Tojeira Formation, Montejunto, Portugal. No. *1*, holotype; nos. *2–10*, paratypes. The types are from sample 24/2P taken in 1978 from the middle Tojeira Formation, Montejunto, Portugal, *Platyna* through *Platynota* Zones, Early Kimmeridgian. Note pore mounds preserved on specimen no. *1*. This sample 24/2P was taken a few meters above the limestone couplet in our Photograph 1

Conoglobigerina grigelisi Gradstein 2017
Plate 18, nos. 1–10.

2013, Conoglobigerina ? avariformis Kasimova, Görög and Wernli, p. 285, fig. 4, nrs. 8–13.
2017, *Conoglobigerina grigelisi* Gradstein, Gradstein (2017a), p. 22, figure 6, nos. 1–10.

Description Low to medium high conical test with a compact spire and 3.5–4 chambers in the last whorl. *H/D* ratio 0.5–1, and rarely over 1. No preferred coiling direction observed. The chambers of the last whorl are large and have deeply incised sutures. Last whorl strongly embraces previous (? 2) whorls such that the earlier part of the test may hardly be visible. Apex generally blunt, rarely



Type species Fig. 7 Upper four specimens are original drawings of *Globigerina helveto-jurassica* by Haeusler 1881; no magnification provided. Lower nine specimens are drawings of *Globigerina helveto-jurassica* Haeusler by Oesterle (1968); Basel Geological Museum, C 25692–694; magnification ×200. *Cordatus, Lamberti and Transversarius* Zones, Middle Oxfordian of Switzerland

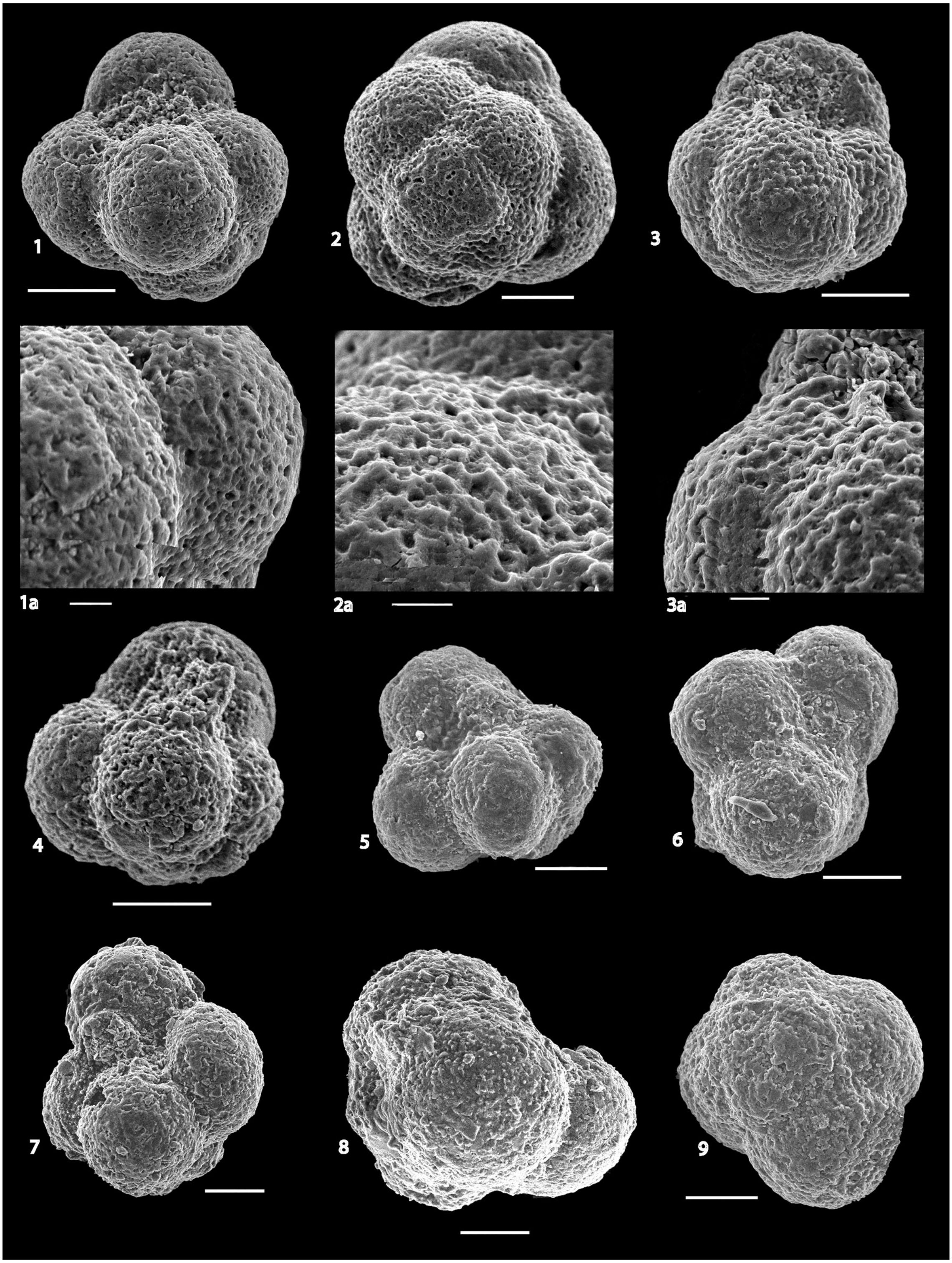


Plate 16 *Conoglobigerina helvetojurassica* (Haeusler). *Scale bars* for all specimens represent 50 µm; *scale bars* for wall texture scans 1a and 3a are 20 µm long and for wall texture scan 2a is 10 µm long. Nos. *1–4*, sample *4* mid, Eisengraben Section, Birmenstorfer Schichten, *Transversarius* Zone, Middle Oxfordian, Canton Aargau, Switzerland. Images nos. *1a, 2a* and *3a* show the reticulate wall texture of specimens *1*, *2* and *3*. The aperture likely was arch shaped in nos. *1, 2* and *3* and clearly loop shaped with lip in no. *4*. Nos. *5–9*. *Conoglobigerina helvetojurassica* (Haeusler), Tojeira Formation, Early Kimmeridgian, Montejunto area, Portugal. Specimen no. *7* is from sample 24/2P; the specimens nos. *5, 6* and *9* are from sample T2/1 and no. *8* specimen is from sample T2/2. The Tojeira specimens have a reticulate wall (imperfectly so on some chambers in specimen nos. *6* and *8*) and arched to looped aperture with lip

