Pforams@mikrotax: A new online taxonomic database for planktonic foraminifera

Brian T. Huber[1,5], Maria Rose Petrizzo[2], Jeremy R. Young[3], Francesca Falzoni[2], Silvia Elena Gilardoni[2] , Paul R. Bown[3], and Bridget S. Wade[3]

[1] *Department of Paleobiology, MRC-121, National Museum of Natural History, Smithsonian Institution, 10th and Constitution Ave., Washington D.C., 20013-7012, USA*

[2]*Dipartimento di Scienze della Terra "A. Desio", Università degli Studi di Milano, via Mangiagalli 34, 20133 Milano, Italy*

[3]*Department of Earth Sciences, University College London, Gower Street, London WC1E 6BT, England, UK*

[5]Corresponding author email: huberb@si.edu

ABSTRACT: A new relational taxonomic database for planktonic foraminifera ("*pforams@mikrotax*") has been constructed and is now freely available online at http://www.mikrotax.org. It represents a major advance from its predecessor, the *CHRONOS* online taxonomic database, which has served the research community since 2005. The benefits of the new database to the research and industrial biostratigraphic communities are many, as it will serve as an immediately accessible taxonomic guide and reference for specialists and non-specialists alike by providing access to a wealth of information and images from original authors and from experts who have inserted recent authoritative updates to planktonic foraminiferal taxonomy, phylogeny and biostratigraphy. The database will be continually updated and used as a guide for training current and future generations of students and professionals who will be able to self-educate on planktonic foraminiferal taxonomy and biostratigraphy. Further investigation of species traditionally included in the Cretaceous genera *Heterohelix*, *Globigerinelloides*, *Marginotruncana*, and *Globotruncana* is required to exclude the use of polyphyletic morphotaxa. The taxonomy for Paleogene planktonic foraminifera is quite stable following publication of the Paleocene, Eocene, and Oligocene taxonomic atlases, but revisions to the taxonomy and phylogeny of Neogene taxa are needed to incorporate results from genetic sequencing studies and recent biostratigraphic observations.

INTRODUCTION

Planktonic foraminifera arguably have the best fossil record on Earth because of their high rates of production, wide distribution in a variety of marine settings, high preservation potential, and relatively rapid speciation rates (Hemleben et al. 1989). As a result, they have been used extensively in biostratigraphic studies (McGowran 2005), they are considered the most important fossil group for interpreting Mesozoic and Cenozoic paleoceanography (Kucera 2007), and stratophenetic studies of their morphology provide significant insights to macroevolutionary and microevolutionary patterns and processes (e.g., Malmgren et al. 1983; Hodell and Vayavananda 1993; Wei 1994; Schmidt et al. 2004; Aze et al. 2011; Ezard et al. 2011; Pearson and Ezard 2014). Although the importance of planktonic foraminifera has increased in biostratigraphic, paleoceanographic, and evolutionary studies, the number of experts who can provide taxonomic training for the next generation of scientists has diminished. For this reason, and because most taxonomic and biostratigraphic information is dispersed in obscure journals or books that are out of print and taxonomic opinions are constantly evolving, the potential value of a universally accessible, high-quality internet database of planktonic foraminiferal taxonomy has never been greater. We describe here our progress toward achieving this goal.

To meet the increasing community demand for online access to accurate taxonomic and stratigraphic information, a team of programmers and taxonomic experts collaborated to build the *CHRONOS* online taxonomic database (OTD) for planktonic foraminifera (http://portal.chronos.org/gridsphere/gridsphere?cid=res_taxondb), which became publicly accessible in 2005. It was built as a PostgreSQL relational database and contains species images, searchable morphologic character states, and links to external databases for graphically displaying biogeographic and stratigraphic species distributions. This planktonic foraminiferal OTD was included as part of a National Science Foundation funded effort to build a centralized cyberinfrastructure called the *CHRONOS* System (http://www.chronos.org/) for integrating stratigraphic databases that are linked by geologic time (Sikora et al. 2006). The planktonic foraminiferal OTD and other tools and databases originally developed in *CHRONOS* continue to be used by many workers (e.g., TimeScale Creator; Age-Depth Plot; CONOP9; Psicat). Termination of *CHRONOS* funding in 2006 occurred before components of the OTD were completed and soon thereafter the future of the *CHRONOS* OTD was in jeopardy because of software malfunctions and database crashes that could not be prevented due to the lack of programmer funding. Nevertheless, the *CHRONOS* OTD provided the taxonomic backbone for integrating diverse palaeobiological data on planktonic foraminifera and therefore played a key role in the emerging field of palaeoinformatics.

