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International Journal of Paleobiology & Paleontology
ISSN: 2642-1283

The Current State of Foraminiferal Research and Future Goals

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Review Article

Volume 4 Issue 1

Received Date: March 26, 2021

Published Date: May 05, 2021

DOI: 10.23880/ijpbp-16000125

Abstract

An overview is presented of the main achievements in studies of the phylum Foraminifera during the previous few decades, especially the last half of the 20th and the beginning of the 21st centuries, and of the most urgent goals of future studies with a special attention to the problems of classification as a base for all other studies.

Keywords: Foraminifera; Morphology; Ecology; Zoogeography; Biology; Molecular Studies; Systematics; Previous Achievements; Goals of Future Research

Overview of the Most Important Achievements in Different Fields of Foraminiferal Research

Foraminiferology dates back to 1826, the year of d'Orbigny's publication on this group of organisms. More than 5000 genera and more than 40,000 fossil and 10,000 recent species have been described so far. The fundamental role of Foraminifera as sensitive indicators of modern and ancient environments is widely known and they are used in ecological studies including pollution monitoring, as well as in petroleum exploration, for applications in biostratigraphy, paleoecology and paleoclimatology, and in many other fields of research.

At the end of the 20th and beginning of the 21st centuries, significant progress in all these foraminiferal studies has been achieved. In addition to traditional research marine areas, Foraminifera were discovered in hypersaline waters as well as in brakish and even in fresh waters [1-4], as well as in ground waters of special high salinity composition [5-7], primitive foraminiferal forms were discovered in soil communities [8]. Extremely important evidence of the role of benthic foraminifera in the process of denitrification of sediments was experimentally obtained [9,10].

A number of works have been devoted to foraminiferal feeding, their role in the food-chains [11-15], to the other aspects of their biology [16-19], to their symbionts [20-30], to the process of growth and formation of the new chambers [17,31-36], Even the problems of foraminifral infestation and diseases and dormancy were touched upon [37-40].

Ecological studies of this period achieved a new level being strictly coordinated with the physical parameters of the studied environments and using new techniques and methods. Laboratory experiments permitted to study the effects on the different foraminiferal species and populations of not only natural, such as t, salinity, O2 and CO2 concentrations, pH and trace elements, but also fuel oil and heavy metal pollution (mercury, cadmium, plumbum). These laboratory results received during the last decades can be found in excellent review of Kathal, et al. analyzing and summarizing such studies.

Problems related to ocean acidification [41], even experimentally shown [42], to the oxygenation of bottom waters [43-45], organic carbon flux [46-52] influencing foraminifera were also investigated.

Studies concerning recent foraminiferal distribution cover now all areas of the ocean including the Arctic and Antarctic and inland seas, and although their study is far from being uniform, nevertheless, it seems that there are no more absolutely blank spots left on the map.

In a short review, it is impossible to mention all the significant publications in these fields.

The amount of knowledge accumulated about the paleogeographic distribution of foraminifera, the knowledge in paleoecology, paleoclimatology, in the study of the influence of ancient volcanic activity on their propagation and extinction, data received in stratigraphy - also does not allow to name here even the most important publications. But the results of the great DEEP SEA DRILLING PROJECT, the blue volumes published after the expeditions, the multiple zonal scales and finally the global correlation of geological deposits elaborated cannot be failed to mention [53-55], as well as the painstaking work of revising the geological ranges of many genera [56,57].

The significant volume of the new data on the foraminiferal nuclear apparatus and its changes during the life cycle, nearly unknown previously, was accumulated during these decades [11,17,19,20,58-83]. These results made possible for the first time to use the characters of the nuclear apparatus in the diagnosis of high rank taxa (classes) [83-85]. Even the most important works in this direction cannot be listed in a shot review; more complete list can be found in the Mikhalevich [83] book. These new studies affected, to one extent or another, all classes, except for the Nodosariata class. Some new methods of research were introduced, one of the most significant of which that started a new era in the foraminiferology were the first applications of electron microscopy to studies of not only skeletal (as it was before since the beginning of the EM studies of the shell wall), but also cytoplasmic structures, cytophotometry of the nuclei in the process of reproduction [64,86].

Since the middle of the 20th century traditional attention to the foraminiferal shell wall as to one of the highly important systematic characters received new opportunities with the Scanning Electronic Microscopy (SEM). It caused the real explosion of the studies of the shell wall ultrastructure nearly in all of foraminiferal classes, both for agglutinated and calcareous variants of shell wall. These studies are widely known and so numerous that it is impossible to site even the most known among them (the list of publications could be found in [83]). Unfortunately, the representatives of the class Nodasariata were unlucky in such investigations. A few results were not able to show the real picture of their calcareous shell wall, obviously because their thinnest structures needed significantly higher magnification. The principally specific organization of the Nodosariata calcareous shell wall was clearly demonstrated with the more perfect Zeiss Σigma VP field emission scanning electron microscope (FESEM) by the Polish authors [87] thus adding one more character to the class diagnosis. Some similar pictures of the Nodosariata's calcareous shell wall were received somewhat earlier [88] (Figure 1), but the quality of the photos received with the less advanced SEM model (Hitachi SEM, model S-570) was of the less clear quality.

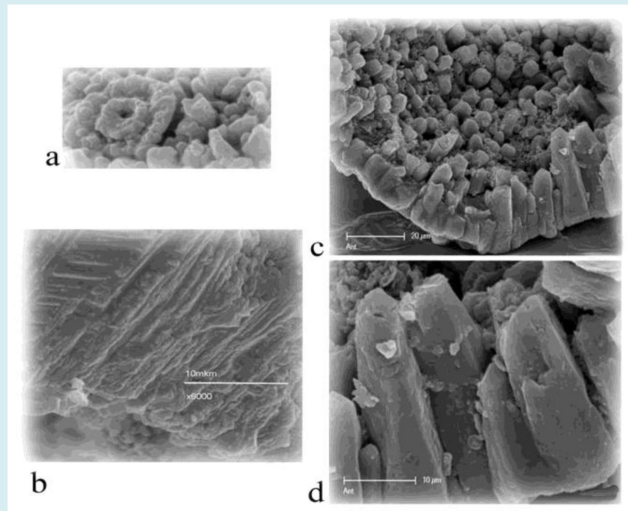

Figure 1: Shell wall ultrastructure of the two *Strictocostella* shells [88].

a. Rough outer surface and pore openings of *Strictocostella matanzana* (Palmer and Bermudez) 1936, with a pore opening between and inside the tubercles (enlarged view of the chamber wall, (×5000).
b. Part of the transverse breaking of the chamber wall of *Strictocostella matanzana* (Palmer and Bermudez) 1936, showing partly inclined parallel plates going from the inner part of the chamber up to the surface and pierced by the narrow pore openings going in the same direction (x 6000).
c. Part of the broken last chamber of *Strictocostella matanzana* (Palmer and Bermudez) 1936 *perytae* Mikhalevich, [88] showing the polygonal crystals (x 3000).
d. *Strictocostella matanzana* (Palmer and Bermudez) 1936 *perytae* Mikhalevich, [88] – part of the previous photo c - showing enlarged polygonal crystals at the edge of the transverse breakage of the chamber wall with the pore opening inside the broken polygonal crystals (x 6000).

The other important event of the last decades of the 20th century was the use of molecular genetic methods – the event of the highest importance in biology. In the study of foraminifera these principally new molecular methods permitted to identify several main phyletic lines (clades) (see below) [89-93], as well as to document some minor clades of marine and even fresh-water foraminifera [94,95], to define the position of Foraminifera among the other unicellular Eukaryots [96,97], to interpret geological age of the main clades using molecular clock analysis [98]. Molecular studies have revealed a twice greater diversity of phylotypes than morphotypes in some single-chambered (monothalamous) foraminifera [99-103], and high genetic variability of some planktonic species [104-108]. They also documented the possibility of existence of a pelagic stage in the life cycle of benthic species [109], and gave many other important, sometimes unexpected results. These methods gave new insight into foraminiferal zoogeography and phylogeography [110-114], molecular ecology using sequencing of environmental DNA (eDNA metabarcoding) gave the possibility to receive necessary results thousands of times more effectively than was possible with traditional methods [115,116]. Metagenomic sequencing became a common, powerful approach to study diversity and functional relationships in marine ecosystems.

Overview of the Most Important Achievements in Foraminiferal Taxonomy and Its Current State

The basis for analysis of all the observed and studied facts and phenomena are classification systems. The word "taxonomy" itself speaks of a systematic approach, which is the most important and generalizing knowledge, the highest level of scientific research, helping to understand the relationship of the studied objects, and the patterns of their development. The most important, outstanding event in this area of Foraminiferology was the publication of a monumental two-volumed edition by Loeblich and Tappan [117], which included all genera and suprageneric taxa known by that time with their complete diagnoses and synonymy. It has become a reference book for every specialist – foraminiferologist. This morphological classification strictly following nomenclatural rules served and still serves as a firm base of classification stability. Its role and importance, its contribution in the development and achievements of all the fields of foraminiferology can hardly be overestimated, it became and remains still an indispensable tool for identification of foraminifera.