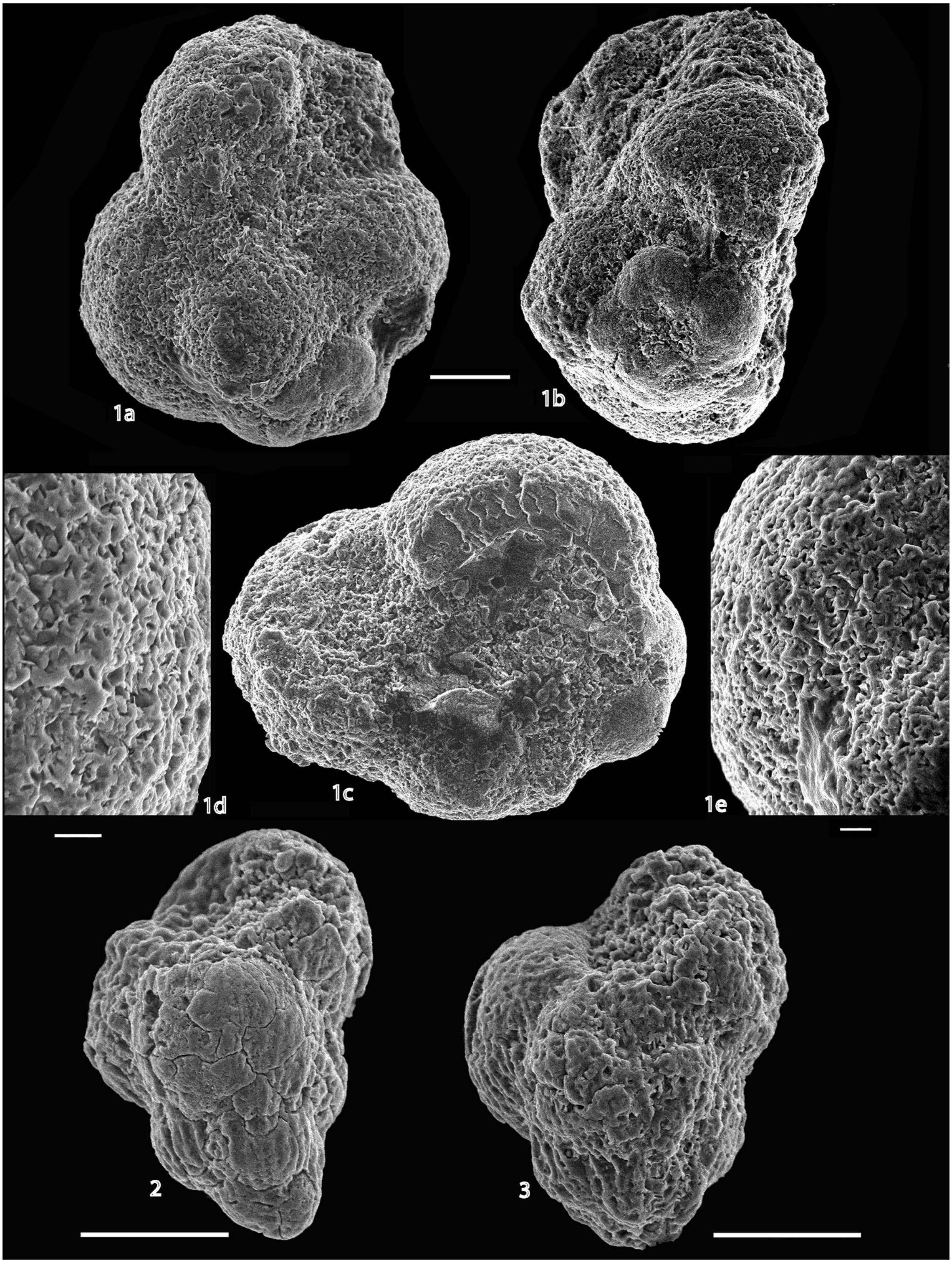


Plate 17 *Conoglobigerina helvetojurassica* (Haeusler), Sample *4* mid, Eisengraben Section, Birmenstorfer Schichten, *Transversarius* Zone, Oxfordian, Canton Aargau, Switzerland. No. *1a* shows umbilical view; no. *1b* shows side view; no. *1c* shows spiral view; nos. *1d* and *1e* show reticulate wall texture. *Scale bar* for the specimen represents 50 µm; *scale bars* for wall texture scans are 10 µm long. This specimen may have been sessile for part of its life cycle; for details see *text*. Plate 4, nos. *2* and *3*. Unknown planktonic genus, sample 4 mid, Eisengraben Section, Birmenstorfer Schichten, *Transversarius* Zone, Middle Oxfordian, Canton Aargau, Switzerland. *Scale bars* represent 50 µm. For details, see *text*

