

# **Ninth International Workshop On Agglutinated Foraminifera**

**Abstract Volume**

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## **Preface**

*The Organizing committee of the 9th International Workshop on Agglutinated Foraminifera (IWAF-9) welcomes everyone to Zaragoza and to its University. We hope that this event will serve to bring together specialists from all over the world by fostering the sharing of ideas and collaboration in the study of agglutinated foraminifera.*

*The IWAF-9 continues a series of meetings devoted primarily to the systematics, (palaeo)ecology and evolution of the largest single group of foraminifera. The IWAF meeting in Zaragoza follows previous meetings held in Amsterdam (1981), Vienna (1986), Tübingen (1989), Kraków (1993), Plymouth (1997), Prague (2001), Urbino (2005) and Cluj-Napoca (2008). The main idea behind this meeting and this abstract volume is to present a general view of current research on the agglutinated foraminifera.*

*We hope you enjoy your stay in the historical city Zaragoza. The city, originally called Caesaraugusta by its founder, the Roman Augustus, then part of the Arab Emirate of Cordoba under the name of Saraqusta, became one of the taifa kingdoms in 1018 and thereafter the capital of the Kingdom of Aragon during the Aragonese era. Like other institutions, the University of Zaragoza had its beginnings in what were known as the Ecclesiastical Schools, whose guiding spirit in the 7th century was the Bishop Braulio (which is the reason why in modern times he was made the patron saint of our University). Later called School of Arts (14th century), it was made a General School of Arts in the 15th century, at the petition of Fernando, the future King of Aragon, and it became a university in the 16th century, during the Renaissance. Today, the University of Zaragoza has more than 35,000 students, and 56 departments offering 54 degrees and 52 master courses.*

*We would like to thank the participation of more than 50 scientists who registered for IWAF-9, and who submitted the 56 contributions that are included in this volume. These contributions are essential to the IWAF-9, and they will certainly make the most of this meeting through interesting discussions and presentation of the latest investigations on agglutinated foraminifera. The organizing committee has worked together enthusiastically to make this meeting possible, and this was in many ways a very pleasant task. We just hope to be able to create a good environment for discussions, and to make you feel like at home. If there's anything you need, just ask any of the members of the staff, and they will be very happy to help!*

*On September 3<sup>rd</sup> you will have the opportunity to check some collections of Upper Cretaceous to middle Eocene benthic foraminiferal assemblages from the Iberian Peninsula, while the "satellite" meeting of the Working Group on Foraminiferal Classification takes place. Afterwards, we will all meet together in the icebreaker party (in case there is any ice left to be broken...). After two intense days of technical sessions and various social events, those who join us for the field trip to the Basque-Cantabrian flysch deposits of Northern Spain will visit some world-wide reference sections that contain very abundant flysch-type agglutinated foraminifera. Some of you might want to stay there forever (oh well, or maybe just a couple of days more) to enjoy the geology and the breathtaking views along the coast.*

*We take this opportunity to thank our sponsors, who contributed to the organizational costs of the meeting. We want to thank the University of Zaragoza (Vicerrectorado de Investigación), IUCA (Instituto Universitario de Investigación en Ciencias Ambientales de Aragón), the Spanish Ministry of Competition and Innovation, the European Science Foundation, The Micropaleontological Society and the Grzybowski Foundation for financial support, the Faculty of Sciences of Zaragoza University for letting us use their facilities, and Celka Microslides for providing some micropaleontological material.*

*We hope you enjoy the meeting, and wish you a very pleasant stay in Zaragoza.*

*The IWAF-9 Organizing Committee*



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*Scientific contributions*

## **New observations on the wall structure and stratigraphic occurrence of *Riyadhella* (Foraminifera) in Saudi Arabia**

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The stratigraphic occurrence of the agglutinated foraminiferal genus *Riyadhella* in the Jurassic formations of Saudi Arabia is reviewed with the intention of developing the *Riyadhella* species as chronostratigraphic markers. The genus *Riyadhella* was defined from Saudi Arabia and *R. regularis* ranging from Early Bajocian to Middle Callovian. In this study, it is present from the upper Bathonian carbonates of the Middle Dhurma Formation (unit D6) to the middle Callovian carbonates of the Lower Tuwaiq Mountain Limestone Formation (unit T1).

The last occurrence of this species characterizes the top of unit T1 (the lower Tuwaiq Mountain Formation/top of the Upper Fadhili Reservoir) in both outcrop and subsurface localities. The last occurrence of *Riyadhella elongata* characterizes the top Hisyan Member (Dhurma Formation top). The youngest stratigraphic range of *R. elongata* was the Early Bathonian and it is now extended to include the Middle Callovian age. New observations of the wall microstructure of *Riyadhella* in thin sections reveal the presence of canaliculate chambers in the neanic and ephebic stages of *Riyadhella regularis*. This has led to an amendment of the taxonomy of *Riyadhella*.

## **Agglutinated foraminiferal diversification and their importance in the Jurassic biostratigraphy of Saudi Arabia**

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Agglutinated foraminiferal occurrences in seven formations of Lower to Upper Jurassic carbonates in Saudi Arabia display similarity with assemblages recorded from other regions of the Tethyan domain. The agglutinated foraminifera show significant generic and specific diversity and provide scope to better define evolutionary lineages in the Tethyan communities during the Jurassic stages. A thin-section based study from 15 exposed sections along the Jurassic outcrop belt in central Saudi Arabia and three shallow-cored wells near the type sections of the studied formations provide an almost continuous succession from the Lower to Upper Jurassic. The study also includes subsurface samples from wells that cored the Jurassic successions from 12 reservoirs in different fields in eastern Saudi Arabia.

The Arabian Plate was tectonically relatively stable throughout the Jurassic and the sediments are dominated by shallow marine carbonates that were deposited in low latitudes of the western Tethys. The Arabian platform drowned periodically and open-marine facies with ammonites and other pelagic fossils were deposited. These facies interfinger with shallow marine facies that display a high diversity of agglutinated foraminifera that allow chronostratigraphic control and enable regional sequences correlation across the Arabian Plate. Intra-platform basins developed during the Middle Jurassic within the shallow marine platform. New foraminifera species, of which most are endemic, evolved within these isolated communities and although their biostratigraphical application is limited, their palaeoenvironmental applications are significant. In order to distinguish the stratigraphic ranges of studied agglutinated foraminifera from the ecological effects on distribution, these ranges are being displayed according to their relative age, based on the accompanying fossils and/or stratigraphic position. Their chronostratigraphic ranges have been determined elsewhere in other Peri-Tethyan regions that were coeval with these carbonate facies. In general, the foraminiferal family Hauraniidae dominated the Lower Jurassic successions; the family Pfenderinidae dominated the Middle Jurassic; and endemic species of subfamilies of Kurnubiinae and Paleopfenderininae dominated the Upper Jurassic carbonates.



## **The effect of the late Tithonian-Berriasian crisis on agglutinated foraminifera: the record from the base of the Sulaiy Formation, Saudi Arabia**

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The base of the Sulaiy Formation in Saudi Arabia is formed of carbonate rocks that were deposited in a subtidal marine platform during the latest Tithonian and earliest Berriasian. The common agglutinated foraminifera of the base of the Sulaiy Formation show abnormally smaller grain sizes compared to the original shapes and sizes of the normal species. This may be a consequence of a crisis that indirectly affected the shapes and sizes of agglutinated foraminifera: the so-called “famine” of Paul and Mitchell (1994). The “famine” is thought to be the result of the dominance and productivity of the radiolarian zooplankton during the late Tithonian and throughout the Berriasian. During this interval, the total diversity of radiolarians reached 180 genera and, in the Hawasina Formation in Oman, reached 120 genera (Kiessling, 2002). The total thickness from the nearest location of the radiolarian red chert of the Raida Formation from Oman is 36 meters and dated as Upper Tithonian-Berriasian based on an assemblage of calpionellids (Simmons and Hart, 1987).

During the latest Tithonian, Price and Rogov (2009) recorded several cooling episodes and low oxygen events from the analysis of  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  isotopes. The cooling events and the low oxygen levels probably explain the high productivity in the radiolarian zooplankton and the high consumption of phytoplankton leaving poor food source and oxygen in the sea water for the agglutinated foraminifera of the inner platforms. The scarce food resources and the limited oxygen in the sea water probably controlled the shapes and size of the agglutinated foraminifera during the late Tithonian cooling events within the normally warm Cretaceous greenhouse period. This crisis is a global event and probably represented the global radiolarian chert distribution. More data are required, from different localities, to confirm it as a global crisis of the agglutinated foraminifera. Kiessling (2002) also records radiolarian productivity peaks in the Famennian, Norian-Rhaetian and Campanian. These intervals should also be investigated to confirm if they also record changes in the assemblages of agglutinated foraminifera.

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## **Microtomography imaging of Paleocene-Eocene agglutinated foraminifera from the Cumuruxatiba Basin, northwestern Brazil**

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Most studies of Tertiary foraminifera from the Brazilian marginal basins are performed on drill-hole samples. Furthermore, the common low abundance of agglutinated foraminifera, together with the poor preservation, has promoted an investigation for an efficient and non-destructive method to improve taxonomic analyses.

Three dimensional microtomography by X-ray transmission represents a non-invasive method to acquire images, capture external morphological features and inner structure imaging. This method has proven to be efficient to study the inner structures found in porous materials such as ceramics (Salvo et al., 2003) and bones (Bedini et al., 2009). Furthermore, microtomographic image acquisition in foraminifera tests have been used to assess the dissolution in planktonic foraminifers (Johnstone, 2010) and the biometric quantification of larger foraminifers (Briguglio et al., 2011).

This study presents the preliminary results of microtomography imaging of agglutinated foraminifera from the Paleocene-Eocene section of the Cumuruxatiba Basin, northwestern Brazilian continental margin.

Analyses were performed on specimens recovered from 15 cutting samples collected from a drill-hole. The sampled interval was made up of siliciclastic sediments from the Urucutuca Formation, which were deposited in bathyal environments. Most specimens show morphological character obliteration due to recrystallization and compression. The poor preservation made the taxonomic classification difficult.

The specimens were analyzed in the Department of Geology Microtomography Laboratory of the Rio de Janeiro Federal University (UFRJ). The following equipment was used is a MicroCT Skyscan 1173, a tomographic system composed of an X-ray source (40-130kV, 8W, <5µm spot size), a detection system (2240 x 2240 pixels, 12-bit) and a manipulation system. The maximum resolution provided by the equipment is four microns.

The analysis was based on selected specimens belonging to the genera *Cribrostomoides*, *Dorothia*, *Haplophragmoides* and *Trochammina*, as these taxa were the most abundant in the studied section. The results indicate that microtomographic images used to characterize the inner structure of agglutinated foraminifera proved to be a reliable method, which facilitated a better understand of the morphology tests avoiding specimen destruction. The degree of imaging detail is strongly influenced by sediments or diagenetic cement infilling of the chambers, as the contrast between the foraminiferal wall and the chamber interior is reduced. However, despite of the presence of calcitic cement infilling the chambers, the inner structures were clearly observed as well as the wall thickness. Furthermore, was possible to obtain cross-sections of the three-dimensional images.

Apart from the morphological approach, spatial density images were acquired in order to access the distribution of the agglutinated grains of different mineral phases. Thus, this appliance may represent an additional method in the study of the composition and texture of the agglutinated foraminifers.

Future investigations using microtomographic images can provide an improvement in the taxonomic analysis of taxa with a complex inner structure.

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## Environmental control on shell structure and composition of agglutinated foraminifera in the Marmara Sea

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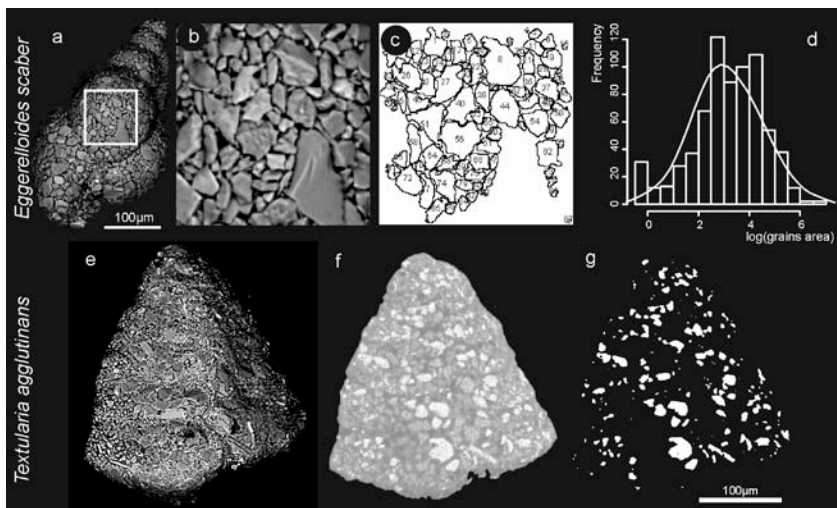
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The study of benthic foraminifera in complex marine system, like the Marmara Sea, represents a key for understanding environmental factors behind foraminiferal species, density, assemblage composition, and shell construction. Based on cross shore water depth transect, this study aims at defining the geochemical conditions at the seafloor and identifying the sediment constraints that act upon agglutinated test construction for selected species. Grain size, mineralogical, and chemical analyses of the shells of species have been performed and compared to the main geochemical conditions within the sediments. Although grains used to construct their foraminiferal tests are agglutinated from among the available grains, both grain size selection and sorting have been revealed. This suggests that the mineralogical composition is related to the species and the sample localization within the basin. Our observations further suggest that bottom water conditions of the Marmara Sea do not have significant influence on agglutinated foraminiferal shell development, which is primarily driven by sediment characteristics.



Grain shape characterization. a) Global SEM back-scattered electrons (BSE) image of a specimen of *Eggerelloides scaber*; b) SEM BSE image of the selected surface for grain analysis, c) Separation of grains that are entirely observed within the selected area and calculation of the shape parameters; d). Distribution of surface of grains (log). Log-normal curve is superimposed. e) Example of quartz analysis

on a specimen of *Textularia agglutinans*; SEM BSE image f) BSE Image after grey level threshold adjustment; g) EDX Silica mapping.

## What caused the *Glomospira* acme during the earliest Eocene?

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The Paleocene-Eocene Thermal Maximum (PETM) event, ~55.5 Ma ago, is characterized by globally elevated temperatures, a negative  $\delta^{13}\text{C}$  excursion and major biotic changes on land and in the oceans. Deep-sea benthic foraminifera suffered the most important extinction in the Cenozoic, with 35-55% of the species disappearing at the Paleocene-Eocene boundary (Thomas, 2007; Alegret et al., 2010).

After the extinction of deep-sea benthic foraminifera, some agglutinated disaster or opportunistic taxa bloomed. The proliferation of species of the genera *Glomospira* (Rzehak), *Glomospirella* (Plummer) and *Repmanina* (Suleymanov) is commonly known as the “*Glomospira* acme” (Kaminski and Gradstein, 2005). Such proliferation has been traditionally associated with a widespread rise of the carbonate compensation depth (CCD) that took place during the PETM (Kaminski and Gradstein, 2005). However, dissolution experiments showed that the absolute abundance of the genera *Glomospira*, *Glomospirella* and *Repmanina* was independent from the %CaCO<sub>3</sub> content and the degree of dissolution (Alegret et al., 2010), suggesting that there must have been a paleoenvironmental control of the *Glomospira* acme. An analysis of the paleogeographical distribution of the proliferation of *Glomospira* spp. during the earliest Eocene allowed us to assess the paleoenvironmental conditions that may have controlled the proliferation of these taxa.

The earliest Eocene *Glomospira* acme at NP9, P5 and E1 biozones occurs in the Tethys region and in the North Atlantic Ocean, including Contessa section in Italy (Galeotti et al., 2004; Giusberti et al., 2009), Polish Outer Carpathians (Morgiel and Olszewska, 1981; Bąk, 2004), Romanian Straja section in the Eastern Carpathians (Bindiu and Filipescu, 2011), Anthering and Untersberg sections in Austria (Egger et al., 2003, 2005), Trabakua Pass and Alamedilla sections in Spain (Coccioni et al., 1994; Alegret et al., 2010), and the Iberian Abyssal Plain (Kuhnt and Collins, 1996). Considering the paleoenvironmental conditions at these locations, the *Glomospira* acme was independent from surface primary productivity and oxygenation of the sea-bottom waters. It is unlikely that the paleolatitude had any influence on the *Glomospira* acme, although further studies should investigate possible differences in extinction rates and availability of empty ecological niches at different latitudes. The relationship between any source of isotopically light carbon and the abundance of *Glomospira* is still subject of study.

On the other side, the input of refractory organic matter through sporadic pulses of terrigenous or siliciclastic material may have stimulated the *Glomospira* acme. These inputs were the result of continental silicate weathering due to the intensification of the hydrologic cycle during the PETM (Dickens et al., 2003). The increased flux of refractory organic matter to the seafloor may have provided an alternative food source for some benthic species that

took ecological advantage over other species. The opportunistic behavior of the genera *Glomospira*, *Glomospirella* and *Repmanina* under stressed, rapidly changing seafloor conditions, and their ability to feed on refractory organic matter, allowed them to occupy the empty, post-extinction niches whenever other taxa could not compete. In addition, the *Glomospira* acme took advantages of a combination of the particular paleogeographic location (Northeast Atlantic and Tethys, with thousands of kilometers of coastline prone to erosion) with various environmental factors, such as the depositional setting at middle bathyal-abyssal paleodepths and in close proximity to paleoslopes.

We conclude that a combination of various environmental factors, such as the CCD rise, the particular paleogeographic distribution of the continental margins and slopes in the Tethys and Northeast Atlantic region, and the depositional setting at middle bathyal-abyssal paleodepths, together with an enhanced hydrological cycle, may have triggered the *Glomospira* acme during the earliest Eocene.

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## **Agglutinated benthic foraminifera and changes of paleoenvironment conditions across the Cretaceous-Paleogene boundary in the Galanderud section, Alborz basin, North of Iran**

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The Galanderud section has been studied for quantitative changes in agglutinated benthic foraminifera. Twenty-five species were recognized in the uppermost Maastrichtian marl and in the K-P boundary clay layer. Three types of assemblages are:

1- Uppermost Maastrichtian assemblages are dominated by calcareous agglutinated wall such as *Spiroplectammina*, *Dorothia*, *Gaudryina* and *Recurvoides*.

2- At this assemblage there has been a drastic decrease in diversity of agglutinated benthic foraminifera within the boundary clay and epifaunal species including *Cibicidoides*, *Anomalinoidea* and infaunal species of *Tappanina* spp. are dominated at this boundary.

3- In the lower Danian some species such as *Dorothia*, *Gaudryina* and *Spiroplectammina* were recovered, although they are low percent.

Regarding the quantitative benthic foraminifera a mesotrophic or relatively eutrophic condition at uppermost Maastrichtian and drastic decrease in surface productivity, collapse of food web and low oxygen condition at the K-P boundary was recognized. The benthic foraminiferal assemblages slowly recover at early Danian, which indicates that surface productivity gradually increased in the early Danian.

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## **Glacial-interglacial changes in deep water ventilation and oxygenation in the Bering Sea, subarctic North Pacific: insights from fossilised deep sea biota**

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The Bering Sea is a semi-enclosed marginal sea in the North Pacific, whose surface circulation is dominated by the Bering Sea Gyre. A large continental shelf of less than 200 m water depth is present in the northern and eastern areas, while the deep basin in the west lies in more than 3500 m water depth. Sea-ice is present over the northern continental shelf during winter and this lasts for over 6 months in the year. The Kamchatka Pass and several passages and straits between the Aleutian Islands serve as the primary passages of North Pacific surface (Alaskan Stream), intermediate and deep waters into the Aleutian Basin, which dominate the Bering Sea. The Bering Sea is a source of Western Subarctic Pacific water, and plays an important role in the circulation of the Western subarctic Pacific Ocean. It is characterised by a cold surface layer during winter and a dichothermal layer at around 100 m water depth during summer. The Bering Sea is a transition region between the cold dry Arctic air mass to the north, and the moist, relatively warm maritime air mass to the south. North Pacific Intermediate Water (NPIW) is currently partly formed through brine rejection during wintertime sea-ice production in the Okhotsk Sea, producing dense shelf water. There is currently no deep or intermediate water forming in the Bering Sea, but studies have suggested there may have been a significant component of NPIW formed in the Bering Sea during the last glacial. Our study aims to understand the oxygenation of intermediate waters over the Bowers Ridge from benthic foraminiferal assemblages, in order to understand the evolution of Bering Sea intermediate water ventilation over the last ~400 kyr. A total of 100 samples have been analysed at 13 cm intervals from Site U1342 (Bower Ridge, central Bering Sea), where 41.35 metres of succession was cored during IODP Expedition 323. The samples are rich in calcareous benthic foraminifera with good preservation, from which a minimum of 300 individuals were normally picked from each sample except where there are lower numbers in the sample. We use assemblage analysis to determine changes in the ecology and water properties in the form of productivity, ventilation and oxygenation of the sea during glacial and interglacial periods of the Pleistocene, for reconstructing changes in palaeoceanography and palaeoecology. Over 30 species of benthic foraminifera have been identified, and substantial changes in assemblages indicate that large and rapid changes to bottom water oxygenation occurred over glacial-interglacial cycles. These assemblage changes are linked with variations in productivity and ventilation.

## **Petrography applied to Micropaleontology: some techniques to unravel the internal chamber subdivision and wall microstructure of agglutinated foraminifera**

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This paper reports a multi-proxy method based on standard mineralogical and petrographic techniques that were tested on isolated specimens of fossil agglutinated foraminifera, mostly belonging to the textulariid group and coming from some Cenozoic successions of the Mediterranean basin. Results allowed us to depict: 1) chamber arrangement and internal morphological features of the agglutinated tests; 2) test-wall microstructures and 3) test chemical and mineralogical composition of the selected grains and the secreted cement.

Agglutinated foraminifera are among the most primitive in the evolution of early Foraminifera and are characterised by the capability to pick up particles from the environment for the construction of their shells. The agglutinated particles are attached to a proteinaceous or mineralised matrix and can be selected or nonselected as to the kind of grains. Particularly, many species are strongly selective, agglutinating grains of a particular mineralogical composition, shape and/or size (e.g. Gooday et al., 1995; Allen et al., 1999; Mancin, 2001; Thomens and Rasmussen, 2008; Armynot du Chatelet et al., 2008; Makled and Langer, 2009; Gooday et al., 2010; Pawlowski and Majewski, 2011). Furthermore, agglutinated foraminifera show very different test morphologies and some of them (above all textulariids) build up their shell according to a complex chamber arrangement (trochospiral or planispiral to biserial and/or uniserial), often with the presence of canaliculate test-wall and an internal chamber subdivision by septa forming alcoves (e.g., Murray, 1994; Parker, 2009; Kaminski and Cetaan, 2011). Unfortunately, the internal test-structure and the complexity of the agglutinated test-wall are usually masked on the outside by the rough surface and only fortuitous abrasions, crushed shells or fitting oriented sections can bright to light these features.

