A Portrait of Foraminifera

Foraminifera are microorganisms of enormous importance – both now and in the past.

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Foraminifera are single-celled organisms that constitute an important part of contemporary marine ecosystems. They are also known from the fossil record in various locations, including the Carpathian Basin – once part of the Paleo-Tethys Ocean. As a result of tectonic movements, the sediments once deposited in the Carpathian Basin now form today's Carpathian Mountains. Foraminifera constitute the basic type of common fossils in the rocks of these mountains. They inhabited the basin during all stages of its development, so they occur in all stratigraphic intervals.

Foraminifera are among the few unicellular organisms that are commonly preserved in the fossil record. This is the result of their capacity to build mineral shells – either calcareous or agglutinated. This considerably increases the probability that they will be preserved in fossil form. Their shells, called "tests," decay only slowly and resist erosion.

Agglutinated foraminifera are among the fossils that occur most commonly in the rocks of the Carpathian Basin. These were benthic organisms – living on the bottom of marine or oceanic basins, on soft beds covered with silt or fine sand. Some were mobile and moved along the surfaces of the floors or within the sediment. Others adopted an immobile lifestyle, settling in a single place. There were also some that attached themselves permanently to hard elements, such as rocks or the shells of other organisms. The development of agglutinated tests, that is, tests made

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from particles of material taken from the immediate environment, is a distinguishing feature of agglutinated foraminifera. These grains are bound together by an organic substance produced by the organism. Under the conditions prevailing in the Carpathian Basin, mainly quartz grains were subject to agglutination. As well as being stable, of good quality and easily available, this was the commonest material in the silt and sand of the deep-water environments. Therefore, the great majority of Carpathian agglutinated foraminifera possess silica tests, which are composed of quartz grains firmly cemented together silica. The origin of this silica bonding is diagenetic. It was the result of secondary formation during fossilization, which entailed replacement of the original organic binder. In some tests, other mineral particles are found as supplementary constituents. These are usually tourmalines, or in rarer instances feldspars, muscovite, zircon (nesosilicates), apatite, or glauconite. Other organisms such as sponge needles, planktonic foraminifera, diatoms, radiolaria, and calcareous nannoplankton have also been used to build tests.

Species identification

Fossil species of agglutinated foraminifera are identified based on the morphological features of the tests. Images are therefore used to perform basic identification of the fossil material. The taxonomic identification of the fossils requires an understanding of the external,

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The deep-water foraminifera of the Carpathians – image of a micropaleontological sample taken under a stereo microscope

Bulbobaculites gorlicensis – a recently described agglutinated foraminifera from the Carpathian Basin; image taken under a stereo microscope

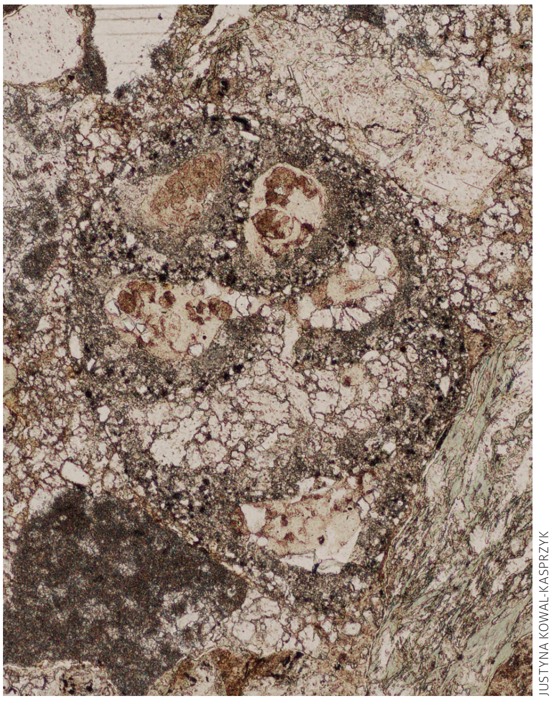
internal, and test structures. The classification of fossil foraminifera is therefore artificial. This is in contrast to contemporary foraminifera, where comprehensive observations of the organisms themselves are supplemented by analyses of their genetic material. The tests of agglutinated foraminifera are diverse, as a result of their adaptations to different environments. The base "unit" of test structure is a "chamber." This is a space enclosed by a wall that has one (or more) main openings known as apertures. Simple foraminifera build uncomplicated one- or two-chamber tests (the initial chamber being known as the *proloculus*), which are bag-like or tubular in shape. The latter may be straight, branched or coiled. Yet the great majority of species existing in the Carpathian Basin built multi-chamber tests, which are structurally individual units combined in a series. The chambers have a variety of shapes, including tubular, round, rectangular-square and triangular. The tests of agglutinated foraminifera take numerous shapes. This results from a configuration in which successive chambers can grow, which permits the creation of a variety of geometric arrangements: unidirectional or coiled, enclosed within a single plane or stretching across a number of planes. The size of the chambers in an individual specimen varies. Usually, they increase in size during test development, so that the youngest chambers are the largest.