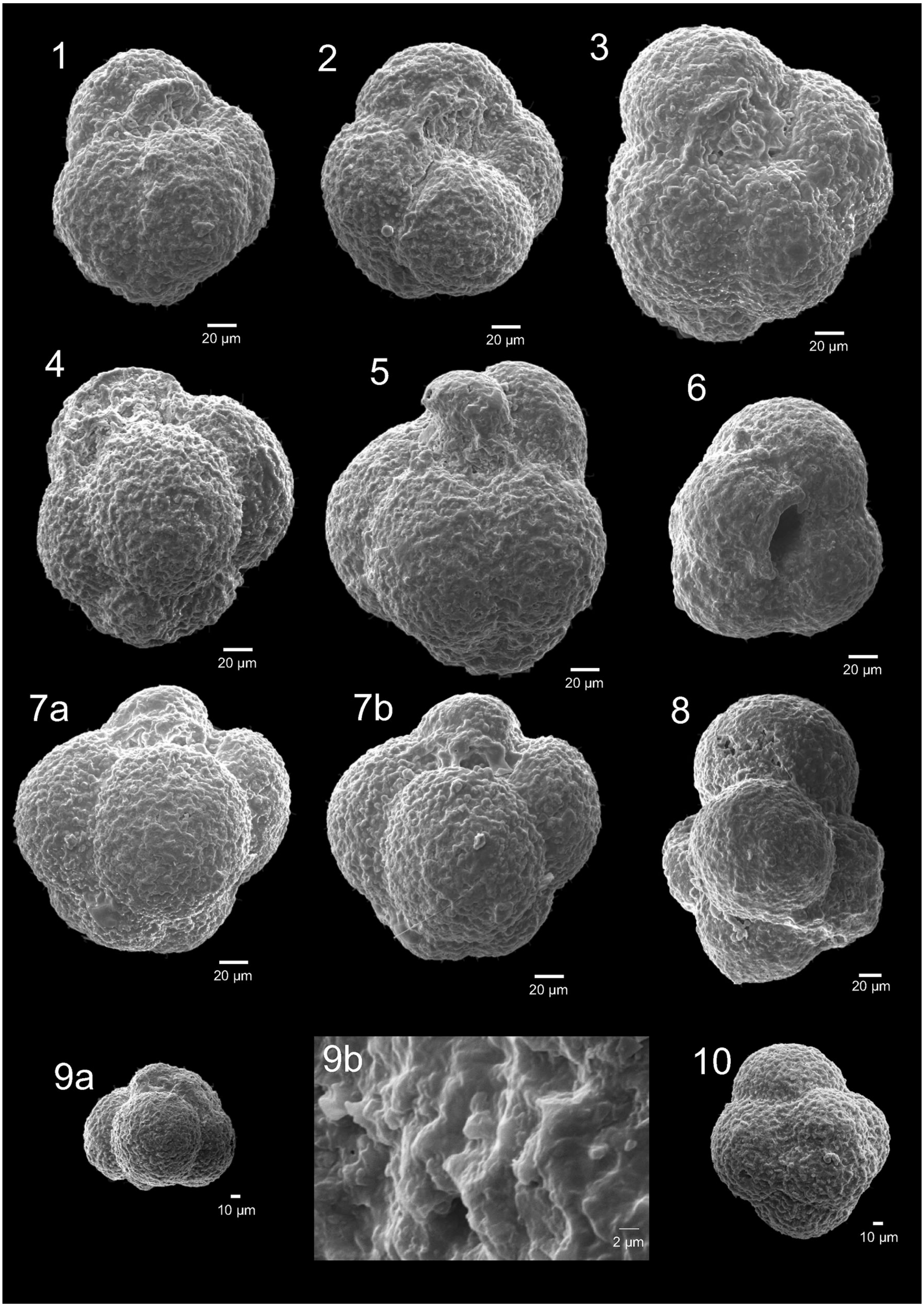


Plate 18 *Conoglobigerina grigelisi* Gradstein, Tojeira Formation, Montejunto, Portugal. No. *1*, holotype; nos. *2–10*, paratypes. Types are from Sample 24/2P taken in 1978 from the middle Tojeira Formation, Montejunto, Portugal; *Platyna* through *Platynota* Zones, Early Kimmeridgian. This sample was taken a few meters above the limestone couplet in Photograph 1

pointed. Umbilical area depressed. Aperture generally a more or less symmetrical arch with lip, rarely comma shaped. Specimens may have a small bulla over the umbilicus with one or two, low-arch apertures; it may resemble the bulla structure of Cenozoic *Catapsydrax* taxa. Wall microperforate, strongly pustulose; pustules form low and broken ridges that create an imperfectly reticulate pattern over the surface of the chambers.

Differential diagnosis Conoglobigerina grigelisi differs from *Globuligerina bathoniana* in its more compact test, strongly embracing chambers in the last whorl, often wider last whorl and wider umbilicus, and by its densely pustulose, reticulate wall sculpture. The pustules form broken ridges that arrange in an imperfect, low reticulate pattern over the whole test. *Globuligerina helvetojurassica* has more spherical, globular chambers which do not so strongly overlap previous whorls as in *C. grigelisi.*

Our specimens in shape somewhat resemble *Conoglobigerina avariformis* Kasimova (1984) from the Bajocian of Azerbaijan. This taxon is poorly documented, but the original description by Kasimova and Aliyeva (1984) mentions a smooth test and low arch aperture. The original drawings of the holotype show that the last whorl much less embraces the test than in *C. grigelisi.* Görög and Wernli (2002) report common *Conoglobigerina aff. avariformis* from the Middle and Late Bathonian of Hungary.

The SEM illustration in Plate 6, nos. 7–9 of a specimen of *Globuligerina avariformis* (Kasimova) donated by G. K. Kasimova to the Museum of Natural History, London, UK shows the rather smooth wall and compact test. The sutures are less incised than in our specimens of *C. grigelisi*. Another key difference is that the Bajocian age specimens from Azerbaijan have a wall with low pustules and ridges, instead of a dense muricate and rather reticulate wall sculpture. In our specimens, the last whorl also is more embracing the older part of the test.

Görög and Wernli (2013) described a morphotype from the Kimmeridgian of SE France under the name *C.?avariformis*, using acetolysis that strongly resembles *C. grigelisi*.

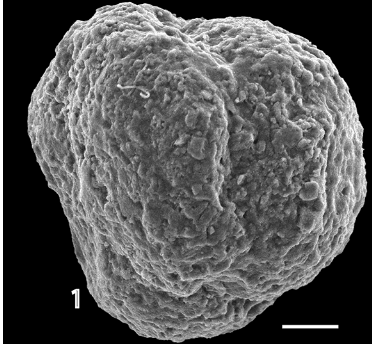
Range Common in the Tojeira Formation, Lower Kimmeridgian of Central Portugal, and observed with few, small specimens in slightly older strata on the Grand Banks. Likely occurs also in the Kimmeridgian of SE France.

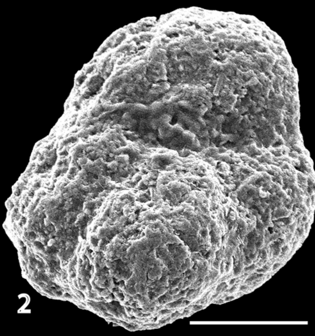
Phylogeny The more embracing test and more advanced wall texture of *Conoglobigerina grigelisi* compared to *Globuligerina avariformis* Kasimova may indicate an evolutionary trend from the latter to the former taxon in Late Jurassic time. The problem is a lack of record of the latter in Callovian through Oxfordian strata.

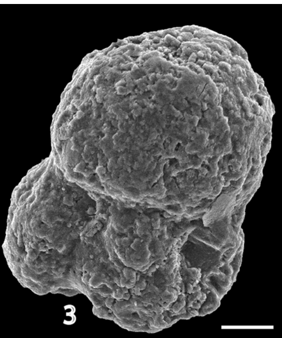
Conoglobigerina gulekhensis **(Gorbachik and Poroshina) 1979**

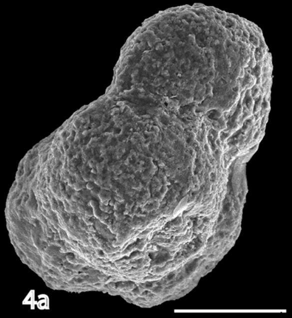
Type species Fig. 9; Plate 19, nos. 1, 2, 4, 8.
1979 *Globuligerina gulekhensis* Gorbachik and Poroshina, p. 286–288, fig. 1a–c.
1979 *Globuligerina caucasica* Gorbachik and Poroshina, p. 288, figs. 2a-3, 3 a–d.

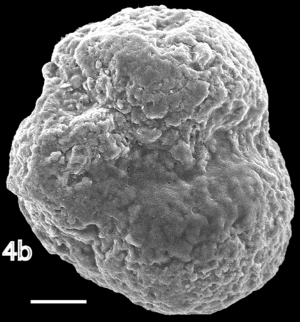
Type species Fig. 9 Holotype drawings of *Globuligerina gulekhensis* Gorbachik and Poroshina (*upper*) and *Globuligerina caucasica* Gorbachik and Poroshina from the Berriasian of Azerbaijan. Maximum test diameter 180 µm of the former and 200 µm of the latter. To the right is shown the cancellate wall texture of another specimen (magnification ×300)

