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The planktonic foraminifera of the Jurassic. Part III: annotated historical review and references

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Abstract Over 70 publications on Jurassic planktonic foraminifera, particularly by East and West European and Canadian micropalaeontologists, are summarized and briefly annotated. It 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 Oxfordian age in Canton Aargau, Switzerland.

Keywords Jurassic · Planktonic foraminifera · Annotated historical review 1881–2015

Annotated historical overview

Jurassic planktonic foraminifera have been studied since the second half of the nineteen's century, but it was not until after the Second World War that micropalaeontological studies started to appear regularly, albeit at a slow pace and often with focus only on taxonomy. Below I list and briefly annotate 29 publications in the period from 1881 to 1981, 26 studies from 1981 to 2001 and 17 from 2001 to 2015.

Despite this scientific effort, knowledge on the origin, test morphology, evolution and geographic and stratigraphic distribution of taxa during the first 40 million years is fragmentary and incomplete. Taxonomic criteria previously applied are not consistent and conflicting (Gradstein et al. 2017).

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With few exceptions, Jurassic planktonic foraminifera publications based on thin-sections are not covered in this review. Emphasis is only on thin-section studies that had impact on our understanding of Jurassic planktonic foraminifera. By the same token, microfossil casts do not allow study of the taxonomically important wall structure and sculpture; reference to such studies is limited to few of historic interest.

The first four, presumably planktonic foraminiferal species from Jurassic strata, were described in the second half of the nineteenth century: *Globigerina liasina* from the Middle Lias of France (Terquem and Berthelin 1875), *G. helvetojurassica* from the Early Oxfordian of Switzerland (Haeusler 1881, 1890) and *G. oolithica* and *G. lobata* from the Bajocian of France (Terquem 1883). Some descriptions were from internal moulds. It was not until 1958 (see below) that more attention was focused on the occurrences of early planktonic foraminifera, with emphasis on free specimens.

1881—One of the earliest studies on Jurassic planktonic foraminifera is by Haeusler (1881). This geoscientist briefly described *Globigerina helveto-jurassica* in free specimens with calcareous test from the Birmensdorfer Schichten, Lower Oxfordian, Canton Aargau region, Switzerland. The description (translated from Latin) runs as follows:

Test rounded, whitish, smooth, rarely a little rough, with 5–6 chambers, the last five ones but little increasing. With larger magnification finely perforate. Many specimens are broken. On good specimens the half-moon shaped openings are easily visible (Our note: This refers to an arch-like aperture). Despite above text, description was inadequate, and no type locality and no holotype were selected (see Oesterle 1968; Stam 1986). Gradstein et al. (2017) shows the original (*'very meagre'*) drawings of *Globigerina helveto-jurassica* by Haeusler in (1881).

1955—From the Alpine orogenic belts in S. Europe and N. Africa, Colom (1955) reported Bajocian-Bathonian micritic, deep water limestones with many pelagic globigerinids, re-appearing in micritic limestones of Early Tithonian age.

1958—Hofman (1958) described *Globigerina jurassica* as follows: Test small (max diameter 0.12 mm), tall, with three turns of a spiral, like a wool ball. Ten to eleven chambers, enlarging during growth, with last whorl of 3–4 chambers, almost equal in size and packed closely. Sutures almost straight, slightly depressed. Aperture an elongated slit, barely visible at base of last chamber. Wall smooth, microperforate.

Variability includes the numbers of chambers in the last whorl 3–4, diameter size; the wool ball shape …. (probably meant as irregularly involute- trochoid coiling) is by Hofman considered to be typical. Hofman's species is from the Bathonian—Early Callovian of SE Crimea, USSR. In order to overcome the lost holotype, Simmons et al. (1997) designated a neotype.

1958—In a short study, Grigelis (1958) reported *Globigerina oxfordiana* from the Lower Oxfordian of Lithuania. It is described as a low-spired test, four globular compact chambers in the last whorl, umbilically placed, low arch aperture with lip; test rough (see also Bignot and Guyader 1971; Stam 1986). One drafted illustration was provided of the holotype, with the aperture poorly visible. This species turned out to be one of the most ubiquitous and long ranging Jurassic planktonic taxa.

1961—Iocheva and Trifonova (1961) described the new taxa *Globigerina conica* and *G.terquemi* using acetic acid on Tithonian limestones from the area of Stubel, NW Bulgaria to obtain glauconitic casts of the specimens. Banner and Desai (1988), also quoted in Simmons et al. (1997), suggest the low-spired *terquemi*- type, with larger proloculus to be the megalospheric generation of the high-spired, smaller proloculus *conica* type.

1961—In a landmark paper, Morozova and Moskalenko (1961) for the first time describe a rich '*Globigerina*' facies, with abundant free specimens. The assemblages are from fine-grained, deeper water (bathyal) shales near the villages of Gunib and Chokh, Central Dagestan, NE Caucasus. The sediments are assigned to the *Parkinsoni* and *Zigzag* Zones of Late Bajocian Early Bathonian age. (note: excellent outcrop sections are visible when 'googling' the area in Google Earth).

The authors report several new taxa, associated with epistominids and discorbids.

Globigerina (Conoglobigerina) dagestanica Morozova: small test, very variable, as expressed in the number of chambers, their arrangement, the shape of the spiral side and the ratio of diameter D to length (H) of the test. H/D ratio of 1 or greater than 1, steep spiral test with three whorls, rapidly increasing in size, aperture umbilical an elongate slit of low crescentic shape, often indiscernible. The final whorl consists of three or four spherical chambers differing but little in size. Megalospheric forms have a rounded, obtuse initial test part. Wall surface rugose, matte.