The method, previously used by Mancin et al. (in press) to detail the occurrence of some functional morphologies and the test microstructure of the agglutinated foraminiferal genus *Colominella* Popescu, 1998, consists of assessing the internal morphological and compositional features by scanning electron microscope (SEM) analyses, performed on isolated individuals. These are firstly oriented and embedded in epoxy resin. Resin mountings were cut in order to obtain a longitudinal section of the individual. The obtained surfaces were mechanically ground with silicon carbide papers and polished with diamond pastes at 6, 3, 1 and 0.25  $\mu\text{m}$ , in order to obtain a smooth surface. Analyses were performed using a Tescan FE-SEM, series Mira 3XMU, equipped with an EDAX energy-dispersive spectrometer (EDS). Spot microanalyses for standardless elemental composition were carried out at 15 mm working distance, using an accelerating voltage of 20 kV, with counts of 100 s per analysis. X-ray mapping (stage mapping) for Si, Al, Mg, Ca, K, Fe and Na.

With respect to similar techniques that perform SEM and EDS analyses mostly on the agglutinated wall surface (e.g. Murray 1994, Bertram and Cowen, 1998; Thomens and Rasmussen, 2008; Makled and Langer, 2009; Gooday et al., 2010; Pawlowski and Majewski, 2011) our method focussed on the cross section for: (i) documenting the internal chamber setting and their morphological features; (ii) measuring the shell thickness and the grain distribution; (iii) emphasizing the presence of parapores penetrating the test walls; (iv) detecting the chemical composition of the grains and the cement, in order to eventually highlight a mineralogical selection/arrangement.

Taking advantage of a multidisciplinary threefold approach with a telescopic increasing resolution, we propose this methodology as a standard approach in micropaleontological studies addressed to better understand test microstructure and composition of fossil agglutinated foraminifera.

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## **Biostratigraphy and paleoenvironments of the Eocene deep water deposits from the northern part of the Eastern Carpathians, Romania**

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Foraminifera and calcareous nannoplankton have been used to establish the age and the paleoecology for a representative section located in the Suceava Valley near Brodina (N 47.87150°, E 25.39642°). The studied deposits belong to the northern part of the Tarcău Nappe, Plopu Unit (Eastern Carpathians) and are represented by a mid- to distal fan turbiditic succession. The age of the Plopu Unit has been a controversial discussion for a long time. Based on the foraminiferal and calcareous nannoplankton assemblages some authors (Juravle, 2007; a.o.) consider that the age of this unit is Late Eocene, while others (Sandulescu, 1987; a.o.) place the Middle/Late Eocene boundary within this unit. The Suceava Valley section is characterized by rich agglutinated foraminifera and calcareous nannoplankton assemblages, representing an ideal setting to restore the main bioevents and the paleoenvironmental parameters. The corresponding period of the characteristic assemblages usually corresponds to the maximum abundance or to local stratigraphic range of one or more species that characterize each assemblage. Thus, the presence of index taxa *Orbulinoides beckmani* in the basal part of the section permits the assignment of these deposits to middle Eocene age; for the upper part of the section the FO and a brief maximum in the relative abundance of *Spiroplectamina spectabilis* and *Reticulophragmium amplexens* is observed, indicating a late Eocene age (Kaminski, 2005). The calcareous nannofossils (LO of *Chiasmolithus solitus*, LO of *Chiasmolithus oamaruensis* and FO of *Istmolithus recurvus*) confirm that the studied section falls in the NP15-NP19 biozone (Martini, 1971) which corresponds with NNTe8-NNTe12 (Varol, 1998). Thus, we affirm that the boundary between the Middle and Late Eocene is located within the the Plopu Unit.

The foraminifera diversity (Hurlbert, 1971), distribution of the agglutinated morphogroups (Setoyama et al., 2011), and CaCO<sub>3</sub> content display a positive correlation throughout the studied section and suggest hydrodynamic and/or tectonic instability. Thus, the occurrences of the calcareous benthic forms are correlated with variations of the CaCO<sub>3</sub> content and suggest oscillations of the CCD. The instability of the paleoenvironmental conditions, as shown by the variation in the organic matter flux (changes in the percentages of M1 and M4b morphogroups along the studied section), can be caused by changes in the direction of the bottom currents. These fluctuations are very similar to those described by Oberhansli et al. (1991) for the Middle Eocene in the Atlantic Ocean, strengthening the similarity between the Eocene paleoenvironment of the Eastern Carpathians and the Atlantic basin.

Calcareous benthic foraminifera (*Dentalina*, *Nodosaria*, *Stillostomella*) are rare in almost all samples, suggesting a possible transport from the shelf; planktonic foraminifera (*Globigerina*, *Globorotalia*, *Subbotina*, *Orbulinoides*) are usually poorly preserved and were identified only in the Middle Eocene. The calcareous nannoplankton assemblage is dominated by the species belonging to the Noelaerhabdaceae (*Reticulofenestra dictyoda*, *R. bisecta*, *R.*

*scrippsae*, *Cribocentrum reticulatum*) followed by the Coccolithaceae (*Coccolithus pelagicus*, *C. formosus*, *C. eopelagicus*). The abundant presence of mid-latitude calcareous nannoplankton taxa (*R. bisecta*, *R. umbilica*, *C. pelagicus*, *Cyclicargolithus floridanus*) indicates temperate waters for the studied interval. Therefore, the depositional environment was probably upper bathyal, close to the CCD, with low oxygen levels, temperate waters and unstable organic matter flux.

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## Agglutinated foraminifera of the Paleocene-Eocene transition in the Forada section (Southern Alps, northeastern Italy)

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The Paleocene/Eocene boundary (ca. 55.6 Ma) is marked by the most intense climatic disruption of the entire Cenozoic: the so-called Paleocene/Eocene Thermal Maximum (PETM; Zachos et al., 2001), characterized by a global temperature increase of 4-5°C (e.g. Sluijs et al., 2007; McInerney and Wing, 2011). The PETM, lasted between 120 and 220 kyr, is globally recognizable in both terrestrial and marine settings by the about 2–3‰ negative carbon isotope excursion (CIE), resulting by a massive, rapid input of light carbon to the ocean–atmosphere system (e.g. McInerney and Wing, 2011). At the base of the CIE a major acidification event occurred in the oceans, as consequence of a rapid and marked shallowing of the calcite compensation depth (CCD; Zachos et al., 2005). Among the profound biological consequences induced by the PETM, the extinction of bathyal and abyssal benthic foraminifera represents the most dramatic event in the deep-sea of the past 100 m.y. (Thomas, 2007). In order to further improve the knowledge of this event in the Tethyan area, we present quantitative data of agglutinated foraminifera across the Paleocene/Eocene transition of the continuous and expanded middle-lower bathyal Forada section (northeastern Italy). At Forada the main body of the CIE is represented by a three meters thick, clay-rich, lithological anomaly (Clay-Marl Unit; CMU), which interrupts the prevailing calcareous marl sedimentation ("Scaglia Rossa" facies; Giusberti et al., 2007). We focused our study on the interval spanning the CMU in order to detect the response of the agglutinated assemblages to the environmental perturbation associated with PETM.

Agglutinated foraminifera constitute a minor component of the foraminiferal assemblage in the upper Paleocene of the Forada section (ca. 20%). Despite its minor role, the agglutinated fauna appears fairly diversified with relatively big-size and well preserved *Ammodiscus*, *Paratrochamminoides*, *Spiroplectammina*, *Subreophax*, *Trochamminoides* and smaller *Glomospira*, *Haplophragmoides* and *Reophax*. Rare specimens of *Hormosina velascoensis* and *Caudammina ovuloides* also occur. A very big-sized litiolite (>500 µm), similar to forms previously described in Maastrichtian Scaglia Rossa beds (Sampò, 1972), occur exclusively in the Paleocene portion of the investigated interval. Agglutinated extinction taxa (*Clavulinoides amorphia*, *Clavulinoides globulifera*, *Clavulinoides trilatera*, *Dorothia beloides*, *Dorothia pupa*, *Dorothia retusa*, *Gaudryina pyramidata*, *Marssonella indentata* and *Remesella varians*) were commonly found at Forada, even if with very low abundance. Their last occurrence is recorded in the uppermost Paleocene samples just below the CIE onset, together with the disappearance of calcareous-hyaline "doomed taxa" of the *Gavelinella beccariiformis* assemblage.

Agglutinated foraminifera become the dominant component (80%) of the assemblage at the very base of the  $\delta^{13}\text{C}$  excursion (basalmost CMU), when highly stressed conditions characterized sea-floor environment. All paleontological and mineralogical features indicate that this portion of the section was deposited in strongly  $\text{CaCO}_3$  depleted waters, very close or below the CCD. In the lowermost Eocene of the Forada section the agglutinated fauna strongly differs from that of the upper Paleocene. It is dominated by very small specimens belonging to *Eobigenerina variabilis*, *Spiroplectammina navarroana*, *Ammobaculites*

*agglutinans*, *Karrerulina conversa* and representatives of the genera *Glomospira*, *Haplophragmoides*, *Saccammina*. These taxa continue to represent a significant component of the assemblage (cumulative percentage ca. 50%) up to + ca 70 cm, despite the massive reappearance of small-sized opportunist calcareous-hyaline taxa. Above this interval, their cumulative percentage decrease to ~20% and remains fairly stable up to the upper portion of CMU (ca. + 300 cm) with some fluctuations recorded in the CIE recovery and post recovery intervals where minor peaks of *Glomospira*, *Eobigenerina variabilis* and *Karrerulina* occur. Such interval likely correlates with the well-known early Eocene *Glomospira* Acme (e.g. Kaminski and Gradstein, 2005).

The aforementioned agglutinated forms of the basalmost CIE represent the first pioneers able to rapidly recolonize the sea floor, displaying a "disaster taxa" ecological behavior. We discard the hypothesis of an artifact assemblage due to post-mortem dissolution, since they are abundant also in the overlying early recovery interval, when the calcareous-hyaline taxa reappear, suggesting progressive deepening of lysocline/CCD. Calcium carbonate undersaturation was not the only factor favoring such agglutinated disaster taxa, but the lack of competition of calcareous-hyaline forms and the enhanced flux of food at the sea-floor played a major role as well. The entire CMU interval at Forada represents indeed a period of accelerated hydrological cycle with increased delivery of terrestrial material and thus nutrients availability in surface waters, leading to intensification of primary productivity and enhanced flux to organic matter to the sea floor. The fluctuations in agglutinated abundance paralleled by other biotic and abiotic signals at the top of the CMU and in the overlying interval likely reflect still perturbed and variable water column and sea floor conditions, including primary productivity and CaCO<sub>3</sub> availability.

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## Late Cretaceous *Uvigerinammina jankoi* lineage in the Carpathian Flysch

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Upper Cretaceous representatives of the *Uvigerinammina jankoi* group are characterized by triserial arrangement (at least in the initial part), rounded periphery, and siphonal aperture. They are cosmopolitan in deep-sea sub-CCD turbidite and hemipelagic facies. Many authors used the first occurrence of *U. jankoi* as the marker for the base of the Turonian with some variation for different basins. The last occurrence is usually reported in the Middle Campanian. Neagu (1990) described *U. praejankoi* that is believed to be less advanced stem form in the *U. jankoi* lineage. In Albian-Cenomanian and Lower-Middle Cenomanian black flysch sediments of the Rača Unit, small specimens of *Uvigerinammina* gr. *jankoi* were observed. The small size and subspherical test shape may indicate their juvenile nature. They, on the other hand, may represent ancestor of both *U. jankoi* and *U. praejankoi*. Biometric study may show whether the form represent distinct species or not.

The biostratigraphic distribution of *U. jankoi* group was studied at continuous Bystrý section in the Silesian Unit, encompassing the uppermost Albian to Upper Campanian (Skupien et al., 2009). The biostratigraphy of the section has been established using dinocysts. Both *U. jankoi* and *U. praejankoi* first appears around the Cenomanian-Turonian boundary. The boundary position is not exactly established. *U. jankoi* became common in the assemblage starting from the Upper Turonian. The consistent occurrence of the species continues into the Lower-Middle Campanian interval of the section and the last occurrence was recorded around the base of the Upper Campanian. At the same level *Caudammina arenacea* has its first continuous occurrence and higher in the section also typical *C. gigantea* start to be common (acme).

Among the *U.* gr. *jankoi* representatives the variability can be seen mainly in following biometric values: angle of chamber adding, proportion of the last chamber to the test length, chamber growth ratio. Typically the chambers of *U. jankoi* are added 120° apart, what forms the triserial aspect of the test. In the terminal stage of *U. praejankoi* the chambers are added about 180° apart what results in the pseudobiserial test. In the *U. jankoi* group some other distinct morphotypes can be seen. Dabagian (1978) figured some of them but consider them as members within *U. jankoi* variability. In fact they may represent distinct species. Following forms were noticed in the Upper Cretaceous of Carpathian and Alpine flysch:

1) Robust form with the last chamber making 76 to 88% of the test length (*U. jankoi* has typically 55 to 63%); Santonian of the Foremagura Unit in Moravia.

2) Narrow form with later chambers arranged in polymorphinid manner resulting in pseudoquadriseiral aspect; Upper Cretaceous red shales of Wienerwald Flysch.

3) Robust form with narrow and peripherally angulated chambers; Upper Cretaceous red shales, Moravian and Rumanian Carpathians.

Morphological variability of defined morphotypes was studied using biometry to confirm separate clusters. The stratigraphical range of the morphotypes needs to be precisely established.



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## Characterization of agglutinated benthic foraminifera biofacies in Upper Cretaceous sediments of the Brazilian equatorial margin

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Two well cores samples with rich and diversified foraminifera assemblage from the CEARÁ 2, localized in the Ceará Basin, Brazilian equatorial margin, were selected for agglutinated benthic foraminifera studies. This study characterized agglutinated benthic foraminifera biofacies in Late Cretaceous (Campanian – Maastrichtian) sediments, from the Ubarana Formation. The samples were subjected to systematic analyses applying, the relative abundance and diversity's parameters, the morphogroups distribution (Koutsoukos & Hart, 1990), and the integration with the sedimentological data. This methodology facilitated the recognition of two biofacies: *Gaudryina laevigata/Gaudryina* sp.1 and *Reophax duplex*.

The *Gaudryina laevigata/Gaudryina* sp. 1 biofacies (core 3 - 1,560.00/1,569.50 m) is predominantly made up of diversified agglutinated benthic foraminifera and rare calcareous taxa. The assemblage is composed of verneuilinids, lituolids, eggerellids, spiroplectamminids, bathysiphonids, haplophragmoidids and ammosphaeroidinids. The most frequent are *Gaudryina laevigata*, *Gaudryina* sp. 1, *Bulbobaculites* cf. *luecke*, *Marssonella kummi*, *Bathysiphon robustus*, *Spiroplectammina spectabilis*, *Recurvoides* spp. and *Haplophragmoides* spp. The morphogroups are mainly represented by infaunal (AG-A), epifaunal to shallow infaunal (AG-B.2) and epifaunal (AG-C) organisms. In this assemblage, the *Gaudryina laevigata* and *Gaudryina* sp. 1 species are dominant, and occur with up to 20% of each. The *Reophax duplex* biofacies (core 2 - 1,377.00/1,386.00 m) is composed of bathysiphonids, hippocrepinids, rhabdamminids, aschemocellids, hormosinids, lituolids, verneuilinids, eggerellids, haplophragmoidids, ammodiscids, rzehakinids and saccamminids. The most frequent taxa are *Rhabdammina discreta*, *Spiroplectammina spectabilis*, *Reophax duplex*, *Trochammina* spp., *Gaudryina* sp. 1, *Bathysiphon* sp. 2, *Rhizammina* sp. 1, *Recurvoides* sp. 1, *Reophax globosus*, *Haplophragmoides trinitatensis*, *Hormosina globulifera*, *Dendrophrya* ? sp., *Reophax texanus* and *Rzehakina epigona*. The most common morphogroups include organisms of epifaunal (AG-C), infaunal (AG-A), and epifaunal to shallow infaunal (AG-B.3, AG-B.2) habits.

The interpretation revealed that the assemblage of the *Gaudryina laevigata/Gaudryina* sp. 1 biofacies is dominated by opportunistic specimens of the verneuilinid group (*Gaudryina laevigata*, *Gaudryina* sp. 1 and *Gaudryina* spp.), and could be an indication of a low oxygen rate interval (Almogi Labin et al., 1990) in sediments deposited in upper bathyal paleoenvironmental conditions. The *Reophax duplex* biofacies (core 2 – 1,377.00/1,386.00 m) shows a microfauna with a predominance of suspension feeding organisms (bathysiphonids, hippocrepinids, rhabdamminids, aschemocellids), associated with hormosinids, lituolids, verneuilinids, eggerellids, haplophragmoidids, ammodiscids, rzehakinids and saccamminids. This proves that this paleoenvironment is deeper (lower bathyal) than the *Gaudryina laevigata/Gaudryina* sp. 1 biofacies. The predominance of agglutinated benthic foraminifera, the low frequency of calcareous taxa and the indication of dissolution in core 2 samples suggest that sediments could be under the lysocline influence. These characteristics are more evident in the core 3 assemblage, dominated by the agglutinated benthic foraminifera. The

principal reason for the dissolution of the calcareous tests could be related to the presence of corrosive acidic bottom water (Koutsoukos, 1996).

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## Comparison of modern foraminiferal population densities from the Caroni Swamp, Trinidad, and Cowpen Marsh, England

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A time series of foraminiferal population densities from two wetlands, the Caroni Swamp in the tropical southern Caribbean and Cowpen Marsh in the temperate northeast England, were compared to determine the significance of environmental differences between marsh and swamp. The Caroni Swamp is located on the eastern side of Trinidad - the most southern island in the Caribbean archipelago. The mangrove swamp opens to the Gulf of Paria where the water salinity and productivity is directly affected by seasonal discharge from the Orinoco River in Venezuela. During a rainy season (July to December) a plume of low density water, with low salinity and high productivity, expands from the northeastern coastline of South America through the Gulf of Paria. This seasonal change in water salinity is expected to affect foraminifera living at the Caroni Swamp, by placing stress on the number of specimens that can be sustained in the harsh conditions typical of tropical swamps. In contrast to the negative effect lower water salinity may have on foraminiferal populations, the Orinoco plume transports coastal “seed” phytoplankton and additional nutrients (eg. tannins) which should encourage population growth. During a wet season Bidigare et al. (1993) found that the subsurface chlorophyll maximum (SCM) averaged  $77 \pm 12$  m, while in a dry season shallower SCM depths were recorded (an average of  $39 \pm 16$  m).

Three stations from highest high tide, mid-tide and lowest low tide were sampled once a month for one year (February 2011 to 2012) at three sites in the Caroni Swamp. At Cowpen Marsh, a transect with 31 stations from high, middle and low marsh was sampled bi-weekly from May 1995 to 1996 by Horton et al. (2006, 2007). For the purpose of this study, only the living foraminifera collected on the 1<sup>st</sup> of each month were examined and compared with those monthly samples from Caroni Swamp. Horton et al. (2006) collected  $10 \text{ cm}^3$  ( $10 \text{ cm}^2 \times 1 \text{ cm}$ ) of sediment from each station in the high marsh (stations 1-5), middle marsh (stations 6-14) and low marsh (stations 15-18). In contrast, four replicates of  $75 \text{ cm}^3$  of sediment from each site were collected at Caroni Swamp, giving a total of  $900 \text{ cm}^3$  ( $75 \text{ cm}^3 \times 4 \text{ replicates} \times 3 \text{ sites}$ ) of sediment per high, middle and low swamp stations.

The average total abundance of foraminifera recorded from high, middle and low swamp at Caroni Swamp was 0.05, 0.11 and 0.06 sp./cm<sup>3</sup>, respectively. In contrast, that recorded from Cowpen high, middle and low marsh were consistently greater: 158, 341.7 and 330.4 sp./cm<sup>3</sup>, respectively. Comparison of the two time series of monthly percentage abundances (sp./cm<sup>3</sup>) shows that foraminiferal populations from Cowpen high marsh steadily increase through the year ( $r = 0.9221$ ,  $p = 0.0005$ ) with a bloom from January to May (winter & spring); Caroni high swamp shows stationarity ( $r = 0.0436$ ,  $p = 0.8868$ ) with a bloom from February to August (dry season). That for Cowpen middle marsh is an almost linear increase through the year ( $r = 0.9899$ ,  $p = 0.0015$ ) with a bloom from August to November (summer & autumn); Caroni middle swamp displays stationarity ( $r = 0.0245$ ,  $p = 0.9355$ ) with a population bloom from July to October (wet season). Percentage abundances of foraminiferal populations from Cowpen low marsh steadily increase throughout the year ( $r = 0.9878$ ,  $p = 0.0014$ ) with no

apparent bloom; Caroni low swamp shows stationarity throughout the year ( $r = 0.1539$ ,  $p = 0.6157$ ) with blooms occurring from April to June (end of dry season) followed by a steep incline in October (wet season). Therefore, high and middle zones in both Cowpen Marsh and Caroni Swamp experience population blooms at opposing seasons: winter, spring and dry seasons in upper zones, and summer, autumn and dry seasons in middle zones. The lower marsh and swamp zone does not show fluctuations foraminiferal population densities pertaining to a particular season.

Pollution should not be a factor responsible for low population densities in the Caroni Swamp because both study locations are protected reserves surrounded by urban and industrial activity that is likely to contaminate each site through drainage networks. However, Cowpen marsh has high foraminiferal population densities that exceed  $100 \text{ sp./cm}^3$  on an average month and a steady growth rate. Caroni Swamp averages not even  $1 \text{ sp./cm}^3$  a month and the growth rate is negligible, such that each population bloom is followed by an equivalent bust. Barbosa et al. (2005) and Debenay et al. (2004) studied foraminifera of mangrove swamps in nearby southeast Brazil and French Guiana, respectively. The study area of Barbosa et al. (2005) was located south of the Orinoco and Amazon rivers, where foraminiferal populations would not be affected by seasonal hyperpycnal plumes of low salinity and high productivity. However, the foraminiferal population densities recorded at each site was nevertheless low ( $\sim 2 \text{ sp./cm}^3$ ). The area studied by Debenay et al. (2004) was affected by increased fluvial discharge during a rainy season. The average foraminiferal population density ranged from  $4 \text{ sp./cm}^3$  in January 1999,  $1 \text{ sp./cm}^3$  in July 2000 and  $22 \text{ sp./cm}^3$  in December 2000. There was significant loss in calcareous species during the rainy season due to increased pore-water pH and lower concentrations of Ca-ions available to form calcium carbonate tests.

