A SURVEY OF THE GENERA OF THE FORAMINIFERA OF THE LITTORAL ZONE IN THE COOS BAY AREA

by

MILDRED RIECHERS

A THESIS

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INTRODUCTION

Problem

This problem was begun in 1939 at the Institute of Marine Biology at Coos Bay and continued in the summers of 1940 and 1941. During the summer of 1939 collections were made in the litteral zone somewhat at random in an effort to determine the habitat of the foraminifera. While a few tests were found in open sandy beach areas, they were obviously dead and abraded from constant wave action. The sand in protected spots behind boulders and the debris collected on the outside surfaces of sea anemones gave negative results. The living specimens, characterized by the glossiness of their tests and the translucency of some forms, were found among plants, where they were common in the sand and mud surrounding the holdfasts of algae and the roots of eelgrass, and adhering to the plants themselves.

The work of collecting, separating, mounting and classifying the specimens went on during the summers of 1940 and 1941 at Coos Bay. Additional material was collected in the winter of 1942-1943 and worked over at the University of Oregon.

This study of the foraminifera of the Coos Bay region is taxonomic in nature. In view of the fact that species are determined on the morphological differences of the test in sometimes widely different sexual and asexual phases of the life cycle, and since comparatively little appears to be known about the life cycle of most species, it seems advisable to limit the classification of most of the specimens described and figured here to genus. In a few instances, specimens have so closely resembled those described and illustrated in the works of Brady (1884) and Natland (1937) that identifying them to species seems justified.

Work on the littoral forms of foraminifera on the Pacific coast is conspicuously lacking. As a matter of fact, data on even the deep-water forms are not extensive. Brady's study of collections made during the voyage of H.M.S. Challenger in 1873-1876 includes material from the Philippines, Hawaii, and mid-Pacific stations southward to the Straits of Magellan. The U. S. Bureau of Fisheries steamer Albatross while engaged in a cable survey in 1891 took innumerable bottom samples along the islands of Japan and the coast of Siberia. U.S.S. Nero made cable surveys across the north Pacific from Hawaii to Midway island, thence to Guam, to Luzon, to Guam, to Yokohama, and back to Hawaii. Much of the dredging done in these areas was in very deep water in red clay areas, and almost no foraminifera were found, but many areas of shallower water were covered with typical Globigerina ooze. Cushman published his extensive work on collections from these three ships and U.S.S. Alert (1910-1916), and notes that the region where the fewest samples were taken is that of western United States, and that the reason is partly that the Albatross when in these waters was often engaged in work other than dredging.

Two papers, of Coe and Allen (1937) and Natland (1938), deal with recent foraminifera of the Pacific coast, but they both refer to Southern California. The former refers to foraminifera only incidentally, in connection with growth of sedentary marine organisms, and the latter describes species mostly dredged from 884 up to 9 fathoms.

Not only in the study of foraminifera has the coast of Oregon been neglected, but Fraser (1937) decries the almost complete lack of material on hydroids from San Francisco bay to Cape Flattery, and states that little shore collecting has been done in this area, and although the Albatross did some dredging off the coast in deeper water, collections have been examined from very few stations. At the present time, less is known of the hydroid possibilities here than in any other area on the whole coast.

Considering that shallow water and littoral zones are by far the best sources for large numbers of species of foraminifera, it seems remarkable that these areas have been neglected. Foraminifera seem to be very common in protected areas where there is plant life, and while they individually are not conspicuous, they in some cases form a considerable proportion of the sand. The commonest of the foraminifera on the British coast, Massilina secans, is found on the southern coasts in stretches of beach miles long, where it makes up as much as 95% of the sand (Heron-Allen and Earland, 1910).

The subject of foraminifera had been of purely scientific interest until 1917, when micropaleontology was applied to the problems of petroleum geology. Fossil foraminifera are used by oil companies in determining the formations through which they must drill. The samples taken with a drill are necessarily small and frequently mixed, and the characteristic formation and the larger fossils often destroyed. Since most foraminifera are so small and so numerous, they make the best and most reliable means of identification.

Most of the zoologists who have studied foraminifera have used the same specific names for Paleozoic, Mesozoic, and Recent forms. They have been most interested in the similarities and relationships of the forms and their environments. Paleontologists, on the other hand, are interested in the fact that fossil species are not always the same as the recent forms; therefore the value of foraminifera in identifying formations lies in the fact that there are differences from age to age in what the zoologists call a single species. It has long been believed that foraminifera were very persistent, the various species living continuously through many geologic periods and that they were of little chronologic value. Only in the last few years has the fact been realized that not only do distinct species of foraminifera characterize the greater periods, but the subdivisions and horizons.

Occasionally foraminifera which seemingly designate a formation reappear several periods later, a fact apparently contrary to the logical statement that a species once extinct never reappears. No doubt this reappearance of species is due to the fact that they existed in some other locality and returned when the temperature, depths, amount of suspended material and other conditions were favorable in the area of deposition (Carsey, 1926).

Geographical Distribution

Foraminifera are usually considered marine organisms. Only certain species of one family, the Lagynidae, live in fresh water. This family has been removed from the foraminifera by some authors, leaving in the order only salt water forms that can be preserved as fossils. Kudo (1939) puts the Lagynidae in Order Testacea, but Døflein (1929), Galloway (1933) and Cushman (1933) put it in the foraminifera. Rhumbler (1904) put most of the Lagynidae in a third order, Filosa. It would seem, therefore, that the Order Foraminifera in general can be called marine. Entzia, a chitinous form in the Trochamminidae, has been found in inland salt water in Hungary, a sea supposed to be the remnants of an old Miocene sea. Cushman (1933) suggests that it is probable that foraminifera will be found in salt or brackish lakes in many parts of the world.

Most species live on the bottom, some on algae, and about twenty-five species are pelagic. The largest and most specialized forms are adjusted to a particular habitat, such as the deep, cold water in which the Astrohrizidae live. The phyloephebic genera, at the evolutionary stage when they are in their prime, such as Verneuilina, Quinqueloculina, and the Nodosariidae and Rotaliidae, live in nearly all marine habitats. Attached forms occur mostly in very shallow and warm water, or in very cold and deep water.

In general, it may be said that temperature is the critical factor in distribution, while depth, except as related to temperature, is much less important. The habitat of the once living forms, as indicated by a fossil fauna, can be learned by a study of the highly specialized or highly degenerate forms, which are much more restricted than the phylo-ephebic genera.

Geologic Distribution

It has been stated that ninety percent of the world has, at one time or another, been covered by the sea. Today seventy percent of the earth's surface is covered by water. Thus foraminifera are found distributed over most of the earth in formations on land as well as under the sea. On Mount Everest, at the 22,000-foot level there is a seam of foraminifera 200 feet thick. They are found in the marble in the quarries of Italy, and in the rock of the Pyramids of Egypt.

It is unlikely that those forms which developed fragile chitin tests have been preserved. The more durable arenaceous group, especially those which have very well-defined tests, are capable of good preservation if conditions are favorable. The calcareous forms are well preserved as a rule, unless there has been leaching, or the material turned to greensand before it was fully fossilized.

The earliest known foraminifer, Cayeuxina Galloway, occurs in the pre-Cambrian of Brittany. The structure of the specimens is obliterated, however, and some of them may be equally well referred to the radiolaria. The Cambrian of the Malverns in England reveals species of Lagena, Nodosaria, Spirillina and others. Silurian foraminifera are known from England and the central United States. Devonian and

Mississippian forms are rare. Pennsylvanian forms occur in many parts of the world, and belong mainly to the families Endothyridae, Nodosinellidae, Textulariidae and Fusulinidae, all of which are extinct, and to the Spirillinidae, which is still in existence.

Triassic forms are rare, and belong to such modern families as the Rotaliidae and Nodosariidae. Foraminifera became abundant with the Jurassic, and Cretaceous forms are numerous and have a modern aspect, except for some highly specialized genera. Eocene and Oligocene foraminifera are abundant, and many of their genera continue to the Recent, but there are several specialized genera characteristic of these epochs. The Recent fauna began with the Miocene, and most of the genera and many species have continued to the present time.

Historical Review

The French naturalist Alcide d'Orbigny was the first to collect the genera of foraminifera into one zoological group. Brady (1884) writes that before d'Orbigny's day the external form of the tests had been studied by a long line of eminent observers--by Plancus and Soldani in Italy, Ledermüller in Germany, Linnaeus in Sweden, Fichtel and Moll in Austria, Walker and Montagu in England, Lamarck and Blainville in France, and many others. The earliest writers considered the foraminera minute varieties of the larger animals which their tests most nearly resembled. They were frequently assigned to such genera as _Nautilus_ and _Serpula_. Later, when they were recognized as distinct organisms, they were put into independent genera but distributed widely among the invertebrate groups. Their true status was not determined until the living organisms were studied, but meanwhile d'Orbigny forwarded the study of the group by putting them in a distinct section in the animal kingdom.

In d'Orbigny's "Tableau Methodique", published in 1826, the Cephalopodous Mollusca (Class Céphalopodes) were divided into three orders, one of which was the Order Foraminifères, divided into five families based upon the manner in which the chambers were combined to form the test. In the meantime Dujardin had described the true character of the Rhizopoda. This removed the foraminifera to a lower position in the zoological scale. In d'Orbigny's later works, the Foraminifères constitute the fourth class of Zoophytes, divided into seven orders based on arrangement of the chambers.

In 1854, Max Schultze published his "Über den Organismus der Polythalamen (Foraminiferen)". In this he divided the Rhizopoda into two sections, Nuda and Testacea: the former, based on Amoeba as its type, included all naked forms, and the latter included all the species having an external shell. The Testacea were divided into two suborders, Monothalamia and Polythalamia. This scheme showed a wider grasp of the subject than did that of d'Orbigny, but it had many obvious disadvantages. For example, by this arrangement, Orbulina and Lagena fall into one primary division, and Globigerina and Nodosaria in the other. On the basis of our present knowledge, such a condition is highly improbable.

Galloway (1933) points out that W. C. Williamson, in 1848 and again in 1858, advanced the idea that there is a great variation in all groups of foraminifera, and maintained that all efforts to classify them are futile because there were no characters on which one could depend. His idea that there was variation in all directions has had considerable influence on the classification of the foraminifera as used by the British workers, whose system has been based upon general structural similarities, and in which they attempted to use as few species, genera, and higher groups, as possible. The English also failed to see any evolution of foraminifera during geologic time.

In the years 1861-2, there appeared almost simultaneously two systems of classification having much in common. According to Brady (1884), the fact that Reuss and Carpenter should arrive independently at conclusions that are identical in their more important features, is some assurance that the results in either case "have some foundation in natural laws." It seems possible that these results might indicate also that both of these workers showed the same fundamental error; i.e., the lack of consideration of the phylogenetic relationships of the group. But such a lack of consideration is understandable since Darwin's "Origin of Species" was published in 1859, and was by no means universally accepted for many years after that.

These systems were based on (1) the number of chambers, whether one or many; (2) material and structure of the test; (3) arrangement of chambers and form of the test. Reuss, in a postscript to his paper, gave another outline, in which the monothalamous, chitinous forms were removed from the group, and classification was based on (1) absence or presence of mural pores; (2) material and structure of walls; (3) arrangement of chambers and form of tests.

Brady (1884) produced a classification which has been standard since that time. It was based on a combination of structural similarities, wall material and structure, number and arrangement of chambers, form of the test and character of the aperture. He made no attempt to make a genetic classification, or to use any one standard to distinguish between genera or families. He says, (p. 58) "The study of the Foraminifera as assemblages of forms grouped round a comparatively small number of central or typical species, as advocated by Carpenter and his colleagues, is, I am convinced, the only means of arriving at a correct understanding of the biological relations of the group."

According to Galloway (1933) Ludwig Rhumbler, in 1897, made the first classification based on a phylogenetic relationship. He interpreted the early ontogenetic stages as the form toward which the line was evolving, rather than as indicating the ancestral form, as agreed upon by most other naturalists.

Workers since then, Henri Douvillé, R. J. Schubert, and J. A. Cushman, have all improved on the earlier systems, particularly that of Brady, but they all make what is to Galloway a fundamental mistake, of assuming that calcareous forms are derived from arenaceous ancestors.

Galloway (1933) published a classification for the group that seems to take the desirable features from the systems of Schultze, Reuss, and Brady, and combines them with what seems to be a logical development of the phylogeny of the group. A comparison of his system with others in current use will be made later.