Globigerina (Eoglobigerina) balakhmatovae Morozova: low spiral text, consisting of two whorls, the first small one with 3–5.5 chambers and the final, large one with 4 chambers; H/D ratio about 0.5. Chambers slightly compressed along their height; aperture small, rounded with narrow rim; wall surface shiny or matte, smooth.

The new species *Globigerina (Conoglobigerina) avarica* Morozova and Moskalenko (1961) from the same strata co-occurs with the above two taxa. It differs in having a narrower and higher test, with up to three chambers in the early whorls, and chambers sometimes in rows (instead of a spiral), as in *Guembelitria* Cushman.

1963—Espitalié and Sigal (1963) described a remarkable epistominid assemblage from the Lower Toarcian and Bajocian of the Majunga Basin of Madagascar, with *Lamarckella, Garantella* and *Reinholdella*. A comparable and rich microfossil Bajocian—Bathonian assemblage, with the same taxa occurs on the Grand Banks of Newfoundland (Gradstein 1976). On the Grand Banks these levels are rich in planktonic foraminifera with hundreds of specimens and several taxa per small sample. The interesting question is if re-sampling, with emphasis on the 60–125 μm fraction, would also recover 'protoglobigerinids' on the Gondwana supercontinent, south of the palaeo-Equator.

1966—Colom and Rangeheard (1966) describe the protoglobigerinid biofacies in thin-sections from the Betic-Balearen belt in SW Europe, ranging from Bathonian into Tithonian. I favour *Globigerina helvetojurassica* as species of choice for these pelagic foraminifers.

1966—Bignot and Guyader (1966) reported the discovery of several dozen small specimens of Jurassic planktonic foraminifera in the Clays of Villers, Le Havre, Normandy, France. The level is Lower Oxfordian, *Mariae* Zone, about 6 m below the *Cordatum* zone with ferruginous oolites. The authors refer the specimens to *G. oxfordiana* Grigelis, despite the fact that in the French specimens the aperture is not perfectly umbilical, higher in shape and sometimes bulimine (looped). These features, although typical in type specimens, originally were not reported in the original publication of this taxon by Grigelis (1958). The authors report that *G. balakhmatovae*, which they re-illustrate from Morozova and Moskalenko (1961), has slightly flattened chambers, and is different. The Jurassic planktonic foraminifera are from a low-energy, shallow marine setting, connected to open sea.

1967—Bé (1966) of the Lamont Geological Observatory released Sheet 108 of Zooplankton, with Abstract of Papers for the Second International Oceanographic Conference, Moscow, 1966. This is a succinct and authoritative description, taxonomic key and illustration of 30 + taxa of living planktonic foraminifera in the Families Globigerinidae and Globorotaliidae. Of particular interest to Jurassic planktonic foraminifera is that Alan Bé underscores the common presence of a bulla (kummer form last chamber) in the microperforate *Globigerinita glutinata* and *G.bradyi.* The latter occurs in subpolar to cold temperate modern oceans. There is no direct phylogenetic link of these two living taxa to Jurassic planktonic foraminifera, but their test morphology and ecology may provide analog information, as will be dealt with in Gradstein et al. (2017, The planktonic foraminifera of the Jurassic. Part I, this issue).

1968—Oesterle (1968) reported on the foraminiferal assemblage in the type locality of the Birmensdorfer Schichten, unterer Malm, Canton Aargau, Switzerland. His description of this species is based on recrystallized, silicified moulds from another locality, the so-called Renggeri Tone from Liesberg, 75 km west of the Eisengraben section, SE of Basel. For details see discussion of *Globuligerina helvetojurassica* in Gradstein et al. (2017, The planktonic foraminifera of the Jurassic. Part I, this issue) on Taxonomy.

1969—In what is the most complete description of a new find of Jurassic planktonic foraminifera, Pazdrowa (1969) presented 'Bathonian *Globigerina* from Poland' from the ore-bearing *Morrisi* Zone clays of Ogrodzieniec, Middle Bathonian. The taxon in question is named *Globigerina bathoniana.* The description is based on about 150 specimens. For details see the description of *G. bathoniana* in the section on Taxonomy in Gradstein et al. (2017). The biota lived in a shallow marine basin with siliciclastic sedimentation.

The senior author (FMG) had the pleasure to exchange from Canada extensive information with Olga Pazdrowa, including specimens and co-fauna, reprints and sem photographs of taxa. The scientific exchange assisted the PhD of Bert Stam at Dalhousie University, Halifax, N.S, Canada (Stam 1986).

1971—Bignot and Guyader (1971, Proceedings of the II Planktonic Conference held in 1970 in Rome), using the original Lithuanian material of Grigelis (1958) and their French material described by them in 1966, erect the subgenus *Globuligerina* under the genus *Globigerina* with a slightly looped (virguline) aperture with a little lip. This was the beginning of the use of apertural shape for generic definition in Jurassic planktonic foraminifera, despite the fact that already Pazdrowa (1969) reported that in *G.bathoniana* apertural shape varies from low arch to high arch to loop (also called virguline or bulimine in shape).

The study of Bignot and Guyader is also important in that it is first to use the scanning electron microscope on Jurassic planktonic foraminifera. It shows in exquisite detail the microperforate wall and dense wall surface pustules (but no reticulate or muricate sculpture) of topotype *G. oxfordiana* (with slightly looped, umbilical-extraumbilical aperture).

1971—Brönnimann and Wernli (1970, reprinted in the Proceedings of the II Planktonic Conference held in 1970 in Rome) reported and illustrated *Globigerina avarica* and *G. balakhmatovae* from Upper Bajocian and Bathonian of the French Jura Mountains. Four specimens of a compact, very low trochospiral form with three chambers in the last whorl are listed as '*Globigerina*' sp. A. The authors note the frequent co-occurrence of discorbids and Jurassic planktonic foraminifera in a deeper water setting. For details on this unique assemblage see also Wernli and Görög (2007).

