The vast majority of foraminiferal taxa are defined according to morphological concepts in which patterns of variation (e.g., morphological discontinuities, subspecific morphoclines) have often been assumed or anecdotally illustrated rather than demonstrated quantitatively. While this practice is not different in principal from that used in many other fossil and Recent groups, the unique attributes of the foraminiferal fossil record make it a natural laboratory where fundamental questions regarding the nature quantitative patterns of morphological variation can be assessed at unprecedented levels of detail. Issues that can be addressed under this research programme, at least in principle, include patterns of intraspecific variation, patterns of interspecific variation, automated object recognition, morphological paleobiogeography, correlation of morphological variation with a variety of physical and biological factors, theoretical morphology, and consequences of combining this information with phylogenetic data for understanding the evolutionary history of this group (e.g., morphological disparity, comparative method studies). This open technical session addresses itself to the presentation of new methods whereby such studies can be undertaken and surveying a range of results achieved thus far. Particular emphasis will be placed on what such investigations can tell us about general nature of evolutionary-ecological processes operating in foraminifera (and marine settings in general), and how such data can be used in taxonomic, systematic, stratigraphic, biogeographic and phylogenetic contexts.
Biometrical study of the benthic foraminifera *Cribroelphidium oregonense* and morphological features of its deformed individuals

Kohei Abe¹ & Shiro Hasegawa²

¹Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba 305-8572, Japan - abekohei@arsia.geo.tsukuba.ac.jp
²Graduate School of Science and Technology, Kumamoto University, 2-39-1 Kurokami, Kumamoto 860-8555, Japan

Intra-specific variations of morphology of foraminiferal tests are considered valuable tools for the environmental understandings. However, the relationships between test morphology and environments do not detected clearly for many species. On the other hand, morphological deformation is considered to occur in more or less stressed environment for a species, but it is not clear to distinguish the deformation from the intra-specific variation of test morphology. In this study, we examine 1) variation of test morphology for a benthic species; *Cribroelphidium oregonense* (Cushman & Grant) that include a lot of “deformed” specimens in its populations, 2) relationships between test morphology and some environmental factors. In the case of this species, deformation mainly consists of reduced chamber-size (Abe & Hasegawa, 2002).

Observed specimens were collected from the Pacific Ocean, coastal area off eastern Hokkaido, during the cruises of GH02 (August, 2002) and GT03 (December, 2003). They are cut at equatorial plane for several specimens and observed using a low vacuum SEM, or directly pictured using a microfocus X-ray system. We measure the areas of each chamber on the photographs of cross section, as a representative of three-dimensional volume of chamber that is fundamentally analogues in shape during its ontogeny. Biometrical analysis of *C. oregonense* has represented the following results:

1) The chamber size of this species increases throughout its ontogeny, and the slope of regression line is consistently 0.003 for every specimen. Therefore this growth ratio of chambers is a peculiar feature for *C. oregonense*.

2) The growth rate of chamber by chamber varies regularly. The timing of increasing and decreasing peaks are correlative quite easily in a living population from a station, and also possible among the populations at different the living assemblage from other stations. Such a periodicity of this species indicates that the origins of reducing or increasing chamber-size are not the ecological factors within the specimens but an external factor, such as seasonal oceanographic environmental changes.

3) The fluctuated growth line of chambers are found not only in “deformed” specimens but also for each normal ones. When the chamber sizes increase or decrease, the chamber sizes are recovered about the size on the regression line within a few chambers. We considered the chamber sizes on the regression line are the “ideal chamber size” for the specimen and the “deformed” specimens are considered nothing but the specimens that the ratio of decreased or increased chamber sizes...
become larger. This supposed to indicate the events that lead to change the chamber sizes are not continuous things, but occurred relatively short scale in time.

