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MORPHOLOGIC VARIABILITY IN THE *GLOBIGERINOIDES-ORBULINA* GROUP FROM THE MIDDLE MIOCENE OF THE CENTRAL PARATETHYS

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Observations are made on the distribution and variability in the *Globigerinoides-Orbulina* group in the Middle Miocene (Badenian) of Central Paratethys. The analysis of distribution and morphological diversity of planktic foraminifera *versus* environmental conditions prevailing in the Badenian of the studied area suggests that regional differentiation of the microfauna was controlled by bathymetric (or bathymetry-related) conditions and the stratigraphic — by climatic and, on a smaller scale, bathymetry-related ones. The differentiation is found within systematic groups (genera and species) of the analysed microfauna. In the case of foraminifera most sensitive to the above changes (representatives of *Globigerinoides*), it is also traceable in their final, adult morphology. The phenotypic nature is ascribed to the bioseries *Globigerinoides-Praeorbulina* and *Orbulina* or *Velapertina*, i.e. *Globigerinoides-Orbulina* group.

Key words: Planktic foraminifera, Miocene, Central Paratethys, biochronology, ecology, taxonomy.

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INTRODUCTION

Of the studied group of planktic foraminifera of the genera *Globigerinoides*, *Orbulina*, *Biorbulina*, *Velapertina* and *Praeorbulina*, the representatives of *Praeorbulina* and *Velapertina* are usually regarded as rapidly evolving, short-lasting, (typical of individual horizons) in the Miocene. At the same time, *Praeorbulina* (similarly as *Globigerinoides sicanus*) is treated as a transitional form in an evolutionary series of *Globigerinoides — Orbulina* (Blow 1956 and other authors) whereas *Orbulina* (often identified with *Biorbulina*) is treated as an isomorph of various species or even genera (Bandy *et al.* 1969; Hofker 1968, Vilks and Walker 1974).

Actually, it is difficult to state whether or not *Praeorbulina* (similarly as *Globigerinoides sicanus*) is a short-lasting and valid, genetically separate taxon. The representatives of both *Praeorbulina* and *Globigerinoides sicanus* may be found among forms figured and described as *Globigerinoides triloba* and *Orbulina suturalis*. These latter are often treated as highly variable, long-ranging forms (Saito 1963; Martinez 1969; Yassini 1975; Benot *et al.* 1975; Martinotti 1981). It should be noted that differences in interpretation of test morphology are especially great in the case of the *Globigerinoides-Orbulina* group.

Velapertina also appears identifiable or, at least, comparable with genera known to live in other time intervals: for example, *Catapsydrax*, *Globigerinita*, *Porticulasphaera*, and *Polyperibola*.

This paper presents some data suggesting that the above mentioned forms may represent heteromorphic phenotypes (ecomorphotypes) of a single species, the distribution and morphological appearance of which was mainly controlled by the environment.

The described material is housed in the Institute of Paleobiology, Polish Academy of Sciences, Warsaw (abbrev. ZPAL).

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MATERIAL AND METHODS

The studied samples were collected in Middle Miocene outcrops in the Central Paratethys: southern Poland, NW Bulgaria, and central Romania. In Poland, samples were taken at Gacki and Korytnica from the northern margin of the Carpathian Foredeep, and Trzęsiny and Monastyrz in the Roztocze area. The Roztocze plateau represents a southward extension of the Lublin Upland and, together with adjoining uplands and the Holy Cross Mts., they form the northern margin of the Carpathian Foredeep (fig. 1).

In Bulgaria, the samples were taken at Staropatica, in the marginal part of the Dacian Basin, representing an outer margin of the Eastern

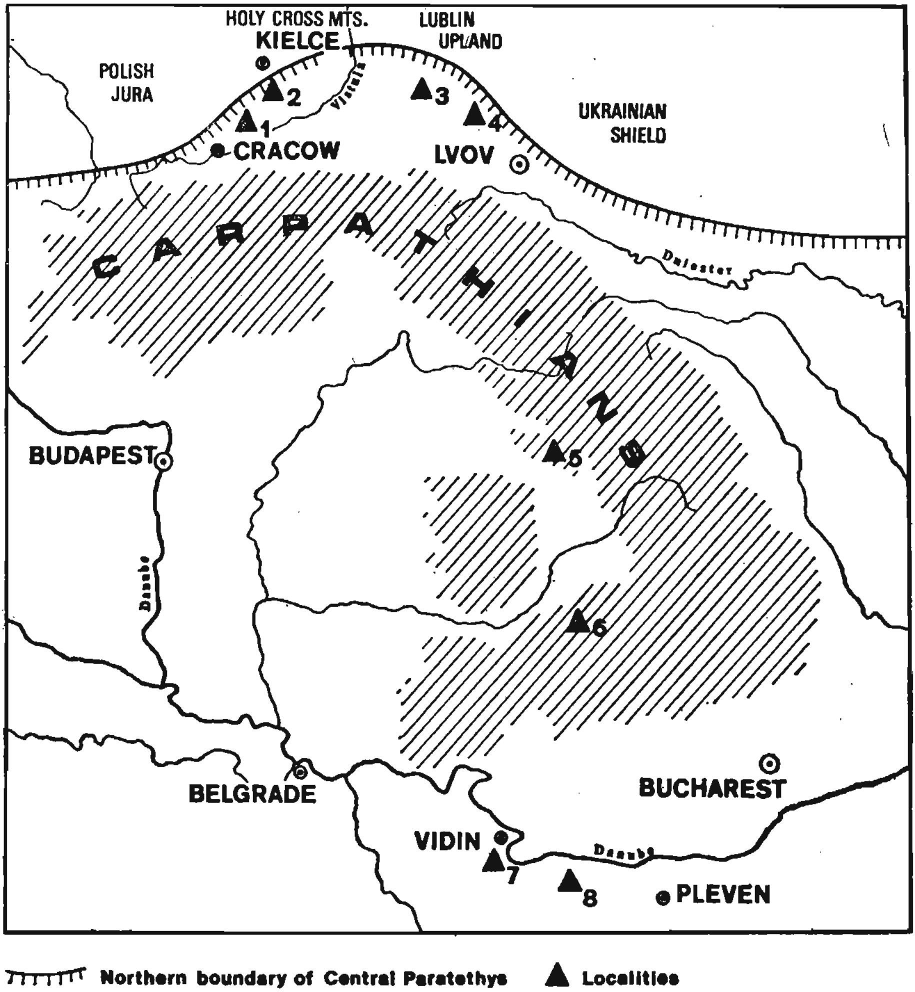

Fig. 1. Distribution of localities with sampled outcrops, indicated by numbered triangles: *1* Gacki, *2* Korytnica, *3* Trzęsiny, *4* Monastyrz, *5* Giurgesti, *6* Apold, *7* Staropatica, *8* Dobrusha

Carpathians (fig. 1). In Romania, sampled localities were in the Rod River valley near Apold and the Dosul River valley near Giurgesti, in the SW and NW parts of the Transylvanian Basin, a depression within the Eastern Carpathians (fig. 1).

The samples, varying in weight from 0.5 to 2.0 kg. were washed in a sieve with meshes 0.087 mm in size. The foraminifera in the larger than 0.087 mm fraction, were identified by me.

Poland

Sample from the section in the quarry at Gacki (Garlicki 1974; fig. 10) represents yellowish, sandy glauconitic marls dated as the Lower Badenian

(*Orbulina suturalis* Zone). The sample yielded a very rich assemblage of planktic and benthic foraminifera. In the benthic assemblages elphidiids and other shallow-water forms are missing, whereas deep-water forms are abundant.

Planktic foraminifera are very common here, being primarily represented by the genera *Globigerina*, *Globorotalia*, *Globoquadrina* and those of the *Globigerinoides-Orbulina* group, indicative of a warm and relatively deep water (at least lower neritic zone) sedimentary environment and good connections with the open sea.

The studied sample of plastic clays from Korytnica comes from the section described, among others, by Bałuk and Radwański (1977) and Hoffman (1977). The clays were dated as the Middle Badenian on the basis of calcareous nannoplankton (Martini 1977). For detailed location of this sample, see Walkiewicz (1977) and Hoffman (1977; fig. 1, sample 1), who also present its faunal content and an ecological interpretation of the sedimentary environment.

Walkiewicz's (1977) microfaunal analysis was made of a washed-out sample. She primarily found large-sized foraminifera, mostly of the family Nodosariidae. The assemblage, however, could not give unequivocal clue for reconstructing sedimentary environment, so she also used results of earlier micropaleontological studies, especially those on the Korytnica clays. On those premises, Walkiewicz (l.c.) interpreted the environment as shallow-water, warm marine.

It is out of the scope of this paper to evaluate the above reconstruction of sedimentary conditions in the Korytnica "Embayment", which was based on other samples than those from the plastic clays. However, the treatment of the microfaunal content in diachronous samples as the basis for reconstruction of sedimentary conditions for the whole sedimentary cycle appears at least questionable.

The studied sample of plastic clays yielded relatively numerous planktic foraminifera, including *Globigerina*, *Globorotalia*, *Globoquadrina* and representatives of *Globigerinoides-Orbulina* group. Moreover, the samples also contained benthic foraminifera typical of rather deep water (at least 100 m deep). Attention should be paid to the complete lack of planktic forms in overlaying deposits.

The estimates of depth of deposition of the plastic clays at Korytnica based on analysis of the microfauna, seem to be consistent with those of Hoffman (1977: 265) according to whom the plastic clays originated "... below the zone of intense light penetration..." since they yielded deep sublittoral molluscan communities.

In the Trzęsiny section (see Jakubowski and Musiał 1979, and Szczechura 1982), two layers were sampled: layer no. 1 — clayey sands from its lower part, yielding rare planktic foraminifera of the genera *Globigerina* and *Globigerinoides*, and layer no. 7 from the upper part of the section composed of marly clays with abundant *Globigerina*, some forms assignable to *Velapertina* and ?*Globigerinoides*, and extremely rare *Orbulina* and *Globorotalia*, but no well-developed *Globigerinoides*. Szczechura (*l.c.*) assigned the lower part of the section to the Middle Badenian, and the upper part to the Upper Badenian *sensu* Papp *et al.* (1978). The age of the Trzęsiny deposits established on the basis of planktic foraminifera appears consistent with that established on the basis of calcareous nannoplankton by E. Martini (see Szczechura 1982).

My studies (Szczechura 1982) on planktic and benthic foraminifera from that section showed a change in environmental conditions in the higher part of the section explainable by deepening and temperature decrease. A depth close to 50 m is inferred in the case of sample no. 1, containing *Globigerinoides*, and about 120 m in the case of sample no. 7, containing *Velapertina*.

The sample from the Monastyrz section (described, among others, by Jakubowski and Musiał 1977) represents marly silt with very rich assemblages of planktic foraminifera, dated as Upper Badenian. Representatives of *Globigerina* predominate here, being accompanied by some *Globigerinoides*-like specimens, rare *Velapertina* and *Globorotalia*, and benthic foraminifera. The latter are represented by numerous deep-water species. The share of shallow-water forms is very small, suggesting deposition in the deep neritic zone.

Bulgaria

The sample from the outcrop at Staropatica (described and figured in: Guide de l'excursion du IX Symposium du groupe "Paratethys", Néogène en Bulgarie du Nort-Ouest; Kojumdgieva 1978: fig. 9, layer 3), represents silty marls very rich in planktic and benthic foraminifera (a part of which were listed by Dikova in Kojumdgieva 1978). The assemblage appears very similar to those from Gacki and the plastic clays from Korytnica, suggesting deposition in at least the lower neritic zone of a warm open sea. Planktic foraminifera here include *Globoquadrina*, *Globigerina*, *Globorotalia* as well as numerous representatives of the *Globigerinoides*-*-Orbulina group*. In the benthos, there is a marked predominance of the deep-water species. Dikova (*l.c.*) dated the Staropatica deposits as the Lower Badenian.

The study also covered single specimens assigned to *Praeorbulina*, derived from Upper Badenian deposits from Dobrusha (see Kojumdgieva 1978: fig. 5, layer 5).