Morphology

The characteristic features of this group are the possession of reticulose pseudopodia and a test. The foraminifera in general are creeping forms, moving slowly by means of their pseudopodia; some are pelagic, such as Globigerina (pl. 3, fig. 1), and some, such as Cibicides (pl. 7, fig. 1), which is found on the stems and leaves of eelgrass, are sedentary, attaching themselves to some object.

If a species of this order were without a test, either as a form that never acquired it or as one having lost it secondarily, it would be placed in the Order Proteomyxa. Minchin (1912) suggests that it is probable that many of the large marine proteomyxa are allied to the true foraminifera, as forms either primitively or secondarily without a test. Rhumbler (1904) put the two groups in the section Reticulosa, and Galloway (1933) has followed the same plan.

The test is the hard structure of foraminifera, and is the feature of most interest to students of the order. It is neither a shell nor the wall of the cell, but actually a skeleton, because during the active life of the animal it is completely surrounded both inside and outside by protoplasm. In the test can be found all the characters used in taxonomy within the order, except for some forms in the family Lagynidae.

The test is composed of one or more chambers or locules. The first chamber formed is the proloculum. Adjoining chamber cavities are connected by an opening through a septum, whence the name Foraminifera, to possess foramina.

In the tests having more than a single chamber the apertures become internal, as a rule. One of the simplest arrangements of chambers, according to Cushman (1910-1916), is a linear series. Another very common plan of arrangement is a planospiral, as in Cornuspira (pl. 1, fig. 1). This may be varied by having the line of coiling in a spiral, and the whole test becoming trochoid, or coiled around an axis in a low spire. Such a test frequently becomes rotaloid, so that all chambers are visible on the dorsal side and only those of the last whorl on the ventral side, as in Trochammina (pl. 2, figs. 1-3). Another common arrangement is a biserial one, the chambers on opposite sides of the axis, as in Textularia. These plans or some modification of them are the fundamental arrangements for the chambers. Frequently more than one plan enters into the ontogenetic development of a species. The test may start with a coiled arrangement and develop a straight stage, or become uniserial after a triserial or biserial stage. The fact that there may be more than one distinct method of growth within one test seems to have a definite phylogenetic bearing on the families in which it appears.

The number of chambers varies from a few to a great many. The chambers are usually simple, that is, undivided, but in some of the higher forms they are divided into chamberlets, usually in free communication. Another characteristic modification in some genera is the development of labyrinthic structures inside the chambers. In general, this seems to be a mark of the culmination of certain lines in development or specialization, and many of the genera which developed such labyrinthic structures are now extinct (Galloway, 1933).

In most foraminifera the wall is perforate. These openings, either large or small, as well as the larger aperture, allow the fine protoplasmic threads access to the exterior.

The wall may be locally thickened, giving rise to a pattern, as is seen in Lagena (pl. 3, fig. 3) and Uvigerina (pl. 7, fig. 4). In the Orbulinidae a highly specialized character is found in the fine spines. These are outgrowths of the wall, and in these pelagic forms, according to Cushman (1933), may be organs of flotation, supporting the foraminifer in the water anywhere from a few feet above the substratum to the surface of the water.

The aperture varies greatly with the different forms. It may be simple and round, fissurine, straight or curved, or may be radiate, phialine, or virguline. There may be accessory apertural characters, as valves, teeth, or lips. The aperture may have an external neck, ectosolenian, or an internal neck, entosolenian. The aperture may be dendritic, cribrate, a line of pores or several lines, or closed by a perforate plate, a trematophore. In some forms there is no aperture.

External characters which have no apparent use are designated as ornamentation, such as striations, plications, costae, reticulations, granules, tubercles, knobs, spines, bosses, carinae, keels and limbations. They occur in all families.

The color of the empty tests is not a prominent feature. Some of the arenaceous forms have iron compounds in the cementing material, imparting to the test a reddish brown color. The sand grains also may give it color, as for example white coral particles or siliceous sands. In the chitinous test the usual yellowish-brown prevails. The secreted calcareous test is white when empty. An exception is the first chambers of Discorbis (pl. 6, fig. 3) which are a light brown. Cushman (1910-1916) suggests that when many species are alive there is probably more or less color which disappears when the test is empty. Fossil specimens are usually the color of the surrounding rock. The surface of living specimens is glossy or matt, and that of fossils usually dull.

The smallest foraminifer measured was 0.2 mm. in diameter, and the largest was about 1 mm. The average size was about 0.5 mm. Galloway (1933) cites Caveuxina and some of the Lagynidae as the smallest foraminifera, from 0.01 to 0.02 mm. in diameter.

Cushman (1933), in common with most of the previous workers, holds that the most primitive form of the test is that of the Astrorhizidae, where there is a central body with numerous irregular channels formed by material collected by the pseudopodia. After the single chamber, according to Cushman (1933), the next stage of development is the formation of an elongate tubular chamber, usually coiled around the proloculum. This may eventually be broken up into chambers, becoming more and more regular. In brief, Cushman's idea is that the primitive forms, except in a few groups, seem to have arisen from the coiled, tubular forms, the evidence of which is seen in the early stages of various primitive forms.

Galloway (1933), on the other hand, maintains that the most primitive form is a globular test, because (1) the proloculum of all forms which have a proloculum is globular, not tubular, and out of it develops other similar, globular chambers or a tube; (2) the spherical form is physically more simple than the cylinder; (3) the earliest foraminifer known, Cayeuxina, is made up of spheroidal chambers; (4) the admittedly most simple and most primitive foraminifera, the Lagynidae, are mostly globular, while the few tubular forms are clearly phylogerontic, or have become decadent as a race. There is no early ontogenetic tubular stage in any of the Rotaliidae, the Buliminidae, the Camerinidae and other families, as there should be if the view be correct that those families evolved from tubular ancestors.

According to Galloway (1933), most authorities since 1860 have assumed that the arenaceous or agglutinated test wall, next to the chitinous wall, is the original texture from which all other types of wall structure have been derived. Galloway claims that the arenaceous forms, particularly the Astrorhizidae, are not primitive, at least not ancestral to more complex forms, but are degenerate or specialized. He bases his claim on the following points: (1) the arenaceous forms do not occur first in the geologic column; they appear in the Silurian and do not become important until the Pennsylvanian, whereas the calcareous, non-arenaceous forms range from the pre-Cambrian, Cambrian and Ordovician onward; (2) most of the Astrorhizidae are found only in Recent deposits and are always rare; (3) they occur mostly in very deep water, indicating specialization for an unusual habitat; (4) the arenaceous forms are many times larger, on the average, than the calcareous, and large forms, among all forms of life, are more highly evolved than their smaller relatives; (5) the arenaceous forms show evidences of uncoiling, whereas if they were primitive they would show that coiled forms were derived from them; this they fail to do; (6) the arenaceous forms are mostly attached and irregular in form, indicating degeneracy, but not a primitive condition; (7) many calcareous forms, as in the Miliolidae and the Textulariidae, have calcareous walls in the early ontogenetic stage, and foreign particles are added in the later stages, showing that the calcareous texture came first; and (8) no known foraminifer has an arenaceous nepionic or neanic stage followed by a calcareous ephebic stage, as would be the case if the arenaceous wall developed into one secreted by the animal. The evidence all favors the conviction that the arenaceous forms were derived from similar chitinous and calcareous forms, and not the reverse.

Galloway (1933) has interpreted the phylogeny of the order and based his classification on these biologic principles and postulates:

1. Foraminifera have evolved in geologic time, and in conformity with biologic laws applying to other lines of organic evolution.

2. The biogenetic law applies to foraminifera just as it does to other organisms.

3. Chronogenesis holds as well for foraminifera as for any other group; earlier forms are ancestral forms when sufficient facts are known.

4. Development of form:

(a) Spheroidal---tubular---irregular

multilocular---tubular---irregular

irregular

(b) Simple---complex---specialized---degenerate

degenerate

degenerate

5. Evolution of wall structure:

Gelatinous---arenaceous

chitinous---arenaceous

granular---arenaceous

fibrous---arenaceous

alveolar---arenaceous (?)

hyaline---arenaceous

porcellaneous

arenaceous

6. The taxonomic values of the various structures in the order of their importance:

Family characters: Material of the walls, arrangement of chambers, number of chambers, character of the apertures.

Generic characters: Shapes of the tests, number and arrangement of septa, character of perforations, character, position and number of apertures, and particular material of the walls.

Specific characters: Ornamentation, size, number of chambers and small differences in any combination of characters, which seem to be constant.

Varietal characters: One small difference which does not occur in all the specimens of a species.

While Galloway directly refutes all previous workers, as represented by Cushman, and apparently is alone in his highly controversial presentation of the phylogeny of the order, particularly in connection with the arrangement of the chambers and structure of the test wall, his arguments seem entirely logical. He cites specific families and genera to confirm his points, whereas other workers merely generalize. For these reasons, Galloway's system of classification has been used in this problem.

Life History

The foraminifera reproduce in two ways, asexually and sexually. Galloway (1933) notes that Munier-Chalmas, in 1880, first discovered the two main forms in the life history, the megaspheric and microspheric. Lister (1906) explained this as due to alternation of generations. In general, the megaspheric form has a large proloculum in which the ancestral stages may be skipped, but the test is comparatively small and outnumbers the tests of the microspheric form up to 300 to 1. The proloculum of the microspheric form is small by comparison with the megaspheric and the ancestral stages are recapitulated to a greater or less degree, and the entire test usually is several times as large as that of the megaspheric form.

Only within the last few years has any conclusive work been done on the details of the life cycle of any species. According to Lister (1906), there is much accumulated knowledge on particular phases of the life history of many forms, but nothing is complete. Lister worked out the life cycle of Polystomella crispa, which according to Myers (1935a) is the first complete account of the life cycle of a dimorphic foraminifer in literature. The evidence presented in support of this life cycle, however, is nowhere verified by adequate cytological proof.

Figure 1 is a diagrammatic presentation of the life history of a typical foraminifer, illustrating the alternation of generations, sexual and asexual, and showing the morphological differences as demonstrated in the two types of tests.

The life cycle of Patellina corrugata (Myers, 1935) marks a definite advance in our knowledge of life processes in the foraminifera in that the cytological evidence presented is complete in every essential.

The work done by Myers on Patellina corrugata shows what is evidently a typical life cycle among the foraminifera.

There is an orderly succession of sexual and asexual generations. This alternation of generations results in a morphological difference in the calcareous tests, depending on the mode of origin. These dimorphic individuals are designated megaspheric and microspheric, and are the gamonts and agamonts, or the sexual and asexual generations, respectively.

Myers (1940), in his work on the life history of Discorbis, found that the gametes are triflagellated, and that their genetic relation-

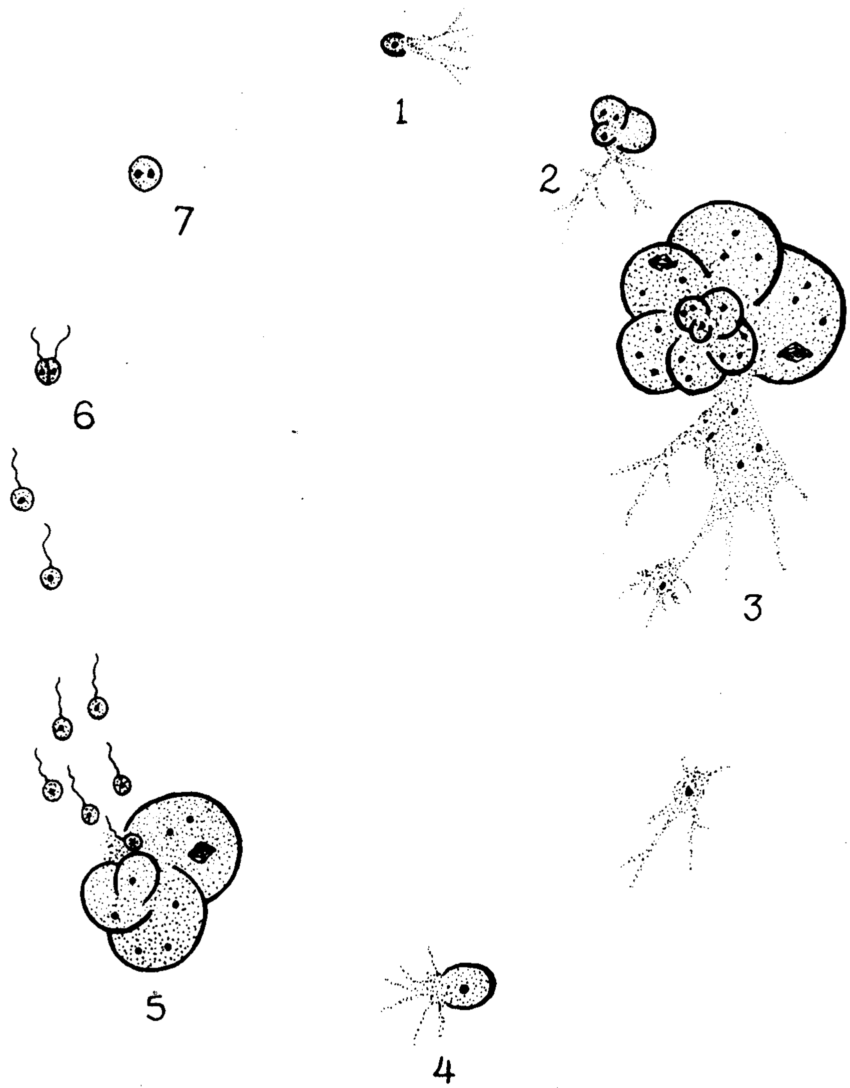

Figure 1

Diagram illustrating the life cycle of foraminifera.