From the time of the first foraminiferal classification systems to the most recent, the number of their families has increased from 5 or 10 [118,119] up to 499 [83,85] and is constantly increasing. Historically, two main themes in the higher systematics of the foraminifera have existed, which could be roughly outlined as follows: (1) Those giving the predominant significance to the shell wall composition, and (2) giving the predominant significance to the plan of structure of the organism reflected in their shell morphology. The electron microscopy that documented shell ultrastructural elements and their diversity strongly stimulated the 1st of them. The same approach was adopted in the Loeblich and Tappan [117] classification.

The 2nd approach predominated in the Russian foraminiferological school. It began with Rauser-Chernousova and Fursenko [120] and resulted in the creation of a new foraminiferal macrosystem based on fundamentally new concepts of their evolution and classification which was elaborated after thorough analysis of morphological and ultrastructural data of representatives of not only Recent but of all the geological periods since the Cambrian [83,85,121-125]. According to these views, foraminifera were regarded as a phylum embracing 5 classes: Astrorhizata Saidova, 1981, Miliolata Saidova, 1981, Spirillinata Mikhalevich, 1992, Nodosariata Mikhalevich, 1992 and Rotaliata, Mikhalevich, [121] (Figure 2). It was shown, that each of these classes represents the separate phylogenetic line that arose independently and in parallel during geological history and achieved in their development a different degree of complexity [84,122]. The agglutinated shell wall, and then the more perfect secreted calcareous wall also arose in parallel in different classes [84] elaborating a special mode of ultrastructure in the calcareous representatives (subclasses) of each of the lines (classes). Morphological analysis permitted to unite the agglutinated trochamminids with discorbids and other rotaliids, some ammodiscids with spirillinids, some agglutinated representatives included earlier into different taxonomic groups – with nodosariatas [121,122,123], miliamminids with miliolids [125]. The formerly heterogenous (polyphyletic) Textulariina, which previously united all the possible foraminiferal morphotypes into a single taxonomic group, were split into several groups according to their morphology and placed as a more primitive subclasses with an agglutinated shell wall as the base of the other multichambered classes [84,121,123] (Figure 2). The more advanced calcareous subclasses of each phyletic line have a calcareous ultrastructure peculiar to each of them, thus the test ultrastructure also has an important albeit subordinate taxonomic significance in comparison with the shell morphology, and it is characteristic for not class-level but subclass-level taxonomy. Under this approach, the agglutinated and calcareous forms of similar morphology within each phyletic line regarded as related [84,121,125], and this is contrary to previous views regarding their similarity as result of convergence. The classification of Kaminski [126-128] embracing agglutinated forms combines to some extent both approaches making it easier for non-taxonomic researchers to identify the taxonomic position of their material.

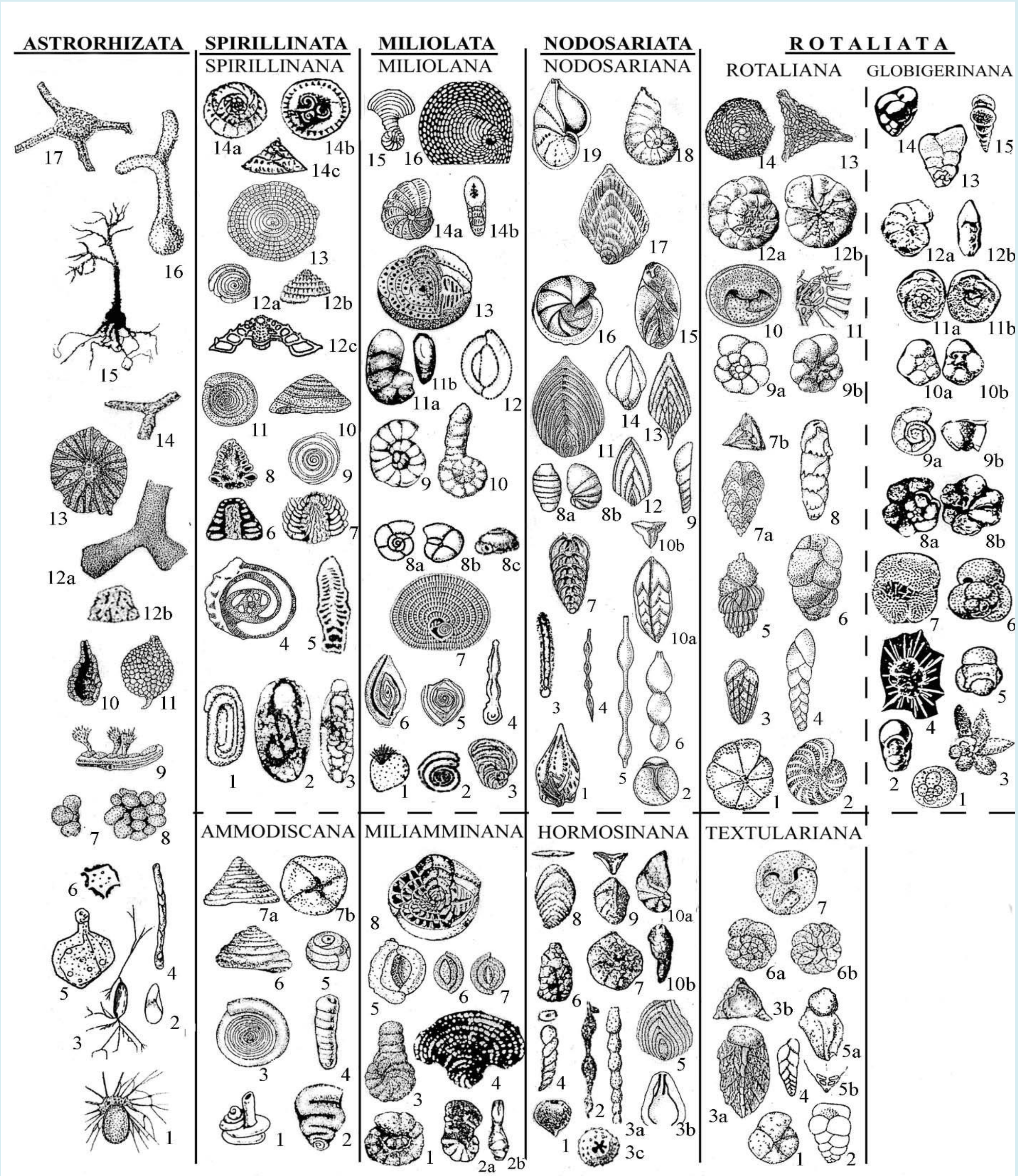

Figure 2: Morphological classification of the Phylum Foraminifera [83,84,85,121-125]: borders between classes marked by complete line, borders between subclasses – by the dotted line (after Mikhalevich, 1992 – modified).

Molecular methods furnish an opportunity for new insight into foraminiferal taxonomy providing taxonomic criteria independent of morphological characters. They already confirmed the monophyly of the foraminifera within the other unilocular Eukaryotes supporting its phylum rank, and within the foraminiferal phylum 4 major clades were

revealed [92]:
1. Unilocular agglutinated and soft-walled shells called as the new class Monothalamea and fully corresponding in their composition and diagnoses to the previous morphoclass Astrorhizata Saidova.
2. The multilocular class Tubothalamea uniting two clades corresponding to the morphoclasses Miliolata Saidova, 1981 and Spirillinata Mikhalevich, 1992, which fundamentally differ from each other based on their shell morphology and shell-wall ultrastructure, moreover, their nuclear apparati are fundamentally different (see diagnosis of the classes in Mikhalevich, 1992, Mikhalevich et Debenay, 2001) [83,84,85,].
3. Multilocular class Globothalamea corresponding to the full morphoclass Rotaliata Mikhalevich, [121] though it also includes a minor clade containing a few representatives surely belonging to the morphoclass Nodosariata according their shell structure and shell wall ultrastructure. In Globothalamea there is also a small clade including *Glandulina* and *Lenticulina* species which surely belong to the Nodosariata morphoclass according to their shell structure and shell wall ultrastructure. *Glandulina antarctica* of this minor clade also differs from that of Rotaliata (= Globothalamea) class in its sequence [92]. These are the only discrepancies concerning these three classes between the two classifications, which may be due to the lack of living studied material as well as difficulties with the molecular study of the hard-shelled foraminifera or because of some other reasons. Thus Nodosariats are again unlucky not being touched by the necessary studies.