1973—Fuchs (1973) produced the first systematic classification of some Jurassic foraminifera, considered by this author to be planktonic. He introduced six new genera (*Polskanella*, *Tectoglobigerina*, *Woletzina*, *Mariannnenina*, *Eoheterohelix* and *Jurassorotalia*) and many new species. Unfortunately, his classification was based on a study of glauconite moulds from Ogrodzieniec, Poland (type locality of *Globigerina bathoniana* Pazdrowa). None of the genera and species erected by Fuchs are accepted; most or all are in fact casts of benthonic taxa. Preservation as glauconite moulds (with many deformed and aberrant shapes) prevents study of vital features in taxonomy. Simmons et al. (1997) provided a useful summary of the data of Fuchs (1973).

1974—Grigelis (1974) showed the stratigraphic and geographic ranges of current Jurassic planktonic foraminiferal taxa on the northern hemisphere, using also the data from Gordon (1970).

1975—The Geological Survey of Canada released Open File Report 334 (by F.M. Gradstein) on the biostratigraphy and depositional environment of the Eider M-75 exploration well, Grand Banks. In the mudstone interval from 9790 to 5560 feet with *Garantella, G.bathoniana and R.crebra* zones, Bajocian—Callovian (co-dated by dinoflagellates—Bars et al. 1979) reasonably preserved Jurassic planktonic foraminifera are common to abundant with several taxa (see Gradstein 1976; Stam 1986). This is the first published report on Jurassic planktonic foraminifera in North America.

1976—The Geological Survey of Canada published Paper 75–30 by Jansa et al. on the 'Stratigraphy of the Amoco Ioe

Murre G-67 well, Grand Banks of Newfoundland. The well sampled a marine sedimentary section of Pliensbachian through Kimmeridgian age. The interval from the *Garantella ornata/G.* aff. *rudia* assemblage through *Reinholdella crebra* var. assemblage of Bajocian through Callovian age yields many specimens assigned to '*Globigerina' bathoniana, 'G'. balakhmatovae* and '*G'. helvetojurassica*.

1976—The 'Proceedings of the First International Symposium on Benthonic Foraminifera in Halifax, N.S., Canada' publishes 'Biostratigraphy and Biogeography of Jurassic Grand Banks Foraminifera' by F.M. Gradstein. A regional stratigraphic range chart reports the occurrence of rich assemblages of '*Globigerina' bathoniana, 'G'. balakhmatovae* and *'G'. oxfordiana* in the *Garantella* through *Reinholdella* var. Zones of Bajocian through Callovian age in many Grand Banks of Newfoundland exploration wells. Several SEM plates illustrate the Jurassic planktonic foraminifera taxa, and geographic maps show that the taxa occurrences link directly to the 'Old World', prior to North Atlantic seafloor spreading north of the Charlie Gibbs fracture zone.

1976—Ascoli (1976) publishes a detailed study on the Mesozoic-Cenozoic microfossil assemblages of the Scotian Shelf, Atlantic Canada. *Globigerina bathoniana* is reported from Bathonian strata, and *G. oxfordiana* from the Oxfordian.

1977—Masters (1977) in his revision of Mesozoic planktonic foraminifera, lumps Jurassic planktonic foraminifera in two morphotypes: a low-spired one, called *G. hoterivica* Subbotina, which evolved from a high-spired one, called *G. jurassica* Hofman. The taxonomic status of *Globigerina? helvetojurassica* Haeusler is determined unclear, due to incomplete description and bad preservation (see Stam 1986).

1977—Very thin, shallow marine Kimmeridgian through Volgian (Tithonian) strata along the Pizhma and Izhma rivers in Timan Pechora, USSR yielded some tests of planktonic foraminifera. The authors (Grigelis et al. 1977) briefly described *Globuligerina stellapolaris* Grigelis sp. nov., as follows: Test small, round, dorsal side low trochospiral, ventral side involute. Spiral of two revolutions with 3–4 chambers per whorl. Chambers round, closely packed; sutures linear and slightly incised. Aperture arcuate within the margin. H/D ratio is 0.72. Calcareous test wall thin and with large pores. The taxon differs from *G. oxfordiana* in the round (not oval) test shape, larger size and more closely packed chambers. (Our note: no mention is made of wall sculpture; an unusual feature is that macroperforate planktonic taxa first appear in mid-Cretaceous; see also the chapter on taxonomy in Gradstein 2017).

1977—Kuznetsova (1977) published an important study on the Foraminifera from the Upper Jurassic and Lower Cretaceous of the Eastern Atlantic DSDP Sites Leg 41, Sites 367 and 370. Palaeo water depth was bathyal to abyssal, and Jurassic planktonic foraminifera were only found as rare casts in one sample (see also Gradstein 1983).

1979—Arif Butt (1979) , U. of Tübingen, produced a detailed foraminiferal study in the Initial Reports of the Deep Sea Drilling Project on the Lower Cretaceous neritic-bathyal sediments in DSDP Leg 47A, Site 397 from Cape Bojador, off Morocco. Well preserved *Hedbergella hoterivica* (now *Favusella hoterivica*) is common, together with several ornate epistominid and lenticulinid taxa.

1980—K.I. Kuznetsova and Uspenskaya (1980) described the new taxa *Globuligerina calloviensis* Kuznetsova from a Lower–Middle Callovian interval with calcareous shales, limestones, mudstones and siltstones in the Sudak synclinorium, Crimea, USSR. It is reported to differ from *G. oxfordiana* in its sub-square, flatter test and tuberous and cellular wall sculpturing. From *G. gulekhensis* it is reported to differ in lower spire, fewer volutions and fewer chambers. But, as Simmons et al. (1997) report, the poor illustrations suggest a smooth wall and do not show the aperture or umbilicus; the authors suggest that it might be a subspecies of *G. oxfordiana*. Note: see *G. oxfordiana* subspecies *calloviensis* in Gradstein et al. (2017).