Romania

The sample of Lower Badenian (*Orbulina suturalis-Globorotalia bykovae* zone) tuffaceous clays from the section at Apold (see description and microfaunistic characteristics given by Gheorghian *in* Bombiţa 1975:

176, layer 2a) is also highly rich in planktic foraminifera. The share of foraminifera in the microfauna approaches 100%. Besides predominating *Orbulina* or *Biorbulina*, numerous individuals resembling *Praeorbulina*, *Globigerinoides*, *Globorotalia*, *Globigerina*, and *Globoquadrina* were also found. Benthic foraminifera, relatively scarce here, form a monotonous assemblage suggesting a deep-water, bathyal, warm-water origin.

The sample from a section in the vicinity of Giurgesti (studied by Gheta and Popescu *in* Bombiţa 1975: 161, layer 3) represents marls assigned by Romanian authors to the *Velapertina iorgulescui* Zone, indirectly correlative with N11, N12, and NN6, and referred to the Kosovian, i.e. Upper Badenian. Washed out sample consists almost exclusively of planktic foraminifera: *Globigerina*, ?*Globigerinoides*-?*Praeorbulina*- and *Biorbulina*-like individuals, and predominating *Velapertina*-like ones. Worth to be noted is the lack of *Globiquadrina* representatives. The assemblage suggests a deep-water origin.

In an earlier work (Szczechura 1982), I used the stratigraphic differentiation of planktic foraminiferal assemblages in the Badenian of the central Paratethys to propose two planktic ecozones. The *Globigerinoides* Ecozone, comprising Lower-Middle Badenian deposits *sensu* Papp *et al.* (1978), is characterized by well-developed, usually numerous representatives of *Globigerinoides*. I also proposed the *Globigerina* Ecozone, comprising the Upper Badenian *sensu* Papp *et al.* (1978) and characterized by the predominance of *Globigerina* and the presence of *Velapertina*. An ecostratigraphic nature has been ascribed to the boundary between these ecozones.

Accepting the above subdivision in this paper, the samples from Korytnica, Gacki, lower part of the Trzęsiny section, Staropatica and Apold are assigned to the *Globigerinoides* Ecozone, and those from the upper part of the Trzęsiny section, Monastyrz and the section from the vicinity of Giurgesti to the *Globigerina* Ecozone.

This marked differentiation in planktic foraminifera is accompanied by the appearance of chemical deposits, salts and gypsum, at the contact between the *Globigerinoides* and *Globigerina* ecozones or within the *Globigerina* Ecozone.

GLOBIGERINOIDES — ORBULINA LINEAGE

The following genera are generally referred to the *Globigerinoides*-*Orbulina* lineage: *Globigerinoides*, *Praeorbulina*, *Orbulina* and/or *Biorbulina*. Numerous species, or subspecies are assigned, moreover, to all these genera.

Globigerinoides was erected in 1927 by Cushman for *Globigerina*-like specimens with supplementary apertures along the spiral suture. *Orbulina* was described in 1839 by d'Orbigny as a unispherical, finely perforated form with small, rounded aperture. Characteristics of *O. suturalis*, erected by Brönnimann (1951), include large variation and great variability of that species. Brönnimann (1951) included into *Orbulina* two more or less spherical forms i.e. *Candeina* d'Orbigny, 1839, and *Candorbulina* Jedlitschka, 1934. Later authors (Blow 1956; Olsson 1964), have divided *O. suturalis* into several species, referable to separate genera i.e. besides *Globigerinoides* and *Orbulina* also *Biorbulina* and *Praeorbulina*.

It should be noted, however, that there exists great confusion in the taxonomy of this group of foraminifera concerning species as well as genera. Taxonomic criteria of the above mentioned genera and the range of variability of the species attributed to them are differently interpreted by individual authors. Moreover the validity of these taxa is not accepted unanimously, and specific or generic ranks of individual taxa are questioned by some authors (Parker 1964; Hofker 1968; Bandy *et al.* 1969; Bé *et al.* 1973; Vilks and Walker 1974; Popescu 1975; Stainforth *et al.* 1975). The ambiguities in evaluations of taxonomic status are further increased by forms displaying intermediate features (Džodžo-Tomić 1979; Parker 1964; Blow 1956; Bandy *et al.* 1969; Stainforth *et al.* 1975).

DISTRIBUTION OF *GLOBIGERINOIDES-ORBULINA* LINEAGE REPRESENTATIVES IN THE BADENIAN OF CENTRAL PARATETHYS

The distribution of planktic foraminifera in the Badenian deposits, referred to the two biochronologic ecozones (see p. 8) made it clear that a close interdependance exists between the environments and the morphotypes. This is especially so in the case of the *Globigerinoides-Praeorbulina-Orbulina* and *Velapertina* lineages, of which particular member corresponds to a definite, characterised below ecozone.

Globigerinoides Ecozone

In shallow-water deposits from the lower part of the section at Trzęsiny as well as the Huta Lubycka locality in Roztocze, the *Globigerinoides-Orbulina* and/or *Biorbulina* lineages *sensu* Blow (1956) are represented by specimens of *Globigerinoides*: *G. triloba triloba* (pl. 1: 1, 2, 4, 5, 8), *G. triloba sacculifera* (pl. 1: 3, 6, 7, 9—11) and *G. ?quadrilobatus* (pl. 1: 12). The specimens usually display markedly inflated, more or less loosely coiled, gradually growing chambers and distinct, generally large primary and secondary (supplementary) apertures. Representatives of *Praeorbulina*, *Biorbulina*, and *Orbulina* i.e. specimens with large ultimate and/or penultimate chambers, are missing in this assemblage.

The relatively rich assemblage of planktic foraminifera found in the sample from Korytnica, i.e. in material deposited in deeper water than that from Trzęsiny, comprises typically developed individuals of *Globigerinoides*, especially *G. triloba triloba* (pl. 2: 1, 2) *G. cf. sicanus* (pl. 2: 3, 4), *Orbulina* (pl. 2: 5, 9—11), *Praeorbulina* (pl. 2: 6) and *Biorbulina*-like forms (pl. 2: 7, 8).

The sample from Gacki, (similar to samples from comparative levels at Staropatica (pl. 5: 1—12) and Apold), representing still deeper and/or more open sea conditions than samples from the lower part of the Trzęsiny section, is exceptionally rich in planktic foraminifera. Individuals of *Globigerina* and *Globorotalia* are here accompanied by *Globigerinoides* (especially *G. triloba triloba*), *Praeorbulina*, *Biorbulina*, and *Orbulina*. However, it is difficult to establish taxonomic affiliation of all individuals present in the sample, especially of those representing *Praeorbulina* and *Orbulina*. These difficulties are encountered at the specific as well as at the generic level, because of the presence of transitional forms. The specimens display great variability in size, general shape, shape and size ratios of individual chambers, primary and secondary (supplementary) apertures, and texture and ornamentation of test walls.

Some individuals may be assigned to known species such as *Globigerinoidese sicanus* (pl. 4: 4, 7), *Biorbulina transitoria* (pl. 3: 6, 7), *Praeorbulina glomerosa* (div. ssp.) (pl. 4: 2, 3, 5, 9, 11), *Orbulina suturalis* (pl. 4: 10, 12), *Biorbulina bilobata* (pl. 3: 9, 11), or some other, more or less similar taxons.

Leaving aside the existing taxonomical criteria and assuming intergradation of established species, it becomes easy to trace two modes in ontogenetic development of tests, involving modifications of the trochospiral coiling to either uni — or bispherical forms (*Orbulina* and *Biorbulina*). *Globigerinoides triloba* attains the *Biorbulina* form by compaction and reduction in size of one of the early chambers, whereas the development of the ultimate chambers remains essentially normal (pl. 3: 1—9, 11). *Biorbulina* (as interpreted by Blow 1956) may attain the shape of *Orbulina* by reduction of height of chambers (pl. 3: 11), whereas marked horizontal sutures enable it to be discriminated from *Orbulina*. Less complicated mode of "development" of *Biorbulina*-like forms is presented on p. 11.

Globigerinoides triloba may attain the *Orbulina* shape by significant increase in size of the ultimate chamber, in association with less well developed earlier chambers (pl. 4: 1—12). The Korytnica specimens with large ultimate chamber display differences in the degree and mode of development of the spiral part (pl. 2: 5, 6, 9—11) suggesting that the large ultimate chambers were developed at different ontogenetic stages of the trochospiral planktic forms.

The increase or decrease in size ratio between successive chambers is accompanied by reduction in size of the primary and secondary apertures.

However, the primary aperture sometimes remains unaffected by the reduction (pl. 3: 9, 11).

The specimens of *Orbulina* from several samples of the *Globigerinoides* Ecozone vary in texture and ornamentation of the test wall. Thin-walled, almost smooth and finely perforated forms with often visible initial spire (pl. 2: 10; pl. 4: 12; pl. 5: 8, 9) are accompanied by coarsely cancellate thick-walled ones (pl. 2: 5, 11; pl. 5: 12), presumably related to increased secondary calcification obscuring the initial spires.

The sample from Gacki yielded a few *Orbulina*-like specimens (pl. 3: 10; pl. 4: 10) with external supplementary tubular structures. These structures are irregularly distributed and usually limited to a small part of the test surface. The specimens resemble *Globigerinatella insueta*.

The sample from Apold yielded damaged *Praeorbulina* (pl. 11: 2, 7), *Orbulina* (pl. 11: 8, 9) and *Biorbulina*-like (pl. 11: 1, 3—6) tests displaying the inner trochospiral stage. These stages differ mainly in their general appearance, ornamentation as well as overall size and location in relation to the last chamber. Some *Biorbulina*-like specimens are characterised by the ultimate chambers of highly variable size; some may appear as thin-walled bulla, developed on fully (pl. 11: 3—5) or not fully developed (pl. 11: 1) *Orbulina* tests. The variability suggests that the specimens belong to different taxa or, which I consider more plausible, differences in growth ratios of the chambers within a single species. It is worth noting that damaged specimens of *Globigerinoides triloba triloba* (pl. 5: 10, 11) from Staropatica also display marked variability in coiling and ornamentation of the chambers in the juvenile stage.

The lack of distinct morphological barriers between representatives of different species of planktic foraminifera (especially in samples representing open sea environment) often impedes the use of the established taxonomy. Moreover, environmental, mainly bathymetric, dependence often modifies morphotypes. The *Globigerinoides* morphotype appears optimum for a shallow, warm environment, whereas a spherical or subspherical shape (*Biorbulina*, *Orbulina*, or *Praeorbulina*) appears better adapted for a deeper-water, warm environment.

Globigerina Ecozone

In samples from the *Globigerina* Ecozone from Roztocze (Trzęsiny, Monastyrz and the vicinity of Giurgesti in Romania) typical representatives of *Velapertina* (*sensu* Popescu 1969, 1975) were found together with forms resembling *Globigerinoides* (*G. sicanus* and *G. triloba*) and *Praeorbulina*. Moreover, small specimens of *Orbulina* and *Biorbulina* occur there.

Individuals resembling *Globigerinoides triloba* are here much scarcer, smaller and more compact in comparison to typical forms from older horizons of the Badenian (*Globigerinoides* Ecozone). They also have less distinct or missing primary and secondary apertures (pl. 6: 3—5; pl. 8: 1, 2; pl. 9: 1). They are accompanied by forms with morphological features similar to the above ones (small-sized and compact tests with weakly developed apertures), except for a trend toward a different development of the ultimate chamber. This chamber is here either smaller (pl. 6: 4) or more or less larger (pl. 6: 6, 8; pl. 8: 4, 5; pl. 9: 5, 8, 11—13) as in typical *Praeorbulina* div. sp. and *Globigerinoides sicanus*, or *Orbulina*.

In all the above mentioned species taxonomic subdivision becomes additionally complicated by development of bullae, supplementary chambers, and reduction of apertures. Supplementary chambers and bullae usually cover the primary aperture (pl. 7: 1—11; pl. 9: 4, 7, 10, 14), but they may also occur elsewhere (pl. 8: 9—13; pl. 10: 1—9) in connection with a tendency to attain a spherical final form of the test (pl. 8: 9—12; pl. 10: 1—9). Especially random pattern of irregularly arranged chambers is displayed by some specimens found in the sample from the vicinity of Giurgesti (pl. 10: 1, 3—9). In this case, bullae are sometimes tubular in cross-section and their distribution is extremely variable. The primary aperture is often limited to a rounded hollow or it completely disappears, whereas the secondary apertures, when present, are developed as circular opening or fissures along sutures at the base of the last chamber (pl. 6: 14; pl. 9: 9, 11, 14) or also along older chambers (pl. 10: 8).