We have created a replacement of the *CHRONOS* planktonic foraminiferal OTD designated as "*pforams@mikrotax*", which can be accessed at http://www.mikrotax.org. This new OTD advances well beyond the *CHRONOS* OTD in its functionality, new content, server stability, and graphical interface. Benefits to the research, student and commercial communities are many, as it will serve as an immediately accessible taxonomic guide and reference for specialists and non-specialists, providing access to a wealth of information and images from original authors and from experts who have provided recent authoritative updates to planktonic foraminiferal taxonomy, phylogeny and biostratigraphy. *pforams@mikrotax* will serve as a continually updated guide for training current and future generations of students and professionals, who will be able to educate themselves on planktonic foraminiferal taxonomy and biostratigraphy.

In this paper we provide an overview of the functionality, content, and oversight of the *pforams@mikrotax* OTD and we discuss areas of Cretaceous and Jurassic planktonic foraminiferal taxonomy and biostratigraphy that still need investigation and revision.

IMPROVEMENTS BEYOND *CHRONOS*

The *pforams@mikrotax* database contains numerous improvements over the *CHRONOS* taxonomic database, including the following:

•Access to species pages through family and genus pages for Mesozoic taxa and shell wall type for Cenozoic taxa. Listings include taxonomic diagnoses accompanied by thumbnail image examples.

•Databases for Neogene, Paleogene, and Mesozoic planktonic foraminifera are all accessible from the top of every taxon page.

•Many new Scanning Electron Microscope (SEM), composite focus light microscope, and thin-section images have been added.

•An original description catalog, which includes all described taxa using their original taxonomic names, is separated from a main catalog, which includes all taxa considered as valid. Links on each catalog page provide easy navigation within the database.

•Bibliographic citations are included in each taxonomic record and are linked to a comprehensive bibliography that can be browsed and searched.

•Stratigraphic ranges are plotted against the 2012 Geological Time Scale (Gradstein et al. 2012) for each taxonomic level with first and last appearances plotted at different levels of known precision (stage, biozone, or age).

•Metadata are provided with each graphical image.

•Data sources are shown for first and last occurrence information presented for taxon ranges.

•A simple search box is located at the top and near the bottom of every page, enabling searches for any part of a taxon name and for occurrence in the basionym, synonym and variant fields of the database.

•Advanced search capabilities are combined into a single user-friendly layout that includes taxonomic criteria and a matrix of morphological characters that can be further constrained by a sliding geologic-age search window.

•Taxon ages are linked to the TimeScale Creator database (https://engineering.purdue.edu/Stratigraphy/tscreator/index/index.php), with age calibrations by stage, zone, magnetochron, and cyclostratigraphy tied to lookup tables that can be updated with new changes to the geologic time scale.

•A *Mikrotax* Range Chart plotter that presents taxon ranges at different hierarchical levels using first and last occurrence ages from within the database compared to occurrence data (plotted in million year bin frequencies) extracted from the Neptune Deep-sea Microfossil occurrence database (http://www.nsb-mfn-berlin.de/). Frequency of species occurrences in DSDP, ODP, and IODP samples provides a proxy for species abundance, although some erroneous age models in Neptune need to be corrected before these outputs can be considered as reliable.

•A greater amount of the database content can be updated by registered users with a variety of editing functions available on separate web-forms for the catalog, images, and main web pages.

•A detailed user guide with labeled screen-shots and a slideshow file are provided for easy instructions on how to navigate and perform searches in the database.

In addition to these improvements, the innovative public comment field, multi-field search capability, and disseminated editing features that were valuable attributes of the *CHRONOS* OTD have been retained in the *Mikrotax* System. These combined features will bring *pforams@mikrotax* to the forefront as a fundamental resource for planktonic foraminiferal taxonomic and biostratigraphic information.