1980—Grigelis and Gorbatchik (1980) re-defined *Conoglobigerina* (with six species) and *Globuligerina* (with about ten species). The latter differs from *Conoglobigerina* in its trochoid or irregular trochoid form and in the presence of a reticulate sculpture in a number of specimens. *Conoglobigerina* links to *Globuligerina* links to *Favusella*. A change in wall surface sculpturing through time is illustrated. The slightly reticulate wall sculpture of *G. stellapolaris* is illustrated. Description and illustration by these authors of a Lithuanian topotype specimen of *G. oxfordiana* with partially or completely confluent tubercles to form irregular and more or less quadrangular cells sculpture (reticulation) is unusual, but also reported as occurring rarely by Simmons et al. (1997, see their plate 2.9, fig. 11). Plate 1, figs. 4a, b of *G. oxfordiana* by Grigelis and Gorbachik (1980) shows a wall surface with elongated pustules.

1981—Using developments in test surface patterns, Alekseeva and Gorbachik (1981) proposed an evolutionary lineage in Jurassic planktonic foraminifera. From *G. bathoniana* to *G. gulekhensis* to *F. washitensis* a development in sculpture of wall surfaces takes place, from irregular, rounded or 'worm-like' pseudomuricae to an irregular network to a honey-comb (faveolate) test surface pattern.

1982—Huddleston (1982) pointed out that Bignot and Guyader (1971) established the new genus *Globuligerina* with specimens from the Oxfordian of France and designated their specimens as type species of *Globigerina oxfordiana* Grigelis. Hence, the specimens of *G. oxfordiana* Grigelis from Lithuania are not anymore the type species. This non-issue is discussed in detail in Gradstein et al. (2017).

1983—DSDP Site 534, on the landward side of marine Jurassic Magnetic Quiet Zone (JQZ), in the Blake-Bahama Basin, established a Middle Jurassic (Bathonian-Callovian) age for the opening of the N. Atlantic Ocean (Sheridan et al. 1983). The site cored abyssal (>2.7 km palaeo water depth) 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, interpreted as transported with gravity flows from shallower strata (Gradstein 1983). DSDP Leg 11, Site 105 in this region yielded similar observation (Luterbacher 1972).

1983—In a significant study, Gorbachik and Kuznetsova (1983) outlined the stratigraphy and palaeobiogeography of Jurassic and Early Cretaceous planktonic foraminifera. Seven key Jurassic planktonic foraminifera taxa are reported with their known ranges (excluding glauconite cast taxa and 'contaminants'). The important observation is made 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. *Globuligerina oxfordiana, G. helvetojurassica* and *Conoglobigerina bathoniana* are considered most suitable stratigraphically, with narrow ranges and wide distribution, from eastern Canada to Crimea to Caucasus between 40 and 60°N. In Late Jurassic, Jurassic planktonic foraminifera extended somewhat further north and south and had widest distribution; this has contributed to improved palaeoclimatic (temperature of watermasses) conditions. The evolutionary trend from Middle Jurassic to Cenomanian is mentioned from irregular pustulose to reticulate wall structure (our note: with *C. gulekhensis* and *C. stellapolaris* as intermediates).

1983—Gorbachik 1983, (in Akad. Nauk SSSR) published an important study on the wall structure of *Globuligerina oxfordiana* (Grigelis) with magnificent SEM pictures of test detail. The calcite wall is radially crystalline with 1 µm microcrystal plates, separated by an organic membrane. Wall sculpture is densely pustulose, the pustules being blunt cones or short ridges which may start to coalesce irregularly on older chambers. Aperture is slightly looped with imperforate rim.

1984—Kasimova and Aliyeva (1984) briefly described *Conoglobigerina avariformis* Kasimova sp. nov. from the Bajocian of Azerbaijan. The holotype illustrations are drawings without wall sculpture information.

1984—The study by Exton and Gradstein (1984) on Early Jurassic (Late Sinemurian through Aalenian) stratigraphy and micropalaeontology of the Grand Banks and Portugal establishes a threefold marine biostratigraphy, with about 25 taxa of foraminifers and ostracods. No Jurassic planktonic foraminifera were found and may not have existed in Early Jurassic time, prior to the Toarcian.

1984—First publication, by Bignot and Janin (1984) on finds of (poorly preserved) *Globuligerina oxfordiana* in the type section of the Bajocian, *Humphriesianum* Zone (Middle Jurassic) in France. The rock is a biomicrite with ferruginous oolites, attesting to the shallow marine nature of the sediment. A detailed palaeogeographic map of the Dogger (175–160 myr) across parts of the Pangaea super continent shows widespread occurrences of Jurassic planktonic foraminifera.

1985—Banner et al. (1985) reported on the important observation of balloon-type float chambers on or over the megalospheric tests of some species of Discorbidae and Cymbaloporidae, enabling a pelagic stage in the life cycle of these benthics.

1985—Grigelis (1985) outlined *Globuligerina oxfordiana* and *G. stellapolaris* using thickness and height ratios of the tests in his monograph on Jurassic foraminifera of the SW Baltic. A regional Upper Bathonian through Lower Volgian (Tithonian) assemblage zonation is proposed using foraminifera.