Reproducibility of species recognition in modern planktonic foraminifera

Nadia Al-Sabouni$^{1,2,3}$ & Michal Kucera$^1$

$^1$Tübingen University, Tübingen, Germany  
$^2$Royal Holloway University, London, U.K.  
$^3$Natural History Museum, London, U.K. - n.alsabouni@gmail.com

Planktonic foraminifera are extensively used in paleoceanographic and biostratigraphic studies. Many of these applications require a high degree of taxonomic certainty and recognition. Any discrepancy between researchers has the potential to affect temperature or diversity reconstructions. Despite this potential source of uncertainty, the reproducibility of species recognition has never been tested. In order to ascertain the degree of species recognition reproducibility, a modern subtropical sample was selected for its high species richness and sieved through the $>125 \mu m$ and $>150 \mu m$ size fractions respectively. These fractions were then split using a microsplitter into aliquots of approximately 300 individuals, and a representative 300 individuals were then selected and fixed. Participants of varying expertise from different institutions were asked to identify each individual and note down their classification. This procedure allowed for a direct comparison of each participant’s identification for each of the individuals. It was then possible to determine the absolute levels of consistency between participants and the overall effects of inconsistency on diversity and temperature estimates. The absolute levels of consistency between all participants were surprisingly low: 50% in the $>150 \mu m$ size fraction and 35% in the $>125 \mu m$ size fraction. When all of the participants identifications were compared individually with one another, the maximum pairwise conformity was found to be 80% in the $>150 \mu m$ size fraction and 65% in the $>125 \mu m$ size fraction. The minimum pairwise concurrence was found to be 65% in the $>150 \mu m$ and 55% in the $>125 \mu m$ size fraction. This implies that there are a substantial number of specimens among modern planktonic foraminifera which are difficult to identify unambiguously. However, it was astonishingly found that the overall effect of this inconsistency was negligible in the $>150 \mu m$ size fraction on SST estimates using the Transfer function technique as well as on diversity estimates. Conversely, in the $>125 \mu m$ size fraction the effect on diversity estimates was found to be significant. The causes and effects of these findings will be outlined later. The fact that the consistency of species identification between two researchers can
Morphological variation through time is often cited as an indication of evolutionary change within a species. *Globorotalia menardii* and *Globorotalia tumida* are two morphologically similar extant species’ of Globorotalid foraminifera. Their biogeographical distribution is tropical to subtropical, they share a distinctive lenticular keeled morphology, however, *G. tumida* shows greater lateral inflation of the test with a heavier surface encrusting of calcite. *G. menardii* has a range of morphotypes that show great variation in the spiral height, ranging from delicately walled finer keeled forms with a compressed test (*G. menardii cultrata*), to the more robust heavily keeled forms (*G. menardii menardii*). An extremely high spired form is also known (*G. menardii gibberula*).

Studies of the biogeographical distribution of menardii morphotypes, show that the Caribbean Sea / Gulf of Mexico are dominated by the relatively compressed *G. menardii cultrata* morphology. The Atlantic Ocean shows increased variation, with the warmer waters showing greatest numbers of the cultrata morphotype, but with the introduction of the more inflated *G. menardii menardii* morphology in cooler waters. The highest spired forms are of *G. menardii gibberula* morphotype which is found towards the most southerly extent of the menardii global range. The Indian Ocean shows the greatest variation in the mix of morphologies present in each sample, this is probably a reflection of the greater oceanographic variation caused by the dominance of the monsoonal circulatory system. However regions that show the highest seasonal SST show the greatest numbers of the cultrata morphotype. The highly inflated *G. menardii gibberula* morphotype is restricted to the southern part of the Indian Ocean. The Western Pacific Ocean shows a similar range of morphologies to those seen in the central Indian Ocean, with the warmest waters being dominated by the cultratid morphotype. The Eastern Pacific samples show both cultrata and menardii morphotypes, but both morphologies
show a restricted size range. *G. tumida* shows a constrained test morphology, with all samples showing a similar range of morphological variation. The lack of regional variation as seen in the *G. menardii* plexus suggests that *G. tumida* could represent either a single global population or cryptic species. *Globorotalia ungulata* identified during this project, shows, apart from the secondary encrusting, great morphological similarity to *G. tumida* which suggests that they are members of the same species. The differences in the secondary encrusting are considered to be ecophenotypic, with *G. ungulata* representing a shallow warm water dwelling juvenile form, and *G. tumida* the deeper dwelling adult form this hypothesis is also supported by results form stable isotope analysis carried out on specimens form the Caribbean.