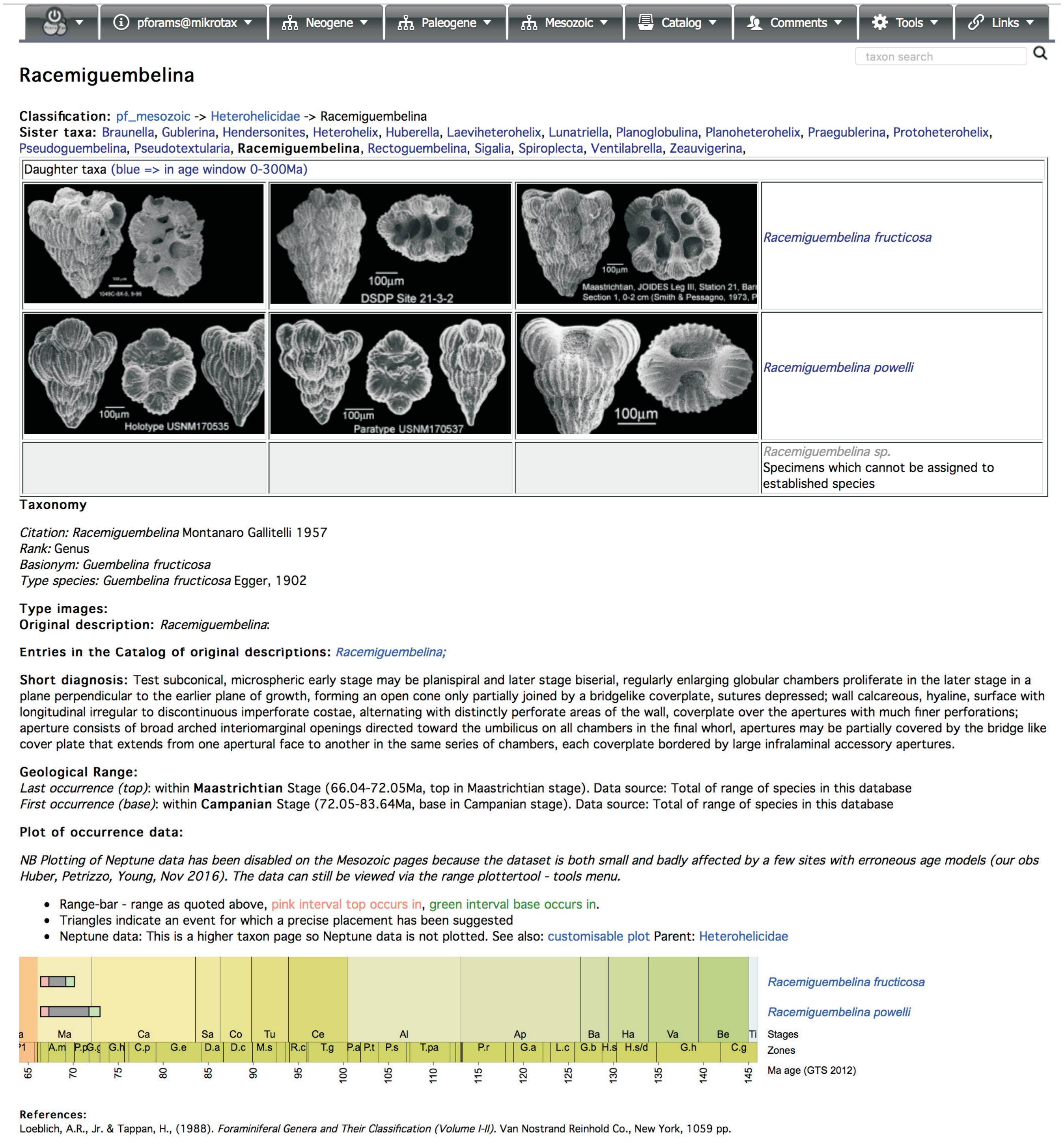
CONTENT AND FUNCTIONALITY OF *pforams@mikrotax*

pforams@mikrotax is a website based on the *Mikrotax* taxonomy content management system that was initially created for the *Nannotax* website (http://www.mikrotax.org/Nannotax3), which was developed as an open access online resource to deliver authoritative taxonomic information for calcareous nannofossils. The system is based on a *MySQL* database that delivers a curated collection of images and text using standard Java Script modules and a small set of custom PHP scripts. Editors of the catalog can log into the database and access a multitude of editing functions using any internet browser.

The database is divided into a "Main Catalog" and "Original Description Catalog". An overview of these catalogs and the sources of their content are discussed below.

Main Catalog

The main catalog contains all species that are considered as valid and it currently includes 495 Cenozoic taxa and 450 Mesozoic taxa, all with more than 2500 images, most of which are SEMs shown with at least three views per specimen. Composite focus light images and thin-section images are included with some species records. Taxonomic information in the main catalog is presented at three hierarchical taxonomic levels. For the Mesozoic planktonic foraminifera, these levels include family, genus, and species, which are each arranged with thumbnail images, diagnoses, and listings of the included taxa. This is differ-



pforams@mikrotax | Neogene | Paleogene | Mesozoic | Catalog | Comments | Tools | Links

taxon search

Racemiguembelina

Classification: pf_mesozoic -> Heterohelicidae -> Racemiguembelina
Sister taxa: Braunella, Gublerina, Hendersonites, Heterohelix, Huberella, Laeviheterohelix, Lunatriella, Planoglobulina, Planoheterohelix, Praegublerina, Protoheterohelix, Pseudoguembelina, Pseudotextularia, **Racemiguembelina**, Rectoguembelina, Sigalia, Spiroplecta, Ventilabrella, Zeauvigerina,

Daughter taxa (blue => in age window 0-300Ma)

Racemiguembelina fructicosa

Racemiguembelina powelli

Racemiguembelina sp.
Specimens which cannot be assigned to established species

Taxonomy

Citation: Racemiguembelina Montanaro Gallitelli 1957
Rank: Genus
Basionym: Guembelina fructicosa
Type species: Guembelina fructicosa Egger, 1902

Type images:
Original description: *Racemiguembelina*:

Entries in the Catalog of original descriptions: *Racemiguembelina;*

Short diagnosis: Test subconical, microspheric early stage may be planispiral and later stage biserial, regularly enlarging globular chambers proliferate in the later stage in a plane perpendicular to the earlier plane of growth, forming an open cone only partially joined by a bridgelike coverplate, sutures depressed; wall calcareous, hyaline, surface with longitudinal irregular to discontinuous imperforate costae, alternating with distinctly perforate areas of the wall, coverplate over the apertures with much finer perforations; aperture consists of broad arched interiomarginal openings directed toward the umbilicus on all chambers in the final whorl, apertures may be partially covered by the bridge like cover plate that extends from one apertural face to another in the same series of chambers, each coverplate bordered by large infralaminal accessory apertures.