1986—Stam (1986) published his erudite PhD study on 'Quantitative analysis of Middle and Late Jurassic Foraminifera from Portugal and its implications for the Grand Banks of Newfoundland' (Utrecht Micropal. Bull. 34). Quoting the abstract: 'Of the 14 Jurassic planktonic foraminifera species described to date, only three can be recognized in the Portuguese and Grand Banks strata, using type material from Poland, France and Switzerland. These three taxa have been re-defined such that they encompass the variation previously assigned to the 14 taxa listed in the literature'. These three taxa are (1) *Globuligerina bathoniana*, (2) *Globuligerina oxfordiana* and (3) *Globuligerina balakhmatovae* with eight, good quality SEM plates of the taxa. With the assistance of H. Bolli and R. Gygi, Bert Stam obtained what they thought were topotypes of the poorly known, oldest literature taxon *Globigerina helvetojurassica* (see discussion under *Conoglobigerina helvetojurassica* in Gradstein 2017). Stam also applied biometrics (H/D ratio) to taxonomy of Jurassic planktonic

foraminifer and established (quantitative) palaeoecological parameters for palaeo depth assessment of Jurassic planktonic foraminifera. Higher spired forms like *G. bathoniana* occur in shallower marine sections than, e.g. *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.

1986—Wernli and Kindler (1986) described isolated silicified specimens assigned to *Globuligerina oxfordiana* from the Callovian-Oxfordian of the Western Alps. Several test measurements are outlined and illustrated. The important observation is made that the posterior margin of the virguline aperture sets forward in the umbilicus, which thus is slightly out of centre. The authors consider lack of information on wall lamination and apertural shape to be detrimental to an attempted taxonomic synthesis in the study in 1980 by A. Grigelis and T. Gorbachik (referred to above).

1986—El Kamar (1986, unpublished) PhD thesis decribed *G. oxfordiana*, *G. bathoniana*, *G. aff. avarica* and open nomenclature taxa of the Oxfordian of Portugal (Montejunto), Spain and France. Some emphasis is on biometric characters of taxa. Spreadsheet-type taxonomic overviews of morphological variation demonstrate morphological variability and emphasize difficulty to understand hierarchy of characters. Some sketches of test shapes remind of *G. tojeiraensis*.

1987—Abundant low- and high-spired Jurassic planktonic foraminifera, with tests up to 340 µm high, and thick-walled are described and illustrated by Wernli (1987) in thin-sections from a 4-m-thick biomicrite of the *Sauzei* Zone, Lower Bajocian in the Rif, Marocco. The limestone also contains abundant debris of echinoderms, filaments, *Globochaete* and diverse foraminifers.

1987—Riegraf (1987) reported on *Globigerina bathoniana* from phosphorite nodules in the Callovian of W. Germany and explains the spread of Jurassic planktonic foraminifera in Callovian-Oxfordian times outside Tethys to be due to widespread transgression. Riegraf adheres to the simplified Jurassic planktonic foraminifera taxonomy of Stam (1986, in his PhD) and adds a detailed bibliography with palaeogeographic maps of Jurassic planktonic foraminifera occurrences.

1988—The oldest Jurassic planktonic foraminifera assemblage in the world was reported by Wernli (1988) in thin-sections from Ammonitico Rosso limestones in the Domuz Dag Mountains of Turkey. The samples are from the *Opalinum* Zone, Lower Aalenian and *Bifrons* to *Variabilis* Zones, Middle Toarcian. Aalenian specimens are thicker walled and bigger (>250 µm) than the ones from the Toarcian (<200 µm). (Our note: the same taxa may be present as listed in the study by Wernli (1987). These strata should be re-sampled and carefully processed with modern techniques for free specimens).

1988—Banner and Desai (1988) revised the classification of Jurassic to Albian *Globigerinina* both phylogenetical and taxonomic. Although emphasis is on the Late Aptian Speeton Clay of Yorkshire, UK, the authors define two Jurassic planktonic foraminifera genera. *Conoglobigerina* Morozova is emended as distinguished from *Globuligerina* by its intraumbilical, low-arched aperture (not high, loop-shaped, asymmetric and 'bulimine'like aperture). *Conoglobigerina* is distinguished from (Cretaceous) *Favusella* by the presence in the latter of a continuously developed reticulum of ridges over the whole test surface.

1989—Agterberg et al. (1989) used an indirect method of cubic spline fitting to quantify abundance data of benthic and planktonic foraminifera in the Upper Jurassic Tojeira shales, Portugal. The objective was to fine correlate with Jurassic planktonic foraminifera two outcrop sections that are about 2 km apart. Four successive Jurassic planktonic foraminifera levels occur that represent flooding horizons. These abundance levels may reflect periods of blooms due to increased watermass fertility. These blooms are not seasonal, but may have occurred with a frequency of about once every half million years.

1989—The authoritative book on 'Modern Planktonic Foraminifera' by Hemleben et al. (1989) shows in fig. 1.2 similarity in gross test morphology between the living microperforate *Globigerinita glutinata* and *Globuligerina bathoniana*. *G. glutinata* is a cosmopolitan, subpolar to tropical taxon, with infra-laminal apertures around its bulla.

1992—Samson et al. (1992) expanded on the original find of *Globuligerina oxfordiana* in the *Scarburgense* Zone, Early Oxfordian of the 'Vaches Noires' along the seaside cliffs at Villes-Sur-Mer, Normandy, France. *G. stellapolaris* is included in the synonymy of *G. oxfordiana*. Using the palaeo water depth model of Stam (1986) the species lived in a shallow marine environment, not exceeding 150 m in palaeo water depth. A palaeogeographic map after the study by W. Riegraf (1987) shows the temperate Tethyan zonal distribution. Wall surface sculpture of the small specimens (<100 µm) is distinctly pustulose to muricate (pointed pustules).

1996—Collins et al. (1996) reported on rare *Globuligerina oxfordiana* (Grigelis) and *G. bathoniana* (Pazdrowa) in relatively shallow marine samples on Galicia Bank, offshore Portugal in ODP Site 901, cores three and five. The

age of the sediments is Tithonian. Our study of the same samples only found *G. oxfo*rdiana (Grigelis) and *G. tojeiraensis* Gradstein, as reported on in Gradstein et al. (2017).