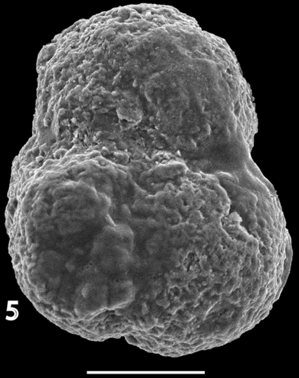

1

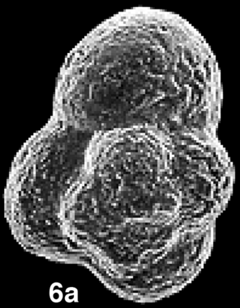

2


3


4a

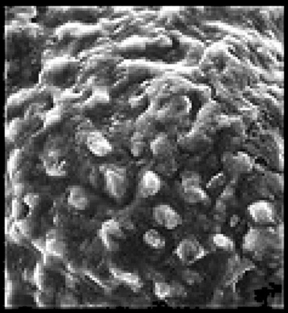

4b

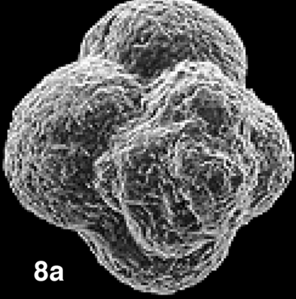

5

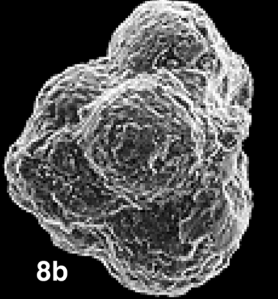

6a

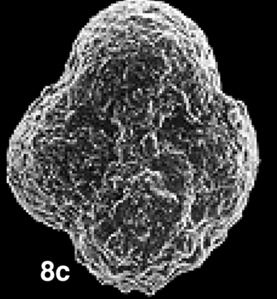

6b


6c


7


8a


8b


8c

◀**Plate 19** *Conoglobigerina gulekhensis* (Gorbachik and Poroshina) and ? *Conoglobigerina* sp. Nos. *6–8* re-illustrated from Simmons et al. (1997), plate 2.6. Nos. *1, 2, 4* and *5* show poorly preserved topotypes of *Conoglobigerina gulekhensis* in our sample from Early Berriasian strata, Tonas River Basin, E. Crimea, Russia. Although poorly visible on the images, the wall texture is reticulate. Nos. *6, 7* and *8* are metatypes of *C. gulekhensis* of Early Berriasian age, village of Ugakh, SE Caucasus, Azerbijan, deposited in the Geological Faculty of Moscow, State University, Russia. Nos. *6* and *7* appear more like *Globuligerina tojeiraensis*; for discussion see *text* on Taxonomy. No. *1*, side view of high spired test; no. *2*, umbilical view with low arch aperture; no. *4a*, side view of medium high spired test; no. *4b*, umbilical view; no. *5*, umbilical view; all *scale bars* 50 µm. No. *3*. ? *Conoglobigerina* sp. with large last chamber, Early Berriasian, Tonas River Basin, E. Crimea, Russia; *scale bar* 20 µm. Nos. *6a, b, c*, (×250). Specimen diameter 160 µm, spiral view, side view and umbilical view with sediment fill or partial bulla. Metatype on no. *7* with enlargement of the wall surface (dorsal side) showing pseudomuricae sometimes fusing into discontinuous, blunt ridges (×1100). Nos. *8a–c*, (×235). Specimen diameter 170 µm, spiral view, peripheral view showing a convex spire and umbilical view with arched, intraumbilical aperture

1997 *Conoglobigerina gulekhensis* (Gorbatchik and Poroshina), Simmons et al. p. 24, 25, plate 2.6, figs. 13–15.
Non 1997 *Conoglobigerina caucasica* (Gorbachik and Poroshina), Simmons et al. p. 24, plate 2.6, figs. 9–12.

Original description Test small, no more than 0.25 mm in diameter, high trochoidal; test contour subquadratic, prominently lobate. The spire forming the initial whorl is often slightly displaced relative to the centre of the ultimate whorl and sharply delineated from the surface. Peripheral margin broad and round. The test consists of 12–13 chambers forming the 2.5 to three whorls of a spiral. Chambers of initial whorls spherical or ellipsoidal, closely appressed. The size of the chambers increases gradually in each whorl; the chambers of different whorls differ appreciably in size. Septal sutures deepened, straight. Umbilicus small and narrow. Aperture opening in umbilicus, arcuate, with barely apparent lip. Test walls finely perforate; the surface appears smooth under the binocular microscope at a magnification of 96×, but distinctly expressed cancellate ornamentation is seen with the scanning electron microscope (at magnifications of 1000 and 3000×). Cells of cancellate ornamentation are irregularly tetragonal, separated by comparatively broad, high, smooth varices. The cells reach a size of 2 µm. Pores round or oval, mainly located within the cells, but sometimes also on the varices. Pores of two orders are seen; small ones measuring about 0.33 µm, and large ones measuring up to 1 µm. Small pores predominate. Test diameter varies between 0.15 and 0.25 mm and the height is 0.6 or 0.7 of the width; these measurements are for type specimens.

Discussion The outstanding diagnosis of Gorbachik and Poroshina (1979) is the English translation of their (originally in Russian) study in the Palaeontology Journal of the American Geological Institute. The description is based on the study of about 80 specimens from the Berriasian of Azerbaijan. Test variation is in height and shape of the test and number of chambers in the whorls. The test can be conical in shape, often bluntly conical, and the last whorl may rarely contain 3 chambers only.

The principal difference between the two contemporary taxa, *C. caucasica* and *C. gulekhensis* is the height of the spire and the very convex spiral side of the latter. However, providing the considerable variation in height of spire and convexity in both these two taxa and in other Jurassic planktonic taxa, the two forms are considered by us to be variants of one species.

The reticulate wall ornamentation of the species suggests that *C. gulekhensis* is related to *Conoglobigerina* in the Jurassic and to *Favusella* in the Cretaceous. It is not clear in what evolutionary lineage *C. gulekhensis* belongs. Curiously, the metatypes re-illustrated from Simmons et al. (1997) on our Plate 19, nos. 6–7 show little sign of reticulation. These specimens, that were originaly assigned to *C. caucasica* by Gorbachik and Poroshina (1979) and by Simmons et al. (1997), readily may be assigned to *Globuligerina tojeiraensis*. Hence, this species appears to extend from Kimmeridgian/Tithonian into Berriasian, but this will require more taxonomic study.

Although poorly visible on our topotypic specimens in Plate 19 from the Tonas River Basin, the reticulate wall texture is clear under suitable magnification.

Gorbachik and Poroshina (1997) list a diverse benthic foraminiferal assemblage from the Azerbaijan samples with numerous epistominids and ceratobuliminids.