Knowing the influence of fluvial plumes on foraminiferal population dynamics at coastal sites subject to monsoonal climates will have important implications for sampling regimes used by micropalaeontologists studying foraminifera living in tropical wetlands. Sampling techniques used in temperate marshes must be distinguished from those that are appropriately suited to the low-density populations found in tropical swamps like Caroni Swamp.

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## Foraminiferal assemblage in Barra Channel mangrove, Conceição Lagoon, southern Brazil

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Coastal regions are very dynamic systems and are affected by many factors, including sea-level changes and human impacts. Foraminifera assemblages are sensible to these changes and due to this, they are useful as environmental indicators of tide ranges, salinity intrusions, limit of sea water influence (bayline) and anthropogenic influences in estuarine systems. The aim of this study was to characterize the modern foraminifera of Barra Channel mangrove at the mouth of Conceição Lagoon (Santa Catarina Island, southern Brazil) and use the assemblage as a recent indicator of tide and human influence.

Barra Channel mangrove fragment is surrounded by urbanized areas and under the influence of a degraded tidal channel. This fragment of mangrove is present in a small area along the 2.8 km channel that connects the lagoon to the sea. In this area was surveyed seven stations along a perpendicular transect to the shoreline. In each station, height was measured in relation to a fixed station (station 1) using a clinometer. The height was corrected by tide level for the time of sampling.

A volume of 10 cm<sup>3</sup> surface sediment was sampled in each station, stored in rose Bengal solution, wet-sieved over 63 µm mesh screens and dried at 40°C. All organisms of each sample were quantified dry under stereomicroscope. Living and dead organisms were considered in the analysis and the total assemblage was used as tide influence indicators. Non-parametric test (Kruskal-Wallis) was applied to identify possible patches and cluster analysis to define the assemblages.

Results showed dead foraminifera density ranging between 12 and 188. This range can be explained by the increase of sum exposure, low organic productivity, and possible human influence. The species *Trochammina inflata* dominance was evident in a richness of 16 species.

According to non-parametric test the samples showed no significant difference ( $p < 0.05$ ), indicating homogeneity between stations. In spite of it, cluster analysis showed the presence of three different station groups: (1) represented by station 1, with dominance of hyaline calcareous species; (2) represented by station 2, with dominance of *T. inflata*, and the presence of agglutinated species and one calcareous specie; (3) represented by stations 3-7, with dominance of *T. inflata* and absence of calcareous forms. These three groups may represent three mangrove zones: lower, intermediate, and upper tidal zones, respectively, but are unrelated to vegetation gradient. Stations 1-4 presented *Spartina alterniflora*, station 5-6 a mix of *S. alterniflora* and *Laguncularia racemosa* and station 7 only *L. racemosa*. The low diversity of plants, the small size of mangrove, and the human trampling can explain the no-relation between foraminifera and vegetation zones.

The large number of living species and hyaline foraminifera dominance shows a constant tidal presence on station 1. From station 3 to 7, the dominance of dead species and agglutinated forms shows an extended tidal absence, turning these areas more restrictive to species occurrence. In spite of foraminiferal assemblages, which corroborate with the tidal zones, the presence of living *T. inflata* in stations 6 and 7 indicate an occasionally high oscillation tide as a result of boat circulation in the channel. The presence of foraminiferal assemblages suggests anthropogenic interference in the mangrove area affecting the ecological and hydrodynamical patterns of the fragment.

## **Bathymetric distribution of Recent agglutinated foraminifera from a transect in Saros Bay and offshore Lesbos Island (central northern Aegean Sea)**

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Living (stained) and dead (unstained) agglutinated foraminifera have been investigated in the central northern Aegean Sea. In March 2003, a total of 22 samples was collected offshore Lesbos Island and along a bathymetric transect in Saros Bay ranging from 15 to 614 m water depth. This study aims at documenting, for the first time in detail, the agglutinated foraminiferal fauna and its bathymetric distribution in the area and elucidating its response to water masses changes. The bottom waters of the shallowest station are more saline and less oxygenated than those of the deeper stations. Assemblages are rich and well-diversified and composed of species coming from both the Mediterranean and the Marmara Sea. The most abundant taxa are *Bigenerina nodosaria*, *Spiroplectinella wrightii*, *S. sagittula*, *Reophax scorpiurus*, textulariids, *Lagenammia atlantica*, *Glomospira charoides* and plenty of tubular forms that increase in abundance at deeper stations (>175 m). Statistical analysis identifies different main assemblages that can be related to the bathymetry and in turn to the hydrological features of the water masses. These results have been compared to those based on calcareous foraminifera from the same samples. This study confirms the suitability of using agglutinated foraminifera as tracers of water masses.



## **Recent sea-level variations and salt marsh evolution in the northern coast of Spain: agglutinated foraminifera as proxies for anthropogenic climate change studies**

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Paleoclimatic information suggests that the recent warming (of anthropogenic origin) is unusual in comparison with the previous 1,300 years (Mann et al., 2008). The most dramatic impact of the global warming is the accelerated rate of sea-level rise over the past century, which is three times higher than in the previous century (Jevrejeva et al., 2008).

The study of local sea-level rise is of great interest in order to forecast the global sea-level rise and also for coastal management and adaptation. In the north of Spain tide-gauge data provides a relative sea-level rise estimate of  $2.08 \pm 0.33 \text{ mm yr}^{-1}$  (Chust et al., 2009) but it only covers the last 60 years. Due to the short spatial and temporal distribution of tide gauges, in the 1990s foraminifera-based transfer functions were developed in order to reconstruct past sea-level variations (Horton, 1999). These transfer functions are based on the modern relationships between salt marsh foraminifera and elevation in relation to the tidal frame. These modern relationships are then applied to sediment cores obtained in salt marsh areas that have evolved naturally to infer past sea levels. Salt marshes are interesting as they provide a more continuous record and smaller reconstruction errors than other coastal environments. These errors are smaller mainly due to the presence of agglutinated foraminifera species such as *Jadammina macrescens* (Brady, 1870) and *Trochammina inflata* (Montagu, 1808).

In addition, the study of regenerated salt marshes can provide key information about the future coastal evolution. In fact, during the last centuries salt marsh ecosystems in the northern coast of Spain have been occupied initially with agricultural purposes and lately to support modern urban and industrial development. These human activities have led to their destruction or degradation of their environmental quality. Rivas and Cendrero (1991) concluded that human occupation of salt marshes and other intertidal areas can be considered as the main geomorphological process in the southern Bay of Biscay during the last two centuries. During the 1960s these reclaimed areas were abandoned due to rural migration to the cities, and the lack of dyke maintenance provoked the entrance of tidal, estuarine water and allowed their natural regeneration.

In order to understand the processes governing salt marsh evolution, we have developed a transfer function model (weighted-averaging) based on agglutinated foraminifera (*J. macrescens* and *T. inflata*) from the Axpe-Norte and Murueta salt marshes (Urdaibai estuary, northern Spain) (error:  $\pm 0.09\text{m}$ ). Then we applied it to one core obtained in the Murueta salt marsh. The chronology is provided by the activity profiles of <sup>210</sup>Pb and <sup>137</sup>Cs. <sup>210</sup>Pb is especially useful to assess sedimentary processes on time scales of about 100–150 years. In order to support the <sup>210</sup>Pb derived chronology we used <sup>137</sup>Cs. This is an artificial radionuclide that was introduced in the environment during the 1950–1960s as a consequence of the detonation of nuclear weapons in the atmosphere (UNSCEAR, 2000). The

reconstructions provided a sea-level rise rate of 2.0 mm yr<sup>-1</sup> for the 20th century, corroborating the previous results obtained in the same area (García-Artola et al., 2009). In order to validate these results, we compared them with the Brest tide-gauge record which is the longest available in the Bay of Biscay (since 1807).

On the other hand, we collected a sediment core in the previously reclaimed Busturia salt marsh (Urdaibai estuary) in order to study the environmental regeneration process. Three distinct depth intervals (DI) were distinguished in the core in terms of presence, abundance and dominance of foraminiferal species (Cearreta et al., 2011). The basal 10 cm (DI3) were characterized by the absence of foraminifera and a very low sand content (average 1%). It is likely to represent the anthropogenic deposit introduced during the reclamation period. The following 8 cm were characterized by DI2 and exhibited very low numbers of foraminiferal tests (average 31), species (average 2) and sand content (average 8%) in comparison with the upper DI1. Consequently, it is interpreted as a zone deposited during the regeneration process from the agricultural soil (DI3) before achieving the regenerated marsh stage (DI1). This upper interval of 19 cm was clearly dominated by agglutinated foraminifera (average 92%) with *J. macrescens* (average 86%) as the main species. The sand content was low (average 12%) and species diversity was very small (average 5). This zone represents the modern regenerated salt marsh environment. Using the <sup>210</sup>Pb and <sup>137</sup>Cs chronologies we calculated a very rapid regeneration process (less than 10 years) related to the high sedimentation rates (14 mm yr<sup>-1</sup>) occurred until the salt marsh was completely regenerated (when slowed down to 3.5 mm yr<sup>-1</sup>), as observed in previous studies from the same coastal area (Leorri et al., 2012).

Under the current scenario of sea-level rise, this rapid natural salt marsh regeneration during recent tidal inundation of previously reclaimed agricultural areas is of great interest for environmental management of coastal zones. In those areas, where extensive reclaimed land is still present, rapid salt marsh restoration could represent a valid adaptation measure against the current sea-level rise, since, as observed, these environments accrete sediment very fast until they reach equilibrium with the tidal frame.

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## **New agglutinated foraminifera, including multichambered taxa, from the Middle Ordovician Hanadir Shale of Northern Saudi Arabia**

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The Hanadir Shale Member of the Qasim Formation is a black shale that represents a middle Ordovician maximum flooding event in the Arabian Peninsula. It is exposed in the Paleozoic outcrop belt in Central Saudi Arabia, however in the north of Saudi Arabia it occurs only in the subsurface. The age of the Hanadir Shale Member is constrained by graptolites and palynomorphs, indicating *Didymograptus murchisoni* zone. We examined samples from the Hanadir Shale collected from three wells drilled in the proximity of the Jauf Graben, north of the city of Al Jauf, Saudi Arabia.

The foraminiferal fauna recovered from the Hanadir Shale Member contains a well-preserved assemblage consisting entirely of agglutinated taxa. Currently, these are the oldest foraminifera reported from Saudi Arabia. As expected, the middle Ordovician assemblage contains numerous simple forms such as *Rhizammina*, *Psammosphaera*, *Saccammina* and *Lagenammina*, which are found in other Ordovician localities worldwide. In addition to the simple forms, we observe a diverse assemblage of litiolids and trochamminids, including the genera *Ammobaculites*, *Bulbobaculites*, *Sculptobaculites*, and diverse trochamminids.

Our finding of coiled, multichambered agglutinated foraminifera in the Hanadir Shale of Saudi Arabia pushes back the known stratigraphic range of the suborder Lituolina to the middle Ordovician. The litiolids found in the Hanadir Shale assemblage are diverse, which implies the true first occurrence of this group of foraminifera is even older. Previous reports of these forms placed their origin in the early Devonian (Loeblich and Tappan, 1987). Our findings also give increased credibility to previously published reports of trochamminids from the upper Cambrian of Nova Scotia (Scott et al., 2003), which were regarded by some researchers as questionable owing to their poor preservation. Some of the trochamminids from the Hanadir Shale show radially elongated chambers, and likely belong in a new genus.

The paleoenvironment of the Hanadir Shale Member in the north of Saudi Arabia is regarded as a deep, normal marine shelf with dysoxic, sometimes anoxic, bottom waters, open to the Paleotethys Sea. This environment fostered the development of the oldest fauna with abundant multichambered agglutinated foraminifera discovered so far. Our finding of agglutinated foraminifera will no doubt contribute to a better understanding of the depositional environment of the Hanadir member in NW Saudi Arabia.

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## **Benthic foraminiferal squatters: species that inhabit the tests of other foraminifera**

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There are scattered literature records of foraminifera that inhabit the tests of other benthic or planktonic foraminifera on an obligate or opportunistic basis. Calcareous species of the genus *Ramulina* (suborder Lagenida) have long been known to adopt this mode of life (Carter 1889; Jones and Chapman 1897; Rhumbler 1911). However, this contribution with focus on monothalamous (single-chambered, non-calcareous) inhabitants. The first report was that of Rhumbler (1894), who described five species of organic-walled allogromiids from the empty shells of the large agglutinated foraminiferan *Saccammina spherica*. The inhabiting test forms an elongate, more or less convoluted tube in *Ophiotuba gelatinosa*, *Dactylosaccus vermiformis* and *Dendrotuba nodulosa*; the other two species, *Rhynchogromia variabilis* and *Rhynchosaccus immigrans*, have ovate to sausage-shaped tests. Only *O. gelatinosa* and *D. nodulosa* appear to be obligate inhabitants. The thread-like, organic-walled species *Nemogullmia longevariabilis* sometimes occupies foraminiferal tests and polychaete tubes, although the association is not obligate (Nyholm, 1956). Christiansen (1971) illustrated an undescribed shallow-water form with long and thin pseudopodia that lives inside empty tests of *Saccammina sphaerica* and feeds exclusively on other foraminifera. In a culture experiment using sediment from the North Sea, Moodley (1990) observed an undescribed monothalamous species that rapidly crawled into empty *Quinqueloculina* shells when offered the opportunity.

Gooday (1986a) found numerous novel monothalamous foraminifera inhabiting empty globigerinacean shells in samples from the Porcupine Seabight (1340 m water depth; NE Atlantic). Many of these forms were apparently obligate inhabitants that constructed various kinds of agglutinated structures (e.g. branched and unbranched tubes and lumps) on the exterior of the host shell. Within the framework of the ECOMAR project, we recently discovered similar organisms inhabiting globigerinacean shells at bathyal depths (~2,500 m) at 4 sites located around 53°N (NW, NE sites) and 49°N (SW, SE sites) on the Mid Atlantic Ridge. One form, assigned to the poorly-known genus *Hospitella*, comprises a series of brown, organic-walled compartments ('pseudochambers'), which occupy the chambers of the host shell and end in a tubular extension that projects externally. Another form, described as a new genus and species, has a cell body enclosed in a very thin, organic wall and containing numerous stercomata and iron-rich xanthosomes. The inhabiting organism constructs a short conical, finely-agglutinated structure on exterior of the host shell. A variety of other forms, including discrete allogromiid-like cells, compact masses of stercomata and protoplasm, and agglutinated spheres, were also found within planktonic shells at the ECOMAR sites.

These inhabitant foraminifera (or foraminifera-like organisms) represented 18% (NW site) 38% (NE station), 39% (SE station), and 46% (SW station) of the stained foraminiferal assemblages at the ECOMAR sites. Although it is often difficult to differentiate between species, our results suggest that inhabitant foraminifera may contribute significantly to biodiversity in the deep sea. This is of interest in the context of recent molecular studies on environmental (sediment) samples. Lecroq et al. (2011) used a Next Generation Sequencing approach to analyse foraminiferal species richness in five different oceanic regions. More than

half (47%) of the Operational Taxonomic Units (OTUs) could not be placed in any high-level taxonomic groups. These undetermined OTUs made up between ~25% and 55% of the foraminiferal assemblages based on microbarcode sequences. At least one third of the OTUs that could be assigned to higher taxa were placed within the monothalamous foraminifera. The monothalamous and undetermined OTUs together represented >80% of OTUs in most of the samples. It is possible that some of the undetermined sequences detected by Lecroq et al. (2011) correspond to inhabitant foraminifera. They therefore represent an overlooked but potentially important facet of deep-sea biodiversity that warrants closer taxonomic scrutiny.

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## **Agglutinated conical foraminifera from the Late Paleocene (Thanetian) carbonates of Cauvery Basin, south India**

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During the late Cretaceous and early Paleogene, sediments of restricted warm shallow marine carbonate environment exhibit high conical, uniserial/ multiseriate agglutinated foraminiferal tests. Their presence in the geological record is intermittent and scanty due to restricted environmental preferences. A chance discovery of large sized high conical agglutinated foraminifera in a late Paleocene subsurface carbonate section in an exploratory well drilled in the south eastern part of Cauvery Basin forms the subject matter of this report. A 35 m thick section of pink and white limestone, marls and clays was examined through well cuttings at a depth of 1765 m. The section lies 165 m structurally higher above the late Cretaceous at this site. The samples are moderately fossiliferous with a large number of agglutinated conical tests besides representatives of *Glomalveolina*, *Discocyclina*, *Orbitoclypeus*, *Nummulites*, *Idalina* and *Miscellanea*.

Finely agglutinated wall, centrally positioned megalosphere, high conical shape, trochospiral nepionic stage, uniserial adult stage with saucer shaped chambers, flat/ convex base and variable marginal apertures facilitate in assigning these to the genus *Fallotella* Mangin, 1954. An elaborate account on the architecture details of the conical agglutinants can be found in Hottinger and Drobne (1980) monograph. Since the high conical tests were retrieved as free specimens from the processed samples, both external surface features and internal structural details were studied through half cut conicals along the mantle line and in oriented thin sections. The conicals display exoskeleton elements as long radial partitions (beams) and short restricted intercalary beams and horizontal partitions (rafters). The endoskeleton exhibits pillars alternating in position and are seen as rounded mounds at the base. The axial plane passes through these pillars. Megalosphere is centrally positioned close to the apex. The apertural face is flat to gently convex with marginal apertures. A thin intercameral foramenal plate with an irregular primary aperture and subcircular secondary apertures communicating between lumen of consecutive chambers was observed. At the species level the quantitative characters were considered as diagnostic; the number of uniserial chambers per unit length, the number of basal apertures per unit length, the apical angle of the cone and the ratio of axial cone length and basal diameter. In the assemblage 3 species of *Fallotella*, namely *Fallotella alavensis* Mangin, *Fallotella kochanskae* Hottinger and Drobne and a new species *Fallotella cauveriana* were identified. *F. alavensis*, a well known zonal marker of Thanetian age SBZ-3 Biozone of Serra-Kiel et al. (1998) is found associated with *Glomalveolina primaeva* Reichel, *Glomalveolina levis* Hottinger, *Discocyclina seunesi* Douville, *Orbitoclypeus ramaraoi* (Samanta) and *Idalina sinjarica* Grimsdale. The faunal report conclusively indicates that the carbonate section is of Thanetian (late Paleocene) age. Detailed account on the associated benthonic foraminifers occurring with *Fallotella* is presented elsewhere (Govindan 2012, MS. under publication). The presence of *Fallotella* in the late Paleocene carbonates of this basin is the only record of its presence in the southern rim of this part of Tethys in paleolatitude of about 15°S, the other reports are from the northern rim of western Tethys above paleolatitude 30°N. The record of these conical agglutinants and associated taxa indicates that the carbonates were deposited in

shallow, less restricted warm open marine waters in an inner shelf setting under regressive conditions possibly at the time of late Paleocene sea level fall (Haq et al., 1987).

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## Foraminifera of the London Clay Formation (Eocene) of the Isle of Wight and their palaeoenvironmental significance

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The London Clay Formation (Eocene) is exposed in the Whitecliff Bay and Alum Bay sections which are located to the north of the chalk ridge which extends east–west across the centre of the Isle of Wight. Whitecliff Bay, at the eastern end of the island, is one of the most complete Paleogene successions (Curry, 1965, 1966) in N. W. Europe and has been the subject of geological research for over 150 years. Agglutinated (e.g., *Bolivinopsis adamsi* (Lalicker), *Clavulina anglica* (Cushman)) and calcareous benthic foraminifera are present throughout most of the formation but planktic foraminifera are more restricted. The so-called “planktonic datum” of Wright (1972), Murray and Wright (1974), King (1981) and Murray et al. (1989) has been refined and incorporated into a new palaeoenvironmental interpretation of the successions at both Whitecliff Bay and Alum Bay. In both of the successions the water depth was < 100 m deep, and probably much less than that in the silt-rich and sand-rich parts of the formation. The planktic taxa are limited to shallow water morphotypes, including *Globigerina chascanona* Loeblich and Tappan and *Globorotalia* sp. cf. *G. esnaensis* (Leroy).

One of the problems facing micropalaeontologists, when undertaking research on the Whitecliff Bay succession, is the preservation of the assemblages in the badly weathered cliff succession compared to that on the foreshore, which often contains faunal/floral elements not recorded in samples that have been collected from the cliffs. The extent of this variability is assessed as it has implications for both biostratigraphy and palaeoenvironmental interpretations.

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## **The distribution of *Miliammina fusca* in three different environmental settings of Malay Peninsular, Malaysia**

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*Miliammina fusca* is a very important agglutinated foraminifera that have been used an indicator of marine pulses (brackish sediments) in Malay Basins especially in upper Group L and Group K. The study of modern analogue has been carried out to study the distribution of *Miliammina* and its assemblages in three different environmental setting i.e Klang Delta (tide dominated), Pahang Delta (fluvial dominated) and Sedili Besar River (wave dominated and estuary). From the observations, the distributions of *Miliammina fusca* are highly related to salinity and sedimentary facies.

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## **Paleoenvironmental interpretations of Early to Middle Jurassic deposits of the southwestern Barents Sea based on benthic foraminiferal assemblages**

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Upper Triassic to Middle Jurassic sediments of the southwestern Barents Sea region compose the Kapp Toscana Group consisting of sandstones, mudstones and shales deposited in shallow shelf to coastal plain environments in an extensive shelf embayment. Mudstone and siltstone intervals of the sand-dominated Nordmela and Stø formations were sampled in two wells (7119-12/1 and 7119-12/2) drilled in the Hammerfest Basin of the southwestern Barents Sea. The age of the formations ranges from Sinemurian to Bajocian.

In total 87 samples were processed for foraminiferal analysis, but only 36 of these, all from well 7119-12/1, were productive. The samples were quantitatively analyzed to assess depositional conditions and transgressive-regressive development. Additionally, the organic carbon and carbonate content of 53 samples from this well section were measured.

The micropaleontological results from well 7119-12/1 reveal that the foraminiferal assemblages are concentrated mainly in three dark mudstone layers of the Stø Formation. The assemblages consist exclusively of agglutinated taxa and reveal extremely low diversities with high dominance of *Ammodiscus* and *Trochammina*. These restricted agglutinated assemblages are interpreted to indicate a salinity-stratified brackish water column created by extensive fresh water input from nearby deltaic systems.

The sediments of the Stø Formation were deposited during transgressional phases in restricted shallow marine hyposaline environments with periodic tendency to low energy and hypoxic conditions. The dark mudstone intervals represent major flooding events. They include maximum flooding surfaces which might be used as regional stratigraphic marker horizons. The absence of foraminifera from Well 7119-12/2 suggests highly brackish marginal marine depositional environments, such as deltaic coastal plains, tidal flats and channels, with strong fresh water influx during deposition of the early Jurassic Nordmela Formation.