The morphoclass Nodosariata was only slightly touched with the studies at the molecular level (a small clade in Globothalamea, such investigations were later began [92] when it was considred that the sequence of *Glandulina antarctica* also differs from that of the Rotaliata (= Globothalamea) class [92]. Each of the molecularly revealed clades of the multichambered forms includes agglutinated and calcareous forms of similar morphology just as was stated in the new morphological classification devised in the Russian School studies between 1980 and 2013 mentioned above. Morphological characters having the primary significance in the diagnoses of each of the molecular classes are the same as in the new morphological classification of the Russian School (1959, 1980–2013) as opposed to the previous traditional classifications: these are plan of structure including shell and chamber form, the prevailing mode of coiling, position of the aperture and its structure (later more often named as distance between successive apertures, though in some cases it does not coincide), etc – in distinction to the prevalent significance of the characters of shell wall composition and ultrastructure in the preceding widely accepted classifications when, for example, forms representing principally all the known varieties of foraminiferal shell structures and the only common feature - their agglutinated shell wall, were united in one taxon Textulariina. Thus, the separation of the Astrorhizata class (= Monothalamea) and multichambered morphoclasses Miliolata (Tubothalamea) and Rotaliata (= Globothalamea) as well as uniting of the agglutinated and calcareous forms within each phyletic line (class) according their morphological features were also confirmed by molecular studies (though less elaborated in molecular studies Spirillinata clada was united in molecular classification with the Miliolata clade). The confirmation of the monophyletic character of the phylum foraminifera and of three of its classes separated previously on the basis of morphology is a great achievement of the new molecular methods and its significance may be compared with the NASA Gravity-Probe program which confirmed Einstein's theory of relativity. At the same time it also confirms the significance of morphological studies and their usefullness for reconstructing of the true evolutionary phyletic lines.

As it was mentioned above, the fourth less studied by molecular methods morphoclass Spirillinata though showing its line, was united with the morphoclass Miliolata. Unfortunately, the 5th morphoclass Nodosariata was nearly overlooked in the molecular studies and it still needs the greater attention, all its multiple taxa were placed in molecular classification scheme as Incertae Sedis. Surely, in all its morphological and shell wall features, in tendencies of its evolutionary development it represents a separate phylogenetic foraminiferal line (class), and on this basis, one can expect that its representatives are genetically different from the representatives of the other foraminiferal classes. A few species examined with such molecular studies (for example *Glandulina antarctica*) already turned out to confirm this assumption being different from the class Rotaliata (Globothalamea) and from the other multichambered foraminiferal class-rank taxa [92].

Thus, Nodosariata again turned out to be investigated less than the other foraminiferal classes. At the same time, this example demonstrates significance of taxonomy helping to elucidate the less studied objects and problems. For instance, for understanding main peculiarities of the life cycles, nuclear apparatus, shell wall ultrastructure, DNA sequences of the main foraminiferal phyletic lines (classes) and Foraminifera as a whole, the study of all these characters in the class Nodosariata would be more important than the additional studies of other not yet studied multiple orders (or of the 11 of the orders in Loeblich and Tappan [117] classification) belonging to the classes where some main features of these characters are known, at least to some extent.

At the same time this example again demonstrates not only importance of morphological methods of study permitting to understand the main phyletic foraminiferal lines (classes) but also the opportunity to see the most problematic taxa in need of clarification of their systematic position with the help of molecular methods: such taxa, first of all, include some closely related species and genera or primitive shells poor in morphological features, for example, unilocular shells or primitive tubular shells such as *Ammodiscus* whose agglutinated representatives may possibly belong to Miliolata or Spirillinata line being undistinguishable morphologically. Molecular methods can also help in solving such a fundamental problem as the problem of species in Foraminifera, of the species borders which was already brightly demonstrated in some works [104,105,109,129-131]. Morphological methods remain the main, and for the fossil forms - the only ones, methods of study. Thanks to electron microscopy, the resolution and significance of these methods have only increased.

Taxonomy, being the basis for the other disciplines, needs to have stability. Its stability is provided by nomenclature codes with the uniform rules for both Recent and fossil organisms.

The purpose of the code is to ensure that each taxon group has only one correct name accepted all over the world.

"When in the 18th century there was a rapid accumulation of new knowledge, many synonyms and homonyms arose, the situation became close to chaos. This necessitated the creation of nomenclature codes with clear rules while maintaining the principle of priority for all names of the previous period. Thus, the scope of the first zoological code [132,133] included all names published since 1758.

The Main Article of this code first formulated the principle of priority, according to which the correct formal scientific name for an animal taxon, a valid name, correct to use, is the oldest available name applicable to it. This is the most important principle - the fundamental guiding precept that keeps the zoological nomenclature stable. [……] This made it possible to ensure the universality, stability and continuity of names that have developed over a long previous period, to settle the changing practice in taxonomy." (https://en.wikipedia.org/wiki/Hugh_Edwin_Strickland)

The first codes legalized the already established practice of preserving the very first name, since only such practice could lead out of the maze.

In the 18th - 20th centuries, there was an intensive accumulation of knowledge about organisms described as taxa of a lower rank - from species to family. Therefore, it were the rules for taxa of this lower level that were regulated in the first codes. Thus these rules did not touch and did not concern taxa of the superfamily rank. Nevertheless, in their practice, scientists adhered to this principle (principle of priority) when describing orders and classes.

At the end of the 20th, the beginning of the 21st century, thanks to the emergence of new research methods, an array of knowledge was accumulated concerning taxa of a higher level - not only of the superfamily rank (which already had been happening for a long time earlier), but also for the those of order and supraorder level, and the class and supra class level also; moreover, names of taxa of the new higher levels appeared, which were not in use earlier (domain and some others). At the same time, the priority of preserving the former taxon's name was often violated, the previous names were not indicated even in synonymy, despite the complete coincidence of the composition and characteristics of the described taxon. This affected all groups of organisms, and to some extent - foraminifera. Among the author names higher then family rank only the order's names authorship survived, but in some cases the rule was violated even in the cases of family level taxa. Under such an approach even the Foraminifera class itself described by d'Orbigny in 1826 (though firstly attributed to mollusks) and several times preserving its author's name even in spite of changing of its rank (from class to the order and then to subclass, again to class and finally to phylum level) would not finally have retained its authorship.

If in the 20th century, in the process of publishing new high rank taxa (order and higher), these fundamental principles of the code were observed in practice, then in the 21st century they often began to be increasingly neglected.

The situation when the names of many groups of organisms began to be used without following the rules of the code (and without mentioning the previous names, even as synonyms) is dangerous and can lead to destabilization of the system similar as it was in the 18th century. The time has come to expand the rules of the code and apply them also to all taxa of a rank higher than the family rank for all groups of organisms. The leading scientists and taxonomists insist on strict adherence to the basic rules of the code when revising new taxa of high rank (class and higher): "Underlying these discussions are principles of nomenclatural priority in the spirit of the codes of nomenclature… As we argued before [134] this [the author meant revision of the taxa - V. Mikhalevich] must be done with care, respecting nomenclatural priority" Adl, et al. [135]. It is very important that this intention is consistently carried out in practice. Thus, for instance, the morphoclass Acantharea Haeckel, 1881 preserved its previous name in molecular classification as its composition and diagnoses reflected its monophyletic character composed at the base of morphological features. Foraminiferal morphoclasses in similar situation were less fortunate – each of the three of them have now two different names.

In the present time when the volume of new knowledge is permanently exponentially growing, role of electronic nomenclature databases, which began at the end of the 20th century is significantly increasing, especially of those giving the classification base. Among them are the Ellis and Messina catalogue which was gradually transformed into an electronic form (http://micropress.org/em/), also several sites devoted to traditional and newly offered foraminiferal classifications have appeared:

http://www.marinespecies.org/foraminifera/ - scientific team headed by B. Hayward (WoRMS) and trying to combine both morphologic and molecular approaches, embracing now more than 18 000 species; S. Brands site http://taxonomicon.taxonomy.nl/;http://www.foraminifera.eu/morphoclass.html representing suprageneric classification of living organisms, including foraminifera; M. Hesemann site based on the morphologic taxonomy, including already more than 15 thousands of recent and fossil species, and a site devoted to molecular classification including already more than 600 species (the last two sites in the framework of the FEUPRO - http://www.foraminifera.eu.). *S. Brands* and *M. Hesemann* sites use morphologic classifications based on the taxonomic approach elaborated by the Russian school, more details may be found in Mikhalevich [136].

Among the important databases, bibliographic databases also ought to be noted. A list of publications on foraminifera was regularly published by Ruth Todd in the Journal of Foraminiferal Research (http://www.cushmanfoundation.org/jfr), more recently also in the journal "Micropaleontology" (http://www.micropress.org/bim/about.php). The Grzybowski Foundation (http://gf.tmsoc.org/foram-refs.html) covers publications of the main body of micropaleontological journals and monographs from 1980 to the present day. Taking into account the ever-increasing number of journals and publications, it can be said that the Foundation is coping with an almost impossible task. On the same site, great attention is paid to the taxonomy of foraminifera, an International Working Group of Foraminifera Classification (IWGFC) has been created to develop their modern system.