1996—Five field expeditions in the Jurassic of Syria by Kuznetsova et al. (1996) yielded insight into diversified shallow marine carbonate platform-type foraminiferal assemblages. Thin, marly or shaly interbeds also yielded rare free specimens of *Globuligerina bathoniana* from Bathonian strata and *G. oxfordiana* from Oxfordian sediments. Specimens of G. *bathoniana* were measured as large as 460 µm and *G. oxfordiana* between 300 and 360 µm. Note: see also Wernli and Görög (1999) and Görög and Wernli (2003, below) for large size specimens in the Tethyan realm. This is a rare record of photic ecozone marine biofacies with larger foraminifera, smaller benthic taxa and isolated specimens of planktonic foraminifera.

1997—This is the year that the British Micropalaeontological Society published 'The Early Evolutionary History of Planktonic Foraminifera' edited by Boudagher-Fadel et al. (1997). The book includes the important chapter on Jurassic planktonic foraminifera by M.D. (Mike) Simmons et al. (1997). Sixteen taxa are documented, mostly with magnificent SEM documentation of metatype (=a topotype or homeotype determined by the original author of its species) material. The museum type taxonomy retains the generic subdivisions of Banner and Desai (1988), with ten taxa in the genus *Conoglobigerina* and three taxa in *Globuligerina*. Three taxa are described under the new generic banners *Haeuslerina* and *Compactogenerina*.

1997—Pawlowski et al. (1997) report from molecular DNA analysis that planktonic foraminifers may evolve 50–100 times faster than some benthic foraminifer lineages. This is attributed to much stronger environmental stress and higher mutation rates under the influence of strong UV radiation on organisms living in the upper watermasses.

1997—Gorbachik and Poroshina (1979) published an important study on new Berriasian planktonic foraminifers from Azerbaijan. The species were collected from variegated sandy clays with molluscs, belemnites, aptychi and a rich foraminiferal assemblage, including agglutinated taxa, discorbids, epistominids, trocholinids, *Patellina*, *Neobulimina* and others. This is a chronostratigraphic interval where information of planktonic foraminifera was lacking. The first appearance of planktonic foraminifers in the Early Cretaceous was generally associated with *G. hoterivica* in the Hauterivian. A good description (but no good SEM pictures to clearly visualize wall surface patterns) is provided of *Globuligerina gulekhensis* sp.nov.

1999—The volume on the Lithuanian–Swedish geotraverse study (Grigelis and Norling, 1999) reports and illustrates well-preserved *Globuligerina oxfordiana* (Grigelis) from a Lower Oxfordian level in a well in Southern Sweden.

1999—In an original and innovative study Wernli and Görög (1999) report on well-preserved and rich protoglobigerinid foraminiferal fauna processed using concentrated acetic acid from hard "Ammonitico Rosso" limestones of Som Hill, Bakony Mountains. The studied series of strata are well defined by ammonites indicating the *Humphriesianum* and *Niortense* Zones (Bajocian). The protoglobigerinid associations are diversified and dominated by large specimens, often reaching 400 µm in diameter. They comprise *Conoglobigerina* aff. *dagestanica, Globuligerina oxfordiana* (medium and large forms), *G.* aff. *bathoniana* (large form), and C. *avariformis* (the latter rarely reported in the literature). Two new taxa are described as follows: *Globuligerina? hungarica* sp.nov. having a large last chamber, and G. *bathoniana gigantea* n.ssp., a gigantic, high trochospiral subspecies.

2002—Ammonitico-rosso beds of the Transdanubian Central Range were studied by Görög and Wernli (2002) and yielded a rich and varied planktonic foraminiferal assemblage of middle to late Bathonian age. The specimens were isolated by acetolysis, preventing wall structure features, but giving a good idea of morphological variation. Most common is *G. oxfordiana* with bulla, followed by *G. bathoniana*. A large thick-walled form assigned to *G. avariformis* is rare. Bajocian limestones in the nearby Som Hill area (Wernli and Görög 1999) contain larger size specimens of *G. bathoniana*. The authors comment the unusual feature that the early evolution of Jurassic planktonic foraminifera begins with large size specimens, also referring to the studies by Wernli on Toarcian-Aalenian 'protoglobigerinids (Wernli 1987, 1988).

2002—Using acid extraction, Korchagin et al. (2002) described a small foraminiferal assemblage, mostly without wall structure and wall texture features from Upper Triassic strata in the Crimea, Russia, with new taxa of *Globuligerina*, *Sphaerogerina* and *Wernliella*. The new taxa are declared to be planktonics. The occurrence of sinistral coiling tests is taken to imply a cold water hydrosphere during the Triassic-Jurassic biotic crisis.

2002—Rare internal moulds (often preserved as pyrite) of Jurassic planktonic foraminifera were recovered from the *Mariae* Zone (Oxfordian) in Dorset, UK (by Oxford et al. 2002). This is the same stratigraphic level from which Samson et al. (1992) described *Globuligerina oxfordiana* in Normandy, France (see also Bignot and Guyader 1966, 1971). The assemblage in the UK is reported to contain *G. oxfordiana, Haeuslerina helvetojurassica* and

Compactogenerina sp. cf. *C. stellapolaris*. The same study also mentions isolated specimens of *Globuligerina* sp. in the Staffin Shale Formation at Staffin, Scotland, of Early to Middle Oxfordian age. The Dorset and Staffin levels contain common agglutinated foraminifers and epistominids and are considered maximum flooding horizons. Another flooding horizon with isolated *Globuligerina* sp. is the *Saccocoma* (microcrinoid) rich Blackstone Band (within Bed 42), Kimmeridge Clay Formation, earliest Tithonian, Dorset Coast, UK.