1. Microspheric form with proloculum
2, 3. Multinucleate microspheric (asexual) generation
4. Megaspheric form with proloculum
5. Gamete formation
6, 7. Formation of zygote

ship is easily demonstrated, since gametogenesis, fertilization, and the development of two- and three-chambered multinucleate microspheric agamonts take place within the excavated tests of two or more mono-nucleate megaspheric gamonts associated in syzygy. This life cycle of Discorbis agrees in general with Lister's account of Polystomella crispa.

Plate 6, fig. 2 illustrates the manner in which the microspheric agamonts develop within the excavated tests of two individuals of Discorbis associated in syzygy.

Method

The samples of mud and sand from which the materials of this study were taken are all from the littoral zone on the coast of Oregon. The samples from which species were described are all from the Coos Bay area in Coos County. A few collections were made at the Tillamook county coast, but the specimens were used for comparative purposes only. No figures or descriptions are made from them.

The samples were collected at low tide when the most tide pools and algae-covered rocks are exposed. Sand and mud surrounding the holdfasts of algae and roots of eelgrass, together with the stems of the plants themselves, were collected. The plant material was removed after the whole mass had been washed vigorously in fresh water.

The samples were decanted to remove most of the fine mud and organic material. While this decanting process took considerably longer than the system of sieves of various mesh sizes recommended by Cushman

(1933), it seemed more efficient because it preserved a larger number of the more delicate tests. The remaining material was allowed to dry thoroughly. To remove the tests from the sand, carbon tetrachloride was poured over the dry material. The empty tests, along with bits of mollusk and crustacean shell and wood, floated to the surface of the heavy liquid. The tetrachloride was filtered from the floating material and the foraminifera picked out by means of a moistened sable brush.

The specimens were studied with the aid of a binocular and a compound microscope. A camera lucida was used for making the outlines of the figures. The specimens were mounted on black-backed cardboard slides with tragacanth gum, which is water soluble, and makes it possible to move the specimens quickly and easily with less danger of breaking the tests than if glue, balsam, or some similar substance were used.

KEY TO THE FAMILIES

Wall agglutinated

    Test spirally coiled with low spire . . . . . . .Trochamminidae

    Test spirally coiled with high spire. . . . . . .Ataxophragmiidae

Wall calcareous

    Wall imperforate, porcellaneous . . . . .Miliolidae

    Wall typically perforate, hyaline

        Aperture radiate . . . . .Nodosariidae

        Aperture not radiate

            Test rotaloid, at least in young

                Chambers closely appressed . . . .Rotaliidae

                Chambers loosely appressed . . . .Orbulinidae

            Test not rotaloid

                Test discoidal, typically plani-
                spiral . . . . .Nonionidae

                Test high-spired to uniserial

                    Aperture virguline. . . . . .Buliminidae

                    Aperture phialine . . . . . .Uvigerinidae

In order to reduce the number of references, the method of Cushman (1927) has been adopted of giving only the original reference, and then a reference to a recent work in which the synonymy is fairly complete, such as Bulletin 71 or 104 of the United States National Museum.

The descriptions of families and genera are mostly from Galloway. The plates are from original drawings.

FAMILY MILIOLIDAE d'Orbigny, 1839

Miliolidae d'Orbigny, Hist. Phys. Pol. Nat. Cuba, 1839, Foram., p. xxxix.

Tests free, rarely attached, typically spirally coiled with each chamber half a coil in length, longer in more primitive and shorter in specialized genera; walls calcareous, with chitinous base, imperforate, porcellaneous in appearance, sometimes covered with sand; aperture typically with a bifid teeth, sometimes simple or cribrate. In brackish water the test may be reduced to a transparent chitinous film, and in very deep water the wall may be only a siliceous film.--Mostly shallow, warm water, few in deep, cold water.--Carboniferous to Recent, forming beds of limestone in Cretaceous, Eocene and Oligocene.

Key to Subfamilies

Test planispiral in young stages . . . . .Cornuspirinae

Test irregular or unilocular . . . . .Nubeculariinae

Test milioline in young stages

    Milioline or embracing in adult . . . . .Miliolinae

    Planispiral or evolute in adult . . . . .Haueririnae

The subfamilies Cornuspirinae and Miliolinae are represented here.

Subfamily Cornuspirinae Reuss, 1861

Cornuspiridea Reuss, Sitz. k. k. Wiss. Wien., Math.-Naturw. Cl., vol. 44, pt. 1, 1861, p. 394.

Genus *Cornuspira* Schultze, 1854

Genotype (first species, designated by Cushman, 1928), *Cornuspira planorbis* Schultze, Organis. Polythal., 1854, p. 40, pl. 2, fig. 21. (Recent, coast of Mozambique.)

Test free, planispiral, composed of a proloculum followed by a long, round or flattened tube, enlarging gradually, sometimes with a few septa; wall porcellaneous, imperforate, smooth except for growth lines; aperture the open end of the tube, lunate or elongate, sometimes constricted with thickened lip. Diameter, up to 31 mm.--Strand down to 1900 fathoms.--Carboniferous to Recent.

Cornuspira sp.

Plate 1, figure 1

Test discoidal, tube enlarging very gradually, with flange extending toward proloculum; no septa; aperture the end of the tube, broadly crescentic. Diameter 0.47 mm. Rare in the sand and mud surrounding the holdfasts of algae.

Subfamily Miliolinae Reuss, 1861

Miliolidea Reuss, Sitz. k. Ak. Wiss. Wien, Math.--Naturw. Cl., vol. 44, pt. 1, 1861, p. 374.

Genus Quinqueloculina d'Orbigny, 1826

Quinqueloculina d'Orbigny, Ann. Sci. Nat., vol. 7, 1826, p. 303.--Cushman, U. S. Nat. Mus. Bull. 71, pt. 6, 1917, p. 42.

Test free; the nucleoconch in the microspheric form consists of an oval proloculum and one or two chambers a coil or less in length, and in the megaspheric form of a larger proloculum and one chamber less than one coil in length; the nucleoconch in both and microspheric and megaspheric forms is followed by chambers one-half coil in length, wound lengthwise about an elongate axis, and spirally transverse to the elongate axis where successive chambers are 144° apart, so that five chambers make two complete whorls and every fifth chamber is radially superimposed on another, adjacent chambers being 72° apart; four chambers are visible from one side of the test and three from the other; wall porcellaneous, smooth or variously ornamented or covered with sand grains, but with very little thickening tissue inside; aperture flush with the surface or with neck, round or elongate, with plate-like or bifid tooth; the aperture alternates from end to end of the test; length up to 3.75 mm., average about 1 mm.--Warm seas, shallow to medium depth, and down to 3000 fathoms.--Jurassic to Recent, abundant Eocene to Recent.

Quinqueloculina sp.

Plate 1, figure 2

Test smooth, entirely calcareous, porcellaneous, compressed; aperture with a rim and protruding bifid teeth. Length 0.89 mm. Fairly common in the sand and mud around plants.

Quinqueloculina sp.

Plate 1, figure 3

Test slightly irregular transversely, porcellaneous or chitinous, rounded in contour; aperture large, with a small rim, entirely toothless. Length 0.86 mm. Fairly common at stations in mud and sand surrounding plants.

This species, while exhibiting most of the characters of the genus, lacks the apertural tooth that is characteristic. However, in general the species seems to fit here.

Quinqueloculina sp.

Plate 1, figure 4

Test smooth, thin, porcellaneous or occasionally chitinous; aperture without rim, with bifid tooth. Length 0.55 mm. Common in sand and mud around algae; in protected bay areas.

FAMILY TROCHAMMINIDAE Schwager, 1877

Trochamminidae Schwager, Boll. R. Com. Geol. Italia, vol. 8, 1877, p. 21.

Test free or attached, rotaloid or nautiloid throughout, or spiral in the young and later evolute or embracing or irregular; chambers numerous, not labyrinthic inside; wall agglutinated, arenaceous or spiculose, or chitinous with included grains; aperture single or multiple, at the base of the septum, on the septum or terminal, or absent.--Shallow, warm water, or deep, cold water, few in temperate water of medium depth; one in continental salt water.--Pennsylvanian to Jurassic, rare; Cretaceous common; Tertiary, rare; Recent, not common.

Key to Subfamilies

Test rotaloid or trochoid, at least in young stages. . Trochammininae

Test nautiloid, at least in young stages . . . . Placopsilininae

Subfamily Trochammininae Brady, 1884

Trochammininae Brady, Rep. Voy. Challenger, Zool., vol. 9, 1884, p. 66.

Genus Trochammina Parker and Jones, 1859

Trochammina Parker and Jones, Ann. Mag. Nat. Hist., ser. 3, vol. 4, 1859, p. 347.--Cushman, U. S. Nat. Mus. Bull. 104, pt. 2, 1920, p. 72.

Test free, rarely attached by the ventral side, rotaloid; spire depressed, visible from the dorsal side, only the last whorl visible from the ventral side; chambers rather closely appressed, 4 to 8 in the last whorl; wall finely to coarsely arenaceous with much cement; aperture a curved slit at the base of the last chamber on the ventral side between umbilicus and periphery. Diameter up to 2 mm.--Shallow to deep, cold water.--Carboniferous, Jurassic to Recent.

Trochammina sp.

Plate 2, figure 1

Test finely arenaceous with much cement, smooth, reddish brown in color; chambers rather inflated, 4-5 in last whorl; periphery rounded; sutures depressed; umbilicus slightly concave, with rounded flat lobes extending about one-fourth the way out on the sutures; aperture a small curved slit along base of last chamber on ventral side. Diameter 0.35 mm., breadth 0.18 mm. Not too common in sand and mud among holdfasts of algae.

Trochammina sp.

Plate 2, figure 2

Test finely arenaceous and smooth; cement reddish brown; chambers somewhat appressed, 5-6 in last whorl; sutures not much depressed; periphery only slightly rounded; dorsal and ventral sides almost flat; umbilicus small, concave; aperture a narrow slit along base of last chamber on ventral side. Diameter 0.53 mm., breadth 0.15 mm. Fairly common in sand and mud around algae.

Trochammina inflata Montagu, 1808

Plate 2, figure 3

Nautilus inflatus Montagu, 1808, Test. Brit., Supp., p. 81, xviii. fig. 3.

Trochammina inflata Carpenter, 1862, Introd. Foram., p. 141, pl. xi, fig. 5.

Test free, trochoid, all the chambers visible on the dorsal side, only the last whorl on the ventral, consisting of about three whorls, with 5-6 in the last one; sutures distinct, wall finely arenaceous, with much cement; ventral face somewhat concave, umbilicus depressed; peripheral margin lobulated; aperture small, arched, a slit on the inner periphery of the septal face, somewhat ventral. Color pale brown, the small primary chambers a dark brown. Diameter 0.45 mm. One specimen of this species was found in a tide pool at Sunset Bay. Three were removed from South slough, in Coos bay, from an alga, in brackish water.

Subfamily Placopsilininae Cushman, 1927.

Placopsilininae Cushman, Contrib. Cushman Lab. Foram. Res., vol. 3, 1927, p. 41.

Genus Haplophragmoides Cushman, 1910

Haplophragmoides Cushman, U. S. Nat. Mus. Bull. 71, pt. 1, 1910, p. 99, fig. 149; Bull. 104, pt. 2, 1920, p. 37.