Different sizes of grain are employed in agglutination, from the very small up to those with dimensions of approximately 100 µm. The size of the mineral material has a significant influence on the external appearance of the test. The majority of the Carpathian foraminiferal species display a preference for the selection of material, that is, specific species agglutinate grains from particular size ranges. There are forms that prefer to use coarse or fine material and forms that use grains of various sizes in test construction. Depending on the species, tests agglutinated from coarse grain have rough or smooth outer surfaces. On the inside, they are usually smoothed and finished with flat surfaces of coarse grains. Though the arrangement of grains in the tests may appear chaotic, the architecture of the tests is an assemblage of mineral elements selected for appropriate size, shape, and configuration. This results in a compact, non-porous wall composed of contiguous elements. Many coarse-grained forms build two-layer tests, in which the outer layer of coarse grains is lined with fine material on the inside. Fine-grained tests usually have thin walls and level surfaces.

Microscopic imaging

Taxonomic designations of foraminifera are based on analyses of microscopic images. It is essential to augment the eye with magnifying apparatus, as most Carpathian foraminifera tests are smaller than 0.4 mm. Micropaleontologists prefer three-dimensional images of specimens, which they usually obtain by using a binocular or a scanning microscope.

Binocular imaging provides the most authentic and direct picture. It captures and retains not only morphological features, but also the original coloring of foraminiferal tests. Due to the relatively low magnifications in stereo microscopy, the individual grains that form the test wall in fine-grained fora-



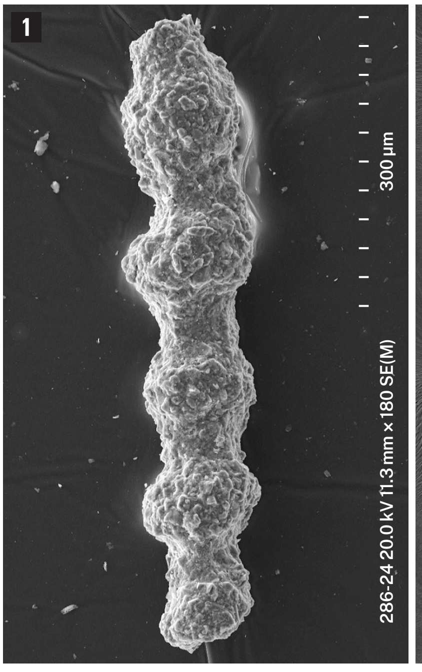
Agglutinated foraminifera on a thin section; image from an optical microscope under transmitted light minifera are indistinguishable. As such, the test surface is shiny and appears smooth. Some fine-grained tests are transparent, which enables observation of their internal structure. In coarse-grained foraminifera, however, the surface texture is visible, but the tests are opaque. To investigate the internal structure, images must be produced by immersion. Using this method, observations are conducted on specimens treated with immersion fluids, which greatly improve the resolution of the image. Depending on requirements, various substances are employed. However, oils, water, and alcohol are the most frequent choices. Analysis of the internal structure proceeds without having to damage the specimen. The tests of Carpathian foraminifera are quite uniform in color, with various shades of grey being characteristic – fossils originating from red mudstones, marls or claystones are the exception, taking on the color tones of the surrounding sediment.