## **Species as the basic units in evolution, biodiversity and biostratigraphy**

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Many concepts have been developed for the base of taxonomy, the biological species. Still there is confusion in these concepts between the ‘substance’ of a species, e.g. which factors makes a species (definition) and how to detect or recognize a species (delimitation). Concepts like morphospecies and chronospecies (= palaeospecies) that are mainly used for fossil specimens, and all methods based on molecular genetic methods belong to the group of concepts for delimitating species.

The species can be defined as a pool of contemporarily interconnected genotypes. This pool can be homogeneous or be divided into geographically separated sub-pools. Interconnectivity within such pools is given by the potential to transfer complete genomes or exchange genome parts through asexual or sexual reproduction. A change in genotype frequencies over successive generations is caused by preferred or restricted genome transfer due to evolutionary factors.

After establishment of new adaptive zones, evolutionary factors lead to species differentiation. Depending on number, duration of the onset and the further role of the new adaptive zones (stable or continuously changing), various methods of speciation – grouped into split off and split up speciation – can be established. True speciation is characterized by a complete loss of the potential to transfer genomes between the new species without the possibility to fuse (hybridise) when their adaptive zones come in contact or overlap. In case of a broad geographical distribution, the area might be differentiated into several adaptive zones, where transferability between subgroups is restricted or even lost. Temporarily disconnected adaptive zones can again become combined, reinstalling transferability between sub-pools of genotypes. Genotypically and morphologically different subgroups preserving transferability are thus not species; taxonomically, these structurally distinct subgroups can be treated as subspecies. Due to this uncertainty in the transition zone, a delimitation of species in the Recent is difficult in genotypically related but geographically separated groups. This is also the case in fossil forms when regarding a single geological horizon.

A strong discontinuity in a single evolutionary line is caused when a new adaptive zone for the species opens contemporaneously with the closing of the previous adaptive zone. This type of speciation, termed ‘quantum evolution’ or ‘punctuated gradualism’, is a special form of a geologically instantaneous ‘split off speciation’, where the mother species becomes extinct.

Contrary to quantum evolution, an instantaneous change in the transformation rate within an evolutionary line does not lead to new species. The clear differentiation in the species transformation rates should be taxonomically treated as different subspecies.

Because the potential to transfer genomes or genome parts is a non operational criterion for delimiting species, the main criterion for recognizing species is character’s homogeneity (including molecular genetic methods). Because molecular genetic methods are restricted to living organisms, morphological criteria have to be used for recognizing and delimitating species by the criterion of homogeneity, especially in the fossil record. Homogeneity (including continuity) has to be checked in the four dimensions ‘shape’,

‘environment’, ‘ontogeny’ and ‘geological time’, allowing to differentiate between subspecies and ‘true’ species, while preserving different generations and ontogenetic (larval) stages within a single species.

## A molecular comparison of *Entzia tetrastomella* and *Jadammina macrescens*

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The genus *Entzia* has first been described from Transylvanian salt marshes more than 120 years ago (Daday, 1884). The only species contained in this genus, *Entzia tetrastomella* resembles the agglutinated foraminifer *Jadammina macrescens* (Brady). Loeblich and Tappan (1987) recognized *Entzia* as a valid genus, close to *Jadammina*. Based on recent morphological investigations of *Entzia* sampled from Romanian salt marshes in Turda by Filipescu and Kaminski (2011), the genus *Entzia* has been regarded as the senior synonym of *Jadammina*.

A molecular investigation of *Entzia* based on partial SSU rDNA sequences reveals that specimens of *Entzia* are genetically more or less identical to *Jadammina macrescens* sampled from Dovey Estuary. Our molecular results therefore confirm previous morphological investigations, suggesting synonymy of the two genera.

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## **New trochamminids with radially elongated chambers from the Paleozoic Black shales of Saudi Arabia: An adaptation for survival in dysoxic environments?**

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As part of an initiative to study Paleozoic organic-rich black shales that comprise the maximum flooding surfaces in Saudi Arabia, samples from Middle Ordovician and Lower Carboniferous black shales recovered from exploration wells drilled in the north of Saudi Arabia were examined for their foraminiferal content. The agglutinated foraminiferal assemblages from these black shales are diverse and contain rich assemblages of lituolids and trochamminids that are new to science.

Among the Middle Ordovician and Lower Carboniferous trochamminids recovered from the wells are new forms that possess petaloid or radially elongated chambers. Because this morphological feature is unknown up to now among the suborder Trochamminina, these distinctive forms are described as a new genus. The new genus is characterized by its very low trochospiral to planispiral coiling, and in possessing radially elongated chambers. Four new species are recognised based on chamber shape and the number of chambers in the final whorl. Three of the species first appear in the Middle Ordovician, Qasim Formation, Hanadir Member shale, whereas the Lower Carboniferous Berwath Formation shale contains one additional species with radially elongated chambers.

The new Paleozoic trochamminid genus displays obvious and striking isomorphism with the Early Cretaceous planktonic foraminiferal genus *Leupoldina* (as well as with primitive species of *Hantkenina* from the Middle Eocene). Among the planktonic foraminifera, hedbergellid species with petaloid to elongated chambers first appeared in the late Hauterivian, just below the anoxic Faraoni Event in the Mediterranean Tethys (Coccioni et al., 2007). The first occurrence of the aberrant planktonic foraminiferal species *Leupoldina cabri*, with its distinctive clublike elongated chambers, is nearly coincident with the onset of Oceanic Anoxic Event (OAE) 1a. Leupoldinids dominate the low-abundance, low-diversity planktonic foraminiferal assemblages found in association with OAE1a in Italy. It has been suggested that taxa with radially elongated chambers such as *L. cabri* represent adaptations to low-oxygen conditions in the upper water column (Coccioni et al., 2006).

The morphological similarities between these Paleozoic trochamminids and some of the deeper-dwelling Cretaceous planktonic foraminifera from the OAE layers imply that such chamber shape and wall structure could represent an adaptation for survival in dysoxic environments at the sea floor associated with a fine grained muddy substrate. Additionally, among the agglutinated foraminifera, increased test porosity would be achieved by selecting coarse agglutinated grains for the construction of the wall, which would increase the dimensions and connectivity of the intergranular space, thereby enabling more efficient gas exchange in a manner analogous to pore function in planktonic foraminifera. The evolution of radially elongated subtriangular chambers and compressed test form would further increase the available surface area of the chambers. It is a striking coincidence that the Paleozoic trochamminids evolved the same strategies to cope with dysoxia at the sea floor that the Cretaceous planktonic foraminifera invented some 330 million years later.

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## **The new and reinstated genera of agglutinated foraminifera published between 2008 and 2012**

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The Agglutinated Foraminifera comprise a large and polyphyletic group of organisms that have developed an organic walled or agglutinated test. Recent molecular studies have pointed out that the Textularida (sensu Loeblich & Tappan, 1987) does not comprise a natural group of organisms – the ability to construct an agglutinated wall probably arose independently within different foraminiferal lineages. The validity of the Loeblich & Tappan classification or any other scheme based on morphological criteria alone has been brought into question by the results of both morphological comparisons and molecular studies (Pawłowski et al., 2003; Mikhalevich, 2004). Nevertheless, a classification scheme of the agglutinated foraminifera that includes all the known modern and fossil genera is a desirable goal that ought to be pursued. In the latest update of the Loeblich & Tappan (1987) classification scheme a total of 747 genera were recognized as valid (Kaminski, 2004). With the inclusion of the allogromids and Xenophyophoracea into the classification scheme and another decade of descriptive work, the number of agglutinated genera recognized as valid has now risen to 847. In the four years since the last Workshop on Agglutinated Foraminifera a total of 23 new genera have been described, including:

ALZONORBITOPSELLA BouDagher-Fadel, 2008

BOWSERIA Sinniger, Lecroq, Majewski, & Pawłowski, 2008

CONICOTHEKA Gooday, Todo, Uematsu & Kitazato, 2008

EOBIGENERINA Cetean, Setoyama, Kaminski, Neagu, Bubík, Filipescu & Tyszka, 2008

GOODAYIA Sergeeva & Anikeeva, 2008

RECTOPROTOMARSSONELLA Kaminski, Bubík & Cetean, 2008

CUNEOSPIRELLA Cherchi, Schroeder & Ruberti, 2009

GERACIA Lewis, 2009

LEPTAMMINA Cedhagen, Gooday & Pawłowski, 2009

NIVEUS Altin, Habura & Goldstein, 2009

PLECTOERATIDUS Kaminski, Setoyama & Tyszka, 2009

SHINKAIYA Lecroq, Gooday, Tsuchiya, & Pawłowski, 2009

CAPSAMMINA Gooday, da Silva, Koho, & Lecroq, 2010

CARTERIELLA Haig & McCartain, 2010

CEDHAGENIA Gooday, Anikeeva & Pawłowski, 2010

NELLYA Gooday, Anikeeva & Pawłowski, 2010

XIPHOPHAGA Goldstein, Habura, Richardson & Bowser, 2010

AMMOGLOBOROTALOIDES Kaminski & Contreras, 2011

BITHEKAMMINA Aranda de Silva, Gooday, Pearse & Cunha, 2011

DUBROVNIKELLA Schlagintweit & Velić, 2011

NAZAREAMMINA Gooday, Aranda da Silva & Pawlowski, 2011

OLGIA Mikhalevich, 2011

PLECTOVERNEUILINELLA Cetean & Kaminski, 2011

Finally, the genus *Jadammina* Bartenstein, 1938 has been placed into the synonymy of *Entzia* Daday, 1884 based on the revision of the type species by Filipescu & Kaminski (2011).

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## A “Flysch-type” agglutinated foraminiferal assemblage from the Lower Carboniferous black shales of northern Saudi Arabia

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A new assemblage of agglutinated foraminifera is described from Lower Carboniferous black shales of the Berwath Formation recovered in an exploration well drilled in northern Saudi Arabia. The recovered sediment consists of bioturbated black shale with stringers of thin siltstone and sandstone, and is the age equivalent of the Barnett Shale of Texas. The recovered assemblage comprises of exclusively agglutinated foraminifera characterized by diverse morphogroups, including free-living tubular forms that can be abundant. In this respect, the assemblage can be compared with the “flysch-type” assemblages described from the Cretaceous and Paleogene of the North Atlantic and western Tethys. The assemblage from Saudi Arabia displays higher diversity than previously described “Kinderhookian” agglutinated assemblages from the Lower Carboniferous shales and limestones in North America.

The key feature that distinguishes the Saudi Arabian, Berwath Formation assemblage from the “Kinderhookian” and “Osagian” agglutinated assemblage described from North America (Conkin, 1961) is the presence of diverse free-living lituolids and trochamminids and the rarity of forms that grow attached to a hard substrate such as *Tolypammina*. Previously reported species of *Ammobaculites* from the North American assemblages contain typical *Ammobaculites* species that are round in cross-section such as *A. pyriformis* Gutschick & Treckman, *A. gutschicki* Conkin, or *A. beveridgei* Conkin & Conkin. In the present material, some species belonging to the genus *Ammobaculites* or *Sculptobaculites* are strongly compressed, to the point of closely resembling the Late Cretaceous to Cenozoic genus *Glaphryammina*. This is the first report of diverse compressed lituolids from the Lower Carboniferous. Even more striking is the presence of trochamminids with petaloid, digitate, and radially elongated chambers that even possess structures akin to primitive tubulospines. The obvious isomorphism between the Lower Carboniferous trochamminids and some Lower Cretaceous planktonic foraminiferal genera such as *Clavhedbergella* and *Leupoldina* is a topic of interest from an evolutionary point of view. Several species will be described as new, and others are left for now in open nomenclature. The finding of new Lower Carboniferous lituolids and trochamminids with distinctive “advanced” morphologies has implications for any hypothesis regarding the evolution and functional morphology of benthic foraminifera in dysoxic environments.

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## **Pliocene dysoxic agglutinated foraminiferal assemblages from IODP Hole 1341B in the Bering Sea: Initial results from IODP Expedition 323**

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The primary objective of drilling at Site U1341 was to study high-resolution Pliocene–Pleistocene paleoceanography in the southern part of the Bering Sea at a western flank location of Bowers Ridge. Previous DSDP coring (Site 188) and subsequent piston core studies in the region documented high sedimentation rates of 100–138 m/m.y., and the presence of appropriate microfossils for paleoceanographic studies.

Drilling at Site U1341 —located at a water depth of 2177 m recovered nearly 600 m of diatomaceous sediment, and provides a record of past intermediate water conditions in the Bering Sea. The site is located just below the modern Oxygen Minimum Zone, which likely caused the formation of laminated intervals in the sediment cores. Fluctuations in the intensity or depth of the OMZ should be captured by benthic foraminiferal proxy records of past oxygenation measured at this site and compared to shallower sites.

We present the first record of agglutinated foraminiferal assemblages from samples collected at 3 m resolution in IODP Hole 1341B. The Pliocene assemblages from the base of the hole to ~320 m consist entirely of agglutinated foraminifera strongly dominated by the infaunal genera *Eggerella*, *Karreriella*, *Martinotiella*, and *Siprosigmoilinella*. Tubular agglutinated forms such as *Psammosiphonella* are very rare. The ecological information gained from this assemblage supports other proxy information indicating high levels of organic productivity in the Bering Sea. Occasional horizons with calcareous benthic foraminifera dominated by buliminids are present, possibly owing to fluctuations in the CCD.

In the upper part of Hole 1341B starting at ~320 m (ca. 2.3 ma), calcareous benthic foraminifera (mostly *Bulimina*, *Globobulimina*, *Uvigerina*, *Melonis*, and *nodosariids*) show improved preservation. This level coincides with the first appearance of abundant sea ice diatoms and radiolarians living in cold and oxygen-rich intermediate water masses. The fauna still indicates dysaerobic conditions, but productivity may have been reduced by seasonal sea ice coverage and an enhanced stratification of the water masses.

## ***Trochammina quadriloba* (Grzybowski) sensu Geroch, 1960 in the Polish Outer Carpathians**

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An agglutinated foraminifera corresponding to *Trochammina quadriloba* (Grzybowski) sensu Geroch (1960) have been found in the foraminiferal assemblages of the Middle-Upper Eocene variegated marls and shales of the Fore-Magura Thrust. The characteristic features of this species are a very rough surface of the test and low, trochospiral coiling with three chambers visible on the umbilical side. Spiral side seems to consist of four chambers however, in some specimens, particularly with higher coiling, more chambers can be observed. Such a species was also described by Jurkiewicz (1967) from the Paleogene deposit of the middle part of the Polish Flysch Carpathians as well as by Samuel (1977) from the Paleogene flysch formations of the Slovakian West Carpathians.

Geroch (1960) included Grzybowski's *Haplophragmium* (*Resussina*) *quadrilobum* in the synonymes of *Trochammina quadriloba* (Grzybowski). Liszka & Liszkowa (1981) in their revision of the foraminifera described by Grzybowski in 1896, after examination of only one specimen from the original collection and basing on their observations from the Cretaceous red shales rejected the opinion of Geroch (1960) and included Grzybowski's species into *Trochammina bulloidiformis* (Grzybowski). Huss (1966) presenting the agglutinated foraminifera from the Upper Cretaceous deposits of the SubSilesian Unit also included Grzybowski's *H. quadrilobum* as well as Geroch's *T. quadriloba* in the synonyms of *T. bulloidiformis*.

Relatively numerous specimens from the Fore-Magura Thrust display some variety but in general correspond perfectly with the Geroch (1960), Jurkiewicz (1967), and Samuel descriptions, drawings and stratigraphic occurrence of the taxa determined as *Trochammina quadriloba* (Grzybowski). This taxa has been noticed in the Middle-Upper Eocene deposits and displays quite compact arrangement of chambers in contrary to Grzybowski (1896) original descriptions and drawings of *H. quadrilobum* and *H. bulloidiforme* as well as Huss (1966) description and illustration of the latter taxa showing spherical, more loosely arranged chambers and described from the Cretaceous deposits of the Flysch Carpathians.

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## The Cretaceous-Paleogene agglutinated foraminifera from the Magallanes or Austral Basin, southernmost South America

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The Austral or Magallanes retroarc basin possesses an almost complete Cretaceous-Paleogene marine clastic sequence, paradigmatic in the middle- high latitudes of the Southern Hemisphere, where agglutinated foraminifera (AF) are common to dominant from the Aptian up to the lower Miocene. The distribution of these AF reflects and at the same time defines the main tectonosedimentary regions: the active Andean margin comprises mostly flysch type cosmopolitan assemblages, while towards the stable platforms mixed calcareous and agglutinated assemblages occur, and on the stable cratonic edge, impoverished assemblages of AF with fairly endemic forms are found. The most outstanding features and relevant taxa of these assemblages are indicated.

In the Hauterivian-Barremian, despite the good to exceptional preservation of calcareous foraminifera, the AF are very scarce to absent, probably due to a selective attack of bacteria on their organic cement in the dominant dysaerobic environments (Loeblich and Tappan, 1989), and consequently, only one species, *Sculptobaculites goodlandensis* (Cushman and Alexander), is locally common.

In the Albian–Cenomanian, with the abrupt onset of oxygenate and open oceanic waters conditions, mixed assemblages appear towards more stable environments (Springhill platform) with well-known cosmopolitan species of the *Marssonella* Assemblage, such as *Spiroplectinata annectens*, *S. complanata*, *Tritaxia gaultina*, *Marssonella oxycona*, and the abundant and conspicuous *Dorothia mordoiovichi* Cañón and Ernst, one of the few apparent endemic species. In marginal environments, the *Ammobaculites* Assemblage contains species common to the Great Artesian Basin, Australia, such as *Bigenerina* cf. *pitmani* (Crespin), *Spiroplectamina egelli* Crespin, *Textularia wilgunyaensis* Crespin, and *Trochammina delicatula* Crespin, (Malumián and Nández, 1990, 2002).

A proxy indicator of Turonian age is given by *Spiroplectina ona* (Malumián and Masiuk) in mixed assemblages in Tierra del Fuego, also widespread in the adjacent Malvinas Basin.

In the upper Santonian-lower Campanian, the *Uvigerinamina jankoi* Assemblage, a well developed flysch type assemblage, is recognized in the southern Patagonian Andes; while in the Fuegian platform, *Textularia juliana* Malumián and Masiuk is the typical agglutinated species within mixed assemblages.

In the regressive facies, of very shallow and probably marshy environments, the so called *Textularia-Spiroplectamina* Assemblage, with high dominance of enfeeble biserial tests, is widespread nearly all over the basin in the Santa Cruz Province. Its appearance is recorded in the Mata Amarilla Formation, outcropping in the Cerro Indice locality, of late Coniacian age according to its *Gauthiericeras* content (Riccardi, 2002). The youngest record of this assemblage is in the subsurface, overlying beds with *Hoplitoplacenticeras plasticum*, considered of late Campanian age (Malumián and Nández, 1990). The Assemblage of *Cribrostomoides* ex gr. *H. rugosus* is recognized and extended from the Andean foothills to

the Atlantic coast overlying the *Spiroplectammina-Textularia* Assemblage, and differs from the latter by the dominance of involute forms.

During the Late Campanian- Maastrichtian, the AF are dominant in both the Southern Patagonian Andes and the Fuegian Andes. In the former, in shallow facies, the first AF of alveolar wall in the basin appears between *Hoplitoplacenticeras* (upper Campanian) and *Maorites* (Maastrichtian) horizons (Náñez and Malumián, 2000). In the Fuegian Andes, the finely stratified black shales include horizons with monospecific assemblages of *Rzehakina lata*, being this genus well represented up to the lower Eocene (Caramés and Malumián, 2006).

The first extensive Atlantic transgression on the Patagonian platform occurs in the Maastrichtian and locally is represented by different agglutinated assemblages. In the northern Patagonia, low diversity assemblages of deltaic type are recorded in the Lefipán Formation. In the Magallanes Basin, *Ammobaculites* type assemblages are distributed on the Springhill platform, while flysch type assemblages are recorded in the Policarpo Formation in Tierra del Fuego Island, dominated by *Thalmannammina* cf. *turbinata* (Brady), *Spiroplectammina spectabilis*, *Recurvoides* sp., *Gerochammina conversa* (Grzybowski), and *Gaudryina healyi* Finlay (Olivero et al., 2002; Náñez and Malumián, 2008; Malumián and Náñez, 2011). The last species is a typical Austral one, originally described from New Zealand and also recorded from Antarctica.

The first appearance of *S. spectabilis* is a proxy for the base of the Maastrichtian, in assemblages where other age indicators are absent. This species is absolutely dominant in the Andean Fuegian organic-rich upper Paleocene, which also contains contrasting and localized horizons with exclusively well preserved calcareous foraminifera (Caramés and Malumián, 2002).

The absence of *Caudammina*, so abundant elsewhere, is an apparent negative general characteristic of the Campanian and Maastrichtian from the Magallanes Basin.

In the only record of earliest Eocene from the Magallanes Basin, a new genus with remaneicid test gross morphology but with calcareous cemented perforate wall, manifests within a mixed assemblage the accentuated endemism resulting after the Paleocene/Eocene turnover (Malumián et al., 2012).

In the Fuegian Oligocene-Miocene the abrupt appearance of deep-water facies is represented by assemblages of cosmopolitan AF under the calcite compensation depth. In the Patagonian platform, in the earliest Miocene, the existence of a current of Antarctic corrosive water is evident by the northward dispersion of the agglutinated *Spirosigmoilinella-Martinottiella* Assemblage, which occasionally includes dissolution resistant calcareous foraminifera of Antarctic origin such as *Antarcticella antarctica* and *Ammoelphidiella*.

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## **A conspicuous agglutinated new genus of calcareous cemented and perforate wall with remaneicid test morphology from the early Eocene southern high latitudes**

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In southernmost South America, the Austral Basin contains a paradigmatic marine Paleogene sequence with representative assemblages of benthic foraminifera in an oceanic hemisphere. These assemblages include several calcareous taxa endemic to high southern latitudes (Malumián and Nández 2011), such as the conspicuous genera *Boltovskoyella* and *Antarcticella*. The latter was originally assigned to a planktonic paleohabit, due to its misleading gross morphology. We add to these taxa of peculiar morphology, a new genus and new species with a wall test agglutinating small foreign particles with very abundant calcareous cement and subdivided chambers that previously led us to misinterpret it as a complex calcareous form (Malumián and Nández 2002). This peculiar form was found in the early Eocene Punta Noguera Formation, in the Tierra del Fuego Island, from outcrops of very difficult access, so that the gathered material is limited.

The new genus has a morphology and paleohabitat similar to those of the subfamily REMANEICINAE Loeblich and Tappan 1964, particularly to the genera *Bruneica* and *Remaneica*: It has a low trochospirally coiled small test; the first two or three chambers are globular and undivided; subsequent chambers are semilunate from spiral view, mushroom-shaped from umbilical view, and subdivided by radial secondary septula; the interiomarginal aperture is situated at the end of a median umbilically directed scarcely perforate projection resembling to that of *Bruneica*. The new genus differs from the organically-cemented REMANEICINAE by the perforate rigid wall, completely calcareous in the initial chambers to very finely agglutinate in the last whorl. It bears scattered perforations, larger on the umbilical side (diameter: 3.75 - 5  $\mu\text{m}$ ) and smaller on the spiral side (2.5 - 3.35  $\mu\text{m}$ ), mostly situated in the last whorl where the agglutinated foreign particles are more evident. Other smaller perforations are preserved as thin and long gypsum infillings (diameter: 2,5  $\mu\text{m}$ ) in the initial chambers of a deeply etched test.