Test free, planispiral; whorls partially involute; sutures depressed; chambers inflated, not labyrinthic; wall finely to coarsely arenaceous, with varying amounts of cement in the different species; aperture a semicircular slit, at or near the inner edge of the last chamber, on or near the inner periphery. Diameter, up to 2.5 mm.--Shallow to deep, cold water, 27-3590 fathoms.--Carboniferous, Jurassic to Recent.

<u>Haplophragmoides</u> sp.

Plate 2, figure 4

Test roughly arenaceous; cementing material reddish brown; chambers inflated, enlarging, 7 in last coil; sutures not well marked; umbilicus filled; aperture a semicircular slit at base of septal face. Diameter 0.83 mm., breadth 0.50 mm. One specimen of this species was found in the sand among the holdfasts of algae.

<u>Haplophragmoides</u> sp.

Plate 2, figure 5

Test nautiloid, smooth, finely arenaceous with much reddish-brown cement; chambers inflated, 7 in last coil; sutures well defined, depressed; umbilicus concave; aperture a crescent near the base of the last septal face. Diameter 0.54 mm., breadth 0.09 mm. Rare in the mud and sand around holdfasts of algae.

FAMILY ORBULINIDAE Schultze, 1854

Orbulinida Schultze, Organis. Polythal., 1854, p. 52.

Globigerinida Carpenter, Introd. Foram., 1862, p. 171.

Tests free, essentially a polythalamous test composed of inflated chambers; trochoid or planispiral in the young and variously modified in the adult to involute, globular or slightly evolute; chambers globular, generally loosely appressed, each retaining its individuality, few as compared with Rotaliidae; walls calcareous, usually thin and hyaline; with large, medium or small perforations; surface minutely spinose or smooth; aperture single or several or none, or a row of pores on the sutures, generally in the umbilicus, sometimes on the inner periphery and also on the top of the spire, simple or sometimes with outer, raised border.--Narly all pelagic.--Pennsylvanian (?); Jurassic, rare; Cretaceous to Recent, abundant.

Genus Globigerina d'Orbigny, 1826

Genotype (designated by Parker, Jones and Brady, 1865), Globigerina bulloides d'Orbigny, Ann. Sci. Nat., vol. 7, 1826, p. 277, Model No. 76.--Cushman, U. S. Nat. Mus. Bull. 71, pt. 4, 1914, p. 5; Bull. 104, pt. 5, 1924, p. 5.

Test free, trochoid or trochoid in the young of the microspheric stage and becoming planispiral in later stages; chambers moderate in number (2-20), globular, not closely appressed but more appressed in the young of the microspheric form; wall calcareous, hyaline, coarsely or finely perforate; surface reticulate or papillate, with pores at the base of the depressions, or smooth in the earlier species; aperture large, a narrow slit to high arch, opening into the umbilicus or between umbilicus and periphery, frequently with accessory apertures in the sutures on the dorsal side of the test; ornamentation practically lacking, except for minute spines in well-preserved, Recent specimens. Diameter, up to 2 mm., average about 0.5 mm.--Pelagic, all oceans, and benthonic; most abundant in warm water.--Pennsylvanian (?), Middle Jurassic to Recent.

Globigerina sp.

Plate 3, figure 1

Test free, hyaline; chambers globular, about 5 in last whorl; wall ornamented with minute tubercles, perforate; aperture large, in umbilicus at base of last-formed chamber. Diameter 0.22 mm. Not common in mud and sand around holdfasts of algae.

FAMILY ATAXOPHRAGMIIDAE Schwager, 1877

Ataxophragmidea Schwager, Boll. R. Com. Geol. Italia, vol. 8, 1877, p. 22

Tests free, rarely attached, trochoid spiral, conical, pyramidal or cylindrical, with three chambers to a whorl in the more primitive genera, evolving toward looser coiling with five or six chambers to a whorl, and toward reduction in the number of chambers in a whorl to two and finally becoming uniserial; walls finely or coarsely arenaceous; aperture a slit at the base of the septum, or a virguline or cribrate aperture in the septum, or terminal, single and round.--Shallow to deep water, mostly in depths of a few hundred feet.--Lower Jurassic to Recent, well represented in Recent seas.

Key to Subfamilies

Test trocheid, 3-6 chambers to a whorl . . . . .Ataxophragmiinae

Test elongate, triserial to uniserial. . . . . .Verneuilininae

Only the subfamily Verneuilininae is represented here.

Subfamily Verneuilininae Cushman, 1911

Verneuilininae Cushman, U. S. Nat. Mus. Bull. 71, pt. 2, 1911, p. 52.

Genus Verneuilina d'Orbigny, 1840

Genotype Verneuilina tricarinata d'Orbigny, Mém. Soc. Géol. France, ser. 1, vol. 4, p. 38, pl. 4, figs. 3, 4.--Cushman, U. S. Nat. Mus.

Bull. 104, pt. 3, 1922, p. 54.

Test free, high-spired, typically pyramidal, usually conical; chambers three to a whorl, closely appressed or inflated; wall finely or coarsely arenaceous; aperture a slit at the base of the last chamber, nearly transverse to the axis of the test, with or without raised rim. Length, up to 4 mm.--Mostly in shallow, warm water, but occuring down to nearly 3000 fathoms.--Lower Cretaceous to Recent.

Verneuilina polystropha Reuss, 1845

Plate 3, figure 2

<u>Bulimina polystropha</u> Reuss, 1845, Verstein. Böhm. Kreid., pt. 2, p. 109, pl. xxiv. fig. 53.

<u>Verneuilina polystropha</u> Brady, 1878, Ann. and Mag. Nat. Hist., ser. 5, vol. 1, p. 436, pl. xx.

Test free, high-spired, somewhat roughly arenaceous but with much cement, light brown in color; chambers inflated, triserial throughout; aperture a wide slit at base of last septum, without rim. Length 0.38 mm. Fairly common in mud and sand surrounding the holdfasts of algae.

FAMILY NODOSARIIDAE Schultze, 1854

Nodosarida Schultze, Organis. Polythal., 1854, p. 53.

Tests free, rarely attached, polythalamous, or monothalamous; chambers arranged in a planispiral coil and embracing to umbilicus in the most primitive forms, the derived forms uncoiling more and more until a straight form is produced, with a tendency to embrace the earlier chambers or to become separated, and becoming separate and monothalamous in the phylogerontic stage; wall calcareous, hyaline, very finely perforate; surface smooth or variously ornamented; aperture on the outer edge of the terminal septum or terminal and central in the higher forms, slitlike in the Robulinae, or ectosolenian, the aperture at the end of a long neck outside the test, or entosolenian, the neck inside the chamber, simple or with a phialine lip.--Marine, benthonic, warm to cold, shallow to deep water and down to over 3000 fathoms, more common in temperate and cold water.--Triassic to Recent. Paleozoic isomorphs belong to the Endothyridae and the Nodosinellidae.

Key to Subfamilies

Aperture round

Test compressed throughout . . . . Frondiculariinae

Test round in adult stages . . . . Nodosariinae

Aperture fissurine. Robulinae

The subfamilies Nodosariinae and Robulinae are represented here.

Subfamily Nodosariinae Reuss, 1861

Nodosaridea Reuss, Sitz. K. Ak. Wiss. Wien, vol. 44, pt. 1, 1861, p. 395.

Genus *Lagena* Walker and Boys, 1784

Serpula (Lagena) Walker and Boys, in Walker, Testacea Minuta, etc., 1784, p. 2, pl. 1, figs. 6-9. Genera named mononominally and Linnean, species not named binominally but binary. (See Opinion 20, Int. Com. Zool. Nomen.)

Lagena (part) Cushman, U. S. Nat. Mus. Bull. 104, pt. 4, 1923, p. 3.

Test free, unilocular except in retarded or monstrous specimens, in which there may be two or more chambers; wall hyaline, very finely perforate; surface variously ornamented; aperture ectosolenian, round, with an elongate, external neck which may have a phialine lip. Length 0.2 to 1 mm., average, about 0.5 mm.--Mostly in cool to cold, shallow to deep water.--Jurassic to Recent.

Lagena squamosa Montagu, 1803

Plate 3, figure 3

Vermiculum squamosum Montagu, 1803, Test. Brit. p. 526, pl. xiv, fig. 2.

Lagena squamosa Jones, Parker, and Brady, 1866, Monogr. Foram. Crag. p. 39, pl. iv, fig. 7.

Test hyaline, ornamented with longitudinal ridges joined at regular intervals with upcurving transverse ridges of equal height; aperture round with short neck without phialine lip. Length 0.26 mm. Rather rare in the sand and mud around holdfasts of algae.

Subfamily Robulinae Galloway, 1933

Robulinae Galloway, Manual of foraminifera, Principia press, Bloomington, Ind., 1933, p. 250.

Genus Robulus Montfort, 1808

Genoholotype, Robulus cultratus Montfort, Conch. Syst., vol. 1, 1808, p. 215, figs.

Test free, nautiloid, lenticular, thick or thin, carinate or keeled; chambers numerous, embracing to umbilicus usually; wall hyaline, very finely perforate, smooth or ornamented; aperture a triangular or elongate slit just below outer point of last chamber; last septum frequently concave. Length, up to 4 mm.--Widely distributed.--Jurassic to Recent, mostly Cretaceous and Lower Tertiary.

<u>Robulus</u> sp.

Plate 3, figure 4

Test nautiloid, lenticular, subequally concave between umbilicus and periphery; chambers embracing to umbilicus, 8 in last coil, narrow and arched; apertural face concave; aperture a slit slightly below peripheral end of wall. Diameter 0.47 mm. Fairly common in mud and sand around holdfasts of algae.

FAMILY NONIONIDAE Reuss, 1860

Nonioninideae Reuss, Sitz. k. Ak. Wiss. Wien, Math.-Naturw. C., vol. 40, 1860, p. 221.

Tests free or attached to plants, mostly nautiloid, the higher forms rotaloid; chambers numerous, closely appressed; walls calcareous, hyaline, finely perforate, with or without canal system which opens at the surface as a row of pores along the septal depressions; aperture a curved slit or a row of pores at the base of the septal face, or one or many pores on the septal face.--Shallow or deep water.--Jurassic to Recent.

Key to Subfamilies

Sutures without pores . . . . Nonioninae

Sutures with large pores. . . . . Elphidiinae

Subfamily Nonioninae Schultze, 1854

Nonionida Schultze, Organis. Polythal., 1854, p. 53.

Genus <u>Nonion</u> Montfort, 1808

<u>Nonion</u> Montfort, Conch. Syst., vol. 1, 1808, p. 210, fig.

<u>Nonionina</u> d'Orbigny, Ann. Sci. Nat., vol. 7, 1826, p. 293.

Test free, nautiloid, involute, biumbilicate, round on the back; chambers numerous, 8-12 in the last whorl, closely appressed; wall calcareous; hyaline, finely but distinctly perforate, smooth, sometimes with umbilical thickening; aperture a curved slit at the base of the last septal face on the inner periphery. Diameter, up to 0.8 mm. Benthonic, in all depths of the sea.--Jurassic to Recent.

Nonion stelligerum Cushman, 1930

Plate 3, figure 5

Nonionina stelligera d'Orbigny, in Barker-Webb and Berthelot, Hist. Nat. Iles Canaries, vol. 2, pt. 2, 1839, "Foraminifères," p. 128, pl. 3, figs. 1, 2 (N. stellifera on plate).

Nonion stelligerum Cushman, Bull. 104, U. S. Nat. Mus., pt. 7, 1930, p. 7, pl. 2, figs. 8-12, pl. 3, figs. 1-3.

Test planispiral, completely involute, compressed, periphery rounded, composed of 8 chambers in the last-formed coil; chambers distinct, toward the umbilical end with a secondary filling, making a stellate ornamentation in the umbilical areas; wall smooth, very finely perforate; aperture a narrow opening at the base of the apertural face, next to the preceding coil. Length 0.43 mm.; breadth 0.08 mm. One specimen of this species was found in a tide pool at Sunset bay.

Nonion sp.

Plate 3, figure 6

Test bisymmetrical; chambers 10-12 in last coil; sutures slightly depressed; wall smooth; umbilicus depressed; aperture a narrow slit at base of last septal face. Diameter 0.33 mm. Rather rare in the mud and sand surrounding the holdfasts of algae.

Genus **Nonionella** Cushman, 1926

Genoholotype, **Nonionella miocenica** Cushman, Contrib. Cushman Lab. Foram. Res., vol. 2, pt. 3, 1926, p. 64.