Geological Range:
Last occurrence (top): within **Maastrichtian** Stage (66.04-72.05Ma, top in Maastrichtian stage). Data source: Total of range of species in this database
First occurrence (base): within **Campanian** Stage (72.05-83.64Ma, base in Campanian stage). Data source: Total of range of species in this database

Plot of occurrence data:

NB Plotting of Neptune data has been disabled on the Mesozoic pages because the dataset is both small and badly affected by a few sites with erroneous age models (our obs Huber, Petrizzo, Young, Nov 2016). The data can still be viewed via the range plottertool - tools menu.

- Range-bar - range as quoted above, pink interval top occurs in, green interval base occurs in.
- Triangles indicate an event for which a precise placement has been suggested
- Neptune data: This is a higher taxon page so Neptune data is not plotted. See also: customisable plot Parent: Heterohelicidae

References:
Loeblich, A.R., Jr. & Tappan, H., (1988). *Foraminiferal Genera and Their Classification (Volume I-II)*. Van Nostrand Reinhold Co., New York, 1059 pp.

TEXT-FIGURE 1
Screen grab from *pforams@mikrotax* Mesozoic Main Page Catalog showing images, text and biostratigraphic range plot for the two valid species included in *Racemiguembelina*. Also note the web page links and taxon search window

ent from organization of the Cenozoic planktonic foraminifera, which uses wall-texture type instead of taxonomic family for the highest classification level. For each taxonomic level, graphical range bars show the precision of first and last stratigraphic occurrence determinations (text-fig. 1). Specimens chosen for illustration are considered as representative of the range of morphologic variability within the species concept.

Original Description Catalog

The second part of the database is the "Original Description Catalog". This is intended to be a comprehensive catalog including all described planktonic foraminifera, providing verbatim copies of original descriptions and remarks, and original illustrations of type specimens, together with English-language translations of descriptions and modern illustrations of type specimens. At present the catalog lists 2200 described taxa, which is close to being comprehensive. While the level of coverage varies from a simple listing of the names, authorship and publication to full coverage, there is useful detail for over half the entries and this is rapidly being expanded. A particular feature is inclusion of many new SEM micrographs of the primary types (holotypes, paratypes, neotypes, lectotypes, and syntypes), with an emphasis on species that are considered as valid.

In addition to the original descriptions, information in the Original Description Catalog includes original and currently used genus and species name combinations, the authors and dates for species names, holotype size dimensions, type locality and age, repository information, and bibliographic references (text-fig. 2). Links to the main database, a taxon search box, and multiple drop-down links allow for easy navigation to other parts of the database from the Original Description Catalog.

Sources of Taxonomic Information

Conflicting opinions on the taxonomy and stratigraphic ranges of planktonic foraminifera continue to the present day as a result of inaccurate original species illustrations, inadequate descriptions, and lost, inaccessible or poorly preserved holotypes. The advent of SEM imaging for illustration of planktonic foraminifera revolutionized their study with their unprecedented image accuracy and resolution at high magnifications, which subsequently led to a new appreciation of the importance of wall texture and other features that have become important in higher-level taxonomic classification (e.g., Blow 1969, 1979; Fleisher 1974; Robaszynski et al. 1979, 1984; Caron 1985; Boudagher-Fadel et al. 1997). The ability to capture high quality SEM images without the application of a conductive coating (e.g., Liu et al. 1998; Olsson et al. 1999; Caron and Spezzaferri 2006; Pearson et al. 2006; Ando and Huber 2007; Georgescu and Huber 2009; Haynes et al. 2015; Wade et al., in press) has been an important development in the clarification of a number of holotype concepts (text-fig. 3).

The advent of the Deep Sea Drilling Project in 1968 and continuation of deep sea drilling up to the present day, along with several land-based drilling initiatives, has provided access to more continuous stratigraphic sequences and better microfossil preservation than has generally been available from outcrop samples. Study of these rich microfossil archives have enabled major refinements of the biostratigraphy of planktonic foraminifera and improved phylogenetic hypotheses through detailed stratophenetic observations. The European Working Group on Planktonic Foraminifera, which included as many as 30 specialists from industry and academia, assembled at numerous meetings between 1976 and 1981. These meetings resulted in two widely cited taxonomic atlases: the first focused on Albian-Turonian species (Robaszynski et al. 1979) and the second focused on Campanian-Maastrichtian globotruncanids (Robaszynski et al. 1984).