Damaged specimens (shown in pl. 7: 1, 3—11) expose their earlier stages, which may be recognized as the *G. triloba* or *G. sicanus* type, because of their fissular apertures, arrangement and size of chambers, and character of test surfaces. Attention should be here paid to a peculiar thickening of the wall of the supplementary chambers. An extension of that thickening may be noted in part of the test in the form of a secondary thickening, perhaps obscuring the primary character of the test surface.

The above mentioned morphological types (possibly except those most similar to *G. triloba*) include typical representatives of *Velapertina* (see Popescu 1969 1975; Popescu and Cioflica 1973; Papp *et al.* 1978). They are characterised, by more or less globulous general appearance, more or less uniform development of tightly coiled chambers (or bullae), small to completely missing primary apertures, and weakly developed or absent supplementary apertures. The supplementary apertures, when present, usually occur at the base of the last few chambers.

Papp *et al.* (1978) noted forms resembling *Globigerinoides sicanus* or *Praeorbulina* representatives among those assigned by them to the highly variable *Velapertina indigena*. It is also worth noting that some authors placed *V. indigena* in the genus *Praeorbulina* (e.g. Łuczkowska 1971) or *Globigerinoides* (Łuczkowska 1955; Alexandrowicz 1963). Stainforth *et al.* (1975) compared *Velapertina* with *Globigerinita* or *Catapsydrax*. In my opinion, this genus may also be compared at least with *Porticulasphaera*, *Orbulinoides*, *Globigerapsis* and *Polyperibola*. It should be stressed that

Liska (1980) also compared the genus proposed by him (*Polyperibola*) with *Velapertina* stating that differences in morphological details of the two forms are sufficient for treating them as systematically separate.[1] The four genera are characterised by bullate tests.

It appeared impossible to establish the systematic position of all *Globigerinoides-*, *Praeorbulina-* and *Velapertina*-like specimens from samples of the *Globigerina* Ecozone because of the presence of intermediate forms. The variability appears very great here, especially in test size and general shape as well as size and shape of apertures, arrangement of chambers, and surface of the test. It is difficult to find two identical specimens, and there exist all kinds of intermediate forms between morphologically extreme types.

Special attention should be paid to the fact that some individuals corresponding to *Velapertina* in their external appearance display somewhat different juvenile interior stages (pl. 10: 7; pl. 11: 10). They are similar to those of *Orbulina* (Hofker 1968; Bandy *et al.* 1969; Vilks and Walker 1974; see also p. 12 here).

The results of studies on Upper Badenian samples from Roztocze and Romania suggest that the group of *Globigerinoides-* and *Velapertina*-like foraminifera represents a morphological series similar to the above discussed series (pp. 9—11) from the *Globigerinoides* Ecozone. In both ecozones, *Globigerinoides triloba* is generally an initial form for the *Globigerinoides sicanus-Praeorbulina* and *Orbulina* or *Velapertina* lineage, indicating a tendency toward spherical ultimate shape of test and reduction of primary and secondary apertures. The difference between the initial form (small-sized and without distinct supplementary apertures) and the final (i.e. not completely spherical) seems to be due to environmental factors which are the same but diachronons compared to those responsible for the optimum development of the initial and final forms of the *Globigerinoides-Praeorbulina-Orbulina* lineage in the *Globigerinoides* Ecozone. *Velapertina* is primarily known from deposits of deep-water origin which gives further support for its assumed dependence of depth.

Attention should be paid to the development of bullae also in some representatives of *Globigerina* in the *Globigerina* Ecozone (pl. 6: 1, 2).

DISCUSSION

In the taxonomy of planktic foraminifera a typological approach (especially when variability is neglected) makes identification at the specific and even generic level easy. However, the above discussed varia-

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[1] According to Liska (1980) *Polyperibola*, in contrast to *Velapertina*, is characterised by presence of supplementary apertures on spiral side of the test. However some specimens from the Upper Badenian of Romania, referred here to *Velapertina* (cf. pl. 10: 8) also have secondary apertures on spiral side.

bility of morphological features regarded as diagnostic results in taxonomic confusion.

It is well known that the general shape of the test of planktic foraminiferal species is related to their life habitat, whereas test size, porosity, wall texture and some other minor morphologic features of individual species are due to adaptation to local environmental conditions including depth, temperature, salinity and other parameters.

Douglas and Savin (1978) established a general model of interdependence between morphology of Mesozoic and Cenozoic planktic foraminiferal species and their depth habitat. Globigerinoids were shown to dwell at shallow depths, and the globigerinids and orbulinids to live at shallow and intermediate depths.

Similarly *Globigerinoides* has been shown to prefer upper surface waters (upper 50 m of the water column, above the undercurrent) whereas *Orbulina* was shown to live at water depths of 50—100 m (Bé and Tolderlund 1971; Bé 1977).

According to Bermudez (1961), the last chamber in planktic foraminifera is responsible for maintaining buoyancy of the test. This point of view was further supported by the studies of Christensen, 1965 (discussed by Boltovskoy and Wright 1976: 165), showing that *Globigerinoides ruber*, a foraminifer regarded as planktic, has a morphologically different, bottom-dwelling stage known as *G. pyramidalis* leading a hemiplanktonic mode of life. Le Calvez (1936) suggested externally and internally different tests of *Orbulina universa* depending on its generation and mode of life. Subsequently, Hofker (1959) interpreted *O. universa* as the adult stage of various species of planktic foraminifera. Later, he (Hofker 1968) considered *Orbulina s.s.* as comprising isomorphs of different genera (e.g. *Globigerina* and *Globigerinoides*). This view was also held by Bandy *et al.* (1969). Hofker (1968) also interpreted *Porticulasphaera* (here *Praeorbulina*) *glomerosa* as an environment-dependant bullate end form of different taxa.

On the basis of differences in morphological details (i.e. in section of spines), Vilks and Walker (1974) assigned *Orbulina suturalis* and *O. universa* to separate species, suggesting, moreover, that *O. suturalis* is an aberrant form of *Globigerina bulloides*, whereas *O. universa* is related neither to *Globigerina* nor to *Globigerinoides*. They stressed appearance of specific features in planktonic foraminifera not before attaining the adult stage.

Bé and Hemleben (1970) noted ontogenetic change in morphology and texture of test of *G. sacculifer*, resulting in its transformation into *Sphaeroidinella subdehiscens*. The difference was interpreted as different growth stages, explained by growth in different depth habitats.

Distribution of planktic foraminifera also depend on sea-water temperature. Foraminifera of the *Globigerinoides-Orbulina* lineage primarily live in tropic and subtropic environments (sea-water temperature at least

20°C; Bé 1977; Bé and Tolderlund 1971). The temperature controls both the geographic distribution of species, the ontogenetic development and morphology of adult forms (size and shape of test, mode of development of both primary and secondary apertures). According to Bé *et al.* (1973) and Colombo and Cita (1980), the size of Recent *Orbulina universa* decreases with lowering temperature. Bé *et al.* (l.c.) also noted that the wall tends to become thinner with increase in test size. This suggests a dependence of thickness of test wall on temperature.

Boltovskoy (1966) noted that specimens of *Globigerinoides ruber* from cold-water environment are small-sized, with small primary aperture and almost completely reduced supplementary ones. The studies of Pleistocene foraminifera from deep-sea cores from various parts of the Atlantic carried out by Emiliani (1969) showed that *G. triloba* tests from a given geological horizon differ in size and number depending on place of occurrence. The studies showed the tests to be dependant of temperature; large-sized, more numerous specimens come from warm areas. Emiliani also noted that different distributions of various subspecies of *G. triloba* (*G. triloba triloba* and *G. triloba sacculifera*) were related to change in temperature.

In the case of trochospiral planktic forms the development of the ultimate chamber may vary markedly. The last chamber may attain larger or smaller size than the preceding ones, or it may attain a bulla-like structure. A small final chamber (kümmerform chamber) may reflect environmental stress (Berger 1969; Hecht and Savin 1970, 1972). According to Malmgren (1974: 103) reductions in size of chambers of Danian planktic species "appeared at various stages in the ontogeny which would favour the environmental stress model. Kümmerforms *sensu lato* are therefore believed to be specimens, in any stage of growth, which were introduced into a water mass area of unfavourable environmental conditions of some kind (probably in food supply, water temperature, or salinity)".

Bé and Hemleben (1979) regard diminutive ultimate chamber and bullae as terminal growth features of secondary taxonomic value. Hecht (1974) in his studies on intraspecific variability in Recent species of *Globigerinoides* noted that the ratio between normally developed specimens and those with reduced and/or flattened ultimate chambers is related to temperature and salinity. The smallest individuals of *G. triloba* were recorded in the North Atlantic and the largest — in the western tropical Atlantic. Hecht also noted a reduction in size of the studied planktic species in response to cooler subsurface water within a single geographic region. This reduction is accompanied by decrease in size of the primary aperture.

This study and those of the previous authors thus indicate that the stratigraphical as well as regional distribution of the *Globigerinoides-Orbulina* group is controlled by environmental conditions. The "variaties" may be treated as phenotypes (ecomorphotypes) related to different environmental conditions. Normally developed specimens of the *Globigerinoides-Praeorbulina-Orbulina* and/or *Biorbulina* lineage appear related to the *Globigerinoides* Ecozone. They reflect optimum environmental conditions (mainly in regard to temperature and salinity), in which the distribution of individual representatives of this bioseries appears locally controlled by bathymetry. Anomalously developed (kümmerform and bullate) specimens of this bioseries (including *Velapertina*) are related to the *Globigerina* Ecozone, reflecting stress environmental conditions; here distribution of individual representatives of this bioseries appears locally controlled by bathymetry also.

Among the environmental factors which may be responsible for stress conditions, and, therefore, the appearance of kümmerforms in *Globigerinoides* and its derivatives, are salinity and temperature. Salinity, however, appears to have been normal as representatives of the discussed bioseries are accompanied by rich foraminiferal benthos and plankton samples (Szczechura 1982). Therefore, salinity may be regarded as sufficient for normal ontogenetic development providing that temperature is optimum. It follows that sub-optimum temperature may be the reason for the environmental stress in this case.

Environmental stress connected with a drop in temperature of surface water at the boundary of the *Globigerinoides* and *Globigerina* Ecozones seems to be supported by a sudden increase in frequency of globigerinas and disappearance of warm-water large benthic foraminifera such as *Borelis*, *Amphistegina* and *Heterostegina*. These benthic forms may tolerate salinity decrease of up to 20‰ as well as hypersaline conditions, and their disappearance should not reflect a salinity change across the boundary (Adams 1976; Larsen 1976; Boltovskoy and Wright 1976).

BIOCHRONOLOGY OF THE *GLOBIGERINOIDES — ORBULINA* AND/OR *VELAPERTINA* LINEAGE

Globigerinoides appears for the first time at the Oligocene-Miocene boundary (Berggren and Van Couvering 1974) or, alternatively, in the Upper Oligocene (Stainforth *et al.* 1975; Stainforth and Lamb 1981), whereas *Orbulina* (and *Biorbulina*) does not appear below the Middle Miocene (Berggren and Van Couvering 1974; Stainforth *et al.* 1975; Thunell 1979; Srinivasan and Azmi 1979; Keller 1980). All these genera range through the present time. However, opinions on the time range of individual species of *Praeorbulina* in Cenozoic successions in different parts of the world appear to be markedly divergent (see Soediono 1967; Hofker 1968; Bandy *et al.* 1969; Berggren and Van Couvering 1974; Stainforth *et al.* 1975; Van Couvering and Berggren 1977; Papp *et al.* 1978; Srinivasan and Azmi 1979; Keller 1980).

Many authors believe that *Praeorbulina* and *Globigerinoides sicanus* are confined to the boundary layers between the Lower and Middle Miocene. This is in accordance with the viewpoint of Blow (1956) that these forms represent an intermediate link in the evolution of *Orbulina* from *G. triloba*. Bandy *et al.* (1969), however, regarded *Praeorbulina* as existing at least throughout the Miocene. The short range of *Globigerinoides sicanus* is also questioned by Stainforth *et al.* (1975: 82), who emphasize the fact that the datum level based on this species is stratigraphically applicable only in areas of especially high rate of sedimentation in the Early Miocene. Moreover some authors (e.g. Saito 1963; Yassini 1975; Martinotti 1981; Thunell 1979; Benot *et al.* 1979) accepted such a great range of variability *O. suturalis* and *G. triloba* recorded from the Upper Miocene that they could incorporate *Praeorbulina* and *Globigerinoides sicanus*. These latter suggestions are supported by Boltovskoy's (1974) record of *G. sicanus* in the Pleistocene section of the Indian Ocean.