These are, in brief, the main results of the study period under consideration, which can be presented in such a short overview. It can be said without exaggeration that our knowledge of foraminifera in the period under review increased exponentially and surpassed the results of previous centuries.

The Goals and Objectives of Further Research

Taking into consideration the above mentioned, the goals and objectives of further research can be outlined as follows.

1. All previous research directions listed above in Part I deserve to be continued and certainly will be continued using all the possibilities of latest research methods.
2. Studies of living species, their biology, their life cycles, their reaction to different physical and chemical factors in laboratory experiments ought to be significantly intensified as historically the primary attention has been paid to the foraminiferal shells. Nodosariata's representative needs such studies in the first place. It is also worth mentioning the importance of reviews in this and the other topics as, for instance, the review on "Experimental Studies on Benthic Foraminifera" Kurtarkar SR, et al. (2017) and some others. Significance of reviews in a situation of the overwhelming publications number can help to advance the other directions of foraminiferal researches.
3. Cytological methods ought to be more widely used, especially in unilocular forms pure in their shell morphological features. Cytological studies of foraminifera may also contribute to the cell theory and understanding of cell evolution, as foraminifera represent a unique highly specific and advanced group of unicellular eukaryotes.
4. Concerning the fundamental significance of taxonomic studies for all the other fields of foraminiferology it would be important:

a. To continue the revision within the major groups (classes, orders) based on new approaches to the foraminiferal taxonomy and evolution offered both by the morphological and molecular schools. Such revision has already been done for the agglutinated groups [123,126-128,137], for miliolates and partially for some other taxa [83,85]. Some representatives of Nodosariata and Spirillinata were transferred from the class Rotaliata to the more appropriate classes earlier – for instance the Paleozoic nodosariates, pleurostomellids [88,122]. Such revision has been started using the molecular methods for the rotaliats [138,139]. But, some of the other major taxa inside the classes ought to be revised using new knowledge and understanding.

b. To publish series of articles and monographs devoted to the separate large taxonomic groups similarly as has been done earlier in the Cushman Foundation special publications, in the VNIGRI monographs, in serial of monographs by Hayward [72], Hayward, et al. [140,141], Mikhalevich & Kaminski [137], in thematic issues of *Micropaleontology,* the *Journal of Foraminiferal Research* and some others.

c. To search and to publish lists of the new genera belonging to different taxonomic groups as well as of the new suprageneric taxa published after the Loeblich and Tappan Treatise of 1987 [117]. The number of genera is steadily increasing, and it is difficult for the specialists who are not purposefully engaged in systematics of the special restricted groups or Foraminiferal taxonomy as a whole to search all the new publications, and sometimes it is impossible not only to navigate the huge number of publications describing new taxa, but also even to track their rapidly growing number. Moreover, it is sometimes difficult to determine the correct position of the new taxon in the foraminiferal phylum. During the last decades such work began and is continued by Kaminski [126,127,142,143,144] for all the agglutinated forms belonging to different foraminiferal classes. I began publications on the new porcellaneous Miliolata genera [136], also tried to add the names of the genera published since 1987 year in systematic review of 2013a book, but for the majority of calcareous forms such special compilation work has not yet been attempted.
d. There are problems of high rank taxa nomenclature, especially those of the class and supraclass level not only in foraminifera and the other unicellular Eukaryotes but in all the other groups of organisms including fungi and plants. In fact, now in many of the living groups, there are two parallel nomenclatures for the same objects or the groups of objects, and molecular nomenclature, as opposed to the previous classical one, is not yet regulated by any Nomenclature Codex. At that, it often does not give the synonymy used as the previous names of the new molecular taxa. Luckily, in the foraminifera this problem is not so insurmountable as in the other groups because the 3 molecular classes uniting morphological clades practically coincide with the four of morphological classes and the discrepancies between the morphological and molecular classifications are minimal as compared to the situation with classifications in many of the other groups of organisms. However, the double names for the three of the foraminiferal classes appeared and a number of problems arise due to incompleteness of the groups covered by molecular studies. The prevalence among the foraminifera of fossil taxa also limits the practical use of the new molecular classification not regulated by NCZC.
e. All the above mentioned studies and goals (a, b, c, d), especially those marked in the point **c**,
f. Should be regarded as preliminary work for a publication similar to the Loeblich and Tappan "Treatise" of 1987 [117], but based on a new understanding of the system and evolution of the foraminifera and including all the newly published taxa. The need for such an edition is long overdue, and only the united effort and collaboration of specialists can make it possible. Only an edition of this kind may provide "... a firm taxonomic base that serves as a key to the identification of the genera and contributes to the stability of nomenclature." [145]. The absence of such an updated modern complete edition similar to the Loeblich and Tappan "Treatise" of 1987 [117], inhibits and slows down the development of all other directions of foraminiferology.
g. To draw attention to the problem of species in the foraminifera and to formulate criteria for their boundaries uniting both morphological and molecular approaches, to study new phyletic lines of multichambered foraminifera with complex morphology discovered by metabarcoding methods in collaboration with morphologists, thus continuing the work began earlier [104,105,129,130,146,147].
h. And last, but not the least – to continue to keep strictly following ICZN rules, not ignoring the ethical norms of the code.

5. To continue searching for the roots of the multichambered taxa within the earlier primitive, mostly unilocular forms of the class Astrorhizata (=Monothalamea). These primitive forms are pure in their morphological characters and namely the cytological and molecular methods are perspective in solving this problem. Some of results in this field already received, and new research on the fossil record has uncovered some early examples of multichambered and pseudomultichambered foraminifera in the Ordovician and Silurian [57,148,149-166].
6. To remember that only an integrated approach using various analytical methods can produce the most effective and promising results.

In conclusion, some ideas that have appeared during my rather long career in foraminiferal studies and which may be of use to younger researchers:

Firstly, in spite of the introduction of new and important methods, the morphological method still preserves its importance: it remains the main method for foraminiferal studies and is practically the only method for fossil forms. Namely, this method permits to formulate the diagnoses of taxa, to perform comparative analysis of different forms, to highlight the taxa with the doubtful taxonomic position, which are in the first place in need of molecular research. Collaboration between specialists in molecular studies with traditional morphologists may bring more fruitful results.

Secondly, the wider a researcher's approach and knowledge of forms and specific problems not only immediate nearest to study but also rather remote, the better may be the results of smaller group studies or immediate problems solved. For example, to understand that fusulinid chomata and recent miliolid teeth are structures identical in their formation and function, one needs to have knowledge of both groups so widely separated in geological time (Figure 3).

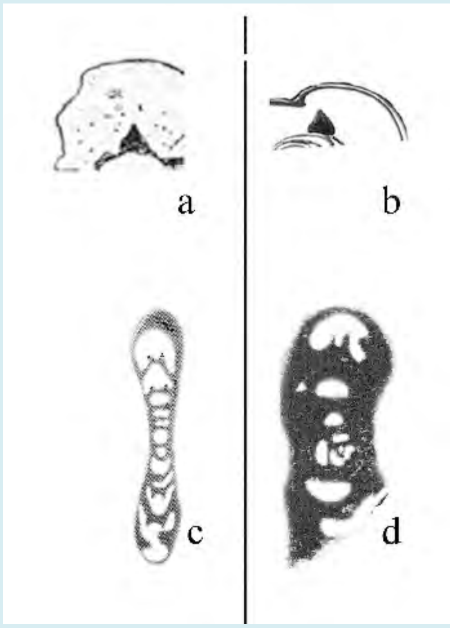

Figure 3: (from Mikhalevich, 2009, part)[124]. Inner apertural structures in fusulinids (a, c) and miliolids (b, d): a – *Endothyra* ex. gr. *similis* Rauser-Chernousova and Reitlinger, 1936; b – *Miliolinella subrotunda* Montagu, 1803; c – *Novella evoluta* Grozdilova and Lebedeva, 1950; d – *Kayseriella decastroi* Sirel, 1999 (after Mikhalevich, 2009 [124]– part) .

References

1. Robert EA, Boudreau REA, Patterson RT, Andrew P, Dalby W, et al. (2001) Non-marine occurrence of the foraminifer Cribroelphidium gunteri in Northern lake Winnipegosis, Manitoba, Canada. J Foram Res 31(2): 108-119.

2. Holzmann M, Habura A, Giles H, Bowser SS, Pawlowski J (2003) Freshwater Foraminiferans revealed by analysis of Environmental DNA Samples. J Eukaryotic Microbiology 50(2): 135-139.

3. Gibson JAE, Quilty PG, Swadling KM, Newman L, Paterson KS (2008) Paratrochammina minutissima n. sp. in brackish, marine-derived lakes of the Vestfold Hills, East Antarctica. Journ Foram Res 38(4): 292-297.