Two types of tests are recognized in the general shape: one is the more common watchglass-shaped form that apparently reaches larger sizes (microspheric form?), and the other corresponds to more conical forms with a prominent umbo on the spiral side (megalospheric form?).

The paleohabit of this new genus, according to its Holocene homeomorphous *Bruneica* and *Remaneica*, would be attached and inhabiting tropical shallow water. This interpretation is also supported by the associated foraminifera, the benthics dominated by attached morphotypes, and the scarce planktonic foraminifera, only represented by small serial forms (Malumián et al., 2009, Malumián and Jannou, 2010). Another close homeomorph genus is *Abyssotherma*, described from the vicinity of deep-sea hydrothermal springs, a contrasting bathymetric but thermally similar paleoenvironment (Brönnimann et al., 1989).

The new genus and new species is an exceptional case as calcareous cemented agglutinated foraminifera in the Magallanes Basin, and its occurrence would reflect the early Eocene warm climate in southern high latitudes.

According to the most recent systematics proposals (*vide* Kaminsky 2004; Mikhalevich 2004), this new genus, despite of the close morphology, would not belong to the organically cemented and imperforate TROCHAMMININA Saidova, 1981, because it has perforate calcareous cemented wall and consequently a firm and resistant test resulting from mineralization of the organic cement by calcium carbonate, and neither to the TEXTULARIINA Delage & Herouard, 1896 because its test gross morphology is uncommon for this suborder.

So that, the high systematic location of this new genus will depend whether the chemical composition and structure of the biogenic deposits of the test wall are regarded to be of major systematic importance or the gross morphology must be taken first into consideration.

This new genus will be formally described, and its high systematic position will be determined depending on the comments we could harvest in this workshop.

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## Functional morphology and paleoecology of the agglutinated foraminiferal genus *Colominella* Popescu, 1998 in the Mediterranean Pliocene (Liguria, Italy)

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Specimens of *Colominella* (Agglutinated Foraminifera) from a Pliocene Mediterranean succession have been analyzed through a multidisciplinary approach to document their test microstructure and to understand their relationship to environmental life conditions. Moreover this paper reports for the first time the occurrence of *Colominella* in a Pliocene succession of the Mediterranean area, thereby extending the known stratigraphical range of the genus.

The genus *Colominella* Popescu, 1998 was first described from the Paratethyan Middle Miocene (Badenian) Kostej (Costei) succession, outcropping in Transylvania (Popescu et al., 1998; Kaminski, 2004b), and is based on a species first described by Cushman (1936) from the same locality (type species *Textulariella paalzowi*). The same species was subsequently reported from the Miocene (Badenian) of the Rauchstallbrunngraben, Vienna Basin (Popescu et al., 1998). The type species is characterised by a very large, elongated, mostly biserial test, with the inner part subdivided by secondary septa forming a typical labyrinthine structure and by its caniculate test wall. *Colominella* likely evolved from the genus *Matanzia* (which is also canaliculate) during the Oligocene to middle Miocene, though the exact timing of its evolutionary first appearance is still unknown (Kaminski and Cetaan, 2011). *Colominella* and *Matanzia* have been recently placed in the subfamily Colominellinae Popescu, 1998 together with other two additional closely-related genera: *Colomita* Gonzales-Donoso, 1968 and *Cubanina* Palmer, 1936 (Kaminski and Cetaan, 2011).

In spite of this recent systematic review, not much is known about the test wall microstructure of *Colominella* as regards to the arrangement and chemical-mineralogical composition of the agglutinated grains and the occurrence of other functional adaptive morphologies probably selected by the life environment.

Results show that Pliocene *Colominella* develops a complex test with a mostly biserial chamber arrangement, but with the internal chamber lumens partitioned by vertical and horizontal plates that form a labyrinthine structure of alcoves. This internal partition occurs from the first chambers but is completely masked from the outside by the thick wall. The test-wall microstructure is characterised by canaliculi (parapores) that are externally covered by a pavement of agglutinated grains. The mineralogical characterization of the agglutinated grains and the secreted cement shows that the grains are strongly selected as regards to size, arrangement and composition, with the coarse grains placed close to the outer wall. Moreover, these coarse grains, are made of monocrystalline quartz, whereas the inner part of the skeleton is mostly composed of dolomite. The carbonate cement is less abundant and appears as cloudy light grey areas among the detrital grains.

The complexity of the agglutinated test, in terms of both internal shape and wall microstructure and composition, is interpreted as an adaptative response to ecological limiting factors that persisted for a long time, as probably occurred during the warm early Pliocene interval in the Mediterranean basin. In particular the co-occurrence of different functional morphologies, such as: the large size, the sessile style-life, the compartmentalised shell with a caniculate wall and a transparent test surface, are here interpreted as adaptations to perform kleptoplastidy and/or to harbour symbionts in order to establish k-strategist relationships that usually develop in stable environments such as in shallow warm waters with a scarce food supply.

In many lineages of larger agglutinated foraminifera, the development of complex inner structure is accompanied by a phylogenetic size increase. The supposed ancestor of *Colominella* was *Matanzia*, which was a deep-water form that became larger once it evolved a canaliculated wall structure. The Middle Miocene type species of *Colominella* from Transylvania probably inhabited a deep neritic to upper bathyal environment. If indeed our Pliocene *Colominella* housed kleptoplasts, then this behaviour represents a modification of pre-existing structures.

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## **Agglutinated species in the assemblages of foraminifera of Ria de Aveiro (N Portugal)**

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This research analyses the (rose Bengal stained and unstained) foraminiferal assemblages distribution in 40 sites of the sub-tidal areas of Ria de Aveiro (Portugal) channels. It also have into account the textural, mineralogical (X-ray diffraction techniques), geochemical (heavy metals concentrations assessed by total digestion of the sediment and by sequential chemical extraction followed by ICP-MS and ICP-OES analysis; and the sedimentary content in TOC) and environmental parameters such as salinity, pH and Eh.

Ria de Aveiro is located on the NW coast of the Iberian Peninsula (40°38'N, 8°45'W). A single artificial inlet, limited by two main jetties allows its intercommunication with the Atlantic Ocean. The lagoon is composed of four main channels and by a complex network of branches, bays and narrow channels intercepted by small islands and large salt marsh areas.

Semi-diurnal tidal currents are the most important feature in the lagoon hydrographical regime (Dias et al., 1999) which is also affected by winds. Several rivers and riverine bodies introduce freshwater into the lagoon being the most important Vouga and Antuã rivers with an average discharge about 50 m<sup>3</sup>.s<sup>-1</sup> -and 5 m<sup>3</sup>.s<sup>-1</sup>, respectively (Moreira et al., 1993) streaming to the central and northeast lagoonal areas. However, the rivers have small contributions in terms of water inputs when compared with the tidal prism, but may have a long-term influence in the residual transport (Dias et al., 2003).

Hydrodynamic conditions are strong in the channels connected with the lagoon mouth where the tidal currents velocities are higher than 2 m/s (Vaz and Dias, 2006).

Currents activity controls the textural characteristics and composition of the sediments in Aveiro lagoon channels. Significant positive correlations among the grain size fractions and the mineralogical and geochemical composition of the sediments highlight that the sedimentary dynamic is controlled mainly by the hydrodynamic conditions. In the areas where the currents activity is low, fine-grained sediments enriched in organic matter and phyllosilicates are deposited and many chemical elements are retained increasing their concentrations. The geochemical pressure is higher in the far end of some of the main channels where the rivers (Pastorinho et al., 2012) and diffuse sources provided by the agricultural fields introduce pollutants into the lagoon. Thus several hot spots of pollutants can be found, for instance in Laranjo Bay area (Pereira et al., 2009) and Aveiro city canals (Martins et al., 2010).

The foraminifera assemblage found in the shallow sub-tidal areas of the channels is composed of about 178 species in the dead assemblage and 108 in the living one. Total dead and living benthic foraminifera abundance is lower than  $\approx 1805$  and  $\approx 540$  specimens per g of sediment fraction 63-500  $\mu\text{m}$ , respectively. Foraminifera density is negatively correlated with coarser sediments.

Shannon Index values (H), used to evaluate the species diversity, of the living assemblage vary from 0.6 to 2.6 and is lower than H of the dead one ( $< 3.3$ ). The highest values of diversity of both assemblages are commonly found in areas under higher marine influence. Foraminifera abundance and diversity of both assemblages have on one hand, significant positive correlations with salinity and Eh values and on the other hand, negative correlations with higher concentrations of heavy metals.

The foraminifera assemblages in the studied sites comprise mainly hyaline carbonated specimens. In most of the areas the assemblages are dominated by *Haynesina germanica* ( $< 80\%$ ), *Ammonia tepida* ( $< 73\%$ ) and *Elphidium* spp. ( $< 64\%$ ; including species such as *E. gerthi*, *E. articulatum*, *E. excavatum*, *E. crispum*, *E. complanatum*, *E. oceanensis* and *E. williamsoni*). In the sandy sediments of protected areas of the lagoon entrance species such as *Lobatula lobatula* ( $< 37\%$ ), *Cibicides ungerianus* ( $< 38\%$ ), *Planorbulina mediterraneensis* ( $< 42\%$ ) and *Gavelinopsis praegeri* ( $< 22\%$ ) can be found. Miliolids mostly represented by *Quinqueloculina seminula* reach in general percentages  $< 10\%$  but rise up to 47% in some sites of Aveiro canals connected with the main lagoonal body.

Nevertheless, one of most interesting features is the dominance of agglutinated species in two main lagoonal areas. Under higher marine influence, on the bottom of S. Jacinto and the inlet Channels where the tidal currents are very strong and the substrate is unstable *Lepidodeuterammia ochracea* ( $< 31\%$ ) and *Tiphotrocha concava* ( $< 36\%$ ), *Remaneica helgolandica* ( $< 6\%$ ), *Trochammina haynesi* ( $< 3\%$ ) for instance, reach higher relative abundance. They can be seen frequently “attached” to sand grains and probably can follow the movement of sand driven by tidal currents. *Cribrostomoides jeffreysi* ( $< 5\%$ ) and *Reophax dentaliniformis* ( $< 3\%$ ) are also found in this area, but in more sheltered zones. Dominance of agglutinated species is also reached in Laranjo Bay (the innermost area of Murtoosa Channel), affected by the influence of River Antuã and other riverine. Crossing the threshold from brackish to freshwater environments, foraminiferal assemblages includes mostly species such as *Trochammina inflata* ( $< 32\%$ ), *Jadammina macrescens* ( $< 29\%$ ), *Miliammina fusca* ( $< 21\%$ ), *T. concava* ( $< 18\%$ ) *Ammotium salsum* and *Tiphotrocha comprimata* ( $< 16\%$ ). This last group of agglutinated species can be considered the most tolerant to higher environmental stress, since they support erratic salinities, as low as high, higher TOC content, lower Eh and pH values and high available concentrations of toxic heavy metals, such as Zn, Cu, As, Co and Hg. However in the most polluted zones of Laranjo Bay their abundance also decays deeply.

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## **Dominance of the invasive agglutinated foraminifera *Trochammina hadai* Uchio in San Francisco Bay, USA, less than two decades after its introduction**

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San Francisco Bay is the largest estuary on the west coast of the United States and consists of several subembayments, including informally named north bay (San Pablo, Suisun, Grizzly, and Honker Bays), central bay (with Richardson Bay), and south bay. A common agglutinated estuarine foraminifera in Japan, *Trochammina hadai* Uchio, was introduced into the estuary between 1981 and 1983; the species' identification has since been confirmed by molecular techniques (Kitazato et al., 1997; Fay et al., 2007). *Trochammina hadai* was probably transported in ballast sediment, anchor mud, or in sediments associated with oysters imported for mariculture (McGann et al., 2000). Following the species' arrival, *T. hadai* proliferated, becoming one of the dominant foraminifera in the estuary today, as well as in 14 other ports and estuaries along the western U.S. from California to Alaska (McGann et al., 2000; McGann, unpublished data). In Japan and along the eastern Pacific seaboard, the species thrives in shallow estuarine waters. Here we present a summary of the arrival and expansion of *T. hadai* in San Francisco Bay, illustrating how quickly and significantly this invasive species has impacted the foraminiferal faunas throughout the estuary.

Starting in the 1960s, the first detailed investigations of the distribution of foraminifera in surface sediments of San Francisco Bay were undertaken by Slater (1965) in Suisun Bay, Means (1965) in Richardson Bay, and Quintero (1968) in south bay. Similar studies continued in the 1970s with the works of Locke (1971) in San Pablo Bay, Conner (1975) in Richardson Bay, and Wagner (1978) whose study locations were situated in parts of south bay, central bay, and north bay. A few years after Wagner's study, Arnal et al. (1980) published a slightly expanded version of Quintero's (1968) south bay study, and Sloan (unpublished data, 1980-1981) acquired surface sediments from north, central and south bay to investigate foraminiferal abundances estuary-wide. In all, these studies analyzed 350 surface samples at 340 sites throughout the estuary over a period of about 16 years.

These samples provide a baseline of the spatial distribution of benthic foraminifers in San Francisco Bay before the introduction of *T. hadai*. *Ammonia beccarii* was the most abundant and geographically widespread species in the estuary; second in abundance was *Elphidium excavatum*. *Haynesina germanica* was most abundant in the shallower regions of south bay and *Elphidiella hannai* dominated the deepest sites of Richardson, central, and north bays. The agglutinated taxa *Trochammina inflata*, *T. macrescens*, *Miliammina fusca*, and *Haplophragmoides subinvolutum* are ubiquitous in the marshes of San Pablo Bay and Richardson Bay, but are mostly rare to absent in south bay except for a few localized occurrences of *T. inflata*. No foraminifera were found east of Honker Bay or in the channel or southern portion of Suisun Bay.

The earliest sample in the estuary in which *T. hadai* was found was in one of four samples collected in 1983 from south bay where the species constituted 3% of the fauna. By 1986-87, *T. hadai* was present at 46 stations and dominating the foraminiferal assemblage, comprising up to 89% of the fauna. In nine samples collected in central and south bays

between 1990 and 1993, *T. hadai* constituted 56% of the foraminifera recovered. In six surveys between 1995-1998, *T. hadai* was found at 17 additional sites and constituted up to 93% of the fauna. In all, *T. hadai* has been found at 91% of 79 stations sampled between 1986 and 1998, being absent in only a few locations and in the extreme northern and southern ends of the estuary where freshwater enters the bay (McGann and Sloan, 1999).

A comparison of samples collected between 1965 and 1998 in central bay clearly demonstrates how the distribution of benthic foraminifera in this one subembayment has changed in less than 20 years due to the invasion of *T. hadai*. A cluster analysis separated these samples into pre- and post-invasion assemblages, illustrating how pervasive the invader has become in central bay. As recently as 2010, 165 samples collected throughout the estuary confirm that *T. hadai* is still widely distributed and dominant.

In 2000, less than two decades after its introduction, *T. hadai* dominated the foraminiferal faunas throughout San Francisco Bay. The species' proliferation is associated with a decline in relative abundance of one of the most common native foraminifera, *E. excavatum*. A 3900-year record of deposition in south bay (McGann, 1995) reveals that *E. excavatum* declined from at least 55% of the fauna in all samples in the core prior to *T. hadai*'s first appearance to a present average of 5% in south bay (McGann and Sloan, unpublished data). Because no sedimentological or environmental changes have occurred since *T. hadai*'s arrival, the sharp decline in abundance of *E. excavatum* suggests the arrival and proliferation of this invasive species in San Francisco Bay has profoundly impacted the native foraminiferal fauna.

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## Reinvestigation of two agglutinated genera of the order Textulariida Delage et Herouard, 1896 (Foraminifera)

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Two species of the two genera (*Norvanganina* Mikhalevich, 1981 and *Spirotextularia* Saidova, 1975) of the order Textulariida Delage et Herouard, 1896, gathered first near the western coast of Africa near Monrovia and Canaries (depth 57 – 620 m) and the second near subtropical part of Atlantic South American coast (depth 38 – 200 m) were previously investigated in our material in the light microscope only (Mikhalevich, 1978, 1981). They were restudied here in SEM. Loeblich & Tappan (1987) considered *Norvanganina* to be “probably synonymous” to *Textularia* and marked that its canaliculate wall was not demonstrated. They also supposed the openings situated along the peripheral margin to be “result of breakage”. The study of the type species of *Norvanganina* – *N. pseudorugosa fistulosa* Mikhalevich, 1981 (= *Textularia valeriae* Loeblich & Tappan, 1987) in SEM had distinctly showed the canaliculate character of its wall. But this canaliculate wall has also a peculiar feature: very dense canaliculate perforations piercing its rather thick wall are covered from above with a thin layer with only rare irregularly disposed subcircular openings of somewhat larger size than densely dispersed regular canaliculate openings. These pseudopore openings are often encircled by a slight rim of the finer material. Thus between this superficial cover and the canaliculated wall the irregular partial additional space is present. A similar shell wall was described in some *Sahulia* (genus of Loeblich & Tappan, 1985) species by Hottinger et al. (1993).

Openings rather regularly disposed along the peripheral margins of *N. pseudorugosa fistulosa* at the lateral edges of their chambers and leading to the chamber lumens are also encircled with a slight rim of finer material which would not be the case if they were a mere breakings. Between these peripheral openings and chamber lumen no chamberlet separated by a sieve plate exists, but the tube wider in diameter than canaliculi and aligned from the inside with the organic matter just as in the more narrower canaliculi joins the chamber lumen with the surrounding space. All these structural features give reason to consider them as additional apertures.

In *Spirotextularia floridana* (Cushman, 1922) chamberlets situated between the additional aperture and chamber lumen separated from the latter by the sieve plate are clearly observed similarly as seen in some other *Spirotextularia* species investigated earlier by Loeblich & Tappan (1985) (in the type species of the genus) and by Hottinger et al. (1993). *Spirotextularia* having distinctly expressed planospiral coil in its initial part belongs to Spirotextulariinae Saidova, 1975, *Norvanganina* – to Textulariinae Ehrenberg, 1838. Additional peripheral apertures were also observed in some other agglutinated genera: *Sahulia* Loeblich & Tappan, 1985 (Textulariinae), *Plotnikovina* Mikhalevich, 1981 and *Siphoniferoides* Sidova, 1981 (Siphoniferoidinae Loeblich & Tappan, 1985 of the family Pseudogaudryinidae Loeblich & Tappan, 1985, order Verneuilinida Mikhalevich & Kaminski, 2004). Thus additional apertures in different agglutinated multichambered genera having different arrangement of their initial shell part and erected elongated biserial or triserial later part demonstrate formation of additional peripheral apertures in parallel in different groups.

Simple additional apertures of *Norvanganina* lacking the peripheral chamberlets represent the more primitive evolutionary development of this feature.

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## Sequence stratigraphic application of foraminiferal facies patterns: Triassic and Jurassic examples

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Main features of foraminiferal facies are outlined in a transgressive-regressive sequence stratigraphic model, which includes depositional conditions ranging from marginal marine settings to offshore shelf positions. The biofacies proxies include stratigraphic distribution of species diversities and frequency of normal marine (contra restricted) taxa. In the sequence stratigraphic framework, biofacies trends are outlined as faunal expansions and reductions separated by trend changes. Faunal expansion means upward increase in diversity and frequency of normal marine taxa leading to well-oxygenated offshore shelf conditions. Faunal reduction is upward decrease in diversity and increase in restricted taxa leading to hyposaline or hypoxic conditions.

Biofacies trend changes reflect major environmental alterations, which are localised to discrete stratigraphic levels or involve wider stratigraphic intervals. Trend changes are useful indicators of sequence boundaries and maximum flooding surfaces, but might also occur within individual systems tracts. The distribution of these facies patterns in the model is supported by modern analogues, showing foraminiferal distribution along transects from shallow to deep water. Application of the model is illustrated by sections through Triassic and Jurassic sequences outlined below.

The Janusfjellet section is located in central Spitsbergen, and comprises Bathonian to Kimmeridgian deposits. The section forms a transgressive-regressive sequence containing a low diversity entirely agglutinated foraminiferal succession of restricted nature. The transgressive systems tract shows an upwards fining lithology from a basis conglomerate through sandy and silty beds to organic-rich shales, implying increasing water depth from beach to offshore shelf. Near the middle of this systems tract a trend change from increasing to decreasing diversity takes place. It suggests that rising salinity during transgression is replaced by decreasing oxygenation as the main restricting factor. The maximum flooding surface is marked by peak in organic carbon content (12%) coupled with minimum diversity suggesting highest degree of stagnation within the sequence. The regressive systems tract shows an upward coarsening lithology from shales to sandstones, associated with expanding diversity suggesting improved oxygenation. Common species include *Trochammina* cf. *kosyrevae* and *Recurvoides scherkalyensis*.

The Flexurfjellet section, in east central Spitsbergen, covers the same stratigraphic interval as the sequence outlined above from Janusfjellet. The biofacies of the two sequences reveals essentially similar trends both in the transgressive and regressive systems tract. A difference is that development of the maximum flooding event occupies a relatively wide stratigraphic interval reflected by an expanded facies trend change zone. A distinct peak of the organic carbon content appears at the base of this zone.

The Brora section in northeast Scotland covers the lower part of the Brora Argillaceous Formation of Early to Middle Callovian age, representing a transgressive-regressive sequence. The transgressive systems tract rests on a subaerial unconformity, and continues in sandy marginal marine strata followed by organic-rich shales. In the lower part of

this systems tract, normal marine conditions are suggested by occurrence of calcareous foraminifera (Lagenina). Presence of a trend change from faunal expansion to reduction suggests upward decreasing oxygenation. This leads to a wide, oxygen depleted maximum flooding zone, with extreme dominance of agglutinated taxa and diversity minima associated with high organic carbon values (10%). The regressive systems tract is typified by upwards expanding diversity and locally high content of sand and calcareous taxa. The maximum flooding interval is heavily dominated by *Haplophragmoides* aff. *pygmaeus* forming nearly monospecific assemblages. In the transgressive and regressive systems tracts, locally common species are *Lenticulina muensteri*, *Planularia beierana* and *Astacolus varians*.