In a horizon from the Central Paratethys recognized as equivalent to almost the whole Middle Miocene (Vass *et al.* 1978), Papp *et al.* (1978) regard the range of *Praeorbulina* and *Globigerinoides sicanus* as limited to the lower Badenian (Moravian). From that horizon they also reported representatives of *Orbulina*. However, Cicha and Zapletalova (1976) reported *Globigerinoides bisphericus* (synonymous with *G. sicanus*) from the Karpatian in the Carpathians, i.e. Lower Miocene deposits. Papp *et al.* (1978) stated that *G. triloba*, known from the Lower Badenian (and Karpatian) extended to the Upper Badenian (Kosovian), and that *Velapertina indigena* is primarily limited to that latter horizon. Łuczkowska (1964) differentiated a *Candorbulina universa* horizon in the early Badenian, characterized by the wealth of representatives of that species. Subsequently, she (Łuczkowska 1978) reassigned the specimens to *Orbulina suturalis*, and dated this horizon as Lower Badenian (Moravian). This general picture of distribution of the index species in the Middle Miocene (Badenian) of the Central Paratethys was subsequently accepted by Steininger (1977) and to some extent by Berggren and Van Couvering (1974) and Van Couvering and Berggren (1977).

The records of *Praeorbulina* and *Globigerinoides sicanus* in deposits from Korytnica, dated as Middle Badenian by Martini (1977), and in the Upper Badenian of Roztocze (Szczechura and Pisera in press and herein) extend their stratigraphic range. At the same time, the dependence between type of environment and distribution of these forms seems to give a good basis for interpreting them as being of ecomorphotypic nature. On the other hand, their various morphological transformations, which may be large enough, may cause attribution of these forms to separate species and even genera. This would explain the troublesome, peculiar stratigraphic and paleogeographic distribution of phenotypes of the lineage comprising *Globigerinoides-Praeorbulina* and *Velapertina*, and also the difficulties in taxonomy of this group of foraminifera.

The existence of forms displaying features intermediate between those of *Globigerinoides* and *Orbulina* (or *Velapertina*) seems to be determined by differences in bathymetry, in other words deepening of the sedimentary basins in which *Globigerinoides* was living. The morphological nature of this bioseries was probably controlled by temperature. Climatic change was responsible for appearance of particular types of *Globigerinoides* and its derivatives depending on actual depth of the basin including final *Velapertina* instead *Orbulina* form.

The climatic change at the boundary of the Middle and Late Badenian (close to the Middle Miocene nannoplakton zone NN6, *sensu* Martini 1977) in the Central Paratethys (Vass *et al.* 1978) coincides with the climatic change roughly dated at that time (Bandy 1968; Berggren and Hollister 1974; Stainforth *et al.* 1975; Savin *et al.* 1975; McGowran 1979; Vergnaud Grazzini *et al.* 1979).

CONCLUSIONS

In the Badenian of Central Paratethys, various species of planktic foraminifera, including those of the *Globigerinoides-Orbulina* group, display different stratigraphic and regional distribution. The stratigraphic distribution was presumably mainly controlled by temperature and bathymetric conditions, which resulted in change of foraminiferal assemblage across the Lower-Middle Badenian and Middle-Upper Badenian boundaries (*sensu* Papp *et al.* 1978). Therefore boundaries may be treated as being of ecostratigraphic nature. The change at the Middle-Upper Badenian boundary was a reduction in size and decrease in frequency of *Globigerinoides*, as well as modification of *Globigerinoides* to *Velapertina* under suitable bathymetric conditions.

The changes in distribution of the *Globigerinoides-Orbulina* group, primarily connected with disappearance or decrease in frequency of foraminiferal plankton as a whole, at the Lower-Middle Badenian boundary were presumably due to the known paleogeographic changes connected with shallowing in the Central Paratethys.

Regional differentiation of foraminiferal plankton in the Lower Badenian was presumably connected with differences in depth of its occurrence, being reflected by differentiation in composition of foraminiferal assemblages and their characteristic morphological types. *Globorotalia*, *Globoquadrina* and complete *Globigerinoides-Orbulina* bioseries are limited to deep-water assemblages only.

All the above mentioned forms may be useful for both local (regional) stratigraphy and interpretations of relative depths and temperatures.

Globigerinoides sicanus, *Praeorbulina*, *Orbulina*, *Biorbulina* and *Velapertina*, treated here as the adult morphotypes, may be of heterogenous (polyphyletic) character. They appear to be the product of a differently modified ontogenetic development of different species, represented by different juvenile stages of these morphotypes. In the case of the Badenian of Central Paratethys, such juvenile stages seem to belong mostly to *Globigerinoides*, the genus most sensitive to environmental changes. It seems possible that *Velapertina* is a kummerform or undeveloped form of *Orbulina*. Tests of more cosmopolitan *Globigerina* and *Globorotalia*, present throughout the Badenian in this region, usually display normal development.

So far existing morphologic criteria used to distinguish members of the *Globigerinoides* — *Orbulina* bioseries are not sufficient to accept their validity for classification of that bioseries.

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JANINA SZCZECHURA

ZMIENNOŚĆ MORFOLOGICZNA W GRUPIE *GLOBIGERINOIDES — ORBULINA* ZE ŚRODKOWEGO MIOCENU PARATETYDY CENTRALNEJ

Streszczenie

W pracy zbadałam rozprzestrzenienie i zróżnicowanie morfologiczne otwornic planktonicznych ze środkowego miocenu (badenu) Paratetydy Centralnej (Polska, Bułgaria, Rumunia). W oparciu o analizę otwornic bentonicznych stwierdziłam, że głębokość na której żyły miała wpływ nie tylko na rozprzestrzenienie regionalne otwornic lecz także na morfologię ich niektórych przedstawicieli.

Rozprzestrzenienie stratygraficzne otwornic planktonicznych zależało, poza batymetrią, także od innych czynników środowiska (temperatury?), niewątpliwie zmiennych w badenie Paratetydy Centralnej, które spowodowały zanik bądź modyfikację ich niektórych grup w młodszym badenie.

W pracy podważyłam dotychczasowe znaczenie biostratygraficzne i podstawy taksonomii grupy otwornic *Globigerinoides-Orbulina* i/albo *Velapertina*, przypisując im charakter ekofenotypowy.

EXPLANATION OF THE PLATES 1—11

Plate 1

Scanning micrographs of specimens of *Globigerinoides* collected from the lower part of the Trzęsiny outcrop (SE Poland) (*Globigerinoides* Ecozone). Specimens are characterised by rather loosely coiled tests, and distinct primary and secondary apertures.

1, 2, 4, 5, 8. *Globigerinoides triloba triloba* (Reuss); 1×75, ZPAL F.XXX/1; 2×75, ZPAL F.XXX/2; 4×75, ZPAL F.XXX/3; 5×75, ZPAL F.XXX/4; 8×60, ZPAL F.XXX/5.
3, 6, 7, 9—11. *Globigerinoides triloba sacculifera* (Brady); 3×75, ZPAL F.XXX/6; 6×75, ZPAL F.XXX/7; 7×60, ZPAL F.XXX/8; 9×60, ZPAL F.XXX/9; 10×80, ZPAL F.XXX/10; 11×60, ZPAL F.XXX/11.
12. *Globigerinoides ?quadrilobatus* (d'Orbigny), ×90, ZPAL F.XXX/12.

Plate 2

Scanning micrographs of specimens of the *Globigerinoides — Praeorbulina — Orbulina* bioseries collected from the Korytnica outcrop (central Poland) (*Globigerinoides* Ecozone). *Globigerinoides predominates* this assemblage.

1, 2. *Globigerinoides triloba triloba* (Reuss); 1×100, ZPAL F.XXX/13; 2×90, ZPAL F.XXX/14.
3, 4. *Globigerinoides* cf. *sicanus* de Stefani; 3×90, ZPAL F.XXX/15, 4×90, ZPAL F.XXX/16.
5, 9, 10. *Orbulina suturalis* Brönnimann; 5×90, ZPAL F.XXX/17; 9×80, ZPAL F.XXX/18; 10×90, ZPAL F.XXX/19.
6. *Praeorbulina* sp., ×90, ZPAL F.XXX/20.
7, 8. *Biorbulina* sp.; 7×55, ZPAL F.XXX/21; 8×90, ZPAL F.XXX/22.
11. *Orbulina universa* d'Orbigny, ×90, ZPAL F.XXX/23.

Plate 3

Scanning micrographs of specimens from the Gacki outcrop (central Poland) (*Globigerinoides* Ecozone). The *Globigerinoides-Praeorbulina-Orbulina* bioseries is here represented by its all forms, however *Praeorbulina-Orbulina* representatives predominate. *Globigerinoides* is characterised by tight coiling and diminutive apertures; see also Plate 4.

1. *Globigerinoides triloba triloba* (Reuss), ×60, ZPAL F.XXX/24.
2—5. *Globigerinoides* cf. *triloba triloba* (Reuss); 2×60, ZPAL F.XXX/25; 3×60, ZPAL F.XXX/26; 4×60, ZPAL F.XXX/27; 5×90, ZPAL F.XXX/28.
6. 7. *Biorbulina* cf. *transitoria* (Blow); 6×60, ZPAL F.XXX/29; 7×90, ZPAL F.XXX/30.
8, 9, 11. *Biorbulina bilobata* (d'Orbigny); 8×80, ZPAL F.XXX/31; 9×60, ZPAL F.XXX/32; 11×60, ZPAL F.XXX/33.
10. *Orbulina suturalis* Brönnimann, damaged specimen, ×60, ZPAL F.XXX/34; a — inner view, showing two-layered test wall, b — outer view, showing initial spire.

Plate 4

Scanning micrographs of specimens from the Gacki outcrop (central Poland) (*Globigerinoides* Ecozone). The *Globigerinoides-Praeorbulina-Orbulina* bioseries is here represented by its all forms, however *Praeorbulina-Orbulina* representatives predominate. *Globigerinoides* is characterised by tight coiling and diminutive apertures; see also plate 3.

1. *Globigerinoides triloba triloba* (Reuss), ×60, ZPAL F.XXX/35.
2, 3, 5, 9, 11. *Praeorbulina glomerosa* div. ssp. (Blow); 2×90, ZPAL F.XXX/36; 3×100, ZPAL F.XXX/37; 5×90, ZPAL F.XXX/38; 9×90, ZPAL F.XXX/39; 11×100, ZPAL F.XXX/40.
4, 7. *Globigerinoides* cf. *sicanus* de Stefani; 4×90, ZPAL F.XXX/41; 7×90, ZPAL F.XXX/42.
6, 8. *Globigerinoides ?triloba triloba* (Reuss); 6×50, ZPAL F.XXX/43; 8×60, ZPAL F.XXX/44.
10, 11. *Orbulina suturalis* Brönnimann; 10×80, ZPAL F.XXX/45; 11×80, ZPAL F.XXX/46.

Plate 5

Scanning micrographs of specimens from the Staropatica outcrop (NW Bulgaria) (*Globigerinoides* Ecozone). The *Globigerinoides-Praeorbulina-Orbulina* bioseries is here represented by all its forms in about equal frequencies. *Globigerinoides* is represented by specimens with distinct, well developed apertures and loosely coiled chambers.

1. *Globigerinoides triloba sacculifera* (Brady), ×50, ZPAL F.XXX/47.
2. *Globigerinoides triloba triloba* (Reuss), ×60, ZPAL F.XXX/48.
3. Transitional form between *Globigerinoides triloba triloba* (Reuss) and *Globigerinoides sicanus* de Stefani, ×100, ZPAL F.XXX/49.
4. *Globigerinoides sicanus* de Stefani, ×100, ZPAL F.XXX/50.
5. *Biorbulina transitoria* (Blow), ×60, ZPAL F.XXX/51.
6. *Biorbulina* cf. *bilobata* (d'Orbigny), ×50, ZPAL F.XXX/52.
7. ?*Biorbulina* sp., ×60, ZPAL F.XXX/53.
8, 9, 12. *Orbulina ?suturalis* Brönnimann; 8×90, ZPAL F.XXX/54; 9×90, ZPAL F.XXX/55; 12×80, ZPAL F.XXX/56.
10, 11. *Globigerinoides triloba triloba* (Reuss); 10×90, ZPAL F.XXX/57; 11×100, ZPAL F.XXX/58.