4. Debenay JP (2009) Foraminifera, chapter thirteen. In: Amiard C, Rainbow PS (Eds.), Environmental assessment of estuarine ecosystems: A Case Study, Florida, pp: 255-280.

5. Brodsky AL (1928) Foraminifera (Polythalamia) v kolodcach pustyni Kara-Kum [Foraminifera (Polythalamia) in the wells of the Kara-Kum desert]. Proc. State Middle-Asiatic Univ., ser. 8 a, Zoology 5: 1-16.

6. Gauthier Lievre L (1935) Sur une des singularites de l'oued Rhir: des Foraminiferes Thalassoides vivants dans les eaux sahariennes. Bull Soc H N Afrique du Nord 26: 142-147.

7. Mikhalevich VI (1976) New data on the Foraminifera of the Ground waters of the Middle Asia. Int J Speleol 8: 167-175.

8. Lejzerowicz F, Pawlowski J, Fraissinet Tachet L, Marmeisse R (2010) Molecular evidence for widespread occurrence of Foraminifera in soils. Environ Microbiol 12(9): 2518-2526.

9. Risgaard Petersen N, Langezaal AM, Ingvardsen S, Schmid MC, Jetten MS, et al. (2006) Evidence for complete denitrification in a benthic foraminifer. Nature 443: 93-96.

10. Lith Y, Langezaal AM, de Nooijer LJ, van der Zwaan GJ (2009) Benthic foraminiferal effect on nitrogen and carbon cycling. Journal of Foraminiferal Research 39(2): 97-111.

11. Lipps JH (1975) Feeding strategies and test function in foraminifer. Proceedings: "Benthonic" 75: 26.

12. Lipps JH, Valentine JW (1970) The role of Foraminifera in the trophic structure of marine communities. Lethaia 3(3): 279-286.

13. Gooday AJ, Levin LA, Linke P, Heeger T (1992) The role of benthic foraminifera in deep-sea food webs and carbon cycling. In: Rowe GT, Pariente V (Eds.), Deep-Sea Food Chains and the Global Carbon Cycle, Kluwer Academic Publishers, the Netherlands, pp: 63-91.

14. Gooday AJ, Nomaki H, Kitazato H (2008) Modern deep-sea benthic foraminifera: a brief review of their morphology-based biodiversity and trophic diversity. Geol Soc Lond Spec Publ 303: 97-119.

15. Alve E (2010) Benthic foraminiferal responses to absence of fresh phytodetritus: A two-year experiment. Mar Micropaleontol 76(3-4): 67-75.

16. Lee JJ, Anderson OR (1991) Biology of Foraminifera. Academic Press. London, pp: 368.

17. Langer MR, Makled VA, Pietsch SJ, Weinmann A (2009) Asynchronous calcification in juvenile megalospheres: an ontogenetic window into the life cycle and polymorphism of Peneroplis. Journal of Foraminiferal Research 39(1): 8-14.

18. Goldstein ST, Bernhard JM (1997) Theme Issue: Biology of Foraminiferida: Applications in Paleoceanography, Paleobiology, and Environmental Sciences. Journal of Foraminiferal Research 27(4): 254-328.

19. Goldstein ST (1999) Foraminifera: a biological overview. In: Sen Gupta BK (Ed.), Modern Foraminifera. Kluwer Academic Publishers, New York, pp: 37-55.

20. Hallock P (1981) Algal symbionts and mathematical analysis. Marine biology 62(4): 249-255.

21. Hallock P (1985) Why are larger foraminifera large?. Paleobiology 11(2): 195-208.

22. Hallock P (2000) Larger Foraminifera as Indicators of Coral Reef Vitality. In: Martin RE (Ed.), Environmental Micropaleontology: The application of microfossils to Environmental Geology, Kluwer Academic/Plenum Publishers, pp: 121-150.

23. Hallock P (2000) Symbiont-bearing Foraminifera: hardbingers of global change?. Micropaleontology 46(1): 95-104.

24. Be AWH, Spero HT, Anderson OR (1982) Effects of symbiont elimination and reinfection on the life processes of the planktonic foraminifer Globigerinoides sacculifer. Marine Biol 70(1): 73-86.

25. Bernhard JM, Buck KR, Farmer MA, Bowser SS (2000) The Santa Barbara Basin is a symbiosis oasis. Nature 403: 77-80.

26. Pawlowski J, Holzmann M, Fahrni JF, Hallock P (2001) Molecular identification of algal endosymbionts in large miliolid foraminifera: 1. Chlorophytes. Journ Eukar Microbiol 48(3): 362-367.

27. Hohenegger J (1994) Distribution of living larger foraminifera NW of Sesoko-Jima, Okinawa Japan. Marine Ecology 15(3-4): 291-334.

28. Hohenegger J (2011) Large Foraminifera. Greenhouse Constructions and Gardeners in the Oceanic Microcosm. The Kagoshima University Museum Bulletin 5: 1-81.

29. Bird C, Darling KF, Russell AD, Davis CV, Fehrenbacher J, et al. (2017) Cyanobacterial endobionts within a major marine planktonic calcifier (Globigerina bulloides, Foraminifera) revealed by 16S rRNA metabarcoding. Biogeosciences 14(4): 901-920.

30. Shaw JO, D'haenens S, Thomas H (2021) Photosymbiosis in planktonic foraminifera across the Paleocene–Eocene thermal maximum. Paleobiology, pp: 1-16.

31. Berthold WU (1976) Biomineralisation bei milioliden Foraminiferen und die Matrizen Hypothese. Naturwissenschaften 63: 196-197.

32. Hemleben C, Be AWH, Anderson OR, Tuntivate S (1977) Test morphology, organic layers and chamber formation of planktonic foraminifer Globorotalia menardii (d'Orbigny). Journal of Foraminiferal Research 7(1): 1-25.

33. Angell RW (1979) Calcification during chamber development in Rosalina floridana. Journal of Foraminiferal Research 9(4): 341-353.

34. Angell RW (1980) Test morphogenesis (chamber formation) in the foraminifer Spiroloculina hyalina Schultze. Journal of Foraminiferal Research 10(2): 89-101.

35. Angell RW (1990) Observations on reproduction and juvenile test building in the foraminifer Trochammina inflata. Journal of Foraminiferal Research 20(3): 246-247.

36. Tyszka J, Raitzsch M, Bijma J, Höher N, Bickmeyer U, et al. (2015) Morphogenetic role of F-actin meshwork in chamber formation: immunolabeling results from symbiont bearing benthic foraminifera. Geophysical Research Abstracts 17: EGU2015-7409.

37. Diz P, Mena A, Nombela MA, Mónica Castaño Carrera, Velo A, et al. (2015) Description of an experimental set up for the culture of benthic foraminifera in controlled pH conditions. Thalassas 31(1): 23-32.

38. Hallock P, Talge HP, Cockey EM, Muller RD (1995) A new desease in reef-dwelling foraminifera: implications for coastal sedimentation. Journal of Foraminiferal Research 25(3): 280-286.

39. Alve E, Goldstein ST (2010) Dispersal, survival and delayed growth of benthic foraminiferal propagules. Journ Sea Res 63(1): 36-51.

40. Ross DG, Hallock P (2016) Dormancy in Foraminifera: a review. Journal of Foraminiferal Research 46(4): 358-368.

41. Roy T, Lombard F, Bopp L, Gehlen M (2015) Projected impacts of climate change and ocean acidification on the global biogeography of planktonic Foraminifera. Biogeosciences 12(10): 2873-2889.

42. Knorr PO, Robbins LL, Harries PJ, Hallock P (2015) Response of the Miliolid Archaias angulatus to Simulated Ocean Acidification. Journal of Foraminiferal Research 45(2): 109-127.

43. Kaiho K (1991) Global changes of Paleogene aerobic/anaerobic benthic foraminifera and deep-sea circulation. Palaeogeography Palaeoclimatology Palaeoecology 83(1-3): 65-85.

44. Kaiho K (1994) Benthic foraminiferal dissolved oxygen index and dissolved oxygen levels in the modern ocean. Geology 22(8): 719-722.

45. Kaminski MA, Boersma A, Tyszka J, Holbourn AEL (1995) Response of deep-water agglutinated foraminifera to dysoxic conditions in the California Borderland basins. In: Kaminski MA, Geroch S, Gasinski MA (Eds.), Proceedings of the Fourth Ninth International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 3: 131-140.

46. Gooday AJ, Turley CM (1990) Response by benthic organisms to inputs of organic material to the ocean floor: a review. Philos Trans R Soc Lond 331(1616): 119-138.

47. Loubere P (1991) Deep-sea benthic foraminiferal assemblage response to a surface ocean productivity gradient: A test. Paleoceanography and Paleoclimatology 6(2): 193-204.