Gametogenic calcification cannot account for the observed variation in the morphology of the *G. menardii* plexus. The ratio of the “x and “y variates is not significantly changed with the over plating of a calcitic curst. Adaption to different depth environments could result in a change of morphology and it is hypothesised that the increase in spire height is an adaption to buoyancy problems in differing water masses. In 1973 George Scott hypothesized that *G. menardii* would show the most compressed (flattest) tests in the warmer waters, this hypothesis was discarded at the time due to lack of supporting evidence, however the evidence presented here appears to support this. The dominance of the cultratid morphology in the Caribbean is seen as a result of the existence of the deep warm waters in the region, while *G. menardii gibberula* is thought to represent an extreme form of the *G. menardii menardii* morphotype showing adaption to the deepest depths.
Glossary and “eForams”: Free rapid access to the current basic knowledge on foraminifera

Lukas Hottinger¹; Jaroslaw Tyszka² & Pawe Topa³

¹Museum of Natural History, CH 4001 Basel, Switzerland
lukas.hottinger@unibas.ch

²Polish Academy of Sciences, Institute of Geological Sciences,
Cracow Research Center, ul. Senacka 1, 31-002 Kraków, Poland
ndtyszka@cyf-kr.edu.pl

³Institute of Computer Sciences, AGH University of Science and Technology,
al. Mickiewicza 30, 30-059 Kraków, Poland
topa@agh.edu.pl

Scientific research on foraminifera today demands access to a specialized library and to extensive collections for direct comparisons. This is the case for taxonomic identifications on the generic and even more so on the specific level, for morphogenetic studies, for the analysis of comparative and functional anatomy of the shells and last but not least for high resolution biostratigraphy. One of the most important basic instruments for this research is Loeblich and Tappan’s book on foraminiferal genera published 1987 and still available from commercial sources for US$ 800. This book, of daily use, resumes the general knowledge on the foraminiferal genera but has nevertheless several drawbacks. In contrast to most volumes of the Treatise of Invertebrate Paleontology, there are no general, descriptive introductions to particular groups of foraminifera, such as fusulinids for instance. The specialised terms supporting the diagnoses are in many cases copied in an uncritical way as they were used in the original diagnoses. These were established over more than a century. Over that period of time, the understanding of the significance and biological meaning of many characters have changed, in different countries in different direction, so that considerable uncertainties about the meaning of terms have emerged.

In order to give rapid and cheap access to the current basic knowledge on foraminifera, eForams is presented here, a project to create an electronic encyclopedia exclusively for foraminifera, along the lines and with the software of Wikipedia project. The modalities of access, choosing collaborators, fixing server capacities etc. will have to be discussed and worked out. We would like in particular to have the workshop to comment on opportunities and ways of realization of an incorporation of taxonomic units in this project, and if yes, at what systematic level.
eForams is driven by MediaWiki engine - software which is widely used in the free internet encyclopedia. One of the main advantages of MediaWiki is its ability to work on documents by using only web browser. Documents are stored on http-servers and available as web pages. Metalanguage used for defining documents layout is a very simplified version of HTML (the language of web pages). MediaWiki also keeps tracks of all changes and synchronizes cooperating editors. However, Wikipedias are freely available to edit by anyone, in particular cases, access and privileges can be strictly controlled by administrators. In our case, we have decided to limit the access for editing eForams. Nevertheless, every foraminiferologist interested in collaboration is welcome. We believe that the registration of all contributors should make this site more reliable. This way all information would be signed avoiding usual criticisms of Wikipedia including its open nature making it unauthoritative and unreliable (see http://en.wikipedia.org/wiki/Criticism_of_Wikipedia). Otherwise, eForams has all other benefits of Wikipedia, including multi-authorship, free access from all computers connected to the web, rapid publication, diverse coverage, and a local search engine. We are looking forward for your criticisms, inspiring comments and further contributions to eForams. The web site is already available at: http://www.eforams.icrs.agh.edu.pl/

We also present an illustrated glossary of morphological terms used to support the description of foraminiferal taxa, published as independent electronic paper in Cahiers de Géologie [http://palaeopolis.rediris.es/cg/fr] and to be incorporated in the same time in eForams.
Morphological variability of *Globorotalia menardii* Banner and Blow in the Caribbean Sea and the eastern Equatorial Pacific during the past 8 million years