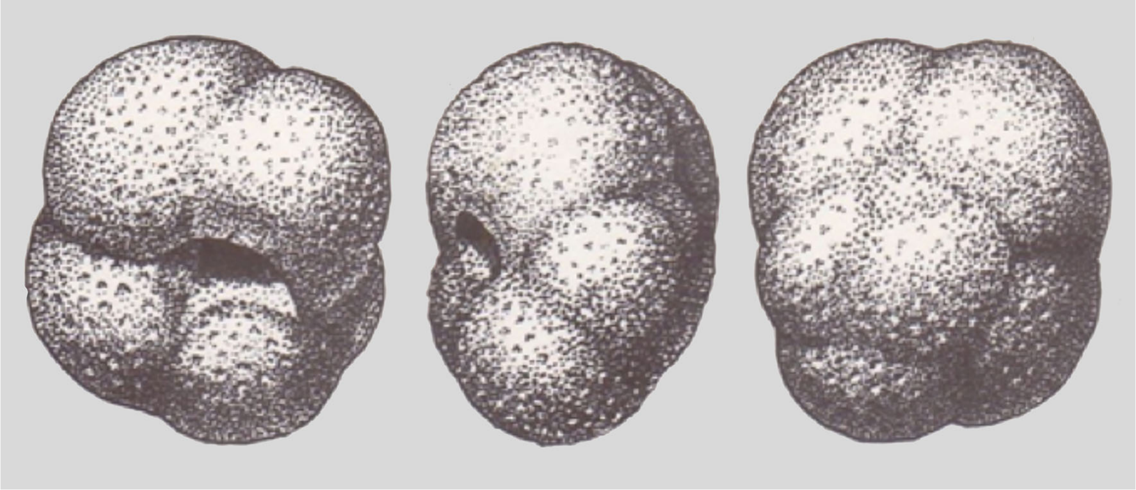
Range Described from the Early Berriasian–Early Valanginian of SE Caucasus, E. Crimea and Azerbaijan.

'Globuligerina' stellapolaris Grigelis 1977

Type species Fig. 10.

1977 *Globuligerina stellapolaris* Grigelis, Doklady Akademii Nauk SSSR vol. 233, 5, p. 926–927.
1997 *Compactogenerina stellapolaris* (Grigelis), Simmons et al., p. 29, plate 2.7, figs. 1–7.
2017 '*Globuligerina*' *stellapolaris* (Grigelis), Gradstein (2017a), p. 23, fig. 7, nos. 1–7.

Original description The test is small, trochoid and round. Dorsal side is low trochospiral, and the ventral side involute. The spire consists of two whorls, with 3 chambers in the first whorl and 4 in the second and last whorl. The chambers are round and adjoin each other closely. Sutures are linear and slightly incised. The aperture is arcuate shaped. The test wall is calcareous, thin and with large



Type species Fig. 10 *Globuligerina stellapolaris* Grigelis. Holotype drawing in 1980 by micropalaeontology graphic artist Sergei Nikolayev, St. Petersburg; magnification ×150

pores (!). The *H*/*D* ratio of the holotype is 0.72 and its test over 200 μm large.

The taxon differs from *Globuligerina oxfordiana* in the round (not oval) shape of the test, greater size, and its more closely packed chambers.

Twenty or more specimens were found in the type area, some fairly well preserved. The types are stored in the Lithuanian Institute of Geological Exploration.

The types of '*Globuligerina*' *stellapolaris* are from very thin Upper Jurassic strata outcropping along the banks of the Pizma and Ishma Rivers in the Pechora Basin. In the chapter on Material a summary is provided of the local stratigraphy. Note that this finding is much further north than the northernmost occurrence of other latest Jurassic taxa of planktonic foraminifera. The unusual occurrence and unusual test taxonomy with large pores are discussed in detail in Gradstein (2017a). The latter study suggests that we may be dealing with *Neogloboquadrina pachyderma* (Ehrenberg).

Conclusions

Rich and diversified assemblages of Jurassic planktonic foramifera from Eastern Canada, Portugal and Dagestan are central to our understanding of morphological variability. Type material was collected and examined from Eastern Canada, Portugal, France, Switzerland, Poland, Lithuania, Central Russia and Dagestan. Most samples yielded well-preserved free specimens. Detail is provided on the geography and stratigraphy of sections studied.

The species concept used in this study is an assemblage species concept. All specimens that form an entire, but gradual morphological range in a sample, are grouped together as one species. This provides a sound taxonomic base, since intergradational series are de-facto part of conspecificity (Mayer et al. 1953), and the concept has been widely applied in fossil and recent foraminifera. Or, as Dawkins (2008, p. 204) elegantly wrote: 'Minor variations are the stuff of evolution (not merely a set of accidental excursions around a created ideal type), but we recognize this only when we are prepared to sum small effects through long periods of time'. Or to phrase it in practical terms for Jurassic planktonic foraminifera: taxonomy should clarify evolutionary and stratigraphic trends and not create new 'species' with few specimens from single localities without insight in correlative value of the taxon. Local ecophenotypic variation should not drive species taxonomy

We 'reject' as valid species all pre-Cretaceous taxa described from glauconitic casts, and do not deal with taxa described from thin-sections. If wall surface patterns can be preserved during acetolysis of limestones, such studies might help to extract free specimens on which taxonomy might be attempted

An attempt is made to link to the taxonomic concept developed for Cretaceous planktonic foraminifera. Hence, the shape of the aperture is not a character at genus level, but wall texture is. Two genera are distinguished, both microperforate: medium high-spired *Conoglobigerina* with reticulate wall surface texture and low- to high-spired *Globuligerina* with almost smooth to pustulose wall. *Globuligerina* probably appeared in late Toarcian (late Early Jurassic) and *Conoglobigerina* first occurred in middle Oxfordian (early Late Jurassic).

Within the two genera, ten species are described, including from older to younger: *Globuligerina dagestanica* (Morozova), *G. avariformis* (Kasimova), *G. balakhmatovae* (Morozova), *G. oxfordiana* (Grigelis), *G. bathoniana* (Pazdrowa), *G. jurassica* (Hofman), *G. oxfordiana* subspecies *calloviensis* Kuznetsova emended, *G. tojeiraensis* Gradstein, *Conoglobigerina helvetojurassica* (Haeusler), *C. grigelisi* Gradstein and *C. gulekhensis* (Gorbachik and Poroshina). The coarse perforate '*Globuligerina' stellapolaris* needs more investigation to establish its identity as a Jurassic or a Late Cenozoic taxon (Gradstein 2017a).

A kummerform last chamber (bulla) is common in most of the taxa, except in *G. balakhmatovae*, where it has not been observed. Some specimens in assemblages of *G. oxfordiana* in Poland and Lithuania show the onset of reticulation on the wall of the last few chambers, suggesting an evolutionary relationship between *Globuligerina* and *Conoglobuligerina* in Oxfordian time.

Acknowledgements Christian Meyers, Walter Etter and Michael Knappertbusch (Basel, Switzerland) provided vital scientific and logistical support and hospitality to unravel the 'mysteries' around one of the first named taxon of Jurassic planktonic foraminifera–*Globigerina helvetojurassica* Haeusler from the Birmenstorfer Schichten near Basel, Switzerland. Maria Rose Petrizzo provided quality sample processing for this study and advice on taxonomy; Evi Bieler and Michael Knappertbusch are thanked for the SEM illustrations of Jurassic planktonic foraminifera in the Oesterle collection of the Natural History Museum in Basel. Michele Goulart de Silva and Giovanni Borgo at ITT Fossil, Unisinos, Sao Leopoldo, Brasil also provided major assistance with SEM illustrations. A number of plates with SEM illustrations of taxa are from the thesis of my PhD student B.Stam (†), (Stam 1986) and from Simmons et al. (1997). We thank Mike Simmons and John Whittaker for permission to use their plates. We also thank R.Wernli and A.Görög for reproduction of two small type species figures. Drafting of all figures was skillfully executed by Gabi Ogg (W. Lafayette, USA). Anna Waskowska acknowledges that her participation in the study was supported by KGOiG WGGiOŚ AGH Statutory Founds (AW). Chief editor Marty Daniel of the Swiss Journal of Palaeontology and two anonymous reviewers provided much appreciated advice to get the manuscript in final shape for publication.