48. Gooday AJ (1993) Deep-sea benthic foraminiferal species which exploit phytodetritus: Characteristic features and controls on distribution. Marine Micropaleontology 22(3): 187-205.

49. Kaminski MA, Kuhnt W (1995) Tubular agglutinated Foraminifera as indicators of organic carbon flux. In: Kaminski MA, Geroch S, Gasinski MA (Eds.), Proceedings of the Fourth Ninth International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 3: 141-144.

50. Langer MR, Silk MTB, Lipps JH (1997) Global ocean carbonate and carbon dioxide production: the role of reef Foraminifera. Journal of Foraminiferal Research 27(4): 271-277.

51. Van der Zwaan GJ, Duijnstee IAP, Den Dulk M, Ernst SR, Jannink NT, et al. (1999) Benthic foraminifers: proxies or problems? a review of paleocological concepts. Earth Science Reviews 46(1): 213-236.

52. Gooday AJ, Bett BJ, Jones DOB, Kitazato H (2012) The influence of productivity on abyssal foraminiferal biodiversity. Marine Biodiversity 42: 415-431.

53. Krasheninnikov V, Hall J, Hirsch F, Benjamin C, Flexer A (2005a) Geological Framework of the Levant. Cyprus and Syria. Jerusalem 1: 498.

54. Krasheninnikov V, Hall J, Hirsch F, Benjamin C, Flexer A (2005b) Geological Framework of the Levant. Levantine Basin and Israel: Jerusalem 2: 826.

55. Krasheninnikov VA, Basov IA (2007) Stratigraphiya paleogenovych otlozhenij Mirovogo okeana i korreljaciya c razrezami na kontinentach [Stratigraphy of Paleogene deposits in the World Ocean and Correlation with Sections on Continents]: Transactions of Geological Institute 583: 316.

56. Kaminski MA, Setoyama E, Cetean C (2008) Revised stratigraphic ranges and the Phanerozoic diversity of agglutinated foraminiferal genera. In: Kaminski MA, Coccioni R (Eds), Proceedings of the Seventh International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 13: 79-106.

57. Kaminski MA, Perdana PRD (2020) Early Silurian Benthic Foraminifera from Saudi Arabia – including the oldest known multichambered lituolids. Stratigraphy 17(3): 141-185.

58. Lee JJ, Freudental HG, Kossoy V, Be AWH (1965) Cytological observations on two planktonic Foraminifera, Globigerina bulloides d'Orbigny, 1826 and Globigerinoides ruber (d'Orbigny, 1839) Cushman, 1927. Journ Protozool 12(4): 531-542.

59. Dahlgren L (1967) On the ultrastructure of the gamontic nucleus and the adjacent cytoplasm of the monothalamous foraminifer Ovammina opaca Dahlgren. Zool Bidrag Uppsala 37(2): 77-112.

60. Berthold WU (1971) Untersuchungen uber die sexuelle Differerierung der Foraminifere Patellina corrugata Williamson mit einen Beitrag zum Entwicklungsgang und Shalenbau. Archive Protistenkunde 113(3): 147-184.

61. Grell KG (1973) Protozoology. Springer, Berlin, Heidelberg 8: 556

62. Grell KG (1979) Cytogenetic systems and evolution in Foraminifera. Journal of Foraminiferal Research 9(1): 1-14.

63. Grell KG (1988) The life-cycle of the monothalamous foraminifer Heterotheca lobata, n. gen., n. sp. Journal of Foraminiferal Research 18(1): 54-74.

64. Voronova MN, Selivanova GV (1976) Isledovanie generativnych jader foraminifery Cibicides lobatulus metodom cytophotometrii. [Investigation of the gennerative nuclei of the foraminifera Cibicides lobatulus with the cytophotometric method]. Protozoology 1: 144-150.

65. Be AWH, Hemleben C, Anderson OR, Spindler M, Hacunda J, et al. (1977) Laboratory and field observations of living planktonic Foraminifera. Micropaleontology 23(2): 155-179.

66. Cesana D (1975) Les stades initaux de la gamogonie chez Iridia lucida Le Calvez (Foraminifera. Lagenidae). Compt Rend Acad Sci Paris. Series D 281(4): 263-266.

67. Cesana D (1978) La mitose gamogonique chez Iridia lucida (Foraminifera, Lagynidae). Annals Scientific Naturele Ser 12, 20(3): 287-320.

68. Roettger R (1978) Unusual multiple fission in the gamont of the larger Foraminiferan Heterostegina depressa. Journ Protozool 25(1): 41-44.

69. Lee JJ (1980) Nutrition and Physiology of the Foraminifera. 2nd (Edn.), In: Biochemistry and physiology of Protozoa, 3: 43 - 66.

70. Lee JJ, Sang K, Kuile Ter B, Strauss E, Lee PJ, et al. (1991a) Nutritional and related experiments on laboratory maintenance of three species of symbiont-bearing large foraminifera. Marine Biology 109: 417-425.

71. Lee JJ, Faber WW, Lee RE (1991b) Granular reticulopodian digestion – a possible preadaptation to benthic foraminiferal symbiosis?. Symbiosis 10: 47-61.

72. Hayward BW (1990) Taxonomy, paleobiogeography and evolutionary history of the Bolivinellidae (Foraminiferida). N Zealand Geol Surv Paleontol Bull 63: 132.

73. Arnold ZM (1984) The gamontic karyology of the saccamminid foraminifer Psammophaga simplora Arnold. Journal of Foraminiferal Research 14(3): 171-187.

74. Goldstein ST (1988) On the life cycle of Saccammina alba Hedley 1962. Journal of Foraminiferal Research 18(4): 313-327.

75. Goldstein ST (1997) Gametogenesis and the antiquity of the reproductive pattern in the Foraminiferida. Journal of Foraminiferal Research 27(4): 319-328.

76. Goldstein ST, Corliss BH (1994) Deposit feeding in selected deep sea and shallow-water benthic foraminifera. Deep-Sea Research 41(2): 229-241.

77. Pawlowski J, Swiderski Z, Lee J (1995) Observations on the ultrustructure and reproduction of Trochammina sp. (Foraminiferida). In: Kaminski MA, Geroch S, Gasinski MA (Eds.), Proceedings of the Fourth International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 3: 233-237.

78. Kitazato H, Matsushita S (1996) 1012 Laboratory observations of sexual and asexual reproduction of Trochammina hadai Uchio. Trans Proc Paleont Soc Jpn 1996(182): 454-466.

79. Krueger R, Roettger R, Lietz R, Hohenegger J (1997) Biology and reproductive processes of the larger foraminiferan Cycloclypeus carpenteri (Protozoa, Nummulitidae). Archiv Protistenkunde 147(3-4): 307-321.

80. Raikov IB, Karajan BP, Mikhalevich VI (1998) Ultrastructure of the gamont Shell and Nucleus in the Polythalamous Foraminifer Elphidium ponticum. European Journal of Protistology 34(2): 153-161.

81. Preobrazhenskaya TV, Tarasova TS (2004) Sexual reproduction of the foraminifer Planoglabratella opercularis (d'Orbigny, 1839) in nature. Biologiya Morya 30(5): 375-379.

82. Habura A, Hou Y, Reilly AA, Bowser SS (2011) Highthroughput sequencing of Astrammina rara: sampling the giant genome of a giant foraminiferan protist. BMC Genomics 12: 169.

83. Mikhalevich VI (2013a) Post-Cambrian Testate Foraminifera as a System in its Evolution. Nova Science publishers, pp: 1-444.

84. Mikhalevich VI (1998) Makrosistema foraminifer [The Macrosystem of the Foraminifera]. Izvestija Russian Academy Sciences. Ser Biological (2): 266-271.

85. Mikhalevich VI (2013b) New insight into the systematics and evolution of the foraminifera. Micropaleontology 59(6): 493-527.

86. Zech L (1964) Zytochemische Messungen an den Zellkernen der Foraminiferen Patellina corrugate und Rotaliella heterocariotica. Archive für Protistenkunde 107: 295-330.

87. Dubicka Z, Owocki K, Gloc M (2018) Micro- and Nanostructures of Calcareous Foraminiferal Tests: Insight from Representatives of Miliolida, Rotaliida and Lagenida. Journal of Foraminiferal Research 48(2): 142-155.

88. Mikhalevich VI (2011) Test wall ultrastructure and taxonomic position of the foraminiferal genus Strictocostella Patterson, 1987. Micropaleontology 57(6): 543-555.

89. Pawlowski J (2000) Introduction to the molecular

systematics of foraminifera. Micropaleontology 46(1): 1-12.

90. Ertan KT, Hemleben V, Hemleben C (2004) Molecular evolution of some selected benthic foraminifera as inferred from sequences of the small subunit ribosomal DNA. Marine Micropaleontology 53(3-4): 367-388.

91. Pawlowski J, Holzmann M, Berney C, Fahrni J, Gooday AJ, et al. (2003) The evolution of early foraminifera. PNAS 100(20): 11494-11498.