Test free, planispiral in young stages, rotaloid in later stages, the later chambers extending progressively farther into the umbilicus on the ventral side. Wall calcareous, finely perforate, smooth; aperture a narrow slit at the base of the last septum, on the inner periphery and extending toward the umbilical region. Diameter, about 0.5 mm.--Mostly in cold water.--Cretaceous (?), Eocene to Recent.

Nonionella sp.

Plate 4, figure 1

Test rotaloid, smooth, calcareous; chambers 8 in the last whorl; sutures not depressed. Length 0.28 mm. This species was fairly common in the sand and mud around holdfasts of algae.

Subfamily Elphidiinae Galloway, 1933

Elphidiinae Galloway, Manual of foraminifera, Principia Press, Bloomington, Ind., 1933, p. 269.

Genus **Elphidium** Montfort, 1808

Elphidium Montfort, Conch. Syst., vol. 1, 1808, p. 14.--Cushman, Contrib. Cushman Lab. Foram. Res., vol. 3, pt. 1, 1927, p. 49.

Test free, planispiral, equilateral, lenticular or nautiliform; chambers numerous, closely appressed, embracing to the umbilical region, which frequently is filled with secondary tissue; wall calcareous, finely perforate, with canal system which opens at the umbilicus and along the sutures by a single or double row of pores, frequently with a regular series of ridges connecting or crossing the sutures externally; aperture a curved slit or row of pores at the base of the septal face on the inner periphery, or numerous pores on the septal face. Diameter, up to over 4 mm.--Cold to warm, shallow water.--Jurassic to Recent, more common from Miocene to Recent.

<u>Elphidium</u> sp.

Plate 4, figure 2

Test lenticular; chambers in last coil 15, closely appressed, embracing to umbilical region which has no secondary tissue; canal system opens along sutures by a double row of pores; sutures without transverse ridges; aperture a row of pores at base of septal face on the inner periphery; septal face flat, perforate. Diameter 1 mm. Common in sand and mud around holdfasts of algae.

<u>Elphidium</u> sp.

Plate 4, figure 3

Test nautiliform, hyaline, coarsely perforate; slightly inflated, chambers 8 in last coil; sutures distinct, slightly raised, without transverse processes; canal system opens along sutures by a single row of pores; aperture a narrow slit at base of the septal face on the inner periphery; septal face convex. Diameter o.45 mm.; breadth 0.18 mm. Fairly common in mud and sand around holdfasts of algae.

<u>Elphidium translucens</u> Natland, 1938

Plate 4, figure 4

Test lenticular, hyaline and glossy; chambers appressed, 9 in last coil; sutures depressed, transverse ridges slightly developed; canal system opens along sutures by a single row of pores; septal face flat; aperture a series of pores at base of the septal face on the inner periphery. Diameter 0.34 mm.; breadth 0.15 mm. Common in sand and mud surrounding the holdfasts of algae.

FAMILY ROTALIIDAE Reuss, 1860

Rotalidea Reuss, Sitz, k. Ak. Wiss, Wien, Math.-Naturw. Cl., vol. 40, 1860, p. 221.

Test free or attached to plants, typically consisting of many chambers coiled in a low spire so that all chambers are visible on the dorsal side and only those of the last whorl on the ventral side (rotaloid), or derived from a rotaloid ancestor and not far evolved from it; chambers numerous, suppressed in the regular form of the test; wall calcareous, hyaline, finely or coarsely perforate; aperture typically a slit at the base of the last septal face, varying in position and modified in the higher and in the degenerate genera. Size 0.5-5 mm. in diameter.--Warm to cold, shallow to deep water, most common in warm, shallow water; some species pelagic.--Triassic rare, Jurassic to Recent common.

Key to Subfamilies

Wall finely perforate . . . . .Rotaliinae

Wall coarsely to medium perforate

Aperture ventral or absent . . . . .Discorbinae

Aperture on periphery

Adult test spiral or irregular . . . . . . .Cibicidinae

Adult chambers annularly arranged. . . . . .Planorbulininae

Subfamily Rotaliinae Schultze, 1854

Rotalida Schultze, Organis. Polythal., 1854, p. 52.

Genus Rotalia Lamarck, 1804

Genotype (first species, designated by Galloway and Wissler, 1927),

Rotalia trochadiformis Lamarck, Ann. Mus., Paris, vol. 5, 1804, p. 184; vol. 8, 1806, pl. 62, fig. 8.--Cushman, U. S. Nat. Mus. Bull. 71, pt. 5, 1915, p. 66.

Test free, trochoid or unequally biconvex, spiral, all the whorls visible on the dorsal side, only the last whorl visible on the ventral side (rotaloid); ventral side with umbo or small umbilicus; chambers numerous, closely appressed, enlarging gradually; wall very finely perforate; surface smooth or ornamented with an exogenous deposit; tubercles, limbate sutures, bosses or costae; aperture a slit at the base of the last chamber near the periphery, or an arched slit midway between umbo and periphery. The larger species may have double septa and interseptal canals. Diameter 0.4 to 2 mm.--Warm to cold, shallow to deep water.--Triassic to Recent common.

Rotalia sp.

Plate 5, figure 1

Test unequally biconvex, deeper on ventral side; ventral side with tuberculate umbo; chambers appressed, 7 in last whorl; wall perforate, hyaline; aperture a slit between umbo and periphery. Diameter 0.39 mm. Rare in sand and mud among holdfasts of algae.

Rotalia sp.

Plate 5, figure 2

Test equally biconvex; ventral side with large tuberculate umbo; chambers appressed, 7-9 in last whorl; periphery carinate with milled edge; wall calcareous; aperture a slit near the periphery. Diameter 0.86 mm. One of the commonest species in sand around holdfasts of algae.

Rotalia sp.

Plate 5, figure 3

Test unequally biconvex, the dorsal side deeper than the ventral; ventral side with depressed umbilicus, the 8-9 chambers in the last whorl clearly marked; periphery rounded; wall hyaline, finely perforate; aperture a curved slit near periphery. Diameter 0.38 mm. Fairly common in the sand around holdfasts of algae.

Rotalia sp.

Plate 5, figure 4

Test equally biconvex, hyaline, perforate; umbo on ventral side tuberculate; chambers much appressed, 7-8 in last whorl; periphery carinate; aperture a slit at base of septal face, midway between periphery and umbilicus. Diameter 0.50 mm. Common in mud and sand surrounding holdfasts of algae.

Subfamily Discorbinae Cushman, 1927

Discorbisinae Cushman, Contrib. Cushman Lab. Foram. Res., vol. 3, pt. 1, 1927, p. 75.

Genus *Discorbis* Lamarck, 1804

Genotype (monotypic), *Discorbis vesicularis* Lamarck, Ann. Mus., vol. 5, 1804, p. 183; vol. 8, 1806, p. 387, pl. 62, fig. 7. (Middle Eocene, Grignon, Paris Basin.)

Discorbis Cushman, U. S. Nat. Mus. Bull. 71, pt. 5, 1915, p. 10; Contrib. Cushman Lab. Foram. Res., vol. 3, pt. 2, 1927, p. 123, pl. 24, fig. 1, topotype.

Test free or attached to organisms by the ventral (apertural) side, rotaloid, dorsal side more convex and showing the spire, only the last whorl visible on the ventral side; chambers numerous, globular or closely appressed, enlarging rapidly, the last chamber frequently constituting a third or more of the ventral side; sutures depressed or limbate; wall generally smooth, hyaline, medium to coarsely perforate aperture at the base of the last chamber, slitlike, widest in or near the umbilicus and extending part way to the periphery, with or without valvular lip. Diameter 0.25 to 1 mm.--Mostly shallow water, some down to 1300 fathoms. --Lower Jurassic to Recent.

Discorbis sp.

Plate 6, figures 1 and 2

Test planoconvex, the ventral side flat or slightly concave; periphery rounded; umbilicus depressed or filled with shell material; chambers appressed, 6-8 in the last whorl; aperture near umbilicus. Diameter 0.40 to 0.65 mm. One of the commoner species in the sand and mud around algae holdfasts. A large proportion of tests were found in syzygy, the ventral sides joined tightly together. Some of them contained 1- to 3-chambered young inside the excavated tests (fig. 2).

Discorbis sp.

Plate 6, figure 3

Test planoconvex, attached by ventral side; tuberculate umbilicus; chambers appressed, 5 in last whorl; wall hyaline, coarsely perforate; the initial one and one-half whorls brown in color; aperture at base of last chamber, slitlike. Diameter 0.32 mm. Common on eelgrass and algae.

Discorbis parisiensis d'Orbigny, 1826

Plate 6, figure 4

Rosalina parisiensis d'Orbigny, 1826, Ann. Sci. Nat., vol. vii, p. 271, No. 1;--Model No. 38.

Discorbis parisiensis Berthelin, 1878, Foram. de Bourgneuf et Pornichet, p. 40, No. 65.

Test planoconvex, rotaloid, the last whorl only visible on the ventral side, hyaline, with greenish color; umbo large-tuberculate; the ventral side covered with rows of fine tubercles; aperture a slit at base of last chamber on ventral side. Diameter 0.51 mm. Rather rare in mud and sand around algae.

Subfamily Cibicidinae Galloway 1933

Cibicidinae Galloway, Manual of foraminifera, Principia Press, Bloomington, Ind., 1933, p. 290.

Genus *Cibicides* Montfort, 1808

Genoholotype, *Cibicides refulgens* Montfort, Conch, Syst., vol. 1, 1808, p. 122, text fig. (Recent, Adriatic.)

Test free or attached to plants by the dorsal side, rotaloid, spire visible on the dorsal side, only the last wherl visible on the ventral side; ventral side usually the more convex, even conical, and umbilicate, dorsal side usually flat; chambers numerous, closely appressed, all alike or the last one much the largest; wall hyaline, coarsely perforate, smooth or with limbate sutures or secondary thickening; aperture a curved slit at the base of the last chamber, on the inner periphery, extending toward the umbilicus on the ventral side, and also continuing on the dorsal side for a short distance along the suture line between the last two whorls. Diameter up to 1.5 mm.--Shallow water to nearly 3000 fathoms.--Triassic to Recent.

<u>Cibicides</u> sp.

Plate 7, figure 1

Test attached to plant by dorsal side, planoconvex, the dorsal side flat except for the much inflated last chamber; wall hyaline, coarsely perforate, smooth; chambers 7 in last whorl. Diameter 0.43 mm. Common on leaves and stems of <u>Phyllospadix</u> and <u>Zostera</u>.

Subfamily Planorbulininae Galloway 1933

Planorbulininae Galloway, Manual of foraminifera, Principia press, Bloomington, Ind., 1933, p. 297.

Genus <u>Planorbulina</u> d'Orbigny, 1826

Genotype (designated by Cushman, 1915), <u>Planorbulina</u> <u>mediterraneanensis</u> d'Orbigny, Ann. Sci. Nat., vol. 7, 1826, p. 280, pl. 14, figs. 4-6, Model No. 79. (Recent, Mediterranean.)

Test attached to plants, compressed, discoidal; chambers numerous, visible from either side, planispiral or annularly arranged, wall hyaline, coarsely perforate; aperture in early portion a slit on inner base of chamber, in later portion of test a round or oval opening at one or both ends of each chamber, on the periphery. Diameter up to 3 mm.--Shallow, warm water, and down to 1125 fathoms.--Eocene to Recent.

<u>Planorbulina</u> sp.

Plate 7, figure 2

Test an irregular disk, compressed, shaped to substratum; chambers annularly arranged; primary chambers on dorsal (attached) side dark brown in color; apertures irregular in arrangement; diameter 0.85 mm. One specimen of this species was found in a tide pool.

FAMILY BULIMINIDAE Jones, 1876

Buliminida Jones, Monthly Micr. Jour., vol. 15, 1876, p. 90.

Tests free, conical, high spired, with three chambers to a whorl, and evolving into forms with more than three chambers to a whorl, or into biserial or uniserial forms; chambers numerous, globular or closely appressed; wall calcareous, hyaline, finely perforate, generally smooth, sometimes striate, costate or spinose; aperture a curved slit at the base of the last chamber, or aperture double, or multiple, or single and terminal, but more commonly a comma-shaped (virguline) opening extending nearly vertically up into the last septal face, generally simple.--Shallow to deep water.--Triassic to Recent.

Key to Subfamilies

Aperture transverse to axis of test, or double or cribrate. Turrilininae
Aperture virguline, parallel to axis of test, or round. . . Bulimininae

Only the subfamily Buliminlnae is represented here.

Subfamily Bulimininae Brady, 1884

Bulimininae Brady, Rep. Voy. Challenger, Zool., vol. 9, 1884, p. 68.