2003—Apthorpe (2003, Sydney, Australia) completed a detailed PhD study on Triassic and Jurassic foraminifera of NW Australia, which includes an important (but not published) analysis of well-preserved Bajocian planktonic foraminifera. This study expands our knowledge on the taxonomy and palaeobiogeography of these forms. The information below was communicated to Gradstein in 2016, when the latter assisted the author with potential publication of this new data.

The planktonic foraminifera are from deep, offshore dredge hauls (two dredge hauls from 4530 to 3900 m and 4530–3500 m) taken on the Rowley Terrace, northwest Australia, in the (now) Indian Ocean. The samples are small in size and contain soft, dark claystone (samples BRM 95/7/8 and BRM 95/28/16) which likely was never buried much, to explain good preservation.

The basis for the chronostratigraphy of the Rowley Terrace Jurassic planktonic foraminifera samples is as follows:

A. *Foraminifera (using northern hemisphere literature)* most likely Middle to Late Bajocian, possibly Early Bathonian; based on *Garantella aff. asteriginoides, Garantella sera, Lenticulina micropunctata, L. cf. munkae*; and new species of *Kaptarenkoella*; abundant *Garantella* spp. and absence of both *Epistomina* spp. and *Lenticulina d'orbignyi.*

B. *Nannoplankton* one sample placed by Richard Howe (Chevron, Australia) at the base of the Early Bajocian *Watznaueria britannica* zone of Bown et al. (1988), on the basis of early forms of *W. britannica*. The same sample and a second one with Jurassic planktonic foraminifera were dated by Sam Shafik as uppermost *Lotharingius contractus* sub-zone of Bown et al. (1988) on the basis of transitional forms between *L. contractus* and *W. brittanica* (Shafik 1994).

C. *Palynology* the Jurassic planktonic foraminifera samples are assigned to the *C. halosa* dinoflagellate zone of Helby, Morgan and Partridge (1987), considered of late Bajocian through early Bathonian age.

Based on foraminifera in well sections above and below these zones also, the Jurassic planktonic foraminifera bearing interval is assigned a Middle to Late Bajocian age. Using the "Australia Mappack Contents 12 July 2016.pdf" from Geoscience Australia the age might be revised to be younger than Middle Bajocian with a slightly uncertain youngest age level, but possibly Early Bathonian.

Detailed picking of the two small samples resulted in many small (aragonitic?) specimen of Jurassic planktonic foraminifera. A SEM picture (communicated by Marjorie Apthorpe to Gradstein in 2016) shows what looks like *G. bathoniana* with a microperforate, pustulose wall, medium high trochospire, pointed apex and loop-shaped aperture with lip. In total, more than 70 specimens were obtained, nearly all extremely small in size and estimated to represent $\sim$1% or less of the total foraminiferal fauna.

Preservation is good to excellent, but many specimens have a broken final chamber. In one sample the specimens are partly infilled with pyrite; in another sample, the interior of tests is empty. Apthorpe took many SEM illustrations of the wall structure of the Jurassic planktonic foraminifera.

The thesis clearly details microperforate and pustulose morphotypes assigmed to *G.bathoniana, G. altissapertura* sp. nov. (our note = *G. oxfordiana*) and *Mermaidogenerina loopae* genus nov., sp.nov. *G. altissapertura* shows a thickened apertural rim (lip) that may have a small plate-like extension of the rim into the umbilicus.

2003—A thoughtful and stimulating research study by Görög & Wernli (2003) outlines current trends and understanding in Jurassic planktonic foraminiferal taxonomy, with emphasis on sculpture of test surfaces. There is a link between U or V shaped trochospire and low- or high-spired tests, possibly visualizing megalospheric versus microspheric generations. But, as the authors write, generational dimorphism is not known from stratigraphically younger planktonic foraminifera.

The widespread occurrence in deeper water strata of Bajocian thick-walled forms may be due to calcitic overgrowth in deeper water living forms. It is postulated that smaller forms were surface dwellers and large ones inhabited deeper water environments. A stratigraphic distribution of Jurassic planktonic foraminifera morphotypes is postulated, with thick-walled forms in deeper marine and stratigraphically older deposits.

An impressive dataset of Jurassic planktonic foraminifera's in thin-sections is used to generate three stratigraphically consecutive Middle Jurassic palaeogeographic maps. It shows a link between abundance, large-sized tests, and sometimes thick-walled Jurassic planktonic foraminifera and deeper water (Tethys) conditions. It is attempted to distinguish two Jurassic planktonic

foraminifera assemblages. The Tethyan association with specimens up to 400 µm in size, and often >70% abundance in foraminiferal assemblages, contains high-, medium- and low-spired taxa, like *G. bathoniana* types and *G. oxfordiana*. Epicontinental settings yield mostly smaller sized tests <220 µm, have a lower abundance in microfossil assemblages and a higher species variety.

2003—A hypothesis is briefly outlined that water mass perturbations during the Early Toarcian extinction event led to evolution from the benthic or mero (partly) planktonic *Oberhauserella* lineage (with aragonite tests), to the planktonic *Conoglobigerin*a lineage (Hart et al. 2003). Oberhauserellids bloomed during the *exartum* subzone (*falciferum* Zone), just before the onset of poorly oxygenated water mass conditions.

2004—Görög & Wernli (2004) studied a rich Jurassic planktonic foraminifera assemblage from Tithonian–Berriasian limestones of the Gersecse Mts in Hungary. Beds above and below are dated by, respectively, calpionellids and ammonites. Muric acid processing prevents wall structure information, but test shapes remind of a form with arched aperture between *Globuligerina oxfordiana* and *Favusella hoterivica* (note: if wall structure could be ascertained the test shapes might reveal *Conoglobigerina helvetojurassica* (Haeusler). Radiolarians are also common, which, together with the calpionellids indicate an open marine, deeper water (bathyal) environment.