The following colleagues, students and technical staff provided assistance with many thanks: Mike Simmons (Oxford, UK), John and Gregory Whittaker (London, UK), Valery Vuks (St. Petersburg), Temirbekova Umuhayabat Temirbekovna (Makhachkala, Dagestan), Walter Hale (Bremen, Germany), David Watkins (Nebraska, USA), Brian Huber (Washington, USA), Holly Turner (Portsmouth, UK), Martin Gibling and Darlene van de Rijt (Halifax, NS, Canada), Kate Jarrett (Dartmouth, NS, Canada) and Slawomir Bebenek and Alexandra Durek (AGH University, Krakow, Poland).

References

Agterberg, F. P., Gradstein, F. M., & Nazli, K. (1989). Correlation of Jurassic microfossil abundance data from the Tojeira sections, Portugal. *Geological Survey of Canada, 89*(9), 467–482.

Andrusov D. (1965). *Geologie der tschechoslowakischen Karpaten II. Akademi (The geology of the Czech-Slovak Carathians II—in Deutch)* (p. 443). Berlin.

Apthorpe, M. (2003). Triassic to early middle Jurassic foraminifera from the northwestern margin of Australia. Unpublished PhD thesis, University of western Australia, Australia.

Banner, F. T., & Desai, D. (1988). A review and revision of the Jurassic-Early Creteaceous Globigerinina, with special reference to the Aptian assemblages of Speeton (North Yorkshire, England). *Journal of Micropalaeontology, 7*(2), 143–185.

Barss, M. S., Bujak, J. P., & Williams, G. L. (1979). Palynological zonation and correlation of sixty-seven wells, eastern Canada. *Geological Survey of Canada Paper, 78–24,* 117.

Bignot, G., & Guyader, J. (1966). Découverte de foraminifères planctoniques dans l'Oxfordien du Havre (Seine-Martitime). *Revue de Micropaléontologie, 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.

Bignot, G., & Janin, M.-C. (1984). Découverte de *Globuligerina oxfordiana* (Foraminifères planctonique) dans le Bajocien stratotypique de la Falaise des Hatcheetts (Sainte-Honorine-de-Pertes, Calvados, France). *Comptes-rendus des séances de l'Académie des sciences. Série 2, Mécanique-physique, chimie, sciences de l'univers, sciences de la terre*, *298*(II, 17), 751–756.

Birkenmajer, K. (1958). *Przewodnik geologiczny po pienińskim pasie skalkowym. Cz. I–IV (Pieniny Klippen Belt of Poland, Geological guide—in Polish), Pts. I–IV* (p. 350). Warszawa: Wydawnictwa Geologiczne.

Birkenmajer, K. (1963). Stratygrafia i palaeogeografia serii czorsztyńskiej pienińskiego pasa skalkowego Polski: stratigraphy and palaeogeography of the Czorsztyn series (Pieniny Klippen Belt, Carpathians) in Poland. *Studia Geologica Polonica, 9,* 1–380.

Birkenmajer, K. (1977). Jurassic and Cretaceous lithostratigraphic units of the Pieniny Klippen Belt, Carpathians, Poland. *Studia Geologica Polonica, 45,* 1–158.

Birkenmajer, K. (1986). Stages of structural evolution of the Pieniny Klippen Belt, Carpathians. *Studia Geologica Polonica, 88,* 7–32.

Bordalo da Rocha, R. (1976). Estudo estratigrafico e palaeontologico do Jurassico do Algarve occidental. Ciencias da Terra 2, Universidade Nova de Lisbon, p. 114.

Brummer, G. J. A., Hemleben, C., & Spindler, M. (1987). Ontogeny of extant spinose planktonic foraminifera (Globigerinidae): a concept exemplified by *Globigerinoides sacculifer* (Brady) and *G. ruber* (D'Orbigny). *Marine Micropalaeontology, 12,* 357–381.

Caromel, A. G. M., Schmidt, D. N., Fletcher, I., & Rayfield, E. J. (2016). Morphological change during the ontogeny of the planktonic foraminifera. *Journal of Micropalaeontology, 35,* 2–19.

Coccioni, R., & Premoli Silva, I. (2015). Revised Upper Albian-Maastrichtian planktonic foraminiferal biostratigraphy and magnetostratigraphy of the classical Tethyan Gubbio section (Italy). *Newsletter on Stratigraphy, 48*(1), 47–90.

Colom, G. (1955). Jurassic-Cretaceous pelagic sediments of the western Mediterranean zone and the Atlantic area. *Micropalaeontology, 1*(2), 109–124.

Collins E.S., Kuhnt, W., & Scott, D.B. (1996). Tithonian benthic foraminifers from Hole 901. Proc. Deep Sea Drilling Project, Sci. Res., vol. 149, pp. 193–201.

Dadlez, R., Marek, S., & Pokorski, J. (2000). *Geological Map of Poland without Cenozoic deposits*. Warszawa: Państwowy Instytut Geologiczny.

Darling, K. F., Thomas, E., Kasemann, S. A., Sears, H. A., Smart, C. W., & Wade, C. M. (2009). Surviving mass extinction by bridging the benthic/planktic divide. *PNAS, 106*(31), 12629–12633.

Dawkins, R. (2008). *The Oxford book of modern science writing* (p. 419). Oxford: Oxford University Press.

Dayczak-Calikowska, K. (1997). Jura środkowa. Sedymentacja, palaeogeografia i palaeotektonika. In: S. Marek, & M. Pajchlowa

(Eds.), Epikontynentalny perm i mezozoik w Polsce (vol 153, pp. 269–282). Prace Państwowego Instytutu Geologicznego.

de Kaenel, E., & Bergen, J.A. (1996). Mesozoic calcareous nannofossil biostratigraphy from Sites 897, 899 and 901, Iberia Abyssal Plain: new biostratigraphic evidence. Proc. Ocean Drilling Project, Sci. Res. vol. 149, pp. 27–59.

Fuchs, W. (1975). Zur Stammesgeschichte der Planktonforaminiferen und verwandter Formen im Mesozoikum. *Jahrbuch der Geologischen Bundesanstalt*, *118*, 193–246.

Gedl, P., & Kaim, A. (2012). An introduction to the palaeoenvironmental reconstruction of the Bathonian (Middle Jurassic) ore-bearing clays at Gnaszyn, Kraków-Silesia Homocline, Poland. *Acta Geologica Polonica, 62,* 267–280.

Gedl, P., Kaim, A., Leonowicz, P., Boczarowski, A., Dudek, T., Kędzierski, M., et al. (2012). Palaeoenvironmental reconstruction of Bathonian (Middle Jurassic) ore-bearing clays at Gnaszyn, Kraków-Silesia Homocline, Poland. *Acta Geologica Polonica, 62,* 463–484.