Genus Buliminella Cushman, 1911

Genoholotype, Buliminella elegantissima (d'Orbigny)=Bulimina elegantissima d'Orbigny, Voy. Amér. Mérid., vol. 5, pt. 5, 1839, p. 51, pl. 7, figs. 13, 14. (Recent, west of South America.)

Test free, elongate, tapering, coiled on a curved axis, tending to become involute in the more specialized species; chambers numerous, three or more to a coil, closely appressed, longer vertically than wide; wall calcareous, hyaline, finely perforate, smooth or slightly striate; aperture comma-shaped, nearly vertical, extending from the last suture up into the last septal face, and tending to be in the incipient umbilicus of the curved test. Length, 1 mm. or less.—Very shallow to 1525 fathoms, averaging about 400 fathoms.—Lower Cretaceous to Recent.

Buliminella sp.

Plate 7, figure 3

Test hyaline, very finely perforate, smooth; chambers closely appressed, 7-10 in a coil; aperture in a depression. Length 0.30 mm. Rather rare in the sand and mud around the holdfasts of algae.

FAMILY UVIGERINIDAE Galloway and Wissler, 1927

Uvigerinidae Galloway and Wissler, Jour. Pal., vol. 1, 1927, p. 74.

Tests free, polythalamous; chambers coiled in a high spire, three chambers to a whorl in the primitive forms, evolving into triserial plus biserial, triserial plus uniserial, biserial plus uniserial, and uniserial in the most highly evolved forms; wall calcareous, finely perforate, smooth, plicate, striate, costate or spinose, aperture terminal, with peristome, or with neck with or without a thickened lip. The family develops in two main directions, (1) to subcylindrical forms, and (2) to trihedral, prismatic forms.--Mostly shallow water, warm or cold.--Jurassic to Recent, more common from Miocene to Recent.

Key to Subfamilies

Test round in section . . . . Uvigerininae

Test triangular in section. . . . . Angulogerininae

Subfamily Uvigerininae Cushman, 1913

Uvigerininae Cushman, U. S. Nat. Mus. Bull. 71, pt. 3, 1913, p. 91.

Genus *Uvigerina* d'Orbigny, 1826

Genotype (first species figured, designated by Cushman, 1931), *Uvigerina pigmea* d'Orbigny, Ann. Sci. Nat., vol. 7, 1826, p. 268, pl. 12, fig. 8; Model No. 67, 1826.--Cushman, U. S. Nat. Mus. Bull. 104, pt. 4, 1923, p. 160.

Test free, conical, subcylindrical or fusiform, round or flattened in cross-section, high-spired, triserial, rarely biserial, becoming less regular toward the final chamber; chambers numerous, somewhat inflated, more closely appressed at the initial end; wall calcareous, hyaline, very finely perforate, smooth, plicate, striate, spinose, or some combination of two or more of these forms of ornamentation, the ornamentation tending to break up or be lost toward the apertural end; aperture terminal, a small tube usually with a phialine lip. Length up to 1 mm. or more.--Shallow water and down to 2600 fathoms.--Upper Cretaceous to Recent, most common from Miocene to Recent.

Uvigerina selseyensis Heron-Allen and Earland, 1909

Plate 7, figure 4

Uvigerina selseyensis Heron-Allen and Earland, Journ. Roy. Micro. Soc., 1909, p. 437, pl. 18, figs. 1-3.

Test subovate, broadest toward the apertural end, chambers numerous, early ones rotund, triserially arranged, later ones more or less trihedral, more loosely arranged, triserial throughout; walls costate, angular; aperture with a short broad neck. Length 0.30 mm. One specimen of this species was found in a tide pool.

Subfamily Angulogerininae Galloway, 1933

Angulogerininae Galloway, Manual of foraminifera, Principia Press, Bloomington, Ind., 1933.

Angulogerina Cushman, Contrib. Cushman Lab. Foram. Res., vol. 3, pt. 1, 1927, p. 69.

Test free, elongate, trihedral, high-spired, three chambers to a whorl in the early and middle portions of the test and uniserial in the later portion; wall calcareous hyaline, finely perforate; surface costate; aperture terminal, round, with phialine lip. Length up to 1 mm. --Temperate, shallow water.--Cretaceous (?), Eocene to Recent.

Angulogerina sp.

Plate 7, figure 5

Test finely costate except for apertural chamber which is tuberculate; aperture with short neck, with almost no lip. Length 0.45 mm. Two specimens of this species were found in a tide pool.

CONCLUSIONS

This study which has been made gives some idea of the possibilities for morphological and taxonomic studies to be found in the foaminifera of this region. Not only are the recent forms of interest, but there are exposed along the ocean front formations of the Eocene, Oligocene, Miocene, Pliocene and Pleistocene periods that yield rich faunas which include foraminifera. Especially notable in this area is Fossil Point, on the east shore of Coos Bay. Since so little has been done in the Oregon coast area, there is a great need for work in the biological field. The newly established Institute of Marine Biology makes excellent headquarters for study in one of the richest areas, zoologically and botanically speaking, on the entire coast of Oregon. This survey merely touches the fringe of the subject of protozoology in general and of foraminifera in particular.

In general, it has been found that foraminifera thrive best in protected areas where there is abundant plant and animal life. Dead tests are to be found in open beach areas, but there are very few living foraminifera there. Such places as tide pools that are lined with algae, and rocks covered with mud and sand entangled in the holdfasts of algae and roots of eelgrass, furnish protection for the tiny animals from heavy wave action. There is also in these places an abundant food supply, diatoms, other protozoa, or any animal small enough to be captured by the foraminifer's pseudopodia. Probably oxygen is plentiful due to photosynthesis.

The large number of species in this area compared with the few species farther north, on the Tillamook County beaches, may be explained on this basis. The rock substratum in the Coos area is sandstone, comparatively soft and rough in texture, allowing animals to bore into the substance of the rock, and giving both plants and animals a firm foothold. The rock northward is basalt, with a hard smooth surface that would make it difficult for organisms to attach themselves. This is demonstrated by the fact that there are comparatively few algae there, and few animals. It would seem, therefore, that the scarcity of foraminifera in the northern area can be accounted for by the fact that there is inadequate protection, and that the necessary food supply is lacking because it in turn is unprotected.

The representation in the families of foraminifera in this study agree in general with the findings of the most recent workers. The families described as being most widely distributed and with the largest numbers of species and individuals, such as the Miliolidae, the Trochamminidae, the Nonionidae and the Rotaliidae, are represented most frequently here. The families whose members are highly specialized, in habitat and in form, are not represented in this area which is not extreme or unique in the environmental factors that influence the distribution of foraminifera.

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PLATE 1

FAMILY MILIOLIDAE

Subfamily Cornuspirinae

Fig. 1. *Cornuspira* sp., x150
- a. lateral view
- b. apertural view

Subfamily Miliolinae

Fig. 2. *Quinqueloculina* sp., x92
- a. side view
- b. apertural view
- c. side view

Fig. 3. *Quinqueloculina* sp., x70
- a. side view
- b. side view
- c. apertural view

Fig. 4. *Quinqueloculina* sp., x70
- a. side view
- b. apertural view
- c. side view

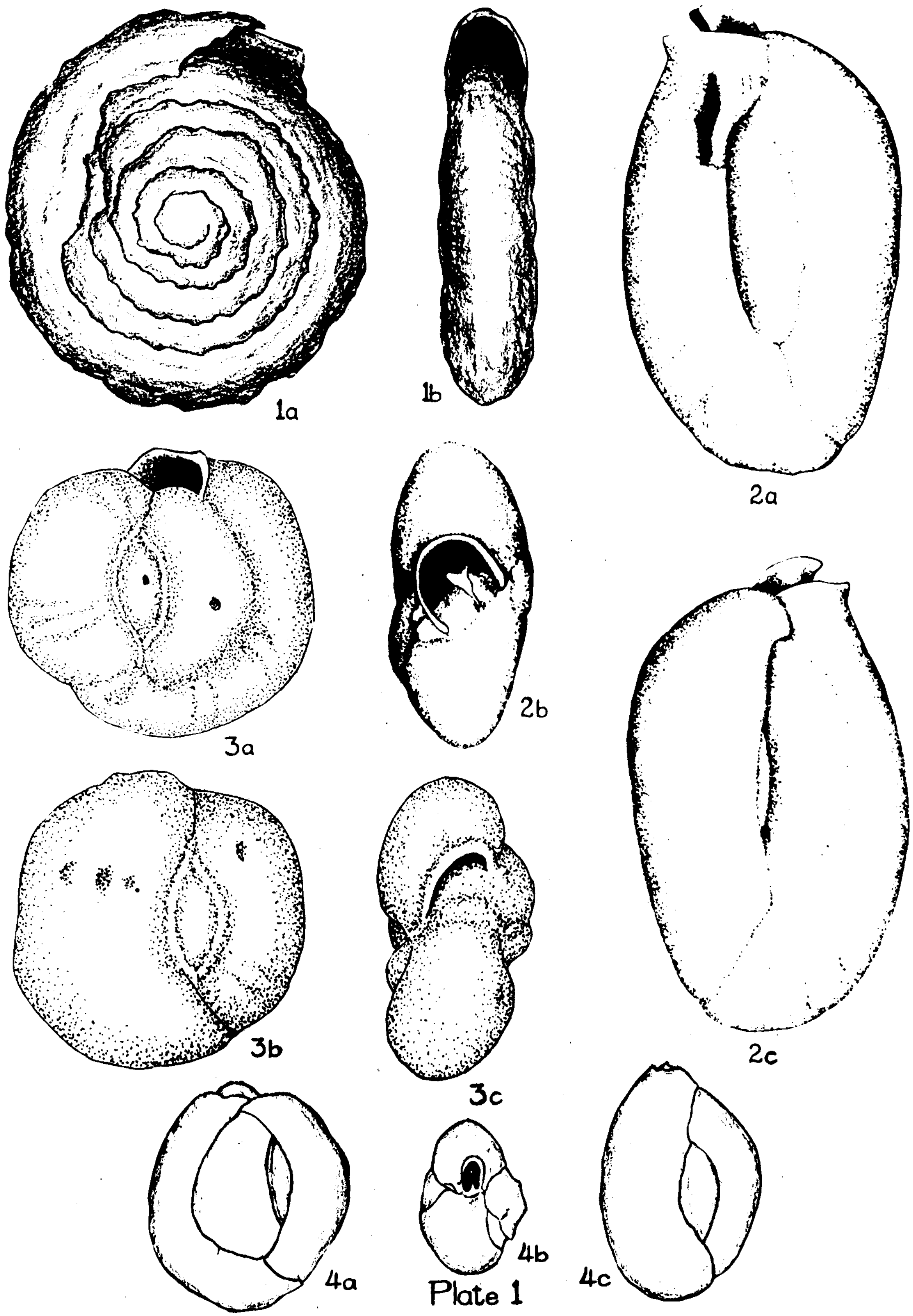

Plate 1

PLATE 2

FAMILY TROCHAMMINIDAE

Subfamily Trochammininae

Fig. 1. Trochammina sp., x185
  a. dorsal view
  b. apertural view
  c. ventral view

Fig. 2. Trochammina sp., x100
  a. dorsal view
  b. ventral view
  c. apertural view

Fig. 3. Trochammina inflata Montagu, 1808, x100
  a. dorsal view
  b. apertural view
  c. ventral view