Michael Knappertsbusch

*Naturhistorisches Museum Basel, Augustinergasse 2, 4001-Basel, Switzerland*

Michael.Knappertsbusch@unibas.ch

The morphological variability of the tropical to subtropical planktonic foraminifer *Globorotalia menardii* during the past 8 million years was quantitatively measured in samples from DSDP Site 502A (Colombia Basin, Caribbean Sea) and DSDP Site 503A (southern Guatemala Basin, eastern equatorial Pacific). Applying computer-aided morphometry spiral height (δx) versus maximum diameter in keel view (δy) were measured for each sample to evaluate shell variability through time. *G. menardii* shows a continuous, (mostly) unimodal, linear but time-progressive increase in δx and δy at both sites until the Late Pleistocene. For these forms the informal designation morphotype *alpha* is suggested. Using the same morphological descriptors the very similar Pliocene menardiform globorotalia species *G. limbata* and *G. multicamerata*, which are thought to have evolved from *G. menardii*, show strong overlap. They can, however, be distinguished from *G. menardii* (morphotype *alpha*) by the angle of the peripheral keel in side view (Φ3) and a consistently higher number of chambers (e>7) in the final whorl. Particularly during and after the final closure of the Isthmus of Panama (ca. 2.4 Ma - 1.8 Ma) morphotype *alpha* tended to rapidly increase its shell size. During the Late Pleistocene *G. menardii* consisted of two different morphotypes, *alpha* and *beta*, with unequal biogeographic distributions: The first persisted from the ancestral smaller forms of morphotype *alpha* until Present and occurs in both cores. Today and in the Late Pliocene this form has a robust shell, a pronounced keel due to stronger calcite secretion and is less inflated in keel view. The second form (beta) appeared for the first time at 0.22 Ma and occurs predominantly at the Caribbean Sea site, although it occurs in low frequencies also at the Pacific site. Morphotype *beta* is more inflated in keel view and has a delicate, shiny shell. Morphotypes *alpha* and *beta* can be well separated in the morphospace of δX versus δY by a line, which fits the equation δy = 3.2 * δx - 160 (δy and δx in µm). Specimens of morphotype *alpha* scatter below the separation line. They are interpreted to represent the extant *G. menardii menardii*, and the Miocene *G. menardii “A”* and *G. menardii “B”* described in Bolli & Saunders (1985) and Bolli (1970), respectively. Morphotype *beta*, which is located above the separation line, is
considered to represent the extant *G. menardii cultrata*. Based on these preliminary data it is suspected, that morphotype beta originated during a very recent evolutionary event in the Caribbean sea, but further research is required to confirm this hypothesis.
Late Eocene evolution of *Spiroclypeus* in Europe

György Less¹ & Ercan Özcan²

¹University of Miskolc, Department of Geology and Mineral Resources, H-3515, Miskolc-Egyetemváros, Hungary - foldgy@uni-miskolc.hu
²Department of Geology, Faculty of Mines, Istanbul Technical University, Ayazağa/Istanbul 34469, Turkey

Eocene *Spiroclypeus* from ten European localities (one of them is topotypical), extending from Spain to Turkey and covering the whole Priabonian have been morphometrically investigated and the equatorial section of A-forms were statistically evaluated. Based on the reduction of the average number of pre-heterosteginid, post-embryonic chambers, populations are grouped into two successive, phylogenetically linked species, *S. sirottii* n. sp. and *S. carpaticus*. The evolution is also proven by the ontogenetical increase of the number of secondary chamberlets in particular chambers, by the increase of the diameter of the first two whorls and by that of the size of the proloculus, although the latter turned out to be also ecologically controlled. This evolution is supported by the stratigraphical succession of populations in the Mossano section (N Italy) and also by the change of accompanying fossils.

Lacking in upper Bartonian beds, the first appearance of genus *Spiroclypeus* seems to be synchronous with the beginning of the late Eocene. The newly described *S. sirottii* is associated with *Heterostegina reticulata mossanensis* and orthophragmines containing still survivor middle Eocene forms, both marking the lower part of the Priabonian. Meanwhile *S. carpaticus* co-occurs with *H. gracilis* and/or with orthophragmines not consisting of survivor middle Eocene forms, both characteristic for the upper part of the Priabonian. The further evolution of the genus in the early Oligocene is not recorded in the northern Mediterranean realm. Thus, at least in Europe *Spiroclypeus sirottii* is a zonal marker for the shallow benthic zone (SBZ) 19 (early Priabonian) while *S. carpaticus* detects the SBZ 20 (late Priabonian).