Gorbachik, T.N. (1983). *Globuligerina oxfordiana* (Grigelis)—a typical species of the genus *Globuligerina* in electron microscope. Akad. Nauk. SSSR, vol. 26, pp. 48–51 (+6 plates).

Gorbachik, T. N., & Kuznetsova, K. I. (1983). Jurassic and Early Cretaceous planktonic Foraminifera (Favusellidea). *Stratigraphy and Palaeobiogeography. Zitteliana, 10,* 459–466.

Gorbachik, T. N., & Kuznetsova, K. I. (1986). Study of shell mineral composition of planktonic foraminifera. *Voprosy Mikropalaeontologii, 28,* 42–44.

Gorbachik, T.N., & Poroshina, L.A. (1979). New Berriasian planktonic foraminifers from Azerbaydzhan. *Paleontology Journal*, *3*, 283–289 **(translated from Russian)**.

Görög, A., & Wernli, R. (2002). The Middle and Late Bathonian protoglobigerinids of Gyenespuszta (Bakony Mts., Hungary). *Revue de Paléobiologie*, *21*(1), 21–34.

Görög, A., & Wernli, R. (2003). Palaeobiogeography of the Middle Jurassic protoglobigerinids (Foraminifera). *Eclogae Geologicae Helvetiae, 96,* 237–248.

Görög, A., & Wernli, R. (2013). Protoglobigerinids of the Early Kimmeridgian of the Jura Mountains (France). *Journal of Foraminiferal Research, 43*(3), 280–290.

Gradstein, F.M. (1975). Biostratigraphy (Foraminifera) and depositional environment of Amoco IOE Eider M-75, Grand Banks of Newfoundland. Geol. Surv. Canada, Open File 334, p. 17.

Gradstein, F.M. (1976). Biostratigraphy and biogeography of Jurassic Grand Banks Foraminifera. Ist Int. Symp. Benthic Foraminifera, Pt. B. Maritime Sediments, Spec. Publ. 1, pp. 557–583.

Gradstein, F.M. (1983). Palaeoecology and stratigraphy of Jurassic abyssal Foraminifera in the Blake-Bahama Basin, Deep Sea Drilling Project Site 534. Init. Repts. DSDP: Washington (US Governm. Printing Office), vol. 76, pp. 537–559.

Gradstein, F.M. (2017a). New and emended species of Jurassic planktonic foraminifera.

Gradstein, F.M. (2017b). The planktonic foraminifera of the Jurassic—Part III: annotated historical review and references.

Gradstein, F., Gale, A., Kopaevich, L., Waskowska, A., Grigelis, A., Glinskikh, L., & Görög, Á. (2017c). The planktonic foraminifera of the Jurassic—part II: biostratigraphy, palaeoecology and palaeobiogeography.

Grigelis, A. A. (1958). *Globigerina oxfordiana* sp.nov.—an occurrence of *Globigerina* in the Upper Jurassic strata of Lithuania. *Nauschny Doklady Vysschei Shkoly, Geologo-Geographicheskie Nauki, 3,* 109–111. **(in Russian)**.

Grigelis, A. A. (1974). Jurassic stage of evolution of planktonic Foraminifera. *Doklady Akademii Nauk SSSR, 219*(5), 1203–1205.

Grigelis, A. (1985). Jurassic Foraminifers of the south-west Baltic area. Mokslas, Vilnius, p. 240 **(in Russian)**.

Grigelis, A., & Gorbatchik, T. (1980). Morphology and taxonomy of Jurassic and Early Cretaceous representatives of the superfamily Globigerinacea (Favusellidae). *Journal of Foraminiferal Research, 10*(3), 180–190.

Gulyaev, D.B., Ippolitov, A.P., Glinskikh, L.A. (2015). III.4 Khurukra [III.4. Khouroukra]. In: V.I. Cherkashin (Ed.), Jurassic deposits of the central part of Mountain Dagestan. Field guide to the VI All-Russian conference "Jurassic system of Russia: problems of stratigraphy and palaeogeography", September 15–20, Makhachkala. Makhachkala: ALEF, pp. 64–80 (in Russian).

Haeusler, R. (1881). *Untersuchungen ueber die microscopischen Structurverhaeltnisse der Aargauer Jurakalke, mit besonderes Beruecksichtigung iherer Foraminiferenfauna* (p. 47). Diss: Univ. Zuerich.

Hart, M. B., Hudson, W., Smart, C. W., & Tyszka, J. (2012). A re-assessment of '*Globigerina bathoniana'* Pazdrowa, 1969 and the palaeoceanographic significance of Jurassic planktic foraminifera from southern Poland. *Journal of Micropalaeontology, 31,* 97–109.

Hemleben, C., Spindler, M., & Anderson, O. R. (1989). *Modern Planktonic Foraminifera* (p. 363). Berlin: Springer.

Herb, R. (1968). Recent planktonic foraminifera from sediments of the Drake Passage, Southern Ocean. *Ecologae Geologicae Helvetiae, 61*(2), 467–480.

Hudson, W., Hart, M. B., Sidorczuk, M., & Wierzbowki, A. (2005). Jurassic planktonic foraminifera from Pieniny Klippen Belt and their taxonomic and phylogenetic importance (Carpathians, southern Poland). *Tomy Jurajskie, 3,* 1–10.

Hudson, W., Hart, M. B., & Smart, C. W. (2009). Palaeobiogeography of early planktonic foraminifera. *Bulletin de la Societé géologique de France, 180*(1), 27–38.

Jansa, L.F., Gradstein, F.M., Harris, I.M., Jenkins, W.A.M., & Williams, G.L. (1976). Stratigraphy of the Amoco-IOE Murre G-67 well, Grand Banks of Newfoundland. *Geological Survey of Canada*, Paper *75*(30), 14.

Jansa, L. F., & Wade, J. A. (1975). Geology of the continental margin of Nova Scotia and Newfoundland. *Geological Survey of Canada, 74–30*(3), 51–106.

Kasimova, G. K., & Aliyeva, D. G. (1984). *Planktonic foraminifera of the Middle Jurassic beds of Azerbaijan: Voprosy Palaeontologii I Stratigrafii Azerbaijana, 479,* 8–19. **(in Russian)**.

Kopik J. (1997). Jura środkowa. Litostratygrafia ilitofacje. Formalne i nieformalne jednostki litostratygraficzne. Jura polska. In: Marek S., Pajchlowa M. (Eds.), Epikontynentalny perm i mezozoik w Polsce. Prace Państwowego Instytutu Geologicznego, vol. 378, pp. 67–129.

Korchagin, O.A., Kuznetsova, K.I., & Bragin, N.Yu. (2002). Find of early planktonic Foraminifers in the Triassic of the Crimea. *Doklady Earth Sciences*, *390*(4), 482–486.

Krobicki, M., Sidorczuk, M. & Wierzbowski, A. (2006). Stop A1—Czorsztyn Castle Klippe–Czorsztyn Succession (Bajocian-Berriasian). In: A. Wierzbowski, R. Aubrecht, J. Golonka, J. Gutowski, M. Krobicki, B.A. Matyja, G. Pieńkowski, & A. Uchamn (Eds.), *Jurassic of Poland and adjacent Slovakian Carpathians* (pp. 23–28). Warszawa: Polish Geological Institute.