Plate 6

Scanning micrographs of specimens from the Monastyrz outcrop (SE Poland) (*Globigerina* Ecozone). The *Globigerinoides-Praeorbulina-Velapertina* bioseries is here represented by all its forms, however, *Velapertina*-like specimens predominate. *Orbulina* is extremely rare. *Globigerinoides* representatives are characterised by small size, tightly coiled chambers and small (or lacking) apertures. Bullate specimens occur. See also Plate 7.

1, 2. *Globigerina* sp.; *bullate* specimens; 1×90, ZPAL F.XXX/59; 2×90, ZPAL F.XXX/60.
3. 4. *Globigerinoides* sp.; kummerform individuals?; 3×60, ZPAL F.XXX/61; 4×90, ZPAL F.XXX/62.
5. *Globigerinoides triloba triloba* (Reuss), ×60, ZPAL F.XXX/63.
6, 8, 12, 13. *Praeorbulina* div. sp.; 6×100, ZPAL F.XXX/64; 8×100, ZPAL F.XXX/65; 12×125, ZPAL F.XXX/66; 13×100, ZPAL F.XXX/67.
7. ?*Biorbulina* sp., ×60, ZPAL F.XXX/68.
9—11, 14. *Velapertina* sp.; 9×60, ZPAL F.XXX/69; 10×90, ZPAL F.XXX/70; 11×60, ZPAL F.XXX/71; 14×90, ZPAL F.XXX/72.
10. ?*Orbulina* sp., ×90, ZPAL F.XXX/73.

Plate 7

Scanning micrographs of specimens from the Monastyrz outcrop (SE Poland) (*Globigerina* Ecozone). *Orbulina* is extremely rare. See also caption of Plate 6.

1—12. *Velapertina* sp.; damaged specimens. Older parts of the test, without bullae, could be referred to *Globigerinoides* (1, 2, 4—11), *Praeorbulina* (3), or even *Globigerina* (12). Bullae entirely or partly cover the test and often make additional thickening of the test wall; 1×60, ZPAL F.XXX/74; 2×60, ZPAL F.XXX/75; 3×60, ZPAL F.XXX/76; 4×60, ZPAL F.XXX/77; 5×60, ZPAL F.XXX/78; 6×60, ZPAL F.XXX/79; 7×60, ZPAL F.XXX/80; 8×60, ZPAL F.XXX/81; 9×90, ZPAL F.XXX/82; 10×90, ZPAL F.XXX/83; 11×90, ZPAL F.XXX/84; 12×80, ZPAL F.XXX/85.

Plate 8

Scanning micrographs of specimens from the Trzęsiny outcrop (SE Poland) (*Globigerina* Ecozone). The *Globigerinoides-Praeorbulina-Velapertina* (or *Orbulina*) bioseries is represented here by its all forms, those referred to *Velapertina* predominate. Specimens are characterised by tightly coiled chambers, and small (or lacking) sutural apertures. Arrangement of chambers is generally very irregular. *Globigerinoides*-like specimens are small and without distinct apertures.

1, 2. ?*Globigerinoides* sp.; 1×60, ZPAL F.XXX/86; 2×90, ZPAL F.XXX/87.

3, 6, 7, 9, 10, 12, 13. *Velapertina* sp.; 3×90, ZPAL F.XXX/88; 6×90, ZPAL F.XXX/89; 7×60, ZPAL F.XXX/90; 9×90, ZPAL F.XXX/91; 10×90, ZPAL F.XXX/92; 12×90, ZPAL F.XXX/93; 13×90, ZPAL F.XXX/94.

4, 5. ?*Praeorbulina* sp.; 4×90, ZPAL F.XXX/95; 5×90, ZPAL F.XXX/96.

8, 11. ?*Orbulina* sp.; 8×90, ZPAL F.XXX/97; 11×90, ZPAL F.XXX/98.

Plate 9

Specimens (scanning micrographs) 1—11 are from one sample, from Giurgesti outcrop (central Romania), specimens 12—14 are from another sample, from Dobrusha (NW Bulgaria); both samples from beds referred to the *Globigerina* Ecozone. Specimens from Giurgesti are figured also in Plate 12 (same sample); *Globigerinoides-Praeorbulina-Velapertina* (or *Orbulina*) bioseries in sample from Romania is represented mostly by *Velapertina*. Removed bullae in some *Velapertina*-like specimens reveal their *Globigerinoides*- or *Praeorbulina*-like appearance. *Globigerinoides*-like specimens are small, without distinct apertures.

1. *Globigerinoides* ?*triloba triloba* (Reuss), ×60, ZPAL F.XXX/99.
2. ?*Biorbulina* sp., ×60, ZPAL F.XXX/100.

3, 5, 8, 11—13. *Praeorbulina* sp.; 3×60, ZPAL F.XXX/101; 5×60, ZPAL F.XXX/102; 8×60, ZPAL F.XXX/103; 11×60, ZPAL F.XXX/104; 12×90, ZPAL F.XXX/105; 13×100, ZPAL F.XXX/106.

4, 7, 9, 10, 14. *Velapertina* sp.; 4, 7, 10, 14 damaged specimens; 4×60, ZPAL F.XXX/107; 7×60, ZPAL F.XXX/108; 9×60, ZPAL F.XXX/109; 10×60, ZPAL F.XXX/110; 14×90, ZPAL F.XXX/111.

6. *Globigerinoides* cf *sicanus* de Stefani, ×60, ZPAL F.XXX/112.

Plate 10

Scanning micrographs of specimens from the Giurgesti outcrop (central Romania) (*Globigerina* Ecozone). *Globigerinoides-Praeorbulina-Velapertina* and *Orbulina* (or *Biorbulina*) bioseries is represented here mostly by *Velapertina*-like specimens. Chambers (or bullae) in *Velapertina*-like specimens are especially numerous, irregularly arranged; secondary apertures are often on spiral side. For further details see comment to Plate 9.

1, 3—9. *Velapertina* sp.; 7 damaged specimen showing *Globigerina*-like initial spire; 8a detail of the spiral side of specimen 8b; 1×60, ZPAL F.XXX/113; 3×60, ZPAL F.XXX/114; 4×60, ZPAL F.XXX/115; 5×100, ZPAL F.XXX/116; 6×60, ZPAL F.XXX/117; 7×60, ZPAL F.XXX/118; 8a×140, 8b×60, ZPAL F.XXX/119; 9×60, ZPAL, F.XXX/120.

2. *Orbulina ?suturalis* Brönnimann, ×60, ZPAL F.XXX/121.

s.a. — secondary apertures

Plate 11

Scanning micrographs of specimens (1—9) from the Apold outcrop (central Romania) (*Globigerinoides* Ecozone). *Globigerinoides-Praeorbulina-Orbulina* (or *Biorbulina*) bioseries here contains rich *Orbulina*- and *Biorbulina*-like forms with differently developed juvenile parts. Some damaged *Biorbulina*-like specimens are formed by bullate *Orbulina*. Specimen 10 is from Monastyrz (outcrop) in SE Poland, from the *Globigerina* Ecozone.

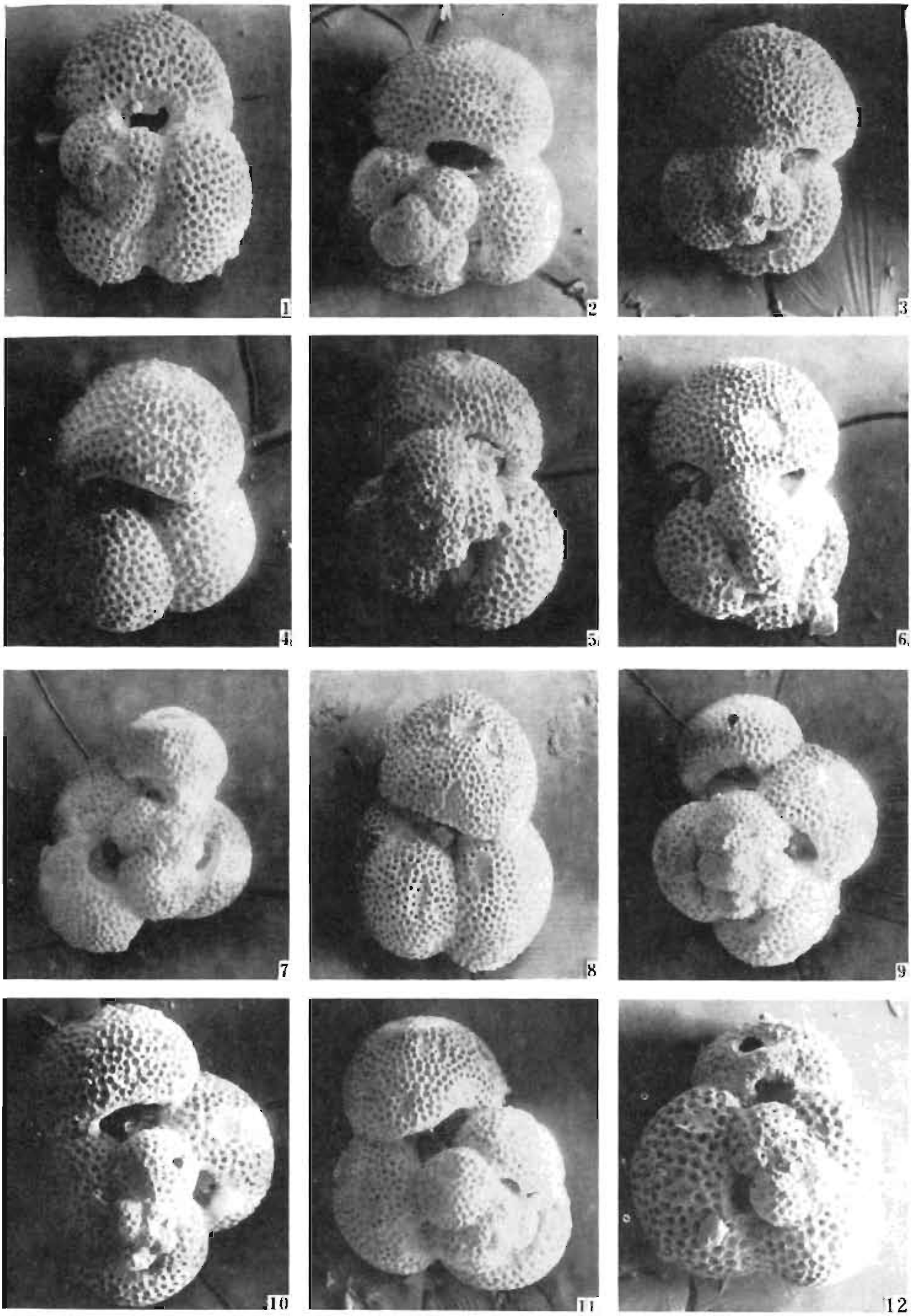
1, 3—6. *Biorbulina* sp.; all specimens damaged, 1b detail of initial part of specimen 1a; 6b detail of initial part of specimen 6a; 1a×140, 1b×60, ZPAL F.XXX/122; 3×70, ZPAL F.XXX/123; 4×100, ZPAL F.XXX/124; 4×70, ZPAL F.XXX/125; 5×100, ZPAL F.XXX/126; 6a×60, 6b×150, ZPAL F.XXX/127.

2. *?Praeorbulina* sp., damaged specimen, ×60, ZPAL F.XXX/128.

7. *Praeorbulina* sp., damaged specimen, ×120, ZPAL F.XXX/129.

8, 9. *Orbulina universa* d'Orbigny; damaged specimens showing differently developed initial spires; 8×60, ZPAL F.XXX/130, 9×75, ZPAL F.XXX/131.