This research was realized in the frame of I.G.C.P. project ¹ 393 having financed also some of Less’ travels. The final phase of the work was sponsored for Less by the National Scientific Fund of Hungary (OTKA, Grants ¹ T 037619, 042799 and 060645) and for Özcan by TÜBITAK (project ¹ YDABAG–101Y060).
Evolution of western Tethyan involute *Heterostegina* from late Bartonian to the end-Priabonian

György Less¹; Ercan Özcan²; Cesare A. Papazzoni³ & Rudolf Stockar⁴

¹University of Miskolc, Department of Geology and Mineral Resources, H-3515, Miskolc-Egyetemváros, Hungary - foldgy@uni-miskolc.hu
²Department of Geology, Faculty of Mines, Istanbul Technical University, Ayazada/Istanbul 34469, Turkey
³Dipartimento del Museo di Paleobiologia e dell’Orto Botanico, Università di Modena e Reggio Emilia, Via Università 4, I-41100 Modena, Italy
⁴Museo cantonale di storia naturale, Viale Carlo Cattaneo 4, CH-6900 Lugano, Switzerland

Eocene involute *Heterostegina* having originated from the *Operculina bericensis-roselli-gomezi* group are widespread in the upper Bartonian and Priabonian beds of the Western Tethys. They have been morphometrically investigated and the important features of the equatorial section of their A-forms were statistically evaluated from thirty-four localities (including five topotypical ones). These localities represent the whole late Bartonian to latest Priabonian interval, mark different ecological conditions and extend from Spain to Armenia. Populations are ranked into three species, *H. armenica*, *H. reticulata* and *H. gracilis* based on the presence/absence of granulation, on the arrangement, shape and density of secondary chamberlets and on the relative size of the proloculus. These species form evolutionary lineages within which (especially within *H. reticulata*) a very rapid evolution could be observed with the reduction of the number of operculinid chambers, the increase of the number of secondary chamberlets (counted at chamber 14) and in the increase of the size of the proloculus, although the last turned out also to be ecologically controlled.

This evolution is proven by the stratigraphical succession of populations in the Mossano section (Italy) and also by superpositions from other localities. The evolutionary changes are also accompanied by the change of co-occurring fossils starting with the disappearance of large-sized *Nummulites*, then followed by the appearance of genus *Spiroclypeus* and then by the disappearance of survivor middle Eocene orthophragmines. Based on the reduction of operculinid chambers as the most reliable parameter, two chronosubspecies of *Heterostegina armenica* (one of them is newly erected) and seven ones of *H. reticulata* (with three new subspecies) are defined biometrically. This allows us to subdivide the shallow benthic zone (SBZ) 18 very cautiously into three
while SBZ 19 into two subzones. *Heterostegina gracilis* (the only species with granulation) characterizes the SBZ 20 zone. The middle/upper Eocene (=Bartonian/Priabonian) boundary is suggested to be placed onto the base of the “Priabona marls” in the Mossano section corresponding to the SBZ 18/19 limit, to the first appearance of genus *Spiroclypeus*, to that of *Nummulites fabianii* and *Heterostegina reticulata mossanensis*. It falls into the upper part of both the P 15 planktic foraminiferal and NP 18 calcareous nannoplankton zones.

The extremely rapid evolution of *H. reticulata* accompanied with relatively large geographic distribution and wide ecological niche allows calibrating larger foraminiferal events around the proposed Bartonian/Priabonian boundary. As a working hypothesis, the extinction of large-sized *Nummulites* seems to be heterochronous in the late Bartonian in having migrated eastward. Relying on data from Italy, Hungary and Turkey, the first appearance of *Spiroclypeus* (with the same evolutionary degree) is proven to be synchronous in the very base of the Priabonian. Mediterranean Eocene involute *Heterostegina* became extinct very probably with no descendants at the very end of the Eocene.