92. Pawlowski J, Holzmann M, Tyszka J (2013) New supraordinal classification of Foraminifera: Molecules meet morphology. Marine Micropaleontology 100: 1-10.

93. Flakowski J, Bolivar I, Fahrni J, Pawlowski J (2005) Actin phylogeny of Foraminifera. Journ Foram Res 35(2): 93-102.

94. Holzmann M, Pawlowski J (2002) Freshwater foraminiferans from Lake Geneva: past and present. Journal of Foraminiferal Research 34(4): 344-350.

95. Siemensma F, Apothéloz Perret Gentil L, Holzmann M, Clauss S, Völcker E, et al. (2017) Taxonomic revision of freshwater foraminifera with the description of two new agglutinated species and genera. Europ Journ Protistol 60: 28-44.

96. Pawlowski J (2010) Evolution of Rhizaria: new insights from phylogenomic analysis of uncultivated protists. BMC Evol Biol 10: 377.

97. Pawlowski J, Burki F (2009) Untangling the Phylogeny of Amoeboid Protists. Journ Eukaryot Microbiol 56(1): 16-25.

98. Groussin M, Pawlowski J, Yang Z (2011) Bayesian relaxed clock estimation of divergence times in foraminifera. Molecul Phylogenetic and Evol 61(1): 157-166.

99. Gooday AJ, Bowser SS, Bernhard JM (1996) Benthic foraminiferal assemblages in Explorers Cove, Antarctica: A shallow-water site with deep-sea characteristics. Progress in Oceanography 37(2): 117-166.

100. Bowser SS, Bernhard JM, Habura A, Gooday AJ (2002) Structure, taxonomy and ecology of Astrammina triangularis (Earland), an allogromiid-like agglutinated foraminifer from Explorers Cove, Antarctica. Journ Foramin Res 32(4): 364-374.

101. Pawlowski J, Fahrni JF, Brykczynska U, Habura A, Bowser SS (2002) Molecular data reveal high taxonomic diversity of allogromiid Foraminifera in Explorers Cove (McMurdo Sound, Antarctica). Polar Biology 25: 96-105.

102. Habura A, Pawlowski J, Haynes SD, Bowser SS (2004) Unexpected foraminiferal diversity revealed by small subunit rDNA analysis of Antarctic sediment. Journ Eukar Microbiol 51(2): 173-179.

103. Habura A, Goldstein S, Broderick S, Bowser SS (2008) A bush not a tree: the extraordinary diversity of cold-water basal foraminiferans extends to warm-water environments. Limnology and Oceanology 53(4): 1339-1351.

104. Darling KF, Wade CM, Kroon D, Leigh Brown AJ, Bijma J (1999) The diversity and distribution of modern planktic foraminiferal small subunit ribosomal RNA genotypes and their potential as tracers of present and past ocean circulation. Paleoceanography 14(1): 3-12.

105. Darling KF, Wade CM, Stuart IA, Kroon D, Dingle R, et al. (2000) Molecular evidence for genetic mixing of Arctic and Antarctic subpolar populations of planktonic foraminifers. Nature 405(6782): 43-47.

106. De Vargas C, Norris R, Zaninetti L, Gibb SW, Pawlowski J (1999) Molecular evidence of cryptic speciation in planktonic foraminifers and their relation to oceanic provinces. Proceed Nation Acad Sci USA 96(6): 2864-2868.

107. De Vargas C, Renaud S, Hilbrecht H, Pawlowski J (2001) Pleistocene adaptive radiation in Globorotalia truncatulinoides: genetic, morphologic, and environmental evidence. Paleobiology 27(1): 104-125.

108. Darling K, Wade CM (2008) The genetic diversity of planktic foraminifera and the global distribution of ribosomal RNA genotypes. Marine Micropaleontology 67(3-4): 216-238.

109. Darling K, Leckie RM (2010) Bridging the benthic/planktic divide. In: Forams 2010 Abstr. Vol. with program. Baylaydruk, Bonn, pp: 74.

110. Darling KF, Kroon D, Wade CM, Leigh Brown AJ (1996) Molecular phylogeny of the planktic foraminifera. Journal of Foraminiferal Research 26(4): 324-330.

111. Darling KF, Wade CM, Kroon D, Leigh Brown AJ (1997) Planktic foraminiferal molecular evolution and their polyphyletic origin from benthic taxa. Marine Micropaleontology 30(4): 251-266.

112. Darling KF, Schweizer M, Knudsen KL, Evans KM, Bird C, et al. (2016) The genetic diversity, phylogeography and morphology of Elphidiidae (Foraminifera) in the Northeast Atlantic. Marine Micropaleontology 129: 1-23.

113. Holzmann M, Pawlowski J (2000) Taxonomic

relationships in the genus Ammonia (Foraminifera) based on ribosomal DNA sequences. Journ Micropal 19: 85-95.

114. Gooday AJ, Jorissen FJ (2012) Benthic foraminiferal biogeography: controls on global distribution patterns in deep-water settings. Annual Review of Marine Science 4: 237-262.

115. Dufresne Y, Lejzerowicz F, Perret Gentil LA, Pawlowski J, Cordier T (2019) SLIM: a flexible web application for the reproducible processing of environmental DNA metabarcoding data. BMC Bioinformatics.

116. Frontalini F, Cordier T, Balassi E, du Chatelet EA, Cermakova K, et al. (2020) Benthic foraminiferal metabarcoding and morphology-based assessment around three offshore gas platforms: Congruence and complementarity. Environment International 144: 106049.

117. Loeblich AR, Tappan H (1987) Foraminiferal Genera and their Claassification. LLC 1: 2.

118. d'Orbigny A (1826) Tableau methodique de la classe des Cephalopodes. Ann Sci Natur 7: 245-314.

119. d'Orbigny A (1839) Foraminifères des Iles Canaries. In: Barker Webb et Berthelot (Ed.), Histoire Naturelles Iles Canaries, Zoologie, Paris 2(2): 119-146.

120. Rauser Chernousova DM, Fursenko AV (1959) Osnovy Paleontologii. Obshcaya Chast', Prosteyshie. [Principles of Paleontology. General Part, Protozoa.] Moscow, pp: 482.

121. Mikhalevich VI (1980) Sistematika i evolyuciya foraminifer v svete novyikh dannyikh po ih citologii i ul'trastrukture [Systematics and evolution of the Foraminifera in view of the new data on their cytology and ultrastructure]. In: Principy postroeniya makrosistemy odnokletochnyih zhivotnyh. Trudy Zoologicheskogo Instituta, AN SSSR, 94: 42-61.

122. Mikhalevich VI (2000) Tip Foraminifera d'Orbigny, 1826 – Foraminifery [The Phylum Foraminifera d'Orbigny, 1826 – Foraminifers]. In: Alimov AF (Ed.), Protisty: Rukovodstvo po Zoologii [Manual on Zoology], pt. 1. Nauka Publishers, St Petersburg, pp: 533-623. (In Russian, with English summary pp. 611 – 616).

123. Mikhalevich VI (2004) On the heterogeneity of the former Textulariina (Foraminifera). In: Bubik M, Kaminski MA (Eds.), Proceedings of the Sixth International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 8: 317-349.

124. Mikhalevich VI (2009) The taxonomic position of the superorder Fusulinoida Fursenko in Foraminiferal system. Paleontological Journal 43(2): 117-128.

125. Saidova Kh M (1981) O Sovremennom Sostojanii Nadvidovych Taksonov Kajnozojskych Bentosnych Foraminifer [On the Present State of the Supraspecific Taxa of the Cenozoic Benthonic Foraminifera]. In: Rauser Chernousova DM, Isakova TN, Reitlinger EA (Eds.), Moscow: Inst Okeanologii P.P. Shirshova, Akademiya Nauk SSSR, pp: 1-73.

126. Kaminski MA (2004) The year 2000 classification of the agglutinated foraminifera. In: Bubik M, Kaminski MA (Eds.), Proceedings of the Sixth International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 8: 237-255.

127. Kaminski MA (2004) The new and revised genera of agglutinated Foraminifera published between 1996 and 2000. In: Bubik M, Kaminski MA (Eds.), Proceedings of the Sixth International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 8: 257-272.

128. Kaminski MA (2014a) The Year 2010 Classification of the Agglutinated Foraminifera. Micropaleontology. 60(1): 89-107.

129. Darling KF, Wade CM, Sicchad M, Trommere G, Schulzf H, et al. (2017) Genetic diversity and ecology of the planktonic foraminifers Globigerina bulloides, Turborotalita quinqueloba and Neogloboquadrina pachyderma off the Oman margin during the late SW Monsoon. Marine Micropaleontology 137: 64-77.

130. Hayward BW, Holzmann M, Grenfell HR, Pawlowski J, Triggs CM (2004) Morphological distinction of molecular types in Ammonia towards a taxonomic revision of the world's most commonly misidentified foraminifera. Marine Micropaleontology 50(3-4): 237-271.