2005—Hudson et al. (2005) studied thin-sections of Ammonitico Rosso limestones of Bathonian through Kimmeridgian age in the Pieniny Klippen Belt, Poland. One set of samples is from a deep water facies, and another from a hypothetical submarine swell. Assemblages have common to abundant Jurassic planktonic foraminifera. There are mostly 3- to 4-chambered forms, reminiscent of *Globuligerina oxfordiana*, with occasional higher spired test of *Conoglobigerina bathoniana*.

2007—One of the most detailed and thoughtful studies with Middle Jurassic protoglobigerinids and oberhauserellids was published by Wernli & Görög (2007). The 30 + marly samples in 11 sections of the Southern Jura Mountains in France span Upper Bajocian through Upper Bathonian and are zoned using ammonites. In this both philosophical (on generic evolution) and taxonomic study the authors describe two *Oberhauserella*, two '*Conoglobigerina*' and two *Conoglobigerina* species. The study refines knowledge on two *Globuligerina* taxa, with detailed text and excellent illustrations. The presence of specimens with two apertures reminds of mid Cretaceous planktonics. Morphological transitions between *Oberhauserella* and *Globuligerina* point to a potential evolutionary relationship.

2009—Hudson et al. (2009) outline palaeobiogeography of planktonic foraminifera, with possible birth during Toarcian time in Turkey (based on the detailed study by Wernli 1988), although no potential ancestors are known. By Bajocian time planktonic foraminifera were known across much of Europe, from East Canada, from North Africa and from the former Soviet Union. In Bathonian time the first 'plankton oozes' locally developed (on highs above the seafloor…). A widespread flood of Jurassic planktonic foraminifera is recorded across NW Europe in Oxfordian time.

2009—Leckie (2009) postulated multiple invasions since Middle Jurassic by a number of different benthic foraminifera in the plankton domain, typically during times of high global sealevel, and perhaps initiated by a dynamic food supply, or oxygen stress in the benthos or extinction in the plankton. Fluctuating sealevel and changing conditions of the Oxygen Minimum Zone are two of the many factors for benthic foraminifers to make the leap into the plankton.

Several unusual extinct or living plankton taxa exist with restricted geographic distribution along continental margins, like *Bifarina, Tenuitella, Rectoguembelina, Zeauvigerina, Streptochilus* and *Gallitellia.* This reminds of the preferred habitat of Jurassic planktonic foraminifera.

2009—The living, triserial planktonic foraminifer *Streptochilus globigerus* is genetically the same species as the benthonic *Bolivina variabilis*. This milestone study by Darling et al. (2009) of a tychopelagic life style in a foraminifer points to potential genetic capacities of benthic foraminifera to overcome major palaeoceanographic upheavals that suddenly modified their biotope. The study also mentions that the living triserial planktonic foraminifer *Gallitellia vivans* had a benthic ancestor in the Miocene. Maybe, microperforate planktonic foraminifera are all polyphyletic. The observations open up new perspective for phylogenetic analysis of Jurassic planktonic foraminifera.

2012—Hart et al. (2012) examined the taxonomy of '*Globigerina bathoniana* and *G. oxfordiana'* (see also Stam 1986, plate 9 and text). The study discusses the role of Jurassic planktonic foraminifera, with calcareous nannofossils and calcareous dinoflagellates, as carbonate ooze providers on Jurassic swells and highs in the Pieniny Klippen Belt of Poland. Radiolarites occur in basinal settings of the Carpathians. This may indicate that a lysoclinal system of the ACD and CCD was in place at palaeo water depth of possibly over 1000 m.

2012—The search by Hart et al. (2012) for a suitable boundary stratotype section for the base of the Oxfordian in southern UK yielded pyritized steinkerns of Jurassic planktonic foraminifera, referred to *G. oxfordiana* and *C. stellapolaris*. Specimens are most common in the

Mariae Zone, Earliest Oxfordian. Jurassic planktonic foraminifera are found in exactly the same zone in NE France (see Bignot and Guyader 1966), representing a Jurassic planktonic foraminifera 'abundance' horizon.

2013—Samples of marls and limestone beds in the *Platynota* and *Hypselocyclum* Zones, Early Kimmeridgian, of the southern Jura Mountains, France, were studied by Görög and Wernli (2013). The microfossil assemblages yield isolated free specimens of Jurassic planktonic foraminifera using acetolysis. Several species are described, including a *G.oxfordiana*-like morphotype with favose test sculpture. The authors consider that this maybe a morphotype transitional to *F. hoterivica.* A single, small (? deformed) specimen with a bulla is assigned to *Compactogenerina stellapolaris* (Grigelis). (note: *G.? avariformis* agrees *with C. grigelisi* and the *G. oxfordiana*-like morphotype agrees with *C. helvetojurassica*).

2014—Clemence and von Hillebrandt (2014) present a detailed and thoughtful study on the origin of Jurassic planktonic foraminifera. The Oberhauserellidae (particularly the transitional form *Praegubkinella racemosa*) have been considered as the benthic ancestor stock of Jurassic planktonic foraminifera (e.g. *Conoglobigerina* and *Globuligerina*; see Hart et al. 2003). A close link exists between the distribution and abundance of *Oberhauserella* and *Praegubkinella* taxa and major environmental stress conditions, such as marine oxygen depletion near the Tr-J boundary and in the Early Toarcian. But benthic *Praegubkinella* is closer in building plan (with toothplate, and inner built foramen, but no tubercles or pseudo muricae) to benthic *Reinholdella*, which evolves from it in Early Jurassic time. The authors conclude that a direct evolutionary line between both groups cannot be demonstrated.

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