This research was realized in the frame of I.G.C.P. project 393 having financed also some of Less’s travels. The final phase of the work was sponsored for Less by the National Scientific Fund of Hungary (OTKA, Grants nº T 037619, 042799 and 060645), for Özcan by TÜBİTAK (project nº YDABAG–101Y060), for Papazzoni by MIUR Cofin 2002–2005 (resp. prof. A. Russo, Modena) and for Stockar by the Cantonal Museum of Natural History (Lugano).
Phylogeny and the evolutionary history of planktonic foraminiferal test size

Norman MacLeod

Department of Palaeontology, The Natural History Museum, Cromwell Road, London, SW7 5BD, U.K. - N.MacLeod@nhm.ac.uk

Body size is interesting to (paleo)biologists owing to its association with a large number of ecological, developmental, and functional constraints. Investigations of size-related phenomena are arguably of more importance to micropaleontologists because of the wide range of sizes characteristic of microscopic organisms and our lack of experience-based intuition regarding how small organisms are constrained by many environmental variables. Until recently, the analysis of body size changes—along with changes in other metric variables—was undertaken with scant attention paid to the phylogenetic context within which such variations occurred. This approach assumes all taxa included in the study have equal phylogenetic relations to one another; obviously an incorrect assumption. Such an approach also leads to confusion of distinct concepts (e.g., describing decreases in the mean size of a multi-taxon assemblages as examples of ‘dwarfing’, which is a lineage-specific phenomenon) with consequent confusion over the correct interpretation of hypothesis tests. A recent study of planktonic foraminifera test size variation (Schmidt et al., 2004. Palaeogeography, Palaeoclimatology, Palaeoecology, 212:159–180) recognized three time-ordered patterns of change that appeared to correlate with temperature and productivity fluctuations in the world ocean. However this study ignored the phylogenetic component of relations among species. The conclusions of this study may be valid in their own context, but they may also not fully express lineage specific trends. Certainly they cannot be used to test macroevolutionary hypotheses. A clade-specific, comparative investigation based on 17 different planktonic foraminifera lineages has identified five distinct modes of evolutionary test-size variation and allowed the relative frequency of these modes to be estimated. Results of this phylogeny-based analysis using the maximum parsimony analysis reveals important patterns undocumented by the Schmidt et al. study. Planktonic foraminifera are characterized by high lineage-specific phylogenetic test size differentials (= net increase-decrease in test size relative to ancestral conditions) during the Lower Cretaceous, but these rates fall off markedly throughout the Upper Cretaceous. Upper Cretaceous planktonic are large, but only because they evolved from large
ancestors. Trans-K-T lineages are characterized by modest levels phyletic size decrease at the intra-specific level, a result consistent with many morphometric studies, but not recovered by Schmidt et al. After the K-T turnover phylogenetic test size differentials increased progressively to an early Paleocene maxima after which it fell to zero in the early Eocene, picked up again in the middle Eocene, and soared to a pronounced peak in the late Eocene. Neogene phylogenetic test size differentials also exhibit a phased character with maxima in the early Miocene and a sustained plateau of dramatically elevated phylogenetic test size differentials for the late Miocene-Recent. Overall, this pattern differs strongly from that proposed by Schmidt et al. (2004), especially through the Cretaceous and Palaeogene. Much more work needs to be done in documenting global patterns of planktonic foraminiferal test size variation. However, the results obtained by this investigation illustrate the importance of adopting an explicitly phylogenetic approach if the richness of planktonic foraminiferal evolutionary dynamics is to be revealed.
Intraspecific variation in Recent populations of *Globigerinoides ruber* from the eastern Indian Ocean: Evidence from test morphology and geochemistry

Aleksey Yu. Sadekov; Stephen M. Eggins & Patrick De Deckker

*Australian National University, Mils road. J7, 0200, Canberra/ACT, Australia*

*aleksey.sadekov@anu.edu.au*

*Globigerinoides ruber* is the most frequently studied planktonic foraminifera, it being a key species used for paleoceanographic reconstruction based on calcite Mg/Ca and δ¹⁸O geochemistry. However, modern populations of *G. ruber* display considerable morphological variation which some earlier studies have divided into several distinct morphotypes (Parker, 1962. *Micropaleontology*, 8, 219-254; Hecht, 1974. *Journal Palaeontology*, 48, 1217-1234). Recent molecular-genetic have further suggested that these morphotypes of *G. ruber* might reflect its phenotypic variation and to also be associated with difference in text composition (Darling et al., 1999. *Paleoceanography*, 14: 3-21; Wang, 2000. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 161, 381-394; Steinke et al., 2005. *Geocham. Geophys. Geosyst.*, 6, Q11005).