10. *Velapertina* sp., damaged specimen showing *Globigerina*-like initial spire, ×100, ZPAL F.XXX/132.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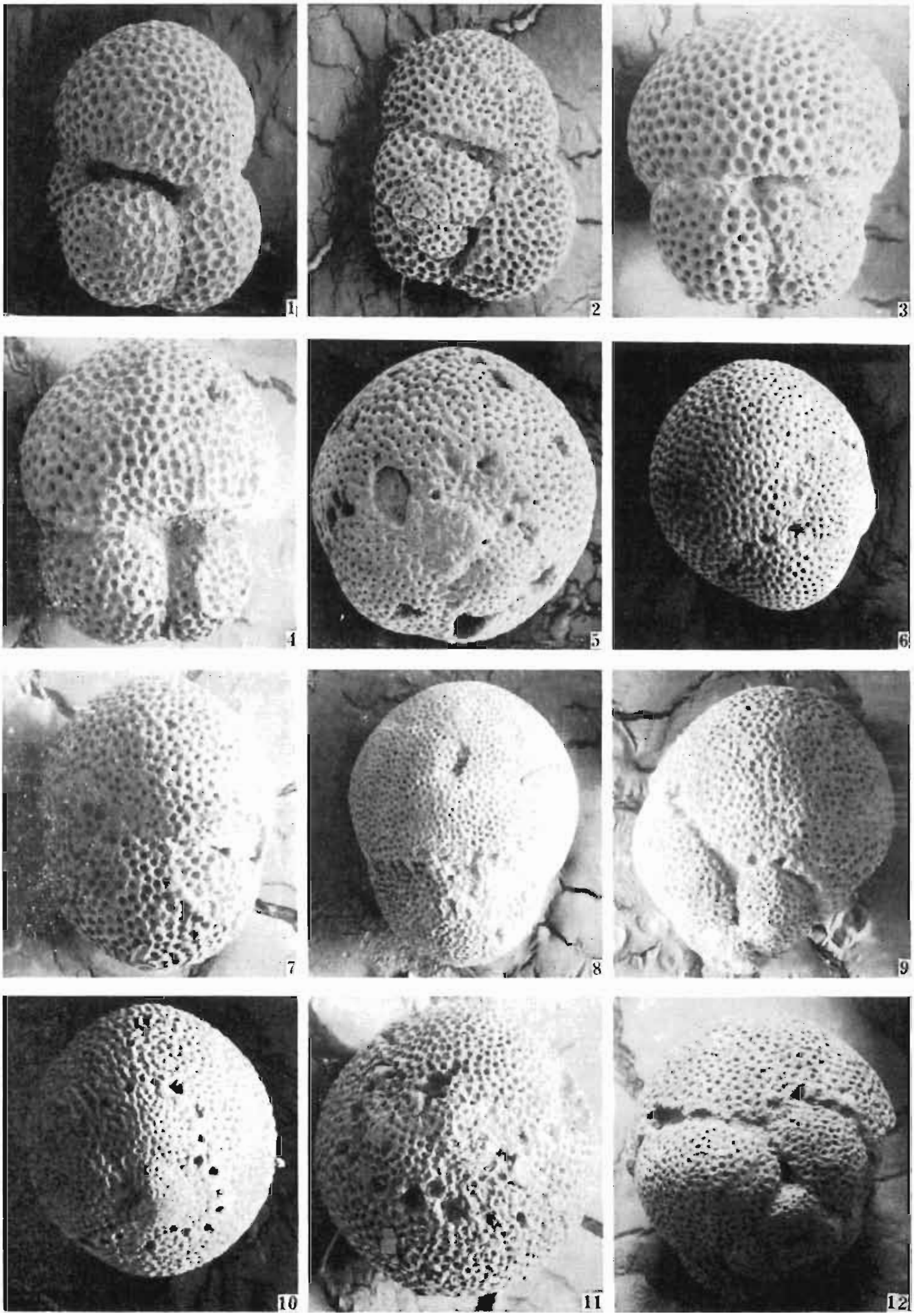
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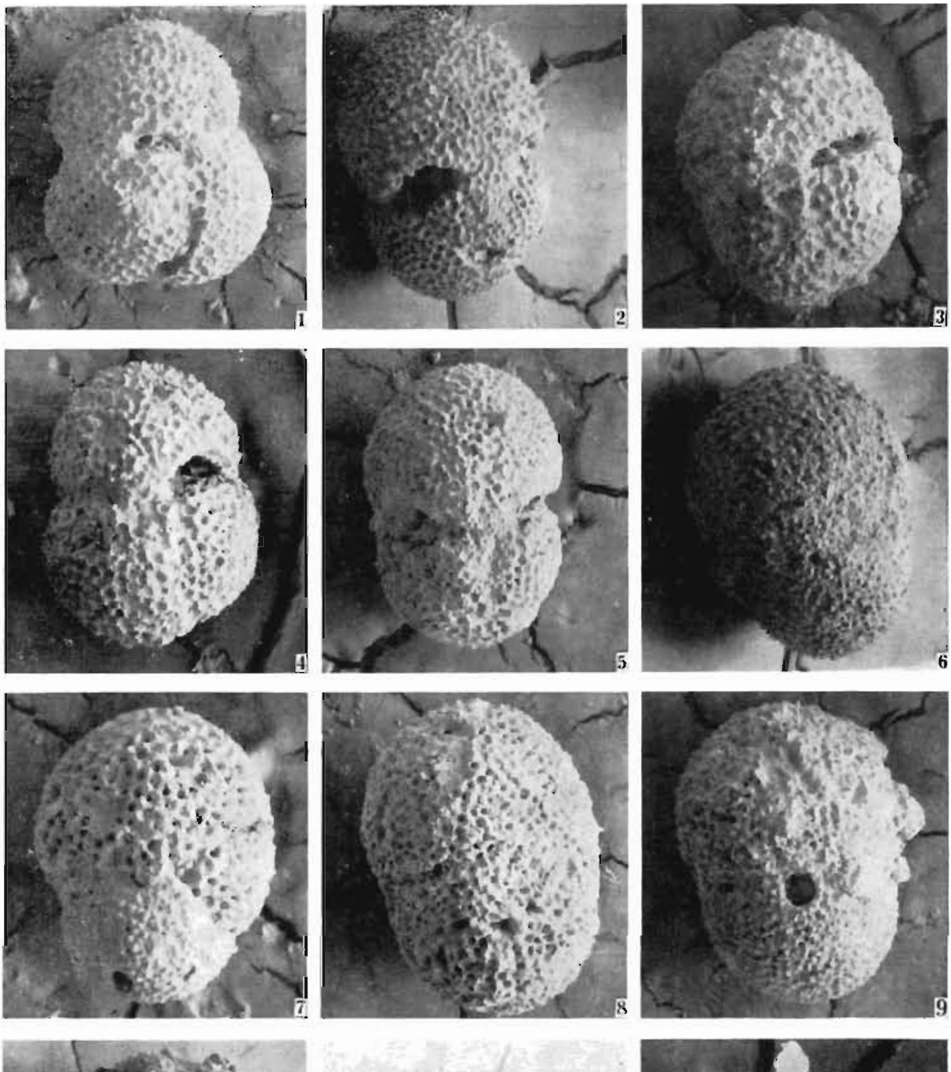
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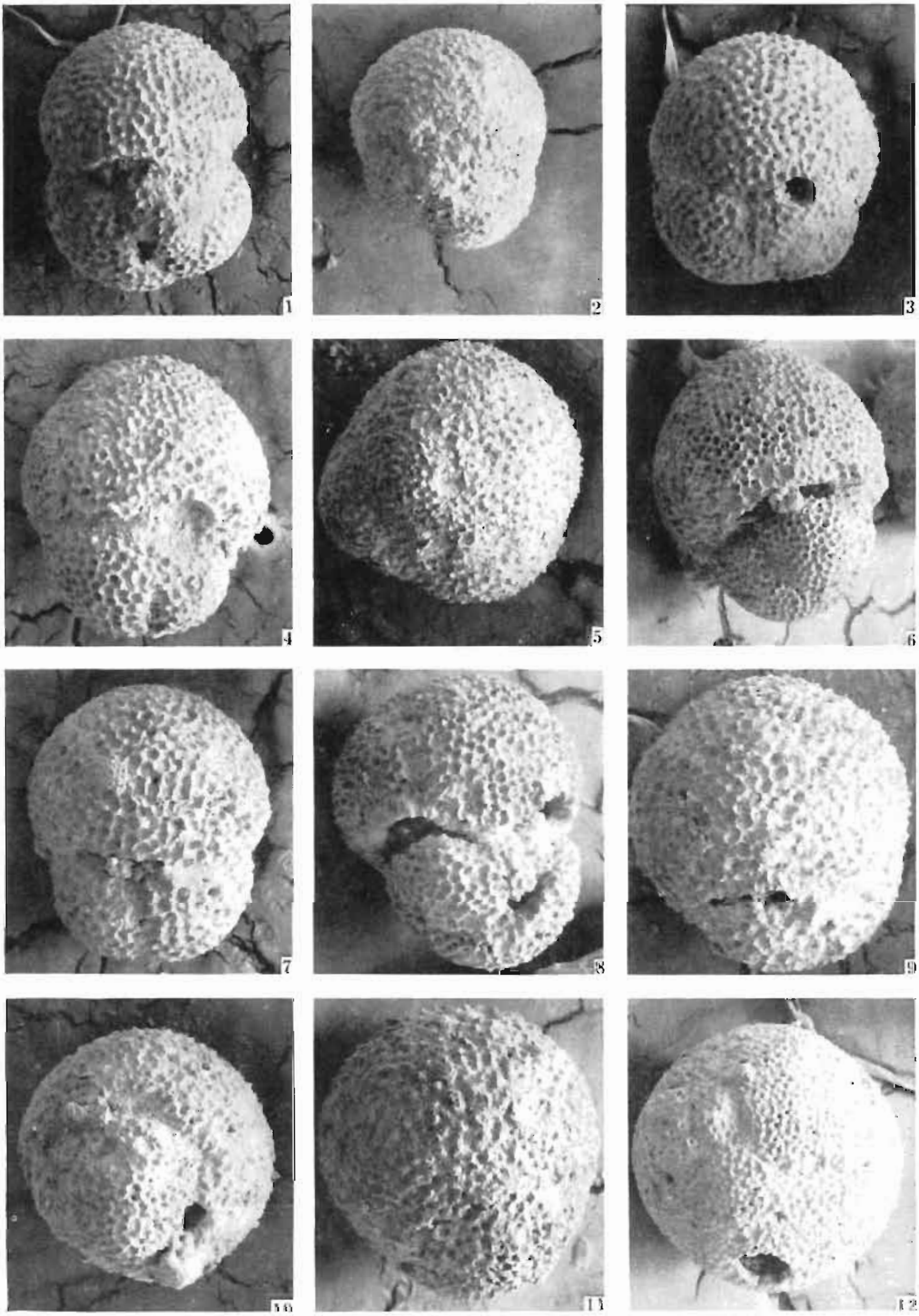
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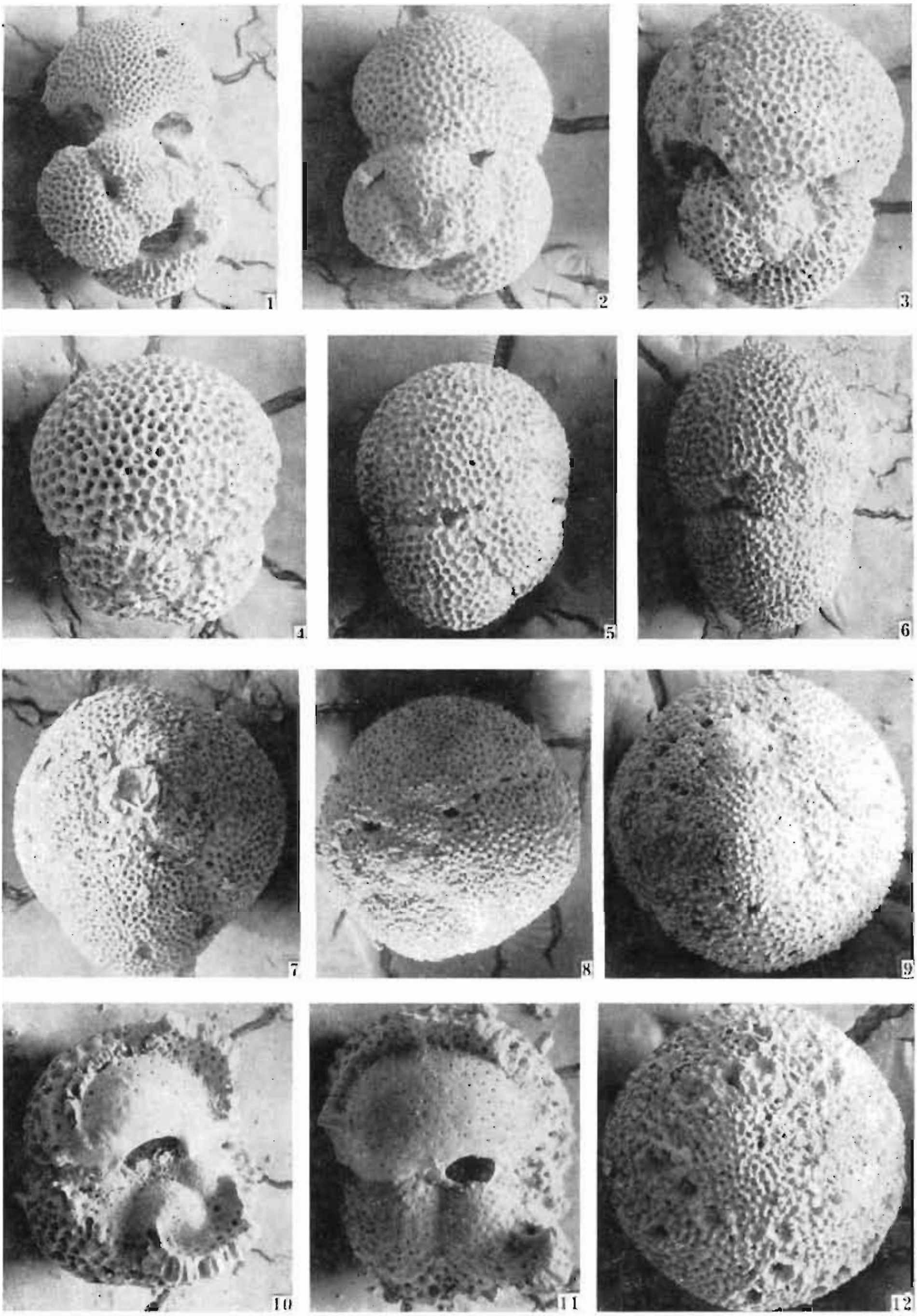
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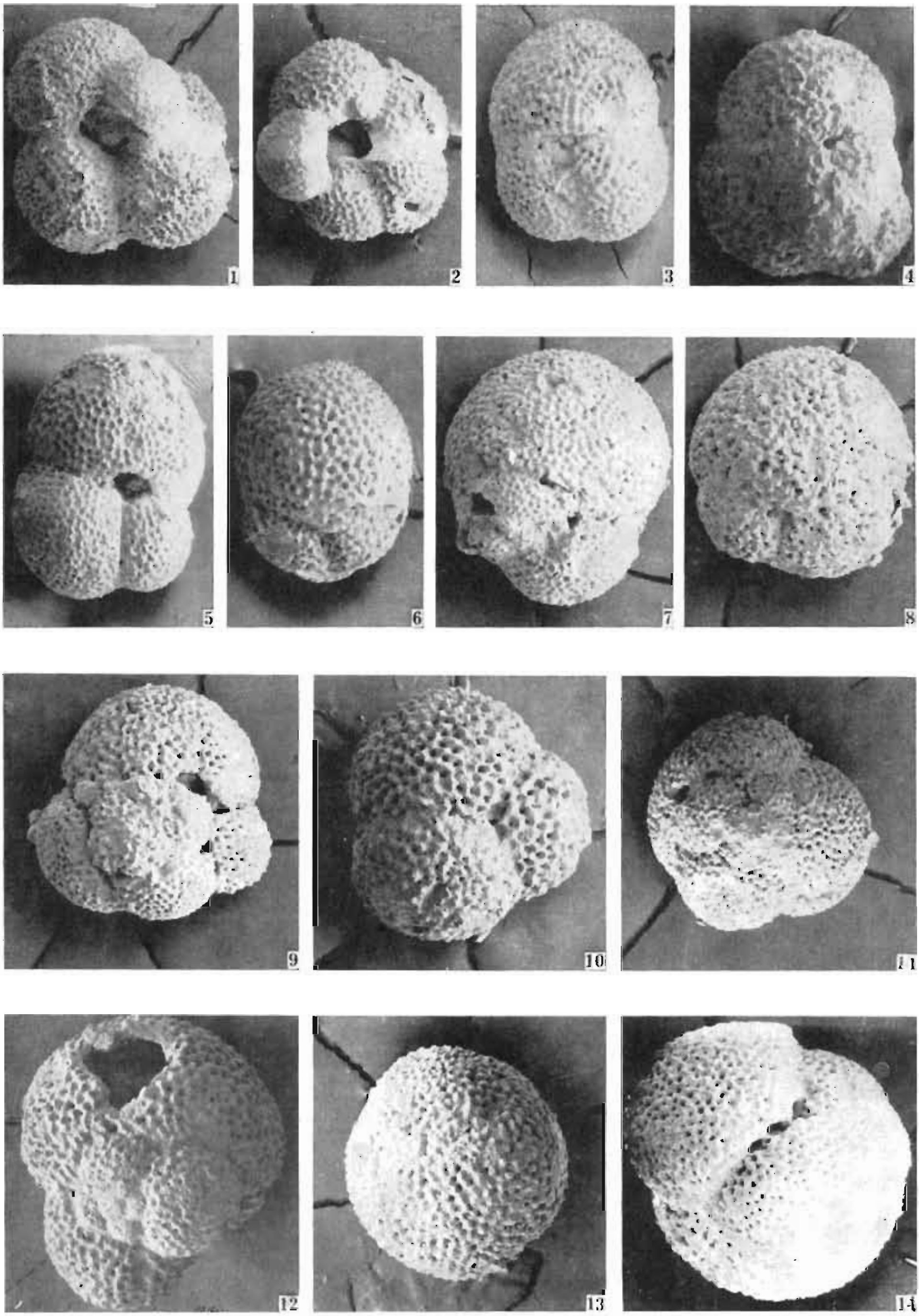