The Paleogene Planktonic Foraminiferal Working Group (PPFWG) formed in 1987 under the auspices of the International Subcommission on Paleogene Stratigraphy (within the International Union of Geological Sciences) to resolve conflicting taxonomic concepts, eliminate polyphyletic taxa through study of stratigraphically ordered samples, and characterize the range of morphologic variability by illustrating specimens from different stratigraphic levels and geographic locations. This collaboration resulted in the publication of the Atlas of Paleocene Planktonic Foraminifera (Olsson et al. 1999) and Atlas of Eocene Planktonic Foraminifera (Pearson et al. 2006), and the Atlas of Oligocene Planktonic Foraminifera will be published within the next year (Wade et al., in press). Images and text from the Paleocene and Eocene atlases are reproduced in the Cenozoic main catalog of *pforams@mikrotax* and content from the Oligocene Atlas will be uploaded after its publication. The Neogene Planktonic Foraminiferal Working Group has yet to meet and begin work toward completion of an atlas for Neogene planktonic foraminifera. Meantime, text and images of Neogene species have been uploaded into the Original Description Catalog of *pforams@mikrotax*.

The Mesozoic Planktonic Foraminiferal Working Group (MPFWG), first formed in 2004 and has met multiple times since then for the purpose of updating the taxonomy, phylogeny and biostratigraphy of Jurassic and Cretaceous planktonic foraminifera. Problems of poor preservation of most type specimens, limited availability of stratigraphically continuous sections that yield well-preserved specimens, and the challenge of polyphyletic lineages have impeded progress toward completion of a taxonomic atlas. Nonetheless, collaborations among working group members has led to numerous publications that present important advances in the taxonomy, biostratigraphy, and phylogeny of a number of taxonomic groups (e.g., Georgescu and Huber 2006, 2007, 2008, 2009; Georgescu 2007, 2008, 2009a, 2009b; Petrizzo and Huber 2006a, 2006b; Gonzalez-Donoso et al. 2007; Desmares et al. 2008; Georgescu and Abramovich 2008, 2009; Lipson-Benitah 2008; Georgescu et al. 2009; Premoli Silva et al. 2009; Falzoni and Petrizzo 2011; Huber and Leckie 2011; Petrizzo et al. 2011, 2015; Ando et al. 2013; Huber and Petrizzo 2014; Falzoni et al. 2014, 2016; Haynes et al. 2015; Petrizzo et al. 2017; Huber et al. 2017). These publications and others provide an updated framework for the classification of the Cretaceous planktonic foraminifera since that of Loeblich and Tappan (1988). The Mesozoic Catalogue within *pforams@mikrotax* includes taxonomic revisions presented in this suite of publications.

The taxonomic working groups will monitor opinions uploaded in the Mikrotax Comment field and new published revisions to planktonic foraminiferal taxonomy and phylogeny. Updates to the Main Catalogue will be made upon reaching majority consensus agreement among working group members.

Cretaceous Polyphyletic Taxa

Despite the progress that has been made by members of the MPFWG in resolving the taxonomy and phylogeny of a number of Cretaceous planktonic foraminiferal taxa, there is still much left to be done, as several important Cretaceous genera are known to be polyphyletic. Below are some of the taxa that need additional work.

pforams@mikrotax | Neogene | Paleogene | Mesozoic | Catalog | Comments | Tools | Links

taxon search

CATALOG OF ORIGINAL DESCRIPTIONS: *Guembelina fructicosa* Egger 1899

This page provides data from the catalog of type descriptions. The catalog is sorted alphabetically. Use the current identification link to go back to the main database.

Higher levels: pf_cat -> G -> Guembelina -> Guembelina fructicosa
Other pages this level: << < G. acervulinoides, G. barnardi, G. boliviniformis, G. carinata, G. cenomana, G. complanata, G. conjakica, G. costulata, G. crinita, G. cubensis, G. cubensis heterostoma, G. dagmarae, G. deflaensis, G. distorta, G. excolata, **G. fructicosa**, G. garretti, G. glabrans, G. globocarinata, G. globulosa striatula, G. goodwini, G. malocaucasica, G. marshallana, G. mauriciana, G. micra, G. midwayensis, G. midwayensis nammalensis, G. moremani, G. morsei, G. multicellaris, > >>

26 9 8 24
Figured specimens

figured-specimen-217.jpg

Guembelina fructicosa

Citation: Guembelina fructicosa Egger 1899
Rank: Species
Type locality: not designated
Type level: Maastrichtian
Holotype Repository: Not given
Holotype number: Not given

Current identification/main database link: *Racemiguembelina fructicosa* (Egger, 1900)