The Juvdalskampen section of central Spitsbergen comprises a Carnian to Norian succession composed of the Tschermakfjellet and De Geerdalen formations. The transgressive systems tract reveals relatively high diversity and increasing frequency of Lagenina, which culminate at the maximum flooding surface reflecting normal marine shelf conditions. The regressive systems tract shows a development from hyposaline prodelta through delta front to delta plain conditions. During the prodelta and delta front phases, there is a diversity reduction and gradual disappearance of calcareous taxa suggesting upward diminishing salinity. Absence of foraminifera from the delta plain deposits and high abundance of terrestrial paynomorphs suggest freshwater conditions. The most common species in the transgressive marine shelf deposits are *Virgulina acricula* and *Mesodentalina* aff. *matutina*. In the regressive prodelta and delta front strata, typical taxa are *Ammodiscus* sp. and *Trochammina* aff. *squamataformis*.

## Mid-Late Cenomanian larger agglutinated foraminifera from W Valles-San Luis Potosí Platform, central-east Mexico

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Several sections were studied from the upper part of the El Abra Limestone, which crops out east of the city of San Luis Potosí, Mexico, and is part of the western section of the Valles–San Luis Potosí Platform. The Valles–San Luis Potosí Platform is part of an extensive carbonate platform system that rimmed the ancestral Gulf of Mexico during the mid-upper Cretaceous and it has been considered to be one of the largest isolated carbonate platforms (200 by 300 km.) in this time.

The El Abra Formation consists of a massive limestone deposit. This sequence provides a rich assemblage of larger foraminifera as well as algae which is reported for the first time from this site. The larger agglutinated foraminiferal assemblage is composed of *Hemicyclammina sigali* Maync, *Daxia cenomana* Cuvillier and Szakall, *Pseudocyclammina rugosa* d'Orbigny, *Dicyclina schlumbergeri* Munier-Chalmas, *Cuneolina pavonia* d'Orbigny, *Cuneolina pavonia parva* Henson, and *Moncharmontia apenninica* (De Castro). The microgranular-agglutinated foraminifera *Pseudolituonella reicheli* Marie, *Nezzazata convexa* (Smout), *N. simplex* (Smout), *Nezzatinella picardi* (Henson) and *Merlingina cretacea* Hamaoui Saint-Marc were also recorded. The algae are *Thaumatoporella parvovesiculifera* (Ranieri), *Bouenia pigmaea* Pia, *Heteroporella lepina* Pratulon, *Lithocodium aggregatum* Elliot.

The El Abra Limestone is dated as mid-late Cenomanian age (*Pseudolituonella reicheli* Zone) based on the stratigraphic range of the most significant foraminifera. The foraminiferal assemblage is correlated with coeval associations recorded in the Mediterranean region. The predominant textures of the El Abra Formation include peloidal-bioclastic packstone-grainstone with minor wackestone. The presence of the foraminifera, algae, and the texture of the limestone suggest a warm shallow-water marine platform deposit.

The benthic foraminiferal species identified are considered to be cosmopolitan forms well represented in the Tethys Realm.



## **Response of agglutinated foraminifera to an early Lutetian carbon-cycle perturbation at the Gorrondatxe section (western Pyrenees, Bay of Biscay)**

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The early Paleogene global carbon cycle and climate evolution were closely related both in the long and short term. A long-term decrease in  $\delta^{13}\text{C}$  values during the Paleocene and early Eocene (58-51 Ma) suggests a continuous flux of isotopically light carbon into the ocean-atmosphere system, which was accompanied by a warming climate scenario. The subsequent rise in  $\delta^{13}\text{C}$  values during the middle-late Eocene coincided with a cooling scenario, which eventually led to the development of permanent Antarctic ice-sheets 34 Ma (Zachos et al., 2001). This long-term evolution was punctuated by several short-lived (tens to hundreds of kiloyears, kyr) episodes in which additional  $^{13}\text{C}$ -depleted carbon was temporarily released (see references in Payros et al., 2012). Negative carbon isotope excursions (CIEs) in  $\delta^{13}\text{C}$  records are among the main hallmarks of these short-lived carbon-cycle perturbations (Zachos et al., 2010). Some of these events caused extreme global warming and have therefore been referred to as hyperthermals, the Paleocene-Eocene Thermal Maximum (PETM) event being the most prominent; hyperthermal conditions are also suspected for other short-lived carbon-cycle perturbations but have not been fully demonstrated to date. These short-lived carbon-cycle perturbations had severe environmental consequences, such as increased chemical weathering and runoff on land, rises in oceanic carbonate compensation depth and transient biological changes. Pelagic sedimentary successions provide the best record of these perturbations, as their deposits stand out as clay-rich reddish layers that coincide with abrupt drops in carbonate content.

A distinctive low-carbonate interval interrupts the continuous limestone-marl alternation of the deep-marine Gorrondatxe section (Western Pyrenees, Bay of Biscay) at the early Lutetian (middle Eocene) C21r/C21n Chron transition. The interval is characterized by increased abundance of turbidites and kaolinite, a 3‰ decline in the bulk  $\delta^{13}\text{C}$  record, a >1‰ decline in benthic foraminiferal  $\delta^{13}\text{C}$  followed by a gradual recovery, a distinct deterioration in foraminiferal preservation, high proportions of warm-water planktic foraminifera and reduced trace fossil diversity.

Trochamminids, including spirally arranged agglutinated taxa that Kaminski and Gradstein (2005) include in trochamminids and litoilids, are the most abundant agglutinated taxa at Gorrondatxe. *Astrorhizids*, *Karrerulina* and *Spiroplectamina* species are also abundant. *Clavulinoides*, *Vulvulina* and *Gaudryina* species dominate among the less common calcareous-cemented agglutinated taxa at Gorrondatxe. During the low-carbonate interval, the diversity of benthic foraminiferal taxa decreases, and epifaunal morphogroups (up to 63%) and agglutinated taxa (up to 72%; mostly organic-cemented trochamminids, *Spiroplectamina spectabilis* and *Pseudobolivina* sp. A) dominate the assemblages. The

abundance of deep-water agglutinated foraminifera in this interval is related to the high supply of clastic material to the seabed. However, additional changes must have affected the seabed, as trochamminids, *Karrerulina* and *Spiroplectammina* species are opportunistic taxa that take advantage of high-stress, strongly fluctuating environments (Kaminski and Gradstein, 2005, and references therein). Interestingly, the increase in these taxa is similar to others documented globally across the PETM and other hyperthermal events (e.g., Thomas, 2007; Alegret et al., 2009a, b; Giusberti et al., 2009). The extinction of deep-sea calcifiers during the PETM has not only been attributed to carbonate undersaturation, but also to changes in oxygenation, food supply and bottom water temperatures (e.g., Winguth et al., 2012). Therefore, the peak in opportunistic agglutinated taxa is probably influenced by these variables.

The onset of the perturbation correlates with the C21r-H6 event recently defined in the Atlantic and Pacific oceans, which caused a 2°C warming of the seafloor and increased carbonate dissolution. The perturbation was likely caused by the input of 13C-depleted carbon into the ocean-atmosphere system, thus presenting many of the hallmarks of Paleogene hyperthermal deposits. However, from the available data it is not possible to conclusively state that the event was associated with extreme global warming. Based on our analyses, the perturbation lasted 226 kyr, from 47.44 to 47.214 Ma, and although this duration suggests that the triggering mechanism may have been similar to that of the Paleocene-Eocene Thermal Maximum (PETM), the magnitude of the carbon input and the subsequent environmental perturbation during the early Lutetian event were not as severe as in the PETM (Payros et al., 2012).

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## **Dominance of agglutinated benthic foraminiferal assemblages during the Early Eocene Climatic Optimum (EECO)**

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The early Paleogene climate was characterized by a late Paleocene to early Eocene warming, which peaked in the so-called Early Eocene Climatic Optimum (EECO, ca. 51-53 Ma), followed by a progressive cooling that culminated at the early Oligocene. A large (2.5‰) drop in  $\delta^{13}\text{C}$  of carbonate spans much of the early Eocene (Zachos et al., 2001), suggesting a long-term increase in the net flux of  $^{13}\text{C}$ -depleted carbon to the ocean and atmosphere.

A 2300-m-thick lower to middle Eocene succession is exposed on coastal cliffs northwest of the city of Bilbao (western Pyrenees, Spain). During Eocene times the area formed part of the bottom of a 1500 m deep marine gulf that opened into the Atlantic Ocean at approximately 35°N latitude. This area received sediments from several sources, notably hemipelagic carbonates, and calciclastic and siliciclastic turbidites. The hemipelagic limestones and marls are rich in calcareous planktic microfossils, which have led to a complete biostratigraphic characterization of the succession (e.g., Orue-Etxebarria, et al., 1984; Bernaola et al., 2006a, 2006b). Payros et al. (2006) defined three turbidite-poor intervals and three turbidite-rich intervals, the former being typified by warm-water planktic foraminiferal assemblages and the latter by cool-water associations. This correlation points toward climatic variations as a possible driving mechanism for both sedimentary and biotic changes, and allows interpretation of the succession in terms of depositional sequences. Allochthonous benthic foraminifera and fragments of other shallow water organisms which were transported downslope by turbidity currents are common at the turbidite-rich intervals, while high-diverse benthic foraminiferal assemblages dominated by calcareous taxa are characteristic of the hemipelagic marls (Ortiz et al., 2011). Agglutinated foraminifera are dominated by trochamminids and astrohizids, typical components of deep water agglutinated foraminifera (DWAF) biofacies (e.g., Kaminski and Gradstein, 2005).

The Lower Eocene succession is about 1000 m thick. The EECO interval (from 300 to 550 m; upper part of nannofossil NP12 and planktic foraminiferal E5-E6 biozones) corresponds to a turbidite-poor interval and shows distinctive characteristics, such as scarcity of hemipelagic limestones, comparatively high content in organic matter (TOC up to 1.11%) and common reddish marls that are enriched in siderite. Bulk  $\delta^{13}\text{C}_{\text{inorg}}$  and  $\delta^{13}\text{C}_{\text{org}}$  records show a marked decrease at the core of the interval of ~4‰ and 1.5‰, respectively. These deposits are characterized by low foraminiferal standing stocks, in some cases barren. When present, foraminifera show a deterioration in preservation, usually with pyrite fillings, a decrease in test size, and low P/B ratios (% planktic foraminifera). Diversity of benthic foraminiferal assemblages decreases noticeably, being dominated by agglutinated taxa (up to >90%), mostly smooth, finely-finished astrohizids and trochamminids. These anomalous characteristics should not be attributed to increased carbonate dissolution on the sea-floor, as a drop in the lysocline and calcite compensation depth probably occurred during the EECO

(Leon-Rodriguez and Dickens, 2010). Therefore, we speculate whether these assemblages are the result of post-depositional or diagenetic dissolution of calcareous foraminiferal test. The presence of siderite and negative  $\delta^{13}\text{C}$  values support the idea that the early Eocene warming may have led to increased rates of organic matter accumulation and formation of bacterial methane (Kroeger and Funnell, 2012), which could have affected diagenetically the foraminiferal assemblages.

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## Multiple origins of the agglutinated wall and the high-level classification of Foraminifera

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Molecular analyses consistently show that the agglutinated species branch within different clades in phylogenetic trees of Foraminifera. Agglutinated astrorhizids mix up with organic-walled allogromiids in the large radiation of early monothalamous foraminiferans (Pawlowski et al., 2003). The genus *Ammodiscus* branches as sister group to Spirillinida. The genus *Miliammina* is closely related to Miliolida (Habura et al., 2006), while the other multilocular textulariids form a paraphyletic group at the base of Rotaliida. In our proposed new supraordinal classification based on molecular data, the agglutinated taxa can be found in all class-level groups. Multiple origins of the agglutinated wall confirm its importance as a major trend in evolution of Foraminifera and its prerequisite for the development of multilocular test.

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## **The Cenomanian/Turonian Boundary Event in the Sawin-19 borehole (SE Poland): restructuring of agglutinated foraminifera assemblages**

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A major paleoceanographic event, often referred to as the Oceanic Anoxic Event II or the Cenomanian/Turonian Boundary Event (CTBE), took place in the latest Cenomanian-earliest Turonian. The CTBE involved among others a significant faunal turnover.

The agglutinated foraminiferal response to the CTBE was studied from a 30-m-thick section in the Sawin-19 borehole, SE Poland, representing the *Rotalipora cushmani*, *Whiteinella archaeocretacea* and *Helvetoglobotruncana helvetica* Zones.

Foraminiferal assemblages from the *Rotalipora cushmani* Zone yield both planktonic and benthic taxa. Planktonic foraminifera form 10-30% of the assemblages. The benthic assemblage is relatively high diverse and is typical of the late Cenomanian; calcareous forms dominate assemblages. Upward the *Rotalipora cushmani* Zone agglutinated component gradually increases. *Tritaxia* spp., presumed infaunal species, form up to 40% of benthic foraminiferal assemblages in the upper part of the Zone and in that interval rare species such as *Arenobulimina sabulosa*, *A. conoidea*, *A. frankei*, *A. advena*, *Pseudotextulariella cretosa*, *Ataxophragmium depressum*, *Gaudryinopsis gradata*, *Verneuilinoides gorzoviensis*, *Plectina cenomana* underwent gradual extinction.

At the boundary between *Rotalipora cushmani* and *Whiteinella archaeocretacea* Zones, *Tritaxia* spp. completely disappear. *Tritaxia pyramidata*, *T. macfadyeni* and *T. plummerae* become extinct. *Tritaxia tricarinata* temporarily disappears.

At the base of the *Whiteinella archaeocretacea* Zone, a rapid increase in the percentage of planktonic foraminifera is recorded, and a high P/B ratio (60-90%) continues upwards. Low species diversity and domination by two to four species are recorded in the assemblages of benthic foraminifera in the lower part of *Whiteinella archaeocretacea* Zone. *Arenobulimina preslii* and *Marssonella oxycona* are immigrants which replaced *Tritaxia* spp.; they are main agglutinated components of benthic foraminifera assemblages in the very basal part of the zone. Higher up, *Tritaxia tricarinata* re-appear and a slow upward increase in a diversity of agglutinated foraminiferal assemblages is recorded.

The pattern of change from diverse foraminiferal communities of the middle *Rotalipora cushmani* Zone to high dominance, low diversity communities at the base of the *Whiteinella archaeocretacea* Zone suggests that changes occurred in the lower part of the water column which was related, in part, to benthic oxygenation and trophic resources.

## **A review of agglutinated foraminifera morphogroups: new data on “living” foraminifera from the Portuguese margin and their application in industrial palaeoenvironmental studies**

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During cruises 64PE252 (September 2006) and 64PE269 (May 2007), 16 multicores were collected with RV Pelagia along the Portuguese margin from open slope and canyon environments. Living (Rose Bengal stained) agglutinated foraminifera and their microhabitats from each core were analysed down to 10 cm. Foraminifera generally showed microhabitat preferences according to their morphological attributes. However, some morphogroups showed fundamentally different microhabitat preferences to those extrapolated in previous published studies (e.g., Jones and Charnock, 1985; Nagy, 1992; Van den Akker et al., 2000).

The major finding of this study was that morphogroup types and their microhabitats at each site broadly correspond to the quantity and quality of available organic matter to the deep sea benthos, which changes in function of water depth and distance from the shore. For palaeoenvironmental purposes we present a revised version of the Van den Akker et al. (2000) morphogroup scheme, combined with the new data from the Portuguese margin. Broad changes in the relative numbers of morphogroups may be sensitive enough to interpret subtle changes in palaeoenvironment. Correspondence Analysis (CA) and Cluster Analysis using PAST analytical techniques were used to statistically cluster samples that characterise certain species assemblages which may also correspond to different sediment facies. We adapt the same methodology to measure the relationship between samples of different lithologies and associated morphogroups. To test the groupings in a geological context it is hoped to present at this meeting some specific examples of interpretation from actual case histories based on cored data from wells. We plan to illustrate the utility of the technique by application to data sets from deep water fan systems within the Cretaceous Atlantic margin, where knowledge of palaeoenvironments and sedimentation rates contribute to the geological modelling of the basin and subsequent reservoir development potential.

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## StrataPlot - a Graphic Correlation Software

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The Graphic Correlation method was developed by Alan Shaw in the late 1950's with the aim to solve stratigraphic problems for which traditional stratigraphy could not provide a solution due to limited resolution. Shaw's original work was published for the first time in his book "Time in Stratigraphy" (1964). The methodology of graphic correlation is rather simple. However, utilization of its full potential requires a large archival database of stratigraphic ranges composited from hundreds to thousands of sections. Construction of such a Composite Standard Database involves a long-term, dedicated collection effort (Platon, 2007). Graphic correlation analysis starts with selecting the most complete available section called the standard reference section (Olin Mann and Lane, 1995). Data from a second best section is then composited via graphic correlation to the reference section. The resulting integration represents the first step towards a composite standard, (Platon, 2007). StrataPlot software application was built for the storage, retrieval, and graphing of biostratigraphic datums. StrataPlot is a stand-alone, Windows-based application that employs the graphic correlation procedure first described by Shaw (1964). The major output of this software consists of a graph that displays the first and last stratigraphic occurrences of fossil species that are in common between an analyzed section and a composite-stratigraphic database representing composited stratigraphic ranges from hundreds or thousands of individual localities. When a new section is analyzed, datums are graphed against a selected composite standard. A successful interpretation results in the analyzed section becoming part of the composite standard against which future sections will be calibrated. StrataPlot is a dynamic system that continually refines its composite standards as the user adds more stratigraphic information. StrataPlot provides a large number of user-friendly, "on-screen" operations that greatly improve the efficiency of the interpretation process. Data from over 2000 global research localities analyzed by Amoco Exploration & Production and later donated to the University of Utah in 1999 by BP-Amoco were loaded in StrataPlot's database (Platon and Sikora, 2005).

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## Recent data on the Upper Cenomanian foraminifers and biostratigraphy of the northern district of Western Siberia

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The Cenomanian deposits of almost the whole territory of Western Siberia are represented by continental facies. They enclose mainly spore-and-pollen complexes, foliar vegetation, and charred plant remains. Formerly, in the northern part of this region, within the Tazovskaya and Purpeyskaya districts, late Cenomanian-Turonian foraminifers were originally studied and two upper Cenomanian microfaunal zones were established: the *Trochammina wetteri* – *T. subbotinae* and the lower *Verneuilinoides kansasensis* zone (Podobina & Tanachova, 1967). Both of these zones are characterized by almost identical composition, and so at present, when studying the Van-Eganskaya sections, they were combined into one zone: the *Trochammina wetteri tumida* – *Verneuilinoides kansasensis* zone. It is lithologically composed of dark-gray, almost black clays of a small thickness (10-15 m) confined to the top of the Uvatskian Horizon (Podobina, 2000, 2009). It has been ascertained that the species composition of this zone in the West Siberian Province is much similar to that of Canadian Province (northern Canada and northern Alaska), confined commonly to the Arctic paleobiogeographical Realm (Podobina, 1995; Wall, 1967; Tappan, 1962). Over many years after the investigation of Cenomanian foraminifers and biostratigraphy in the Tazovskaya and Purpeyskaya areas (Podobina & Tanachova, 1967), there have been no reports on studies of fossils of marine organisms, specifically the Cenomanian foraminifers from the northwestern Siberia. Later, the report by V.A. Zakharov et al. (1989) was published, regarding the discovery of the marine Cenomanian based on the finds of mollusks in the north of Siberia. This work describes the section (transitional strata) of the Cenomanian-Turonian in northern Siberia (the Nizhnyaya Agapa River, northeast of the town of Dudinka). The upper Cenomanian was established by the finding of the mollusks *Inoceramus pictus* Sowerby and the Lower Turonian by *Inoceramus labiatus* (Schlotheim). No microfaunal forms or micropaleontological remains were discovered.

Presently, the sufficient data have been obtained by the present author for studying the late Cenomanian foraminifers from the top of the Uvatskian Horizon within seven sections of the Van-Eganskaya area situated northwards the latitudinal flow of the Ob' River in the central part of Western Siberia. Rocks containing these forms are almost uniform lithologically: gray-coloured silty-sandy deposits. The foraminiferal assemblages are of poor systematical composition and mainly represented by insufficiently well preserved, coarse- and medium-grained agglutinated quartz-siliceous tests. Only in one section (borehole 2031, depth 945.0 m), in the clayey rocks of the Uvatskian Horizon underlying the Turonian clays of the Kuznetsovskian Horizon, well preserved foraminiferal tests were found, entering the *Trochammina wetteri tumida* – *Verneuilinoides kansasensis* Assemblage of the upper zone. In the subjacent deposits of this section (borehole 2031), poorly preserved tests were encountered characteristic for the assemblages of all seven borehole sections of the upper Cenomanian.

In the rocks confined to the lower part of the upper zone, the clayey beds were mainly traced indicating the deepening of the basin with the encroaching Boreal transgression. The more highly evolved forms of the order Ataxophragmiida, including tests of the genus *Gaudryinopsis* were detected from these beds. At the same period the foraminifers evolved,

composing the *Trochammina wetteri tumida* – *Verneuilioides kansasensis* Assemblage; the beds containing this assemblage were distinguished as the upper zone of the same name.

As a whole, the assemblage of this upper zone is impoverished and composed of the following characteristic species: *Labrospira rotunda* Podobina, *Haplophragmoides variabilis* Podobina, *Ammobaculites wenonahae* Tappan, *Haplophragmium ivlevi* Podobina, *Ammoscalaria senomanica* Podobina, *Spiroplectammina longula* Podobina, *Trochammina wetteri* Stelck & Wall subsp. *tumida* Podobina, *Verneuilioides kansasensis* Loeblich & Tappan.

The second assemblage of the Upper Cenomanian lower zone *Saccammina micra* – *Ammomarginulina sibirica* from the sections of the Van-Eganskaya area is characterized by a somewhat different species composition than that of the superjacent one. The lowermost beds of this zone contain primitive foraminifers of the genera *Rhabdammina*, *Psammosphaera*, *Saccammina*, and *Hyperammina*. The presence of primitive forms is indicative of the beginning of the Late Cenomanian Boreal transgression, which did not reach the latitudinal flow of the Ob' River. Judging by the upward rocks and microfauna of the lower zone, an alternation of transgressive and regressive cycles occurred in the process of the Late Cenomanian Boreal transgression. The beds containing primitive forms of this zone alternate with beds containing coarse-grained tests of the relatively highly evolved taxa belonging to the families Haplophragmoididae (genera *Labrospira*, *Haplophragmoides*) and Haplophragmiidae (genera *Ammomarginulina*, *Flabellammina*).

The combined foraminiferal assemblage of this zone was established, including the following species: *Psammosphaera laevigata* White, *Hippocrepinella oblongiovalis* Bulatova, *Saccammina micra* Bulatova, *S. orbiculata* Bulatova, *S. scabra* Bulatova, *S. testideformabilis* Bulatova, *S. sphaerica* (M. Sars), *Crithionina dubia* Bulatova, *Thurammina papillata* Brady, *Hyperammina aptica* (Dampel & Mjatluk), *Reophax inordinatus* Young, *Trochamminoides ivanetzi* Podobina, *Labrospira rotunda* Podobina, *Haplophragmoides variabilis* Podobina, *Ammobaculites wenonahae* Tappan, *Ammomarginulina sibirica* Podobina, *Ammoscalaria senomanica* Podobina, *Flabellammina acuminulata* Podobina, *Trochammina wetteri* Stelck & Wall subsp. *tumida* Podobina. Besides, there were encountered species of sparse secreted calcareous forms of the genera *Valvulineria*, *Eponides*, *Gavelinella*, *Cibicides*, *Cibicidoides*, *Praebulimina*, *Bolivina*, *Heterohelix*. The species composition of this assemblage is characterized by a predominance of diverse primitive and sparse, very small secreted calcareous forms. Numerous foraminifers of two zones specified above have their analogues and vicariants in the Cenomanian deposits of the Canadian Province.