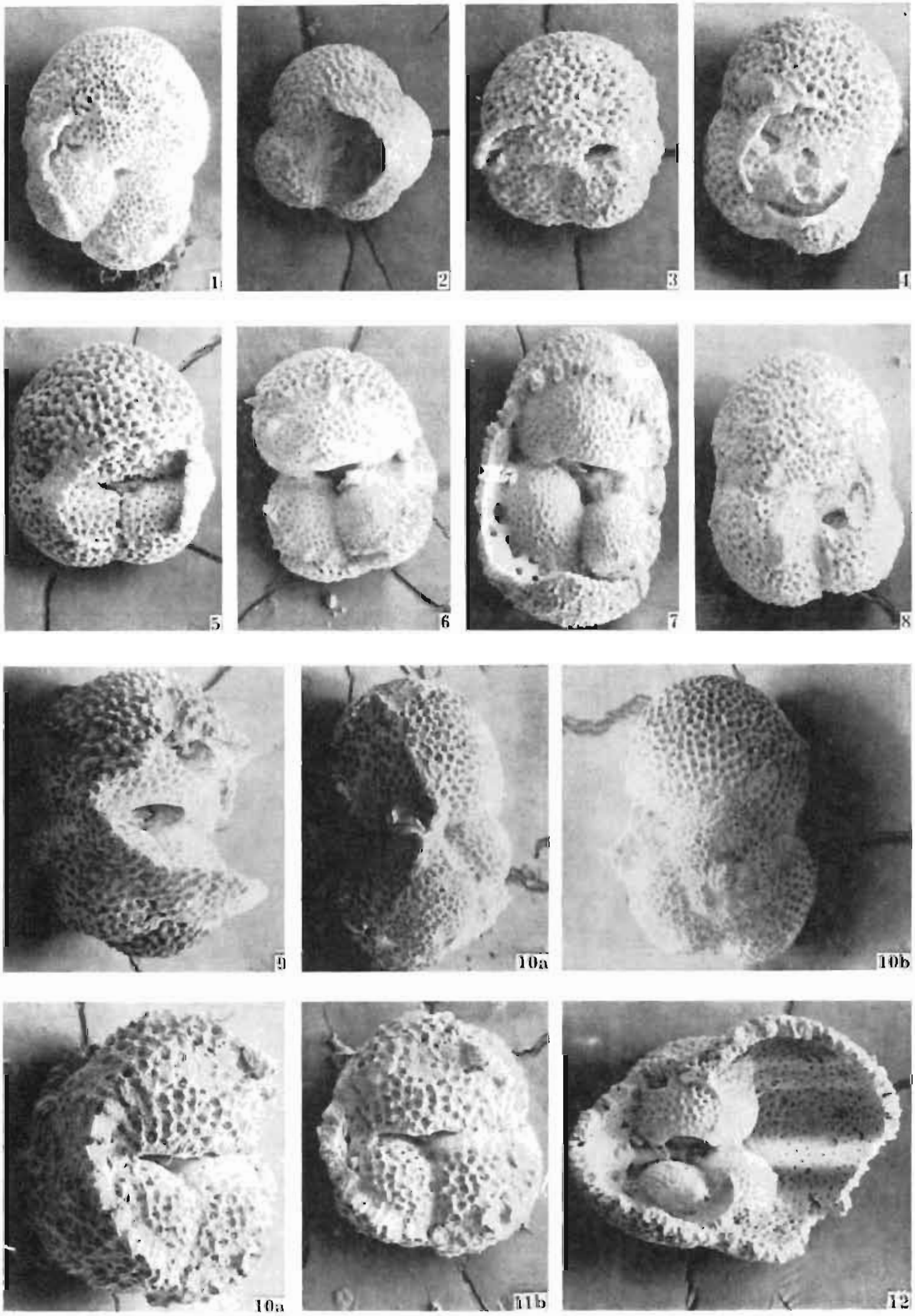
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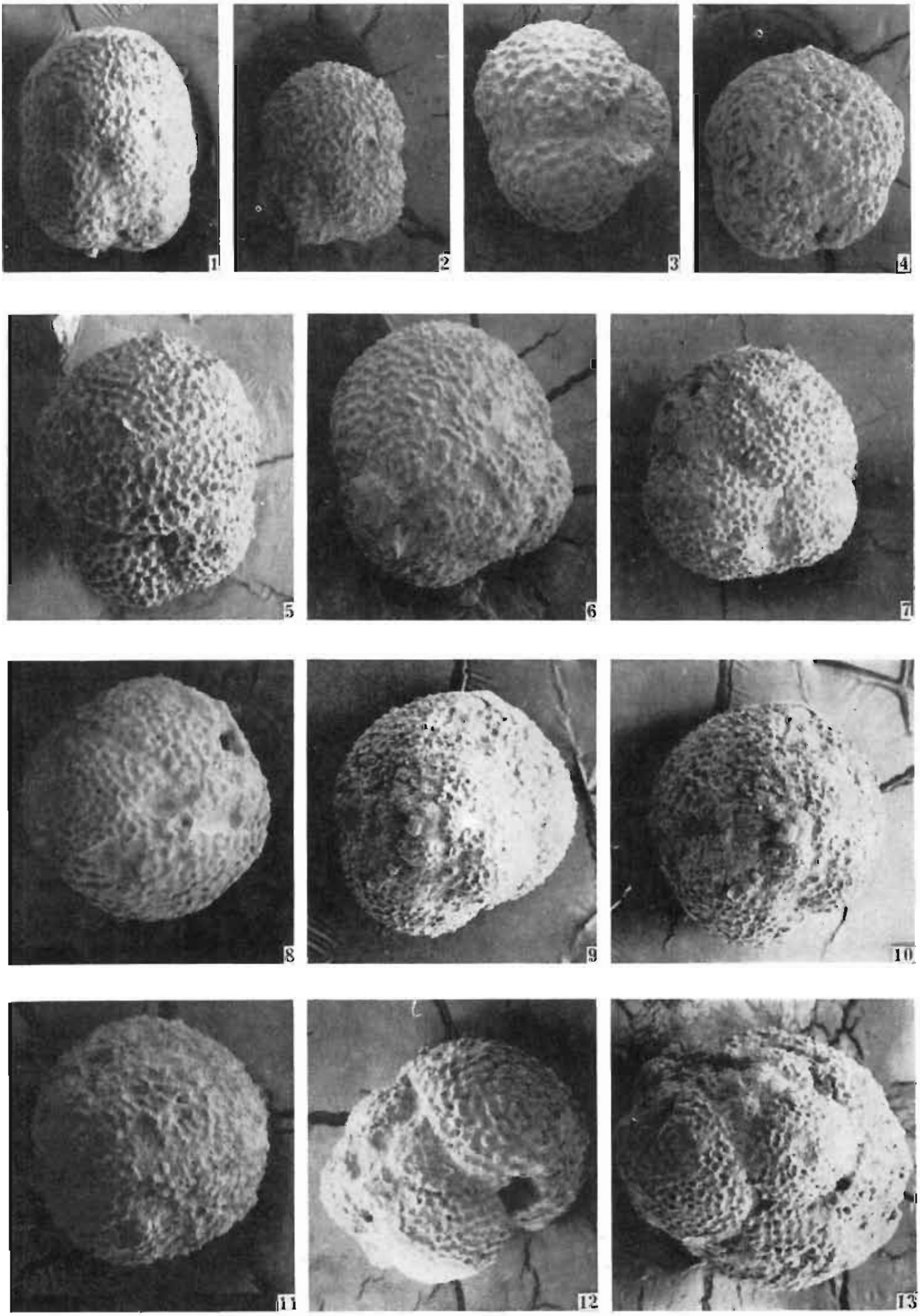
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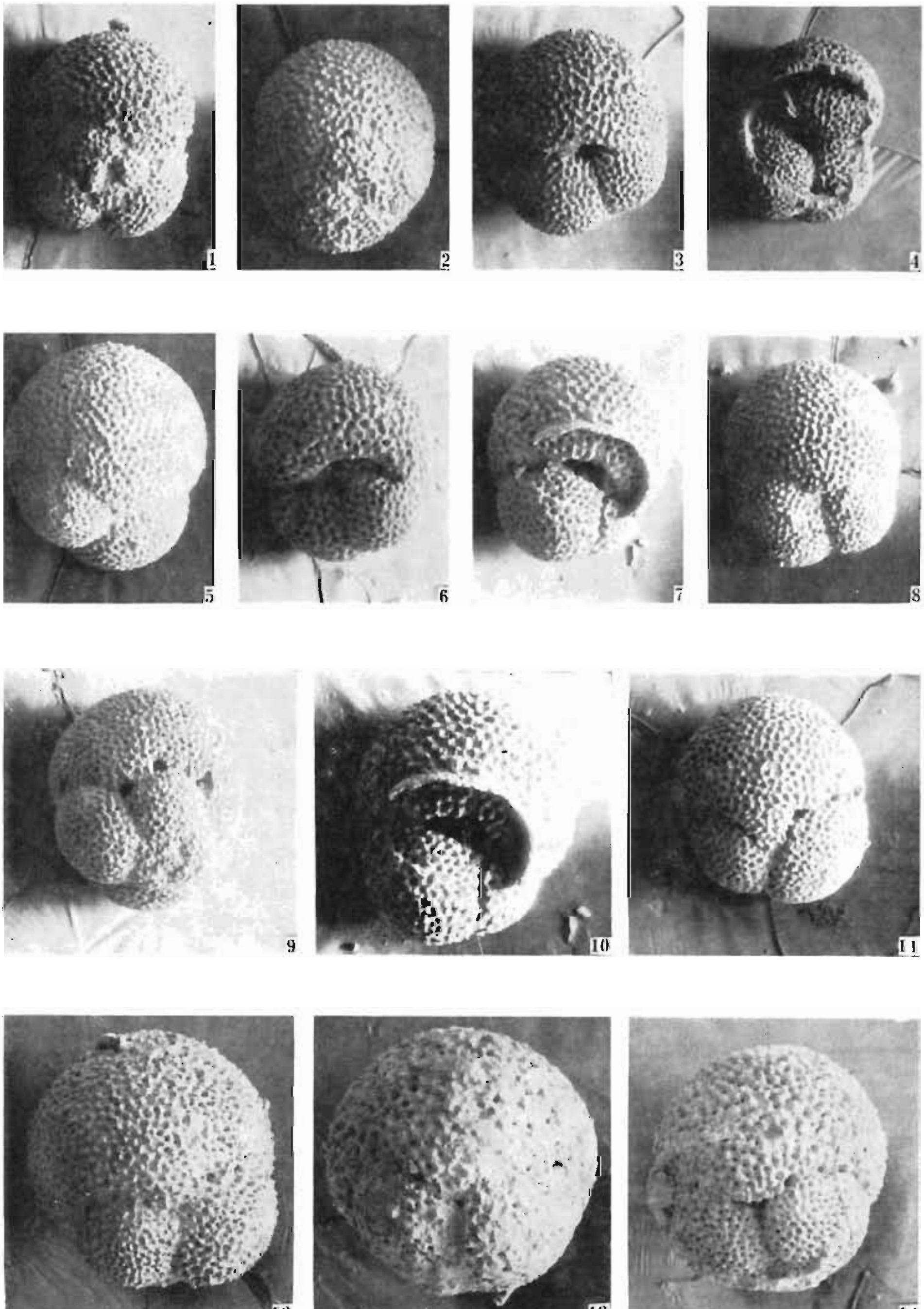