Original Description: A cup-like distinguishes this species with tests of 0.20-0.50 mm which arise from a single, simple chamber or form a straightening spire. Juvenile tests differ from G. decurrens and similar forms by their increasing width as shown in Fig. 25, 26. Third chambers are inserted between the two alternating ones of the biserial row, and the chambers are positioned one upon the other in the whorls and with the insertion of more chambers at times distinctly widening. At the anterior, the juvenile tests show the last two chambers co bulging terminations of the test, with a broadly gaping opening in the border of the test axis. In the cross-section of the cone of the rounded off larger tests, the middle portion of the commonly damaged cone bottom remains recessed, and the chambers of the last whorl open freely with their borders into the depression of the test. All tests pore ribs which rise freely and are strongly constructed; because the chambers retain more or less the same size in the later whorls, the test surface resembles that of blackberries. Reuss shows a figure of Gaudryina siphonella Reuss from Hermsdorf in his study about the Fossil Foraminifera and Entomostraca of the region of Berlin in 1851, which may belong here.

References:
Egger, J.G., (1899). Foraminiferen aus den Kreidemergeln der Oberbayerischen Alpen. *Abh. Kon. bay. Akad. Wiss. Mnchen, Cl. 2*, **21**(1).

TEXT-FIGURE2
Screen grab from *pforams@mikrotax* Primary Type Catalog page showing original type illustration, repository information, and original description for the holotype of *Guembelina fructicosa* Egger 1899. Note the different textured background compared to the Main Catalog. Also note the web page links and taxon search window.

Genus *Globigerinelloides*

Most Cretaceous planispiral species have traditionally been included in the genus *Globigerinelloides* because of their coiling mode. However, a stratigraphic gap spanning ~4 m.y. separates the extinction of Early Cretaceous species of *Globigerinelloides*, including the type species *Globigerinelloides algerianus* Cushman and ten Dam 1948, from Late Cretaceous planispiral species that have also traditionally been included in *Globigerinelloides*. Clearly they do not all belong to the same lineage. Differences in wall texture and wall-pore diameters among the planispiral taxa have been used by some authors to separate several Cretaceous planispiral lineages [e.g., *Alanlordella* Boudagher-Fadel 1995; *Macroglobigerinelloides* (nomen nudem) Premoli Silva and Verga 2004], but the reliability of those features for discriminating between planispiral taxa been questioned (e.g., Moullade et al. 2002; Verga and Premoli Silva 2002, 2003, 2005; Petrizzo and Huber 2006a). Members of the MPFWG have been analyzing well preserved Late Cretaceous planispiral assemblages from stratigraphically continuous deep sea and land-based sequences in order to infer ancestor-descendent relationships and propose a new taxonomy and phylogeny for Late Cretaceous species that have previously been assigned to *Globigerinelloides*.

Family *Heterohelicidae*

Recent studies on Cretaceous biserial and multiserial taxa have emphasized the taxonomic importance of the initial coiling mode and wall-texture features within this morphologically diverse group, and this has led to significant revisions to their taxonomy and phylogeny (Georgescu and Huber 2006, 2007, 2008, 2009; Georgescu and Abramovich 2008, 2009; Georgescu et al. 2009; Haynes et al. 2015). Although nearly all species with a wholly biserial chamber arrangement had been included in *Heterohelix* Ehrenberg 1843 for decades after Loeblich (1951) resurrected the genus, this taxon is now considered as being correctly applicable to only a limited, monophyletic set of species (Georgescu and Abramovich 2009; Georgescu and Huber 2009), and at least 15 additional genera have been erected for

Late Cretaceous biserial taxa during the past decade. Significant revisions to the taxonomy and phylogeny of Albian-Cenomanian biserial species by Georgescu and Huber (2009) has more recently been followed by morphometric study of exceptionally well-preserved Turonian biserial assemblages by Haynes et al. (2015), which resulted in further revision of the group. Additional studies are required to trace the biserial lineages through the Coniacian–Maastrichtian to determine their appropriate taxonomic classification. Until then, most Coniacian-Maastrichtian biserial species are temporarily classified under "*Heterohelix*".

Family *Globotruncanidae*

Transitional overlap between marginotruncanid and globotruncanid species has been recognized since the study of Wonders (1980), but clarification of differences and the phylogenetic relationship of both taxa still requires additional research. Species currently included in the genus *Marginotruncana* show some profoundly different morphologic characteristics that suggest the genus is polyphyletic. For example, the features and shape of the umbilical sutures vary from being nearly depressed in *M. schneegansi* to strongly raised in *M. coronata*, and they are nearly U-shaped in *M. pseudolinneiana*, but V-shaped in *M. undulata*. Characteristics of the peripheral margin are also very different for species included in this group. For example, *M. coronata* and *M. pseudolinneiana* have two keels separated by a wide imperforate peripheral band, whereas *M. marianosi* and *M. sigali* have one keel. Similarly, the relationship between single- and double-keeled species that were included in *Globotruncana* by Robaszynski et al. (1984) [e.g., *G. insignis* Gandolfi 1955 and *G. rosetta* (Carsey 1926)], needs further investigation. Careful stratophenetic observations of well-preserved assemblages spanning the Turonian–Santonian interval will determine whether more lineages should be recognized within the morphologically diverse marginotruncanids and globotruncanids.