Subfamily Placopsilininae

Fig. 4. Haplophragmoides sp., x70
  a. lateral view
  b. apertural view

Fig. 5. Haplophragmoides sp., x100
  a. lateral view
  b. apertural view

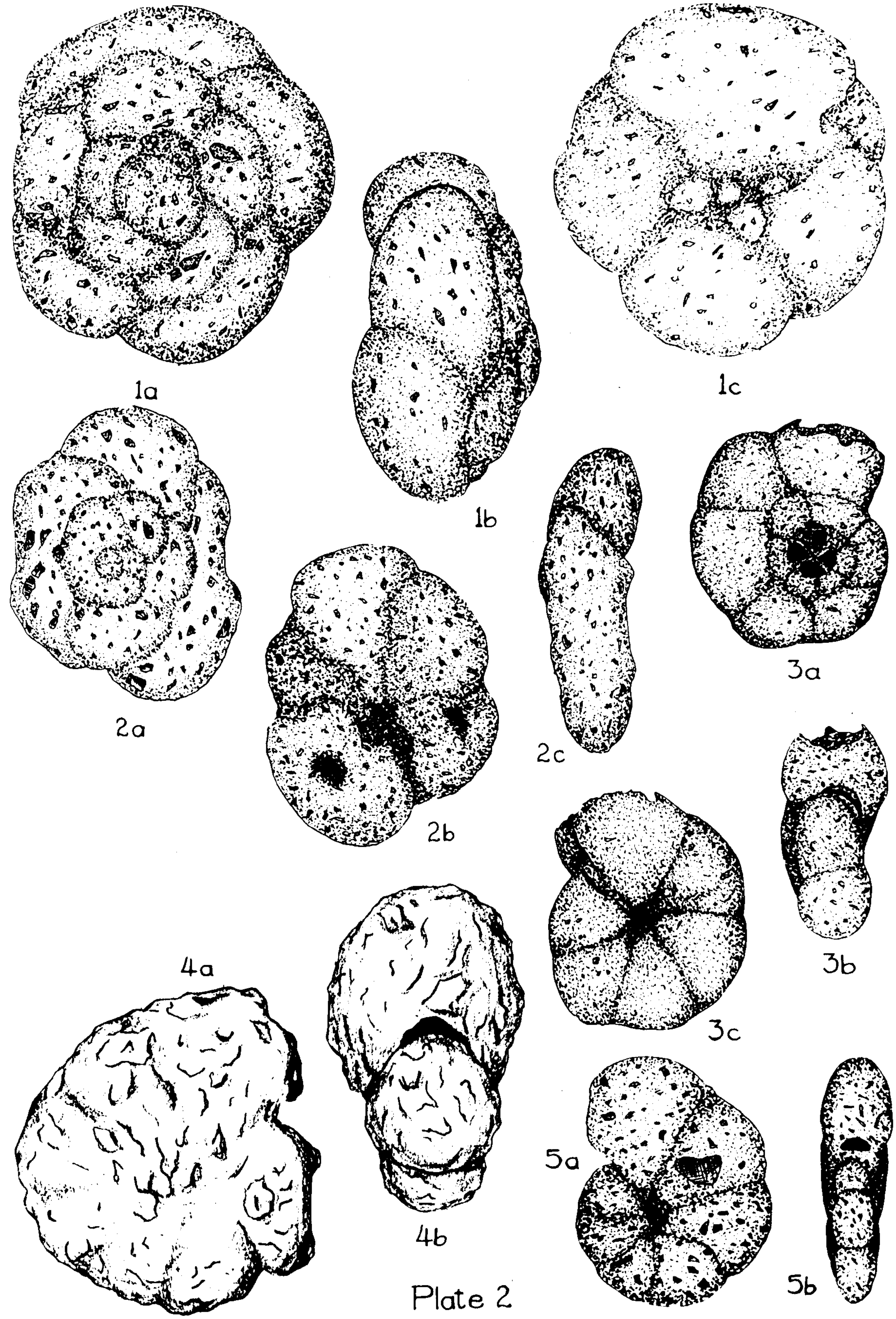

Plate 2

PLATE 3

FAMILY ORBULINIDAE

Fig. 1. *Globigerina* sp., x260
a. dorsal view
b. ventral view

FAMILY ATAXOPHRAGMIIDAE

Fig. 2. *Verneuilina polystropha* Reuss, 1845, x185
a. lateral view
b. apertural view

FAMILY NODOSARIIDAE

Subfamily Nodosariinae

Fig. 3. *Lagena squamosa* Montagu, 1803, x185
a. lateral view
b. apertural view

Subfamily Robulinae

Fig. 4. *Robulus* sp., x100
a. lateral view
b. apertural view

FAMILY NONIONIDAE

Subfamily Nonioninae

Fig. 5. *Nonion stelligerum* Cushman, 1930, x100
a. lateral view
b. apertural view

Fig. 6. *Nonion* sp., x185
a. lateral view
b. apertural view

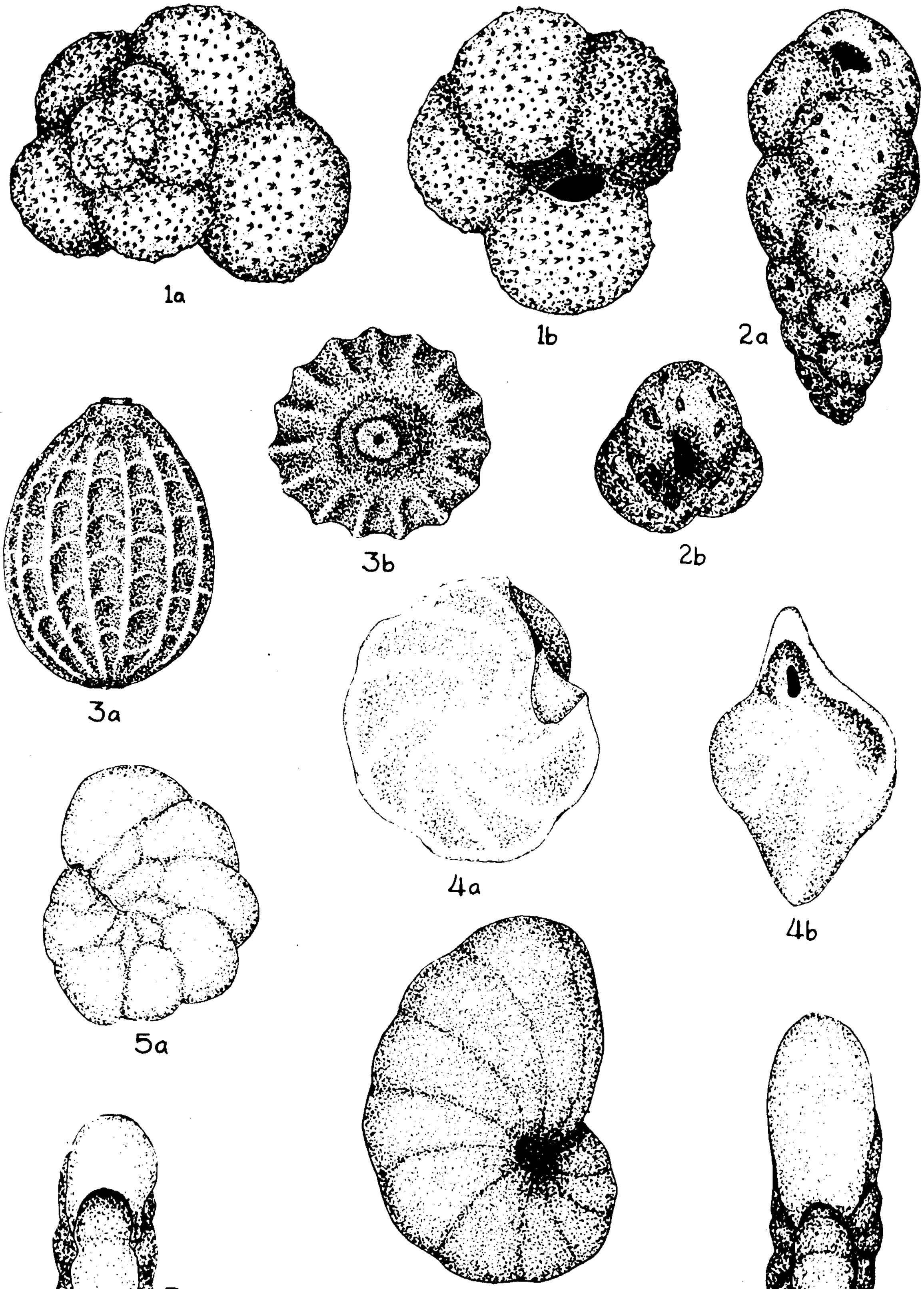

Plate 3

PLATE 4

FAMILY NONIONIDAE

Subfamily Nonioninae

Fig. 1. *Nonionella* sp., x185
a. ventral view
b. apertural view
c. dorsal view

Subfamily Elphidiinae

Fig. 2. *Elphidium* sp., x60
a. lateral view
b. apertural view

Fig. 3. *Elphidium* sp., x150
a. lateral view
b. apertural view

Fig. 4. *Elphidium translucens* Natland, 1938, x185
a. lateral view
b. apertural view