We have analysed *G. ruber* populations from multiple deep sea core-tops collected in the Eastern Indian Ocean. Detailed test morphometry coupled with individual test geochemistry determined by laser ablation ICPMS were used to assess morphotype subdivisions. We found particular morphometric parameters (i.e. primary aperture aspect-ratation, depth of test sutures) to have specific latitudinal distributions and thus possibly reflect biogeographical specification of *G. ruber* phenotypes. Other parameters (i.e. relative height of test trochospire, shape of the last chamber) on the other hand display gradational changes across the *G. ruber* population. Estimated calcification temperatures, derived from measured test Mg/Ca compositions, of low and high aspect ratio trochospire tests of *G. ruber* shows significant correlation with seasonal variation in water mass structure. This relationship suggests that some variation in *G. ruber* morphology occurs in response to environmental changes.
A comparison of CART and discriminant analysis of morphometric data in foraminiferal taxonomy

Pratul Kumar Saraswati1 & Sanjeev V. Sabnis2

1Department of Earth Sciences, Indian Institute of Technology – Bombay, Powai, Mumbai 400076 India
2Department of Mathematics, Indian Institute of Technology – Bombay, Powai, Mumbai 400076 India
pratul@iitb.ac.in

Traditionally, taxonomists have relied on qualitative and dichotomous characters for foraminiferal classification and discrimination. The advantages of quantification of morphological characters have been demonstrated by many in resolving the problems of taxonomy and evolutionary history. The unprecedented growth of information technology has made a strong case for quantification of morphological data and automated recognition of foraminiferal species. The automated recognition is possible either by image analysis or by statistical methods. The most commonly used statistical procedure by paleontologists is discriminant analysis of morphological data. The technique was originally developed based on the assumption of multivariate normality of the data set. The morphometric data generally deviate from normal distribution and, therefore, it violates the basic assumption of the method used. Here we use an alternative, non-parametric method, called Classification and Regression Tree (CART), to distinguish three closely resembling species of Middle Eocene Nummulites from western India. The species include N. beaumonti, N. neglectus and N. stamineus. We measured diameter and thickness of the test and five other parameters in oriented sections of 55 specimens. The data was analyzed by CART using Statistical Analysis Software (XLMiner). Thirty three data sets were randomly selected as training data to construct the tree. The tree uses two variables, thickness (T) of the test and height of the chamber in the final whorl (HL), as important variables to distinguish the three species. In the validation-data only one of the sixteen specimens was misclassified, while all the six test-data were assigned to correct classes. The same morphometric data were also analyzed by multi-group discrimination. Two discriminant functions account for nearly 100% discrimination. Both, CART and multigroup discriminant
A comparison of CART and discriminant analysis of morphometric data in foraminiferal taxonomy
Pratul Kumar Saraswati & Sanjeev V. Sabnis

analysis thus appear to be equally efficient in discriminating the three species. However, CART reduces the number of requisite variables for prediction without increasing the misclassification error. The most important advantage of CART though is that the success of the technique in classification does not depend on the normality of the data. It is not easy to determine to what extent the deviation from normality would affect the performance of the technique and therefore the reliability of prediction. The applications of CART in medicine and anthropology have shown that the technique also handles the missing data very efficiently. We suggest CART as a better option for class assignment in foraminiferal taxonomy for several reasons:

1) it does not require normal distribution of variables;
2) it can also accept data-set with some missing variables;
3) it may reduce the number of variables required for prediction; and
4) it quickens species discrimination and, therefore useful for well-site geologist.
Morphometric data on topotype assemblage of *Miogypsina (Lepidocyclina) drooger* from Kachchh, India

Swarndeep D. Singh¹ & D. S. N. Raju²

¹Paleontology Laboratory, Geology Division, K.D.M. Institute of Petroleum Exploration, Oil & Natural Gas Corporation Ltd., Kaulagarh Road, Dehradun-248 195, India
swarndeep@yahoo.com