Family *Hedbergellidae*

Development of a more stable taxonomy of the hedbergellids is needed to improve Cretaceous planktonic foraminiferal biostratigraphic and taxonomic framework. Revision of Early Cretaceous hedbergellids is ongoing, but problems encountered include their rare occurrence, poor preservation and low morphological diversity. Moreover, the validity of some morphologic features that have been used to discriminate some genera and species remain a matter of debate (e.g., chamber elongation: Boudager-Fadel et al. 1997; Verga and Premoli Silva 2005). Detailed study of extraordinarily well-preserved assemblages spanning the Aptian/Albian boundary at several deep-sea sites by Huber and Leckie (2011) enabled a major revision to the Aptian-Albian hedbergellid taxonomy. Observations of taxonomically and stratigraphically consistent differences in wall texture, wall pores, and apertural features led these authors to determine that species that should be included in *Hedbergella* became extinct at the end of the Aptian, whereas lineages that survived this extinction and then diversified during the Albian were assigned to *Microhedbergella* and *Muricohedbergella*. Additional hedbergellid genera have been named during the past decade (*Liuella* Georgescu 2008; *Pseudoclavihedbergella* and *Pessagnoina* Georgescu 2009b; *Hillsella* Georgescu & Carrigy 2012), but understanding how these and other Late Cretaceous hedbergellids are related to the mid-Cretaceous lineages needs much additional study.

Evolution of Jurassic Planktonic Foraminifera

The taxonomy and biostratigraphy of Jurassic planktonic foraminifera have been significantly updated and revised by Gradstein et al. (2017a, b) following detailed SEM and thin-section study of topotypic specimens and samples from Canada, Portugal, France, Switzerland, Poland, Lithuania, Russia and Dagestan. Some of the studied samples yield specimens that are remarkably well-preserved, providing new information on wall microstructure and microtextures, while other material had to be studied in thin-section. Results of these studies will be uploaded into the *pforams@mikrotax* database. Additional work is needed to determine the timing and phylogenetic origin of the Jurassic planktonic foraminifera as well as their relationship to descendent Cretaceous species.