131. Weber AAT, Pawlowski J (2014) Wide occurrence of SSU rDNA intragenomic polymorphism in Foraminifera and its implications for molecular species identification. Protist 165(5): 645-661.

132. Strickland HE (1842) Report of the Twelfth Meeting of the British Association for the Advancement of Science Held at Manchester in June 1842. London: John Murray, pp: 105-121.

133. *Strickland HE (1843) Report of a Committee 'appointed to consider the rules by which the nomenclature of zoology may be established on a uniform and permanent basis'.*

134. Adl SM, Simpson AGB, Lane CE, Lukeš J, Bass D, et al. (2012) The Revised Classification of Eukaryotes. Journ Eukaryotic Microbiol 59(5): 429-493.

135. Adl SM, Bass D, Lane CE, Julius Lukeš, Conrad Schoch L, et al. (2019) Revisions to the classification, nomenclature, and diversity of eukaryotes. Journ Eukaryotic Microbiol 66(1): 4-119.

136. Mikhalevich VI (2018) New foraminiferal genera of the superfamily Alveolinoidea (Miliolata, Saidova, 1981) published after 1987 year. Fundamantal and Applied Paleontology. LXIV Session of Paleontological Society, St. Petersburg, pp: 82-83.

137. Mikhalevich VI, Kaminski MA (2007) Revised systematic of Schlumbergerinida (phylum Foraminifera). In: Kaminski MA, Coccioni R, Marsili A (Eds.), Proceedings of the Seventh International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 13: 157-166.

138. Scweizer M, Pawlowski J, Kouwenhoven T, Van der Zwaan B (2009) Molecular Phylogeny of Common Cibicidids and Related Rotaliida (Foraminifera) Based on Small Subunit rDNA Sequences. Journal of Foraminiferal Research 39(4): 300-315.

139. Holzmann M, Pawlowski J (2017) An updated classification of rotaliid foraminifera based on ribosomal DNA phylogeny. Marine Micropaleontology 132: 18-34.

140. Hayward BW, Hollis CJ, Grenfell HR (1997) Recent Elphidiidae (Foraminiferida) of the South-west Pacific and fossil Elphidiidae of New Zealand. Inst Geol and Nuclear Sci, Monograph, pp: 1-170.

141. Hayward BW, Kawagata S, Sabaa A, Grenfell H, Kerckhoven L, et al. (2012) The last global extinction (Mid-pleistocene) of deep-sea benthic Foraminifera (Chrysalogoniidae, Ellipsoudinidae, Glandulonodosariidae, Plectofrondiculariidae, Pleurostomellidae, Stilostomellidae), their late Cretaceous-Cenozoic history and taxonomy. Cushman Foundation for Foraminiferal Rsearch 43: 1-408.

142. Kaminski MA (2008) The new and reinstated genera of agglutinated foraminifera published between 2000 and 2004. In: Kaminski MA, Coccioni R (Eds.), Proceedings of the Seventh International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 13: 47-55.

143. Kaminski MA (2011) The new and reinstated genera of agglutinated foraminifera published between 2005 and 2008. In: Kaminski MA, Filipescu S (Eds.), Proceedings of the Eighths International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 16: 53-59.

144. Kaminski MA (2017) The new and renamed genera of agglutinated foraminifera published between 2008 and 2012. In: Kaminski MA, Alegret L (Eds.), Proceedings of the Ninth International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 22: 95-105.

145. Kaminski MA (2014b) Will we ever have a new foraminiferal "Tretise"? FORAMS 2024, Chile, 19 – 24 January 2014Abstract Volume, In: Marchant M, Hromic T (Eds.), Grzybowski Found Spec Publ 20: 2.

146. Holzmann M, Kaminski MA, Filipescu S, Pawlowski J (2012) A molecular comparison of Entzia tetrastomella and Jadammina macrescens. In: Alegret L, Ortiz S, Kaminski MA (Eds.), Ninth International Workshop on Agglutinated Foraminifera, Grzybowski Found Spec, pp: 42.

147. Kathal PK, Bhalla SN (1996) Intraspecific variation and palaeolatitudinal significance of Rotorboides granulosum- less known Recent foraminifera of tropical waters. Rev Paleobio 15(1): 79-85.

148. Kaminski MA, Perdana P (2017) New Foraminifera from the Lower Silurian Qusaiba Shale Member of Saudi Arabia. Micropaleontology 63(1): 59-66.

149. Kaminski MA, Perdana PRD, Abouelresh MO, Babalola L (2019) Late Ordovician agglutinated foraminifera from the Ra'an Shale Member of Saudi Arabia as indicators of the O40 Maximum Flooding Surface. Stratigraphy 16(1): 27-39.

150. Goldstein ST, Habura A, Richardson EA, Bowser SS (2010) Xiphophaga minuta, and X. allominuta, nov. gen, nov. spp., new monothalamid foraminifera from coastal Georgia (USA), Cryptic species, gametogenesis, and an unusual form of chloroplast sequestration. Journal of Foraminiferal Research 40(1): 3-15.

151. Anderson OR (1988) Comparative Protozoology - Ecology, Physiology, Life History. Springer Verlag.

152. Bowser SS, Israel A, Samuel M, Russel MG, Reider CL (1984) Surface transport properties of reticulopodia: do intracellular and extracellular motility share a common mechanism? Cell Biol Intern Rep 8(12): 1051-1063.

153. Bowser SS, Travis JL (2002) Reticulopodia: Structural and behavioral basis for the suprageneric placement of granuloreticulosan protists. Journal of Foraminiferal Research 32(4): 440-447.

154. Bowser S, Habura A, Pawlowski J (2006) Molecular

evolution of Foraminifera. In: Katz LS, Bhattacharya D (Eds.), Genomics and Evolution of Microbial Eukaryotes. Oxford Biology, Chapter 5: 78-93.

155. Goldstein ST, Barker WW (1990) Gametogenesis in the monothalamous agglutinated foraminifer Cribrothalammina alba. Journ Protozool 37(1): 20-27.

156. Giusberti L, Kaminski MA, Mancin N (2018) The bathyal larger lituolid Neonavarella n.gen. (Foraminifera) from the Thanetian Scaglia Rossa Formation of northeastern Italy. Micropaleontology 64(5-6): 417-434.

157. Hohenegger J, Yordanova E, Hatta A (2000) Remarks on West Pacific Nummulitidae (Foraminifera). Journ Foram Res 30(1): 3-28.

158. Kaminski MA (2000) The new and reinstated genera of agglutinated foraminifera published between 1986 and 1996. In: Hart MB, Kaminski MA, Smart CW (Eds.), Proceedings of the Fifth International Workshop Agglutinated Foraminifera, Grzybowski Found Spec Pub 7: 185-219.

159. Karavaeva NI, Nestell GP (2007) Permian foraminifers of the Omolon Massif, northeastern Siberia, Russia. Micropaleontology 53(3): 161-211.

160. Lehmann G, Roettger R, Hohenegger J (2006) Life Cycle Variation Including Trimorphism in the Foraminifer Trochammina Inflata from North European Salt Marshes. Journal of Foraminiferal Research 36(4): 279-290.

161. Lipps JH (1983) Biotic interactions in benthic Foraminifera. In: Tevesz MJS, McCall PL (Eds.), Biotic interactions in Recent and fossil benthic communities. Plenum Publishing Corp, pp: 331-376.

162. Mikhalevich VI (2017) The role of information resources in the development of organism systematics in biology and paleontology (on the example of the phylum Foraminifera d'Orbigny - phylum Foraminifera d'Orbigny, 1826). Omega science, International Center of Innovative Research.The role and place of information technology in modern science. Magnitogorsk, pp: 10-12.

163. Nestell GP, Mestre A, Heredia S (2009) First Ordovician Foraminifera from South America: A Darriwilian (Middle Ordovician) fauna from the San Juan Formation, Argentina. Micropaleontology 55(4): 329-344.

164. Rosch AR, Pellizari VH, Almeida CS, de Sousa Eduinetty Ceci PM, Holzmann M, et al. (2021) New phylotypes of foraminifera in subtropical Brazilian coastal waters revealed by environmental DNA metabarcoding. Journ Sedimentary Environm 6: 13-23.

165. Roettger R, Krueger R, De Rijk S (1990) Trimorphism in Foraminifera (Protozoa), verification of an old hypothesis. Europ Journ Protistol 25(3): 226-228.

166. Kurtarkar SR, Linshy VN, Amrata K, Rajeev S, Nigam R (2017) Experimental Studies on Benthic Foraminifera: an Update on the Changing Trends and Challenges over the Past Decade. In: Kathal P, Nigam R, Talib A (Eds.), Micropaleontology and its Applications Kathal, Sci Pub, India, pp: 311-330.