²10, Siddhartha Enclave, General Mahadev Singh Road, Dehradun-248 001, India

*Miogypsina (Lepidosemicyclina) drooger* Mohan and Tewari Zone occupies an important position in the Indian biochronostratigraphy since the reservoirs of the giant oil field of Bombay High pertain to this zone. A rich assemblage of the topotype material from Kachchh is morphometrically analysed for the better understanding of the variation in the population and its relation with the closely related species. The mean value of $V$ is recorded as 77.5 for 24 specimens of *Miogypsina (Lepidosemicyclina) drooger* Mohan and Tewari. The detailed study of Miogypsinidae from the nearby exposures in Kachchh and a continuously cored offshore well#ED-D from Bombay Offshore has helped in the better understanding of the evolution of *Lepidosemicyclina* lineage from *Miogypsina (Lepidosemicyclina) thecideaeformis* Rutten to *Miogypsina (Lepidosemicyclina) drooger* Mohan and Tewari through *Miogypsina (Lepidosemicyclina) talukdari* Raju and Singh.
Modeling of foraminifera: Linking molecules and morphology

Jaroslaw Tyszka & Pawe Topa

1Institute of Geological Sciences, Polish Academy of Sciences, Cracow Research Centre, ul. Senacka 1, 31-002 Kraków, Poland
ntyszka@cyf-kr.edu.pl
2Institute of Computer Sciences, AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Kraków, Poland

Theoretical morphology covers two conceptual areas focused on morphology of organisms, including the simulation of organic morphogenesis and the analysis of the possible spectrum of organic forms via hypothetical morphospace construction. Our studies focus on emergence of shell patterns in the simulated growth of polythalamous foraminifera. Previous models have referred to fixed reference axes and neglected apertures. We present a new approach in foraminiferal modeling applying a moving reference system referred to apertures, which are introduced based on minimization of the local communication path, i.e. a distance between two apertures (Topa & Tyszka 2002. Lecture Notes in Comp. Sci. 2329: 97–106; Labaj et al., 2003. Lecture Notes in Comp. Sci. 2657: 669–678). The model applies following parameters defining a relative position of a successive chamber: translation factor that controls an overlap of successive chambers, deviation angle (deflection), and rotation angle, as well as the growth factor of chambers applied in the isometric growth. The growth factor can be replaced by 3 additional parameters - scaling ratios – which are defined to simulate allometric chambers. All parameters are either predetermined or selected at random from given ranges that mimic phenotypic variability of a shell.

This moving-reference model focuses on real morphologic characteristics and follows stepwise natural biological processes (Tyszka & Topa, 2005. Paleobiology, 31 (3): 526–541; Tyszka, 2006. Lethaia, 39 (1): 1–12). The model proves that apertures are essential in foraminiferal morphogenesis. Simulated foraminiferal shells based on this model indicate that their varieties are much wider than morphotypes developed by fixed reference models. It is especially well suited for simulating gradual and abrupt changes in chamber growth patterns as features characteristic for real foraminiferal shells. For...
instance, switchovers from planispiral or streptospiral to biserial or uniserial shell arrangements can be simulated. Nevertheless, this model is still not able to simulate forms with the longest global communication path connecting foramina, such as *Lenticulina* or other lagenids. This is due to the assumptions that chambers are spheroidal and that an aperture does not shape any chamber. On the other hand, empirical observations have shown that apertures often have a strong impact on the shape of a chamber, e.g., chambers tend to show specific apertural structures, such as necks, radial structures, depressions around apertures etc. In order to simulate such forms, it is necessary to leave this geometric approach and focus on more “in-depth” models based on realistic intracellular dynamics (Tyszka & Topa, 2005; Tyszka, 2006; Tyszka *et al.*, 2005. *Studia Geol. Polon.*, 124: 143–157).

This novel approach has been tested based on the Diffusion-Limited Aggregation (DLA) model that mimics formation of the foraminiferal cytoskeleton (Tyszka *et al.*, 2005). The simulated two-dimensional forms resemble either a reticulopodium or a microtubular fan supporting the organic ‘Anlage’ during the chamber formation. The results are promising, but the model still needs further development. We suppose that the emergent model is the best alternative for foraminifer modeling. Such a future model should incorporate recent knowledge on cytoskeletal dynamics focused on simplified interactions of proteins.

This research is sponsored by the Polish Ministry of Education and Science (Grant nr 3 PO4D 048 24). For more details see: [http://www.eforams.icsr.agh.edu.pl/](http://www.eforams.icsr.agh.edu.pl/)