Kuznetsova, R.I., & Uspenskaya, Y.A. (1980). New finds of planktonic Foraminifera in the Upper Jurassic deposits of the Crimea. Translated from Doklady Akad. Nauk. SSSR, 1980. *254*(3), 748–752.

Leckie, M. (2009). Seeking a better life in the plankton. *PNAS, 106*(34), 14183–14184.

Luterbacher, H. (1972). Foraminifera from the Lower Cretaceous and Upper Jurassic of the Northwestern Atlantic Ocean. Init. Repts. DSDP 11, Washington (US Governm. Printing Office), pp. 561–591.

Magomedov, A.M., Temirbekova, U.T. (1974). New data on the Jurassic stratigraphy in Dagestan. Proceedings of the USSR Academy of Sciences. Geological Series, No. 2, pp. 140–144 (in Russian).

Matyja, B. A., & Wierzbowski, A. (2003). Biostratygrafia amonitowa formacji częstochowskich iłow rudonośnych (najwyższy bajosgorny baton) z odsłonięć w Częstochowie. *Tomy Jurajskie, 1,* 3–6.

Matyja, B.A., & Wierzbowski, A. (2006). Field trip B1—Biostratigraphical framework from Bajocian to Oxfordian. Stop B1—Gnaszyn clay pit (Middle Bathonian–lowermost Upper Bathonian. Ammonite biostratigraphy. In: A. Wierzbowski, R. Aubrecht, J. Golonka, J. Gutowski, M. Krobicki, B.A. Matyja, G. Pieńkowski, A. Uchman (Eds.) Jurassic of Poland and adjacent Slovakian Carpathians. Field trip-guidebook, pp. 154–155. 7th International Congress on the Jurassic System, 6–18 September 2006, Kraków, Poland.

Mayer, E., Linsley, E. G., & Usinger, R. L. (1953). *Methods and principles of systematic zoology* (pp. 106–126). New York: McGraw-Hill Book Co.

Morozova, V. G., & Moskalenko, T. A. (1961). Foraminiferes planktoniques des depots limitrophes du Bajocien et du Bathonien du Daghestan central (Nord-East du Caucase). Translated from Voprosy Mikdropalaeontol. *SSSR, 5,* 3–30.

Oesterle, H. (1968). Foraminiferen der Typlokalitat der Birmenstorfer-Schichten, unterer Malm. *Eclogae Geologicae Helvetiae, 61*(2), 695–792.

Ogg, J.G., & Hinnov, L.A. (2012). Jurassic. In: Gradstein et al. (Eds.), *The geologic time scale 2012* (vol. 2, pp. 732–791).

Olsson, R. K., Hemleben, C., Berggren, W. A., & Huber, B. T. (1999). Atlas of Palaeocene Planktonic Foraminifera. *Smithonian Contr. to Palaeobiology, 85,* 252.

Pazdrowa, O. (1969). Bathonian *Globigerina* of Poland. *Rocznik Polskiego Towarz. Geol*, *39*(1–3), 41–56, +plates.

Samson, Y., Janin, M.-C., & Bignot, G. (1992). Les globigerines (foraminiferes planctoniques) de L'Oxfordien inferieur de Villes-Sur-Mer (Calvados, France) dans leur gisement. *Rev. Palaeobiol., 11*(2), 409–431.

Sidorczuk, M., & Nejbert, K. (2008). Genesis of ferromanganese crusts in Jurassic pelagic limestones at Stankowa Skała, Pieniny Klippen Belt, Poland: sedimentological and petrological approach. *Volumina Jurassica*, *6*, 75–85.

Simmons, M.D., Boudagher-Fadel, M.K., Banner, F.T., & Whittaker, J.E. (1997). The Jurassic Favusellacea, the earliest Globigerina. In: M.K. Boudagher-Fadel, F.T. Banner, & J.E. Whittaker (Eds.), *The early evolutionary history of planktonic Foraminifera* (pp. 17–53). London: Publ. British Micropal. Soc. Publ. Series, Chapman & Hall.

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

Stam, B. (1986). Quantitative analysis of Middle and Late Jurassic Foraminifera from Portugal and its implications for the Grand Banks of Newfoundland. *Utrecht Micropaleontology Bulletin, 34,* 167.

Stanley, S. M., Ries, J. B., & Hardie, L. A. (2002). Low-magnesium calcite produced by coralline algae in seawater of Late Cretaceous composition. *Proceedings of the National Academy of Sciences, 99*(24), 15232–15236.

Thomas, F.C., & Murney, N.G. (1985). Techniques for extraction of foraminifers and ostracodes from sediment samples. Canad. Techn. Rept. Hydrographic and Ocean Sciences 54, p. 23.

Wernli, R. (1987). Les protoglobigerines (Foraminifers) du Bajocien inferieur des sofs (Rif, Maroc). *Eclogae Geologicae Helvetiae, 80*(3), 817–829.

Wernli, R. (1988). Les protoglobigerines (foraminiferes) du Toarcien et de L'Aalenien du Domuz Dag (Taurus Occidental, Turquie). *Eclogae Geologicae Helvetiae, 81*(3), 661–668.

Wernli, R., & Görög, A. (1999). Protoglobigerinids (foraminifera) acid extracted from Bajocian limestones (Hungary). *Revista española de micropaleontología, 31*(3), 419–426.

Wernli, R., & Görög, A. (2007). Protoglobigérines et Oberhauserellidae (Foraminifères) du Bajocien-Bathonien du Jura méridional, France. *Revue de micropaléontologie 50*, 185–205.

Wernli, R., & Kindler, P. (1986). Les'Protoglobigérines' du Callovo-Oxfordien de Châtillon-sur-Cluses (Préaples internes, Haute-Savoie, France. *Eclogae Geologicae Helvetiae, 79*(1), 137–147.

Wierzbowski, A. (1994). Late Middle Jurassic to earliest Cretaceous stratigraphy and microfacies of the Czorsztyn Succession in the Spisz area, Pieniny Klippen Belt, Poland. *Acta Geologica Polonica, 44,* 223–250.

Wierzbowski, A., Jaworska, M., & Krobicki, M. (1999). Jurassic (Upper Bajocian-lowermost Oxfordian) ammonitico roso facies in the Pieniny Klippen Belt, Carpathians, Poland: its fauna, age, microfacies and sedimentary environment. *Studia Geologica Polonica, 115,* 7–74.

Wilson, C., & Gradstein, F. (1994). Sedimentology and Tectonics of the Mesozoic of the Lusitanian Basin, Portugal. Field Guide for the Open University, UK and Saga Petroleum, Norway (not published).

Wilson, R. C. L., Hiscott, R. N., Willis, M. G., & Gradstein, F. M. (1990). The Lusitanian Basin of West-Central Portugal: mesozoic and Tertiary Tectonic, Stratigraphic and Subsidence History. *A.A.P.G Memoir, 41,* 341–361.