The studies on foraminifers from seven borehole sections revealed the constant increase of transgression in the late Cenomanian (lower and upper zones), causing deepening of the basin. However, these depths were relatively moderate and did not surpass the range of depths characteristic for the upper part of the modern shelf. This is shown by the predominance of beds with coarse-grained, inadequately preserved agglutinated tests. Along with the above-indicated forms, sparse secreted calcareous tests were encountered in some interbeds, especially in the lower zone.

The foraminifers of the assemblages are assigned to the following orders: Ammodiscida (superfamily Haplophragmiidea, families Haplophragmoididae and Haplophragmiidae), Textulariida (family Textulariidae), Ataxophragmiida (families Trochamminidae and Ataxophragmiidae), Rotaliida (families Discorbidae and Anomalinidae), Buliminida (family Buliminidae) and Heterohelicida (family Heterohelicidae). They are

predominated by taxa with an agglutinated wall, and secreted calcareous forms are sparse; the forms are comparatively small and rare, they are mainly encountered in rocks of the lower zone.

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## The record of Toarcian Oceanic Anoxic Event by agglutinated foraminiferal morphogroups from Northern Siberia

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The Early Toarcian Oceanic Anoxic Event (T-OAE) was one of the most important environmental changes of the Mesozoic, resulting in a mass extinction event of benthic groups in marine ecosystems (Wignall et al., 2005). Typically, the T-OAE is characterized by the record of organic-rich sediments associated with a negative excursion in  $\delta^{13}\text{C}$  coincident with a sea-level rise (from Jenkyns and Clayton 1997 to Suan et al., 2011). The main aspects of the T-OAE on foraminiferal assemblages are well documented in low latitudes of Western Tethys domain but few data are available from high latitudes. The analysis of foraminiferal life-habits is a useful tool for interpreting oxygenation and nutrient availability. This research is focused on the analysis of foraminiferal assemblages for interpreting the incidence of the T-OAE in benthic habitats from North Siberia.

The Kelimyar River section exposes a Pliensbachian-Toarcian marine succession (28.2 m-thick) composed by siltstones and sandy siltstones deposited close to the Early Jurassic North Pole in a relatively deep shelf environment (middle sublittoral zone) (Nikitenko, 2008). The upper Pliensbachian corresponds to the Kyra Formation and the Toarcian correspond to Kelimyar Formation. The succession is characterised by a condensed *antiquum* Biozone comprising few centimeters. The beginning of the *falciferum* Biozone is represented by the Kurung Member with finely laminated black shales and high values of total organic carbon (TOC, 6 wt.%) and a negative carbon isotopic excursion. The upper part of the Kelimyar Formation has TOC values < 1wt.% and higher values of  $\delta^{13}\text{C}_{\text{TOC}}$  (Suan et al., 2011).

The foraminiferal assemblages consist of benthic forms belonging to the suborders Textulariina, Lagenina and Robertinina. The foraminifera are mainly agglutinated and secondarily calcareous-perforated test forms, comprising 30 genera (18 agglutinated, 11 calcitic hyaline and 1 aragonitic hyaline). Eight morphogroups have been differentiated.

MG-A: forms with tubular unilocular shells and inferred epifaunal suspension-feeding habit (*Hyperammina* and *Jaculella*).

MG-B: globular unilocular shells, including epifaunal, passive depositivorous (*Lagenammina*, *Tolypammina* and *Saccammina*).

MG-C: elongated, subcylindrical, multilocular species, with infaunal detritivorous scavengers (*Ammobaculites*, *Bulbobaculites*, *Reophax*, *Spiroplectammina* and *Verneuilinoides*).

MG-D: spiral multilocular species living as detritivorous epifauna (*Ammoglobigerina*, *Evolutinella*, *Kutsevella*, *Recurvoides* and *Trochammina*).

MG-E: flattened taxa with proloculus and a spiral or irregular chamber, adapted to an epifaunal to phytal, herbivorous and detritivorous (*Ammodiscus*, *Glomospira* and *Glomospirella*).

MG-G: aragonitic taxa with a plano-convex trochospiral test, being seaweed epifaunal grazing herbivores (*Conorboides*).

MG-J: calcitic elongated multilocular shells with shallow infaunal life style (*Anmarginulina*, *Astacolus*, *Dentalina*, *Eoguttulina*, *Globulina*, *Ichthyolaria*, *Marginulina*, *Nodosaria*, *Palmula* and *Pyrulinoides*).

MG-K: biconvex, planispiral and multilocular forms being epifaunal to deep infaunal, active deposit-feeder (*Lenticulina*).

The mid of the late Pliensbachian was characterized by the dominance of epifauna represented mainly by *Trochammina* and secondarily *Conorboides*, *Ammodiscus*, *Hyperammina*, *Glomospirella* and *Lagenina*. Calcitic and aragonitic foraminifera are present but with decreasing trends. Considering morphogroups, the foraminiferal assemblage is dominated by MG-D, MG-G, MG-E and MG-A. The abundance of foraminifera is relatively high (~ 60 specimens/100 g). The  $\alpha$ -diversity index also decrease from 5 to 2. The rest of the late Pliensbachian is characterised by dominance of *Trochammina*, the record of *Ammodiscus*, *Hyperammina*, *Reophax* and *Kutsevella*, as well as increasing values of *Glomospira* and *Recurvoides*. The main morphogroups are the same than in the first stratigraphic interval but MG-G is not recorded. Calcitic hyaline tests also disappear. Respect to the base of the section studied the abundance of foraminifera is higher but showing a decreasing trend in the top of the Pliensbachian. The  $\alpha$ -diversity index and the number of genera follow in a decreasing trend from the bottom of Kelimyar section (values usually < 2).

The lowermost part of the Lower Toarcian in this section (exactly the *antiquum-falciferum* biozone boundary) is characterised by an abrupt increase of TOC (maximum 6 wt.%) and a negative carbon isotopic excursion of 6‰ ( $\delta^{13}\text{C}_{\text{TOC}}$  of -32‰, Suan et al., 2011). These values persist 1.4 m over the Pliensbachian-Toarcian boundary. The base of the Kurung Member (Kelimyar Formation) is characterised by the disappearance of *Ammodiscus* and *Kutsevella*. The assemblage is dominated by increasing *Trochammina* and *Hyperammina* and secondary *Glomospira* and *Bulbobaculites*. The onset of the black shales deposition is marked by an abrupt decrease in foraminiferal abundance (12 specimens/100g) and a rapid recovery (275 specimens/100g), lead by *Trochammina* and also MG-C together with diversity decrease. TOC values are still high (from 1.5 to 4.0 wt.%) in the rest of the Kurung Member (upper part of *falciferum* Biozone and lower part of *commune* Biozone). The lower part of this stratigraphic interval is marked by relative increase of infaunal forms like *Reophax* and *Bulbobaculites* (MG-C), but the main feature of this interval is the decrease in *Trochammina* and *Hyperammina* and the local abundance of *Saccamina*, *Tolypamina* and *Evolutinella*. Foraminiferal abundance drastically decreases, and some levels are almost barren (1 genus).

Overlying the Kurung Member, the Kelimyar Formation shows TOC values < 1 wt.%. Abundance of foraminifera increases upwards. The assemblage is characterised by increasing percentages of *Ammodiscus*, *Trochammina*, *Lenticulina* and *Verneulinoides*. The top of the *braunianus* Biozone coincides with a peak in infauna represented by *Lenticulina* (MG-K). Other *Lagenina* also increase in this boundary. *Saccamina* and *Bulbobaculites* disappear in the Upper Toarcian. *Hyperammina*, *Glomospirella*, *Glomospira* and *Evolutinella* are locally abundant. A bloom of *Trochammina* has been recorded in the uppermost Toarcian.

## Interpretation

Benthic habitat fluctuations in nutrient availability and oxygenation rate are limiting palaeoenvironmental parameters, exerting considerable control on the composition and relative abundance of foraminiferal assemblages.

The Late Pliensbachian is represented by a foraminiferal assemblage dominated by epifauna (mainly MG-D and MG-E), with high content of *Trochammina*, but with a progressive diminution in diversity and number of genera. This suggests an unfavourable microhabitat for infaunal forms probably with salinity fluctuations. *Trochammina* has been proposed as opportunist epifaunal taxa that tolerate salinity fluctuations (Nagy et al., 2010). The decreasing proportions of aragonitic and calcitic hyaline tests confirm the progressive unstabilization of the benthic environment.

The beginning of the Lower Toarcian (*antiquum-falciferum* biozone boundary) is correlated with the transgression of the T-OAE (increase of TOC and negative carbon isotopic excursion). This event is marked by an abrupt decrease on abundance of foraminifera and diversity, indicating dysoxic conditions in the sea-bottom. Probably, totally anoxic conditions were not developed due the record of benthic foraminifera as well as monospecific associations of thin-shelled bivalves and thin-shelled ostracods (Nikitenko and Mickey 2004). In foraminifera, only r-strategist *Trochammina* shows a rapid increase after the debut of the black shales, congruent with the relation of this opportunistic genus with high TOC and poorly oxygenated sediment water interface (Bąk 2000; Reolid et al., 2010). Without tough competition, *Trochammina* rapidly reproduced and augmented their population. During the rest of the Kurung Member, high TOC (from 1.5 to 4.0 wt.%) and probably a poorly oxygenated sediment-water interface persist. In spite of the local increase of infaunal forms of the MG-C and MG-B, the main feature of this interval is the diminution of *Trochammina* and the dramatic decrease of abundance of foraminifera and diversity.

After the Kurung Member the favourable conditions come back with the oxygenation of the bottom, as indicate the diminution of TOC values (< 1 wt.%) and the increasing abundance of foraminifera (mainly MG-E), including infaunal forms like *Lenticulina* and *Verneuilioides*. Except in the case of MG-E, the proportions of other morphogroups and genera strongly fluctuates in the upper Toarcian, probably indicating not stable conditions as corroborates the bloom of *Trochammina* at the topmost Toarcian.

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## Regional diversity of agglutinated foraminifera from western and eastern Venezuela (Neogene to Pliocene). A preliminary report

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The present study describes the Early Miocene to Pliocene diversity of agglutinated foraminifera from three different sections in Venezuela. These include: 1) Agua Salada Group, western Venezuela (Falcon Basin), 2) Carapita Formation Eastern Venezuela Basin (EVB) and 3) Offshore Venezuela (Tres Puntas, Cubagua and Cumana formations). The main objective of this study is to establish a precise correlation of these stratigraphic units using well-preserved agglutinated foraminifera from the AGS and Carapita outcrops and to compare them with poorly preserved microfaunas from the exploration wells.

Age determinations were possible using planktonic foraminifera interpolated or adapted from the Cenozoic tropical planktonic foraminiferal scheme of Wade et al. (2011). To determine the general depth distribution I have used classical publications such as Renz (1948), Phleger and Parker (1951), Bandy (1967), van Morkhoven et al. (1986), Whittaker (1988), Robertson (1988) and Kaminski and Gradstein (2005). Terminology and numerical bathymetric estimates were taken from van Morkhoven et al. (1986).

Important studies have been made on the Agua Salada Group (ASG). H.H. Renz (1948) was the first to chart the Neogene diversity of agglutinated foraminifera from the Falcon Basin (ASG) and compare them with different localities from the Caribbean. The type section of the Agua Salada Group is located northwest of the town of Chichiriviche between the locality of El Pozon and The Menes of Acosta, Falcon State.

In the EVB the Carapita Formation is ~ 4500 to 6000 m thick in outcrops, extending from northeastern Anzoátegui and North of Monagas States to the Gulf of Paria. This formation is both an important oil reservoir towards the east and the main seal rock for the Late Oligocene to the Early Miocene reservoir in the north of Monagas State. Important studies have been made on the Carapita Formation by Hedberg (1937), Franklin (1944) and a series of internal/unpublished foraminiferal reports by the National Oil Company of Venezuela (PDVSA) have been carried out by Fournier (1957), Jouval and Villain (1986), Saint Marc (1988), De Cabrera and De Macquhae (1990) and Sanchez (2006, 2010).

In addition samples from 20-exploration wells located offshore Venezuela (Ensenada of Barcelona, West and East Blanquilla, and North of Paria) have been analyzed in this work.

In the studied area the ASG spans the Late Oligocene to Late Miocene (zones O6 to M12) and the agglutinated foraminifera assemblages are characterized by: *Ammobaculites* cf. *strathernensis*, *Ammodiscus parianus*, *Glomospira charoides*, *Cyclammina cancellata*, *Haplophragmoides carinatum*, *H. coronatum*, *H. emaciatum*, *Textularia abbreviata*, *T. leuzingeri*, *T. panamensis*, *T. pozonensis*, *Textulariella miocenica*, *Trochammina pacifica*, *Valvulina flexilis*, *Valvulina jacuarensis* and *V. pachyhellus*. On the other hand, the Carapita Formation in the outcrop section spans Early to Middle Miocene (zones M3 to M6) and the agglutinated foraminifera assemblages are distinguished by: *Dorothia brevis*, *Cyclammina cancellata*, *Haplophragmoides carinatum*, *Valvulina flexilis*, *Alveovalvulinella pozonensis*, *Glomospira charoides*, *Valvulina flexilis*, *Paratrochamminoides irregularis*, *Valvulina jarvisi*



and *V. spinosa*. Finally, the stratigraphic section studied from offshore Venezuela (20-exploration wells) spans Early Miocene to Pleistocene (zones M3 to PT1) and the agglutinated foraminiferal assemblages are followed by: *Cyclammina cancellata*, *C. acutidorsata*, *Valvulina flexilis*, *Reticulophragmium venezuelanum*, *Bathysiphon carapitanus*, *Glomospira charoides*, *Alveovalvulinella pozonensis*, *Valvulina flexilis*, *Valvulina jarvisi*, *Trochammina pacifica*, *Ammodiscus parianus* and *Haplophragmoides carinatum*.

Paleobathymetric interpretation suggests that the Agua Salada Group, Carapita and Tres Puntas formations were deposited at upper to middle bathyal depths ( $\geq 200$ -1,000 m).

Unexpectedly, I found that the Lower Miocene to Pliocene sections are highly discontinuous, with hiatuses as long as 4 Myr. The Miocene/Pliocene boundary is discontinuous and diversity of agglutinated foraminifera increased from the Middle Miocene to the Early Pliocene rather than decreasing the benthic foraminifera in the Early Pliocene.

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**Palaeoenvironmental and palaeogeographic implications of Campanian agglutinated foraminifera from the Lomonosov Ridge (ACEX, IODP Expedition 302)**

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On the Eurasian side of the Arctic region, the record of Late Cretaceous foraminifera is so far published only from Western Siberia (e.g. Podobina, 2000) and the SW Barents Sea (Setoyama et al., 2011a, b). Most of our knowledge on Arctic foraminifera so far comes from the studies of the Canadian and North American Arctic regions (e.g. McNeil, 1997). This is mainly due to a hiatus spanning for most of the Upper Cretaceous in Spitsbergen and in the Northern and Eastern Barents Sea. These known Arctic faunas show no or only very low similarities to each other, and represent their own palaeobiogeographic entities, the Western Siberian fauna, the cosmopolitan deep-water agglutinated foraminiferal fauna and the Canadian–North American Arctic fauna, though in many Late Cretaceous palaeogeographic reconstructions of the area, open marine connections are depicted. The Upper Cretaceous sequence (Campanian) was recently recovered from the Lomonosov Ridge, which was a part of the Barents–Kala margin at that time, during the Arctic Coring Expedition (ACEX), IODP Expedition 302. The drilling site is located between the Canadian–North American Arctic, the Barents Sea and Western Siberia, and thus the analysis of Late Cretaceous foraminiferal assemblages of the Lomonosov Ridge may shed light on the faunal connections of the Arctic regions and provide data for a more precise geographic reconstruction of the Arctic region during that time. With these purposes, we analysed four samples from lithostratigraphic Unit 4 (Campanian) of the Lomonosov Ridge recovered during ACEX.

The foraminiferal assemblages of Unit 4 are composed completely of agglutinated foraminifera with 29 taxa including three new species. The assemblages are highly dominated by recurvoids and trochamminids. A shallow, restricted, probably brackish environment is inferred from the relatively low diversity and the high dominance of the assemblages. A few species in common with the Late Cretaceous fauna of the Beaufort-Mackenzie Basin and Western Interior Sea are recorded in the Lomonosov Ridge assemblages, whereas no common species is identified with the West Siberian and SW Barents Sea fauna. Between the latter two regions, only several cosmopolitan deep-water species are shared. These indicate some faunal communication between the Canadian–North American and the Lomonosov Ridge areas, and their isolation from the coeval Eurasian fauna in Western Siberian and SW Barents Sea during the Campanian. Therefore, it is likely that the Arctic Ocean was isolated from the North Atlantic faunal province with very limited or no marine connections between the Arctic, North Atlantic and Western Siberia over the Barents Shelf area during the time period. We also suggest that the Late Cretaceous palaeogeographic reconstructions of the Barents Sea region depict marine connections that may have not existed at all or were extremely restricted.

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## **Morphogroup analysis of Late Cretaceous–Paleogene agglutinated foraminifera from Indian Harbor M-52 well, Labrador Sea**

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The Late Cretaceous foraminiferal assemblages of Indian Harbor M-52 well drilled in the Hopedale Basin in the Labrador Sea were previously investigated by Gradstein and Berggren (1981), Kuhnt et al. (1989) and Gradstein et al. (1994). Classical deep-water agglutinated foraminiferal (DWAF) biofacies, namely the flysch-type fauna (Gradstein and Berggren, 1981) and the high-latitude slope assemblages (Kuhnt et al., 1989), were defined, in part, based on the Late Cretaceous assemblages from the well. The quantitative data of the assemblages were, however, not published in the original studies, and the description of the assemblages given was qualitative due to the large number of wells examined. This study investigates a different set of samples from the Upper Cretaceous–Paleogene sequence recovered by M-52 well from the one analysed previously with the main objective of a semiquantitative palaeoenvironmental analysis of the foraminiferal assemblages using morphogroup analysis.

The foraminiferal assemblages are consistently dominated by DWAF, and highly diversified. Calcareous benthic and planktic foraminifera are often rare, while the former being more common than the latter. The calcareous specimens are invariably etched indicating early diagenetic dissolution. The interval, which was previously estimated as Maastrichtian, is now regarded as the early–middle Campanian (10,750–10,660 feet) based on the concurrence of *Caudammina gigantea* and *Uvigerinammina jankoi*. The age of the overlying sequence up to 10,480 feet is estimated to be late Campanian to Maastrichtian, corresponding to the *Caudammina gigantea* zone of Geroch and Nowak (1984).

A mesotrophic, well-oxygenated environment with bottom currents was inferred from the presence of all morphogroups, the consistent dominance of tubular forms (M1) and the common occurrence of infaunal forms (M4). The relatively high diversity and the dominance of DWAF, especially tubular forms, indicate a possibly lower–middle bathyal setting for the Alexis and Markland formations. The frequent occurrence of *Reticulophragmium*, *Budashevaella* and streprospirial forms in the Cartwright Formation, which are characteristic of “Foraminiferal Biofacies 3” in the Eocene outer neritic–upper bathyal facies in the Barents Sea (Nagy et al., 2000), together with a general decreasing trend in diversity and the relative abundance of M1, indicate regional shallowing which may well be related to the Selandian–earliest Thanetian regression suggested by Dickie et al. (2011), or the sediments in the samples are derived from cavings.

The interval between 10,750 and 10,690 feet is thought to belong to the Valanginian–Albian volcanic Alexis Formation. The foraminiferal assemblages are, however, dominated by Late Cretaceous DWAF, and this suggests that this sequence may belong to either the Markland Formation or the transitional unit between the Bjarni and Markland formations described by Dickie et al. (2011).

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## **Palaeobiogeography of Late Cretaceous agglutinated foraminifera in the Arctic, Atlantic and Tethyan regions**

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The wide geographic distribution of Late Cretaceous deep-water agglutinated foraminifera (DWAF) has been demonstrated by various studies (e.g. Kuhnt et al., 1989; Kuhnt and Moullade, 1991) in the Tethyan–Atlantic regions. Recently, we analysed Late Cretaceous foraminiferal assemblages of the southwestern Barents Sea (Setoyama et al., 2011a, b) and the Lomonosov Ridge (Setoyama et al., 2011c), whose taxonomy and compositional data were never published before. The taxonomic data from these studies provided us an opportunity to investigate the geographic extent of the cosmopolitan DWAF in the high palaeolatitudes, and also the affinity between the fauna of circum-Arctic regions of which on the Eurasian side only a little is from Western Siberia. In order to estimate the faunal similarity between different regions throughout the Tethyan–Atlantic–Arctic transect, the data set was compiled from direct observation of assemblages (the Lomonosov Ridge, SW Barents Sea, Norwegian Sea and Labrador Sea) and data from published literature from 17 regions. It consists only of the presence/absence data so as to discount palaeoenvironmental signatures. Data from the SW Barents Sea and the Norwegian Sea are biostratigraphically calibrated using dinocysts.

Although the data set includes only the presence/absence data, the agglutinated foraminiferal assemblages are distinguished largely by environments and regions by cluster analysis suggesting that some taxa are confined to certain environments and possibly physically isolated areas. Clustering of the assemblages is less ambiguous on the basis of the genus data than the species data. The results of correspondence analysis shows a clear separation of the shallow-water Arctic assemblages, the chalk fauna, the Western Siberian fauna and the Atlantic–Tethyan deep-water fauna, whose subgroups largely correspond to the classical DWAF biofacies (Kuhnt et al., 1989). Very limited or no marine connections between the Arctic (Canada, North America and Lomonosov Ridge), North Atlantic and Western Siberia over the Barents Sea are inferred from the separation of the Canadian–North American and the Lomonosov Ridge Arctic assemblages from the Western Siberian and the SW Barents Sea fauna. A majority of calcareous-agglutinated foraminiferal species are confined to the Tethyan and Atlantic chalk facies where calcareous benthic and planktic foraminifera are also often well-preserved. The availability of calcium carbonate and the corrosiveness of pore waters, thus, appear to be major controlling factors imposing on calcareous-cemented taxa the limited palaeogeographic distribution and occurrence in the fossil records of the northern high latitudes. Although the variability in food influx and oxygenation of bottom waters exert influence on the composition of assemblages as reflected by DWAF biofacies, their effect on the palaeobiogeographic distribution of Late Cretaceous DWAF is rather local. In contrast to calcareous-cemented taxa, organic cemented DWAF are, in general, cosmopolitan, and it seems that they occur wherever environments are tolerable for them.