Electron microscopes, on the other hand, produce indirect images by scanning the surface under examination with an electron beam. This makes it possible to investigate specimens with great precision. Images made by electron scanning are universally employed in foraminifera research because they offer very large magnifications. They are also employed in analyses of the general morphology of specimens, as well as in detailed investigations of the individual components of tests. However, only pictures of the external surfaces of the elements under investigation can be obtained by this type of imaging. To determine the internal structure of a foraminifera test and peer inside it, it is necessary to expose its interior by opening it mechanically. The resulting image is usually presented in varying shades of grey, but it can also be colored using a computer.

More advanced microscopic analysis techniques that involve scanning internal structures by tomography are also now being used in micropaleontological research. Using this method to image foraminifera is quite time-consuming, and so the specimens studied in this way are carefully selected. Computerized micro-tomography is a high-resolution method that provides a base for modeling tests in a variety of three-dimensional cross-sections. It is a non-invasive technique that does not disturb a fossil's structure.

Obtaining three-dimensional images of Carpathian foraminifera is not always easy because they occur in sedimentary rocks and are a part of them. These rocks respond to the environment in which the foraminifera were deposited and in which they underwent a process of fossilization. In most cases they are mudstones or marls. More rarely, they are limestones, sandstones, or cherts. The image of foraminifera that can be obtained therefore depends very much on the degree to which the test is integrated with the rock. If the tests are not firmly attached, they are separated to obtain single, complete shells that can be examined using the methods set out above. If, however, the foraminifera is firmly bonded with the rock, use is made of thin sections, that is, thin slices of rock prepared as microscopic preparations, adapted for analysis with optical equipment. The image of a foraminifera on such a thin section is always a two-dimensional cross-section of the test. It offers a good opportunity to examine the wall structure, but interpretation of the morphology of the whole test is sometimes limited and depends on the particular cross-section being observed. Depending on the shape of the test, transverse or longitudinal cross-sections are optimal for identification, while the most accurate determinations are possible when there are several different cross-sections of fossils of the same type evident on a single section.

It has become customary in micropaleontological practice to produce illustrations of fossil foraminifera, especially of holotypes (the specimen on which the description of a species is based). Such reference illustrations have become an integral part of taxon definition and form an important part of the documentation used in most micropaleontological work. In the nineteenth century and in the first half of the twentieth, this involved depicting the morphology in a paleontological drawing, sketched based on an observed microscopic image – usually showing the specimen from different sides and clearly presenting the diagnostic features of the taxon. Today, reference images are preserved by photographic techniques, in a common and widely available procedure. Therefore, as well as performing a diagnostic function, imagery also performs a documentary function. ■



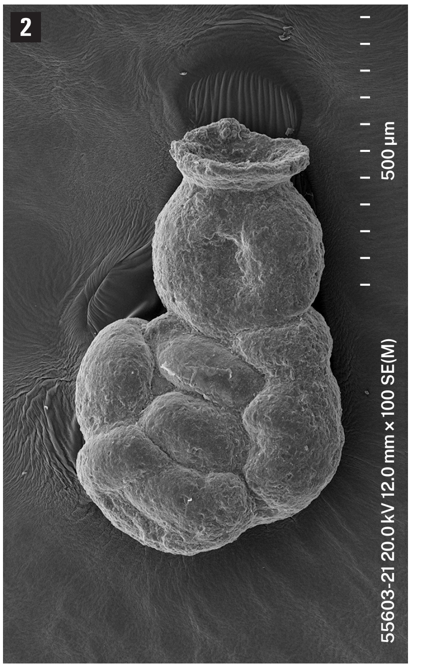


Photo 1
Sample of the genus *Reophanus*. Image from a scanning electron microscope

Photo 2
Sample of the genus *Paratrochamminoides*. Image from a scanning electron microscope

Further reading:

11th International on Agglutinated Foraminifera, Micropaleontological Foundation Kraków, http://micropresseurope.eu/

Foraminifera Gallery – illustrated Foram catalog, https://foraminifera.eu/

Jones R.W., *Foraminifera and their Applications*, 2013.