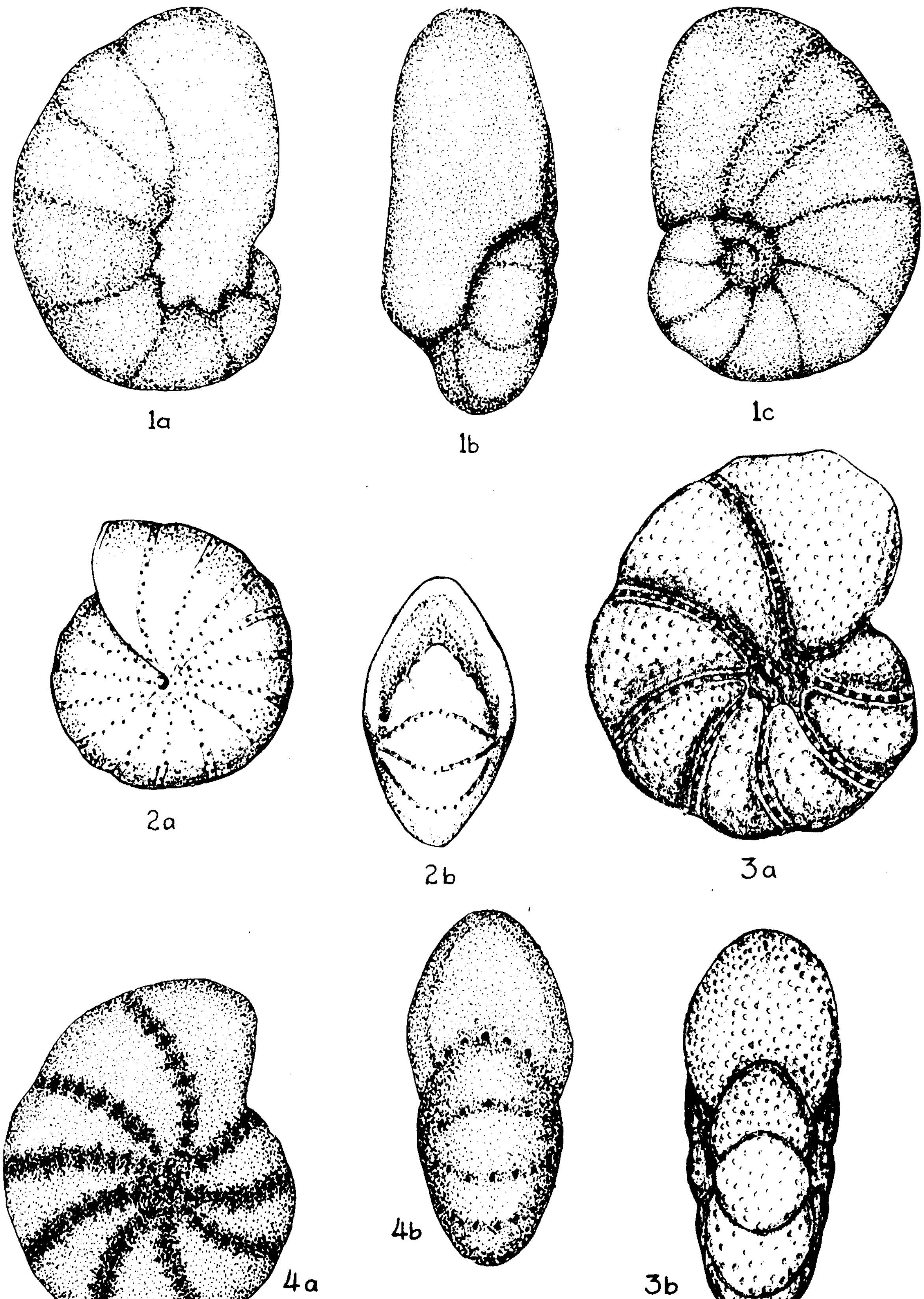

Plate 4

PLATE 5

FAMILY ROTALIIDAE

Subfamily Rotaliinae

Fig. 1. *Rotalia* sp., x150
a. dorsal view
b. apertural view
c. ventral view

Fig. 2. *Rotalia* sp., x70
a. dorsal view
b. ventral view
c. apertural view

Fig. 3. *Rotalia* sp., x150
a. dorsal view
b. ventral view
c. apertural view

Fig. 4. *Rotalia* sp., x100
a. dorsal view
b. ventral view
c. apertural view

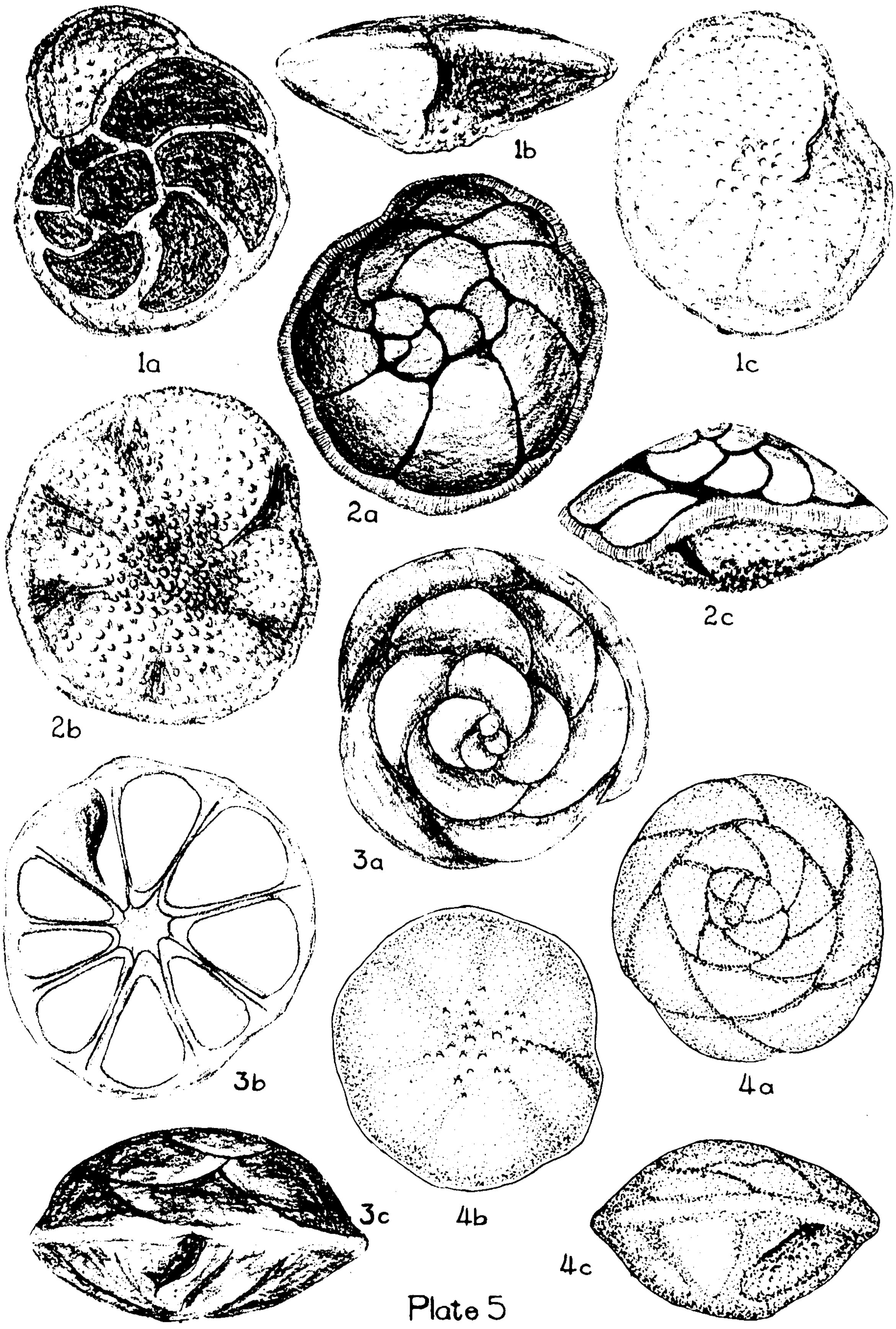

Plate 5

PLATE 6

FAMILY ROTALIIDAE

Subfamily Discorbinae

Fig. 1. _Discorbis_ sp., x60
a. dorsal view
b. ventral view
c. peripheral view

Fig. 2. _Discorbis_ sp., x140
a. and b. pair of excavated tests
showing brood of young

Fig. 3. _Discorbis_ sp., x165
a. dorsal view
b. ventral view
c. peripheral view

Fig. 4. _Discorbis parisiensis_ d'Orbigny, 1826, x100
a. dorsal view
b. peripheral view
c. ventral view

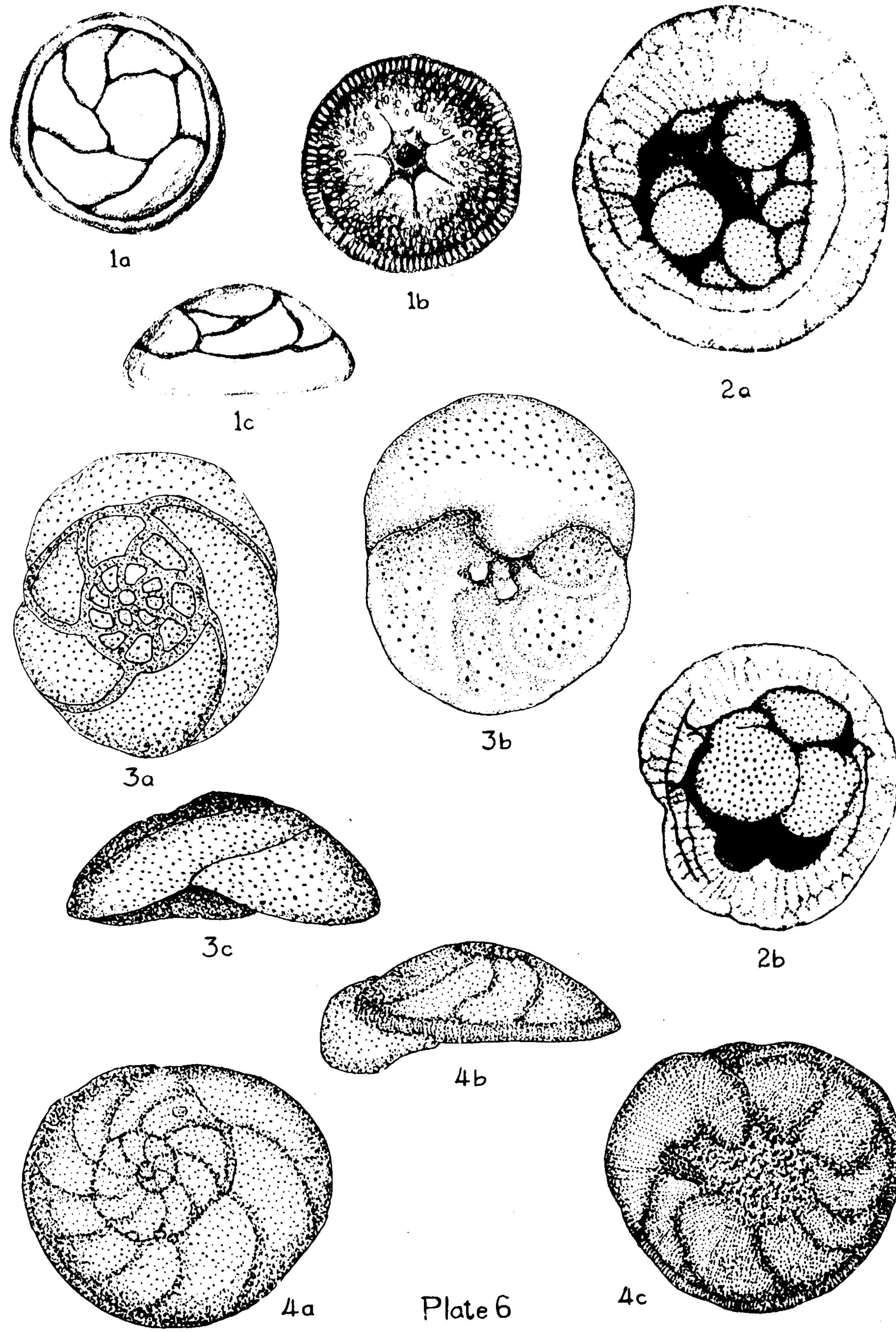

Plate 6

PLATE 7

FAMILY ROTALIIDAE

Subfamily Cibicidinae

Fig. 1. Cibicides sp., x128
 a. dorsal view
 b. ventral view
 c. apertural view

Subfamily Planorbulininae

Fig. 2. Planorbulina sp., x70
 a. dorsal view
 b. apertural view
 c. ventral view

FAMILY BULIMINIDAE

Fig. 3. Buliminella sp., x185
lateral view

FAMILY UVIGERINIDAE

Subfamily Uvigerininae

Fig. 4. Uvigerina selseyensis Heron-Allen and Earland, 1909, x185
 a. lateral view
 b. apertural view

Subfamily Angulogerininae

Fig. 5. Angulogerina sp., x100
 a. lateral view
 b. apertural view

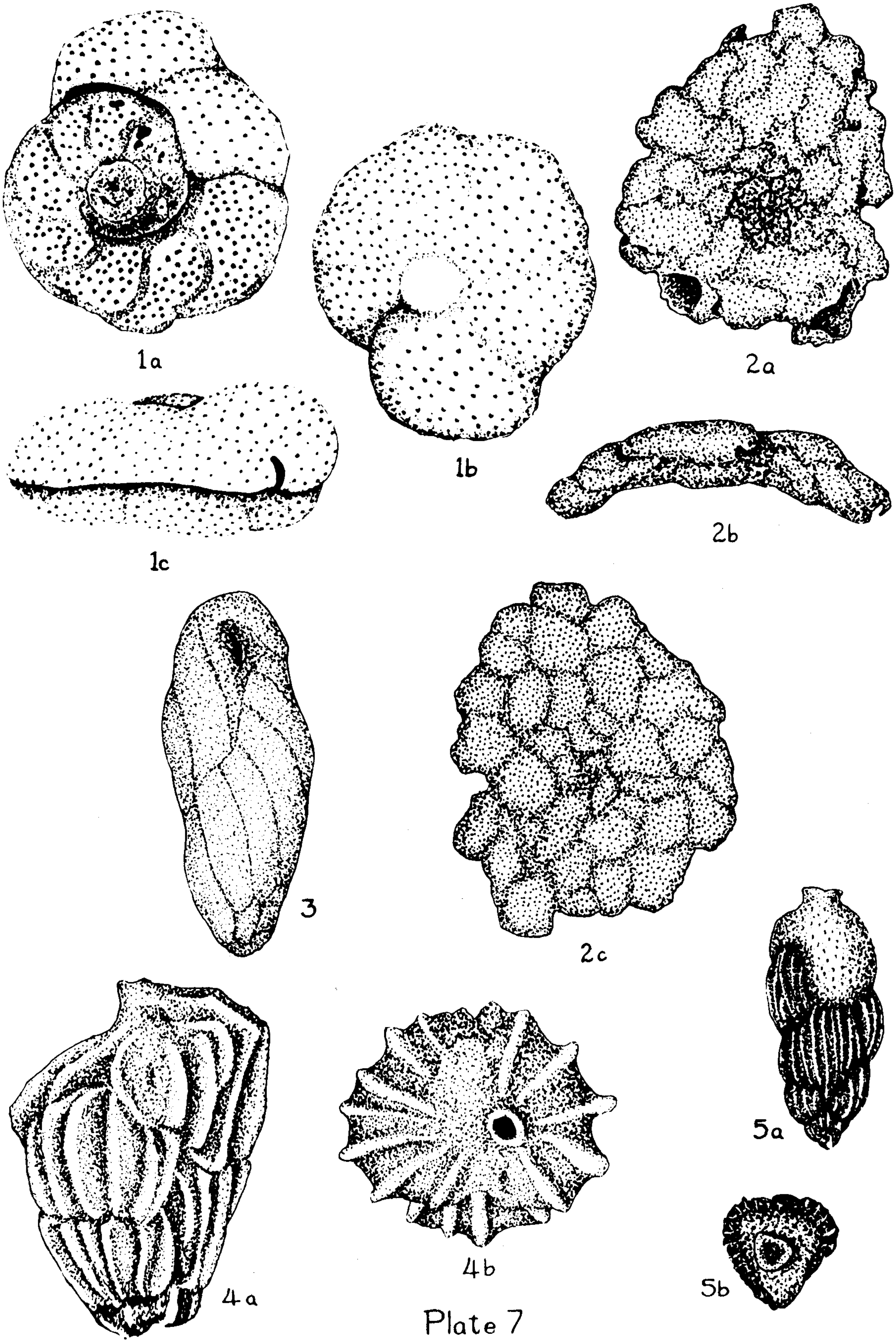

Plate 7