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## **Agglutinated foraminiferal assemblages across the Oligocene-Miocene transition in northwestern Transylvanian Basin**

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The Oligocene-Miocene boundary was placed in the north-western Transylvanian Basin in the Vima Formation based on planktonic foraminifera (*Globigerina ciperoensis*, *Globigerinoides primordius*) and calcareous nannoplankton assemblages (Popescu, 1975; Mészáros, 1991). Late Oligocene agglutinated and calcareous foraminiferal assemblages were described by Iva and Popescu (1971).

The section of Fântânele (Vima Formation) has been chosen in order to characterize the Oligocene-Miocene transition. The deposits consist of laminated and compact shales with high proportions of organic material, with rare intercalations of sandstones. Foraminiferal assemblages are usually well preserved but in some cases the preservation is poor and deformations of individuals have been observed. Biodiversity is relatively low along the entire section, decreasing in younger sediments. Morphogroup analysis (based on Nagy et al., 1995, and Van den Akker et al., 2000) and taxonomical study resulted in identification of three main agglutinated assemblages and a few transitional, alternating along the section. Early assemblages are dominated by shelf assemblages with small calcareous benthics. These are followed by the *Reticulophragmium* assemblage, lacking planktonic and calcareous benthic individuals, probably associated with the change of CCD level. The following *Spiroplectamina carinata* assemblage, associated with small planktonic and various sized calcareous benthic foraminifera specific to the shelf (*Bulimina* sp., *Uvigerina* sp., *Cibicidoides* sp.), suggests periods with increase in oxygen and decrease in nutrient supply. Assemblages with *Rhabdammina* spp. appear in the middle and upper part of the section and indicate upper bathyal environments with low organic matter flux, supported by the presence of large *Uvigerina* species. Transitional assemblages contain agglutinated foraminifera of different morphogroups and have a sporadic occurrence. Reappearance of the *Reticulophragmium* assemblage, together with calcareous benthics from oxygen minimum zones and the last occurrence of agglutinated foraminifera have been recorded in the uppermost part of the section. The youngest assemblages are mostly represented by small calcareous benthics (*Bulimina* sp., *Bolivina* sp.) indicating low oxygen levels.

Planktonic foraminifera probably correlate the lower part of the section with the Late Oligocene, while the presence of *Globigerina ciperoensis*, *Globigerina ottnangiensis*, *Tenuitellinata selleyi* a.o. in the upper part of the section probably indicate the Early Miocene.

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## The life cycle of *Entzia* (Foraminifera) in the salt marsh at Turda, Romania

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The study is focused on the modern agglutinated foraminifera living in a small salt marsh, in Turda, Romania. This marsh owes its presence to the Miocene deposits from Transylvania Basin, and is located less than a kilometer from the famous Maria Theresa Salt Mine. The studied area is the only place so far in Romania, a living *Entzia* population has been found. The future evolution of this *Entzia* population is endangered by human activity.

Earlier records of the *Entzia tetrastomella* were mentioned by Daday (1884) from a locality in the city of Deva that no longer exists. The salt marsh in Deva is now beneath a health clinic car park.

The samples for this study were collected monthly in order to follow the life cycle of the *Entzia* population. This species can be found today among the roots of the halophyte plants, in the uppermost centimeters of the mud. Two samples were collected at fixed time intervals for the purpose of monitoring the *Entzia* population and measuring different parameters, such as humidity, conductivity, salinity, pH, and temperature. The samples were stored for 24 hours in 40% alcohol (Vodka) with Rose Bengal, in order to distinguish between dead and live specimens. To document the entire life cycle of the species the following analyses have been carried out: test size, dynamics of population, number of chambers, and ratio between live and dead specimens.

Based on the obtained measurements (test size and number of chambers) the largest specimens have been found in December–January and July–August when the asexual reproduction took place; the smallest specimens appeared in March–May when sexual reproduction can be presumed. This pattern is also sustained by the numbers of live and dead specimens (in January and August).

## **Agglutinated benthic foraminifera during ocean acidification: what holds them together?**

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Deep-sea benthic foraminifera suffered rapid, severe extinction at the beginning of the Paleocene-Eocene Thermal Maximum (PETM), a period of extreme global warming. Such extinctions are rare, because the habitat of deep-sea benthic foraminifera is very large and their motile propagules enables them to re-migrate quickly from refugia after local-regional disappearance (e.g., Thomas, 2007). The cause(s) of the PETM extinction thus must have been global. Warming, de-oxygenation, ocean acidification, changes in export productivity or some combination of these have all been implicated (Thomas, 1998; Alegret et al., 2010; Speijer et al., 2012; Winguth et al., 2012). Acidification, however, might have been a more important driver of the extinction than thought until recently.

First, ostracods (metazoans which share deep-sea environments with benthic foraminifera) did not suffer major extinction during the PETM (Webb et al., 2009). Active metazoans are more sensitive than protists to oxygen depletion, but marine ectothermic metazoans with an extensive extracellular fluid volume may be less sensitive to ocean acidification than protists (Melzner et al., 2009). This different sensitivity to acidification thus might explain the different response of foraminifera and ostracods to the PETM.

Second, at the rates of acidification estimated for the PETM, the effects of acidification are modeled as less severe at neritic than at bathyal-abyssal depths (Hoenisch et al., 2012), and the benthic extinction was much less severe at neritic than at bathyal-abyssal depths (Alegret and Ortiz, 2006; Speijer et al., 2012).

Third, with PETM ocean acidification, the lysocline and calcium carbonate compensation depth (CCD) in the oceans moved upwards. At depths below the lysocline (i.e., in a large part of the world's oceans) calcite saturation in pore waters may have risen as the result of carbonate sediment dissolution. Under such conditions, infaunal species calcifying from pore waters will experience less undersaturation than epifaunal species calcifying from bottom waters, and thus be under less stress (e.g., Brown et al., 2011). This difference in saturation of bottom and pore waters thus could explain the increase in relative abundance of infaunal taxa during the PETM observed at many sites. An increase in relative abundance of infaunal taxa during ocean acidification thus may be a proxy for acidification, and not for decreased bottom water oxygenation and/or increased food supply, in contrast to accepted use (e.g., Thomas, 2007).

We can test the hypothesis that acidification was an important cause of deep-sea extinction by studying extinction of agglutinated foraminifera during the PETM: obligatory calcite-cemented or calcite-particle using agglutinated foraminifera would be expected to suffer extinction at rates similar to those of calcareous foraminifera, whereas organic-agglutinated taxa would be expected to have preferentially survived. It has indeed been argued that the Deep-Water Agglutinated Foraminiferal assemblages (DWAF) commonly seen in flysch-settings, at least some of which occurred below the carbonate compensation depth and did not use calcite in test construction, suffered less severe extinction at the PETM

than calcareous taxa (Kaminski et al., 1996; Galeotti et al., 2004; Bak, 2004; Speijer et al., 2012). DWAF assemblages underwent widespread faunal turnover, including changes in relative abundance, dominance and diversity, with low-diversity post-PETM assemblages (the diminutive ‘*Glomospira*’ assemblage). The various authors disagree, however, on the severity of the extinction, and the interpretation of the environment of the assemblage dominated by the highly opportunistic *Glomospira*.

Agglutinated genera in mixed calcareous/agglutinated assemblages (*Clavulinoides*, *Tritaxia*, *Dorothia*, *Marssonella*, *Trochamminoides* and *Gaudryina*) suffered severe extinction during the PETM: if these taxa exclusively used calcite particles and/or calcite cement they would have suffered similar stress as calcareous species. These genera, classified in Suborder Textulariina or Order Textulariida, are said to use ‘particles cemented by calcite’, but there are few actual observations on the chemical composition of their cement. If the agglutinated taxa which became extinct during the PETM indeed all used calcite in test construction, the importance of acidification as cause of deep-sea extinction would be confirmed. If non-calcite using and calcite-using taxa suffered extinction to the same extent, other factors may have been more important, e.g., extinction of large taxa during warming because of the higher metabolic rates, thus higher food requirements. The study of wall composition of Paleogene agglutinated foraminifera thus may contribute significantly to our understanding of the ecological effects of high atmospheric levels of CO<sub>2</sub> through global warming and ocean acidification.

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## **Foraminiferal design: Morphogenesis of agglutinated chambers**

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Charles Darwin wrote to William Benjamin Carpenter in 1872 “The case of the three species of protozoan (I forget the names) which apparently select differently sized grains of sand, etc., is almost the most wonderful fact I ever heard of. One cannot believe that they have mental power enough to do so, and how any structure or kind of viscosity can lead to this result passes all understanding.” We are still amazed like Darwin was how foraminifera select grains and construct their shells. What do we know about it in 2012? Do we understand more?

We do know that agglutinated foraminifera as “unicellular organisms are superb builders of their houses, possessing the know-how to build using naturally occurring ‘bricks’ and ‘cements’ with enviable skill” (Ehrlich, 2010). Foraminifera are excellent architects implementing their shell designs by iterative growth of chambers with skills inherited from generation to generation. The problem is that it is still not clear how they do it.

A considerable progress in phylogenetic studies may direct us toward better understanding of evolutionary and morphogenetic relationships in Foraminifera. Recent molecular phylogenetic studies have shown that agglutinated foraminifera should not be treated as a monophyletic group any more (e.g., Pawlowski et al., 2003). It further means that the higher rank classification, presented by Loeblich and Tappan (1987, 1992), separating the foraminiferal orders based upon their shell composition, mineralogy and structure cannot be applied. Gross test morphology is a better approach for higher groups of foraminifera (e.g. Mikhalevich, 1998, 2000; Mikhalevich & Debenay, 2001).

It simply means that a test or shell design is more important than a fabric of its wall. Actually, in polythalamous foraminifera, the most characteristic feature is an overall chamber shape, which includes either tubular or globular forms. The same pattern of chamber shapes is observed both in agglutinated and calcareous foraminifera that implicates their similar evolutionary and morphogenetic origin. This conclusion comes from molecular phylogenetics (e.g., Pawlowski et al., 2003; Groussin et al., 2011) and from theoretical morphogenetic studies (Tyszka and Topa, 2005, 2007; Tyszka, 2006). If the same patterns of chamber morphologies are shared in agglutinated and calcareous foraminifera and both groups are phylogenetically relatively closely related, it might be assumed that both of them use similar morphogenetic structures and chamber formation strategies to achieve similar constructional results.

Most similar are bilocular or multilocular tubular foraminifera, including such groups like porcelanous miliolids, agglutinated rzehakinids and ammodiscids. All of them agglutinate their tubular chambers, but porcelanous foraminifera agglutinate their wall from internally secreted grains formed in vesicles as high Mg-calcite microneedles. In contrast, true agglutinated foraminifera construct their walls from foreign, external grains collected nearby. An overall shape of chambers is probably designed by dense anastomosing networks of microtubules covering organic templates with permanently open apertures during the chamber formation. Globular chambers are distinctly different because they are formed on a closed balloon-like, elastic structure, which is a template for a final chamber. Apertures in such

chambers are created at the end of chamber formation. The distance between successive apertures is usually minimized that contrasts with tubular chambers, which form the longest aperture-aperture distance.

Details of chamber formation in agglutinated foraminifera have not been extensively studied. The only exceptions are investigations conducted by H. Bender (1992) who observed and analysed *Textularia candeiana*, utilizing organic and calcitic cements for constructing its test. This biserial foraminifer builds alternation chambers, which grow in two rows. Chamber formation starts with collecting sediment grains by granuloreticulopodia and storing them around the aperture. Then a translucent cytoplasmic bulge is expanded and organic envelopment of agglutinated particles is created. The main problem is that there is no Primary Organic Sheet known from globular calcareous foraminifera. It is supposed that the Agglutinated Organic Composite (AOC) is an analogue structure, which is shaped before ultimate mineralization of the agglutinated wall by secretion of either organic matrix and calcitic crystals. Calcite cementation progresses from outer to inner wall (Bender and Hemleben, 1988; Bender, 1992). It is worthwhile to mention that the most stable organic lining in agglutinated foraminifera is the IOL, i.e. Internal Organic Lining. All other linings are quite chimerical and not always preserved (Gooday and Cloughera, 1989).

It is surprising that agglutinated and calcareous globular chambers follow a very similar morphogenetic path and probably employ similar morphogenetic structures based on cytoskeleton filaments, organic membranes, and various associated proteins. On the other hand, both groups are phylogenetically and morphologically related, therefore, similar morphogenetic procedures seem to be more than justified.

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## DWAF assemblages associated with turbidite depositional systems

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Paleocene deep-water agglutinated benthic foraminifera assemblages (DWAF) were studied in core samples from three wells of the Campos Basin, Brazil. DWAF dominate the recovered microfauna found in turbidite depositional system sediments (Ubatuba Formation, Geribá Member) bearing oil reservoirs. DWAF assemblage paleoecology is a strong tool used in paleoenvironmental reconstructions and in the documentation of paleoceanographic changes. Campos Basin Paleocene siliciclastic turbidite sediments were analyzed to see the DWAF assemblage (“*Rhabdammina* fauna”) response to different types of events (sea-level relative changes, of benthic foraminifera extinction event at the P/E boundary). The study’s objective presents an integrated framework of sedimentological, biostratigraphical and paleoecological data, focused mainly on regional and stratigraphical distribution analysis of DWAF assemblages in a turbidite depositional setting and the interpretation of their response to different events of apparent global expression during the Paleocene.

This studied Paleocene section was accumulated in a slope and deep basin depositional context, with hemipelagic sedimentation dominance, punctuated by gravitational sedimentation events, mainly integrated by hyperpicnal flux deposits comprised of sandstone and diamictite fans, deposited in sheets or infilling channels and small variable-size basins. Based on sedimentological, biostratigraphical and paleoecological data the Paleocene section was subdivided in the following units: lower (lower Paleocene), middle (lower-middle Paleocene) and upper (upper Paleocene).

Two principal DWAF biofacies were characterized in the studied interval, specially differentiated by the contribution of calcareous microfossil organisms. Biofacies A, totally dominated by agglutinated forms, and Biofacies B, with an abundance of agglutinated forms associated with variable proportions of calcareous taxa (benthic and planktic). The stratigraphical distribution of both biofacies shows good correlation with the lithofacies and reflects the depositional turbidite paleoenvironment. The DWAF assemblage attributed to “*Rhabdammina* fauna” dominates the biofacies A and B, and is composed of a group of taxa that shows relatively high diversity and variable abundance. The group of taxa with organic cement (*Hyperammina*, *Kalamopsis*, *Psammosiphonella*, *Bathysiphon*, *Rhabdammina*, *Rhyzamina*, *Tolypamina*, *Ammolagena*, *Saccamina*, *Ammodiscus*, *Glomospira*, *Rzehakina*, *Haplophragmoides*, *Recurvoides*, *Reticulophragmium*) is abundant, diversified and dominates the assemblages. The group with calcareous cement (*Clavulinoides*, *Dorothia*, *Gaudryina*, *Marssonella*, *Spiroplectamina*, etc.) presents lower abundance and diversification values than the previous groups.

The lower unit sediments (lower Paleocene) show a regular distribution for all the studied wells. Lithofacies composed of conglomerates and sandstones, and medium-fine sandstones characterize the turbidite system proximal and intermediate parts. The contact with the immediately following sequence is a regional erosive surface.

The microfauna associated with the hemipelagic deposits of parts of this unit were characterized by the occurrence of intervals dominated by the of the Biofacies A agglutinated forms, where *Kalamopsis*, *Bathysiphon*, *Psammosiphonella*, *Rhabdammina* *Hyperammina*,

*Ryzammina*, *Saccammina*, *Ammodiscus*, *Glomospira*, *Karrerulina*, *Verneuilinoides*, *Recurvoides*, *Haplophragmoides*, are abundant, and *Ammolagena*, *Subreophax*, *Tolypammina*, *Rzehakina*, *Marssonella*, *Dorothia*, *Clavulinoides*, *Spiroplectammina*, *Conotrochammina*, *Trochamminoides*, *Trochammina* are scarce. In this unit, the Biofacies A is intercalated with Biofacies B.

Biofacies B is represented by a more diversified assemblage integrated with well-diversified benthic calcareous (*Pyramidulina*, *Lenticulina*, *Fronidularia*, *Laevidentalina*, *Marginulina*, *Pseudonodosaria*, *Nodosaria*, *Bucherina*, *Oolina*, *Favulina*, *Stilostomella*, *Pseudovigerina*, *Bulimina*, *Aragonia*, *Loxostomoides*, *Coryphostoma*, *Guttulina*, *Ramulina*, *Pullenia*, *Stensioeina*, *Gavelinella*, *Anomalinoides*, *Gyroidinoides*, *Nuttalinella*, *Alabamina*, *Cibicidoides*, etc.) and planktonic (*Morozovella*, *Igorina*, *Subbotina*, etc.) taxa, with an expressive participation of the Biofacies A agglutinated taxa

The intermediate unit (lower-middle Paleocene) has a more restricted distribution (minibasins) and is relatively thicker than the previous unit, and includes the Barracuda reservoirs. The best represented lithofacies are composed of sandstones related to the proximal and middle parts of the turbidite system. The foraminiferal assemblages are dominated by the DWAF. In Biofacies A, *Kalamopsis*, *Rhabdammina*, *Psammosiphonella*, *Ammodiscus*, *Karrerulina*, *Haplophragmoides*, *Recurvoides*, *Trochamminoides*, *Reticulophragmium* are the most abundant taxa, and *Hyperammina*, *Dendrophyra*, *Rzehakina*, *Hormosina*, *Saccammina*, *Psammosphaera*, *Glomospira*, *Dorothia*, *Spiroplectammina*, *Reticulophragmium* and *Conotrochammina*, are scarce. In the Biofacies B, the calcareous taxa are represented by a few specimens of *Laevidentalina*, *Dentalina*, *Lenticulina*, *Pyramidulina*, *Lagena*, *Angulogavelinella*, *Cibicidoides*, *Stensioeina* and *Gyroidinoides*, always associated with abundant Biofacies A agglutinated forms.

The upper unit (upper Paleocene) has a regional expression and is characterized by intercalated of bioturbated fine-medium sandstones, silty and shale lithofacies, interpreted as the more distal part of the turbidite system.

In the bioturbated siltite and shales the benthic assemblage is exclusively composed of the abundant and well-diversified “*Rhabdammina* fauna”. In Biofacies A, *Ryzammina*, *Kalamopsis*, *Psammosiphonella*, *Rhabdammina*, *Tolypammina*, *Ammodiscus*, *Karrerulina*, *Recurvoides*, *Haplophragmoides* are abundant, and is in a continuum form in the interval, while *Saccammina*, *Psammosphaera*, *Hormosina*, *Subreophax*, *Ammolagena*, *Rzehakina*, *Glomospira*, *Glomospirella*, *Conotrochammina*, *Trochamminoides*, *Trochammina*, *Ammoanita*, *Spiroplectammina*, are scarcer. Biofacies B, only occurs in the interval lower levels where the calcareous taxa have little frequency (*Lenticulina*, *Nodosaria*, *Pyramidulina*, *Laevidentalina*, *Lagena*, *Bulimina*, *Stensioeina*, *Pullenia*, *Alabamina*, *Cibicidoides*, *Nuttallides*, *Gyroidinoides*, etc.), showing dissolution and fragmentation signals, until the complete disappearance of all the calcareous taxa.

The first event identified in the studied section was the important late Selandian sea-level eustatic variation. This event is represented by a regional unconformity that put it in contact with deep-water turbidite sediment dominated by a rich and diversified “*Rhabdammina* fauna”, with a unit composed of a more proximal and confined turbidite sediments where the “*Rhabdammina* fauna” is poorer. The extinctions of *Clavulinoides aspera*, *C. trilatera* and *Verneuilinoides polystropha* are related to this paleoenvironmental change.

The second event that affects the deep-water benthic foraminifera (BEE) is an extinction event frequently related to the Paleocene–Eocene Thermal Maximum (PETM). This extinction event influence on deep-water benthic calcareous and agglutinated foraminifera assemblages has been globally documented. The extinction of a large number of species is explained by the influence of global climatic and oceanic circulation changes. Among these changes, the sharp shoaling of the CCD, identified approximately at the Paleocene-Eocene transition, could be related with the massive extinction of the deep-water benthic foraminifera. Some calcareous and agglutinated benthic foraminifera species, whose extinctions are frequently related to the PETM or BEE events, configured a correlative event in the studied late Paleocene interval.

This event showing probably the effect of the CCD shoaling and the intensification of its corrosive effect occurs in two steps in the Campos Basin late Paleocene section, affecting the benthic assemblages at different times. In the first step, calcareous taxa such as: *Stensioeina beccariiformis*, *Cibicidoides velascoensis*, *Alabamina midwayensis*, *Nuttallides* sp., *Gyroidinoides quadratus*, *Gyroidinoides globosus* show dissolution and fragmentation signals, finally, all the calcareous taxa (benthic and planktic foraminifera and also nannofossils) disappear abruptly. The second step is characterized by the sudden extinction of an important group of agglutinated species that were very abundant in whole the Paleocene section. Among them *Ammodiscus cretaceus*, *Ammodiscus pennyi*, *Psammosiphonella cylindrica*, *Kalamopsis grzybowskii*, *Trochammina globigeriniformis*, *Haplophragmoides suborbicularis*, *Ammolagena clavata*, *Subreophax guttifer*, *Reophax elongatus* and *Ammoanita ruthvenmurray* are the most representative taxa.

## **A baseline survey of agglutinated benthic macro-foraminifera in the Barents Sea, Norway**

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Industrial benthos surveys of the Barents Sea have largely excluded recovery of macro-scale foraminifera primarily due to the time consuming nature of the traditional methods of analyses. However, evidence shows that large tests are very predominant within the macrofauna at a number of established survey sites. This study aims to provide an overview of agglutinated benthic foraminifera in an environmentally sensitive area of high biodiversity.

Large benthic foraminifera (>1 mm) tests, of predominantly agglutinated composition, have been recovered from grab samples from sampling stations in the south western Barents Sea. The diversity and species abundance of living (rose-bengal) stained specimens are determined to obtain a baseline survey for modern macrofauna activity.

The recovered agglutinated species consist predominantly of *Hyperammina*, *Rhabdammina*, *Saccorhiza ramosa*, *Astrorhiza* and *Saccamina*, with species dominance varying between stations. Morphotype habitat preferences are subsequently under investigation and recently obtained sedimentological data will provide additional information to the existing knowledge of water mass properties.

The large tests provide surfaces for surrounding benthic foraminifera with sponge spicules incorporated in many of the tests. Future work will expand on this to explore the potential interactions and relationships with the surrounding fauna.

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