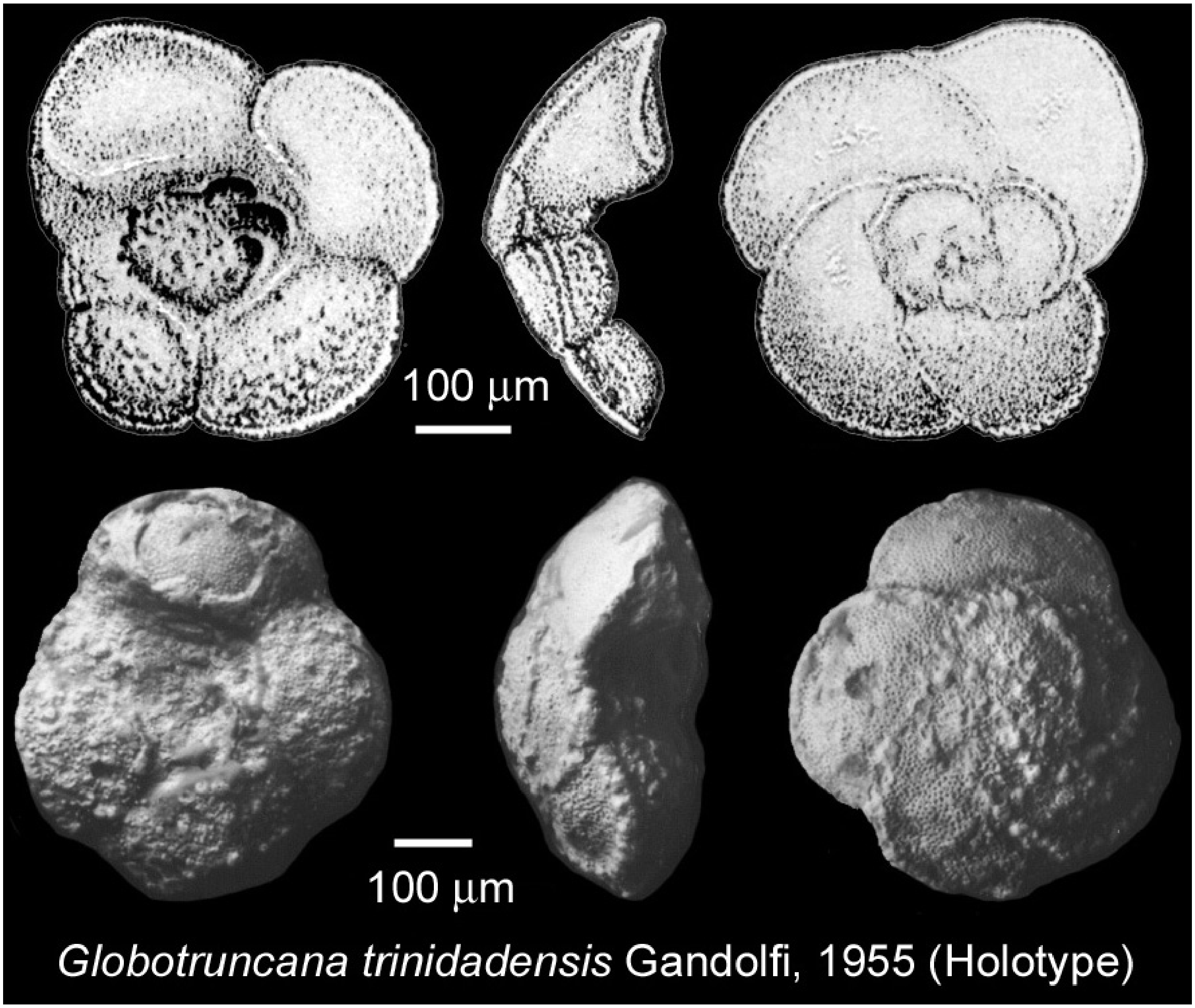
RESEARCH AND EDUCATION BENEFITS

The state-of-the-art taxonomic and stratigraphic information included in *pforams@mikrotax* provides a valuable benefit to micropaleontology specialists in private industry and in academia. Quick online access to the database will enable faster decision making by industrial micropaleontologists working in both onshore and offshore settings, where expert taxonomic and biostratigraphic knowledge is critical to management of subsurface boreholes. Access to clear, historical synonymies in a single-source database will be make it much easier to re-interpret and update old industrial reports as the need for improved subsurface correlation increases. The benefits are particularly obvious in situations where access to academic literature is limited or non-existent, such as on offshore rigs and in remote locations; the online database will speed up taxon identification, improve stratigraphic precision for origination and extinction levels, provide a more efficient means of communication among specialists, students, and teachers, and enable effective communication of ideas through reference to common images and data sets. Such information will also speed up age determinations for shipboard scientists working on IODP expeditions where drilling decisions are dependent on quick and reliable microfossil age control.

By providing ready access to taxonomic minutiae, original descriptions, and illustrations of type specimens, *pforams@mikrotax* will be used by the academic research community as a reliable resource that will facilitate accurate planktonic foraminiferal species identification and age determinations for paleoceanographic, biostratigraphic, and taxonomic studies. Geochemists, magnetostratigraphers, petroleum engineers, and many other geoscientists frequently use and need to interpret data derived from planktonic foraminifera. The database will allow information on any taxon to be searched and will provide the key reference sources to interpret names. As a clear synthesis of working taxonomy, *pforams@mikrotax* will also allow students and trainee industrial biostratigraphers to learn current planktonic foraminiferal taxonomy much faster than has been possible.

FUTURE DIRECTIONS

As noted above, the Main Catalogue in *pforams@mikrotax* database will be continually updated by members of the MPFWG following review of publications where new taxa are defined and revisions to the evolution and phylogeny of planktonic foraminifera are proposed. Efforts will be made to broaden participation in the working groups to increase diversity of taxonomic and stratigraphic expertise by getting additional colleagues from academia and industry to join. Decisions will



TEXT-FIGURE 3
Original holotype illustration and SEM images of the holotype for *Globotruncana trinidadensis* Gandolfi. Note in the edge (middle) view of the drawn images (upper series) that the convexity of the spiral side is exaggerated and the test is shown to be very thin in comparison to the environmental SEM images of the holotype from The Natural History Museum in London. Note also the exaggerated lobateness of the holotype in the spiral view (upper right). Such inaccuracies have contributed to uncertainty and inconsistency in the understanding of species concepts.

continue to be based on majority opinions of the Mesozoic, Paleogene, and Neogene working groups.

We anticipate that *pforams@mikrotax* will become the primary resource for updating taxonomic concepts and biostratigraphic ranges that are used by micropaleontology experts who participate in the IODP, and by the TimeScale Creator, the Neptune Sandbox and Paleobiology databases. As portions of the phylogenetic tree for the planktonic foraminifera are resolved and incorporated in *pforams@mikrotax*, phylogenetic tree visualizations can be added as datapacks to TimeScale Creator. Linking other databases to the carefully vetted, authoritative source of taxonomic and phylogenetic information presented in *pforams@mikrotax* will considerably improve the stability of taxonomic concepts applied by students and professionals working in disparate areas of the geological and biological sciences. The additional information included in the metadata files and bibliography of *pforams@mikrotax* will also be valuable resources for various research communities.

In addition we are interested in applying the *Mikrotax* system to other groups of organisms, especially other microfossil groups. We are currently exploring potential collaborations, but we also welcome inquiries from any other interested workers.

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