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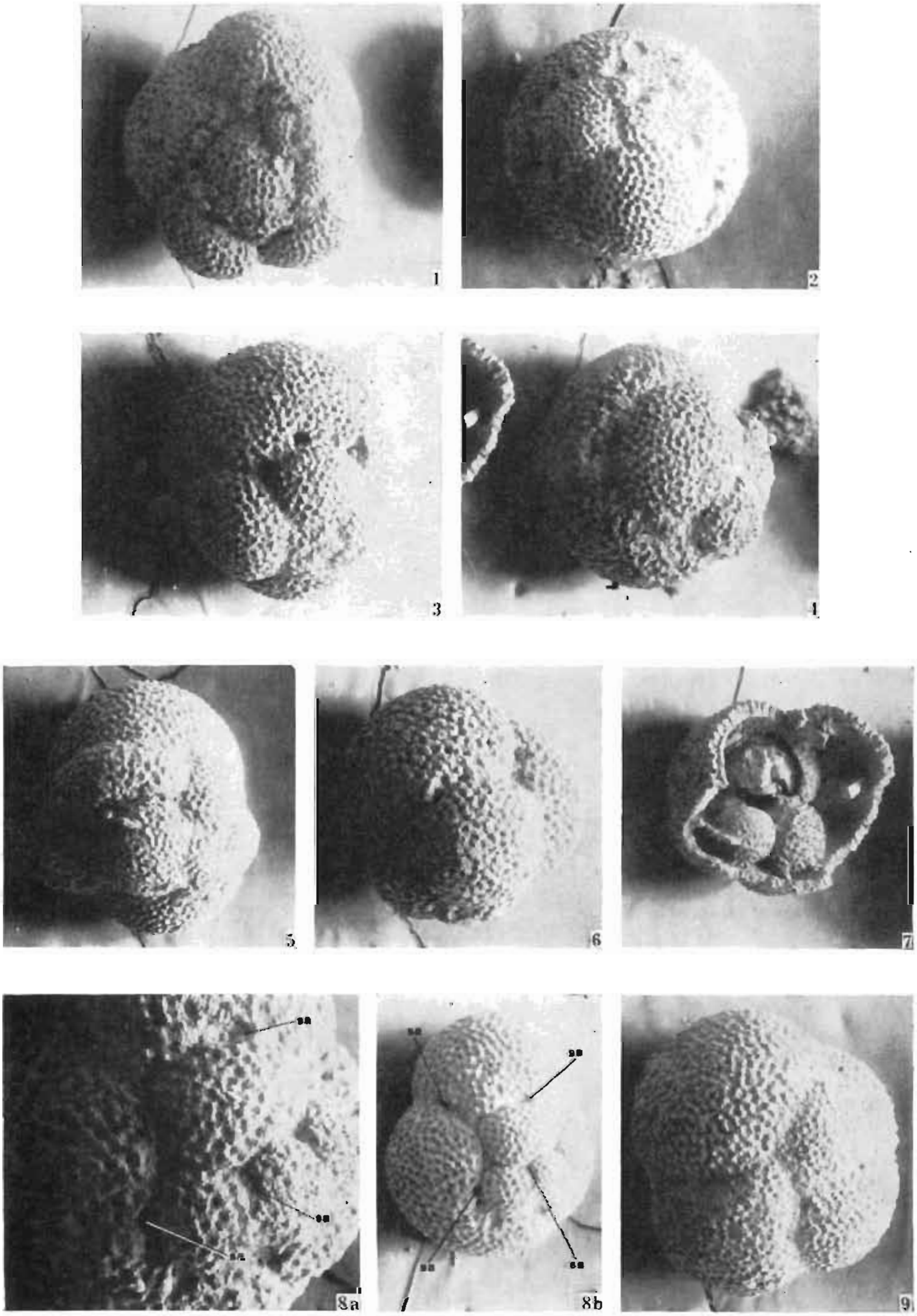
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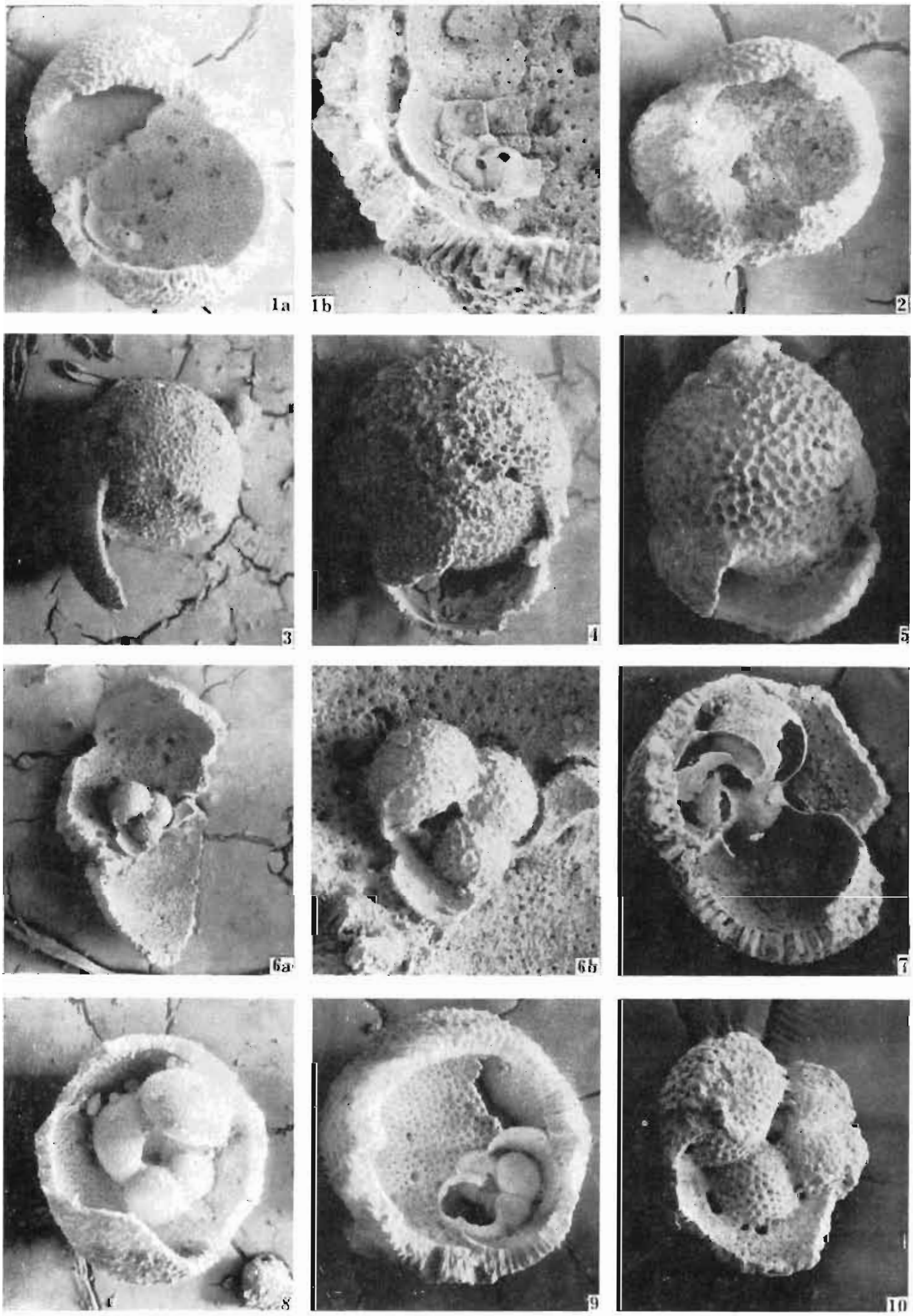
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