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By RAYMOND C. DOUGLASS

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A study of the genus Orbitolina, *its type species, morphology, and stratigraphic and geographic distribution in North America*

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THE FORAMINIFERAL GENUS ORBITOLINA IN NORTH AMERICA

By Raymond C. Douglass

ABSTRACT

The foraminiferal genus *Orbitolina* has been useful as an index fossil in the Cretaceous rocks of the circumglobal equatorial belt for nearly a century. In Europe and the Near and Middle East enough work has been done on the species to allow their use for approximate correlations within the Cretaceous sedimentary rocks. The study of American specimens of *Orbitolina* had been almost neglected although they were used in a rather cursory fashion for markers of the Lower Cretaceous Trinity strata. Three species had been described and assigned to *Orbitolina* in the United States, but the validity of each of the species had been questioned. A study of the genus *Orbitolina*, its type species, its morphology and the stratigraphic and geographic distribution in North America are presented in this report.

Stratigraphic sections were measured throughout the area of Lower Cretaceous outcrop in Texas, New Mexico, and Arizona, and samples of *Orbitolina* were taken from these measured sections. Several thousand thin sections were prepared from which 8 species of *Orbitolina*, 7 of them new, were recognized. *Orbitolina texana* (Roemer) was found to be confined to the lower part of the Glen Rose limestone and its equivalents. *Orbitolina minuta* n. sp. is essentially confined to the upper part of the Glen Rose limestone and its equivalents. Four of the species are known only from the Arizona and New Mexico region. The species of *Orbitolina* are useful stratigraphically, but all their characters—internal as well as external—must be considered. The use of thin sections for the study of *Orbitolina* is essential.

One of the first things that had to be determined was the correct concept of the genus *Orbitolina*. The type species had not been determined by earlier authors, although four species had been suggested at various times. With careful study of the early literature, it became apparent that the type species is *Orbulites lenticulata* Lamarck, 1816=*Madreporites lenticularis* Blumenbach, 1805 by monotypy.

The type species had never been studied using modern techniques. This paper presents the first description and illustrations of the type species based on internal as well as external characters.

The American forms of *Orbitolina* had been referred to the species *Orbitolina concava* (Lamarck) by Silvestri and others. The necessity of understanding *O. concava* was apparent. Many misconceptions about *O. concava* had been developed and propagated until the modern concept no longer included the original material on which the species was based.

Topotype material of *Orbulites concava* Lamarck, 1816, was restudied. For the first time both the internal and the external characters are described and illustrated. *Orbitolina concava* (Lamarck) is not conspecific with any of the North American forms.

A thorough knowledge of the morphology of *Orbitolina* is essential to the interpretation of the features as seen in thin section. Carefully oriented sections were prepared and models built up illustrating the morphology. A new technique was adapted for multiple sectioning of specimens of *Orbitolina*. Using this technique, several oriented sections can be prepared from one specimen, enabling the correlation of features seen in axial, basal, and tangential sections. This technique should prove useful in the study of similar small objects, and therefore is described and illustrated.

The early chambers of microspheric and megalospheric specimens were not well known. A technique for their study was developed and is described. The morphology of the early chambers of both generations is described and illustrated. The nature of the nepionic and neanic chambers of the microspheric generation is described and documented for the first time. The previous supposition of an early trochoid spire in microspheric specimens is rejected in favor of a flaring planispiral coil. This discovery must be considered in a study of the phylogeny.

Charts are presented showing the stratigraphic and geographic distribution of *Orbitolina* in the Texas, New Mexico, and Arizona sections. These charts should prove useful in the study of both surficial and subsurface samples of Trinity equivalents from Florida to Arizona.

INTRODUCTION

BACKGROUND AND PURPOSE

The genus *Orbitolina* is known to occur throughout the circumglobal equatorial belt often referred to as Tethyan or Mediterranean. (See fig. 29.) All the reported occurrences are from rocks of Cretaceous age and most are from Lower Cretaceous rocks. The absolute range of the genus is still unknown. The first definite occurrences of the genus are reported from Tibet (Cotter, 1929), Burma (Sahni, 1937), and southern Japan (Yabe and Hanzawa, 1926), in the upper part of the Neocomian. The latest occurrences are reported from the Cenomanian of France (Lamarck, 1816), Spain (Martin, 1891), Italy (Prever, 1909), and Arabia (Henson, 1948). Studies of the distribution and speciation of European and Near-East forms by Douvillé (1912), Silvestri (1932), and Henson (1948) indicate the practical use of the species of *Orbitolina* in stratigraphic correlations within the Cretaceous.

Orbitolina has been recognized in America since 1849 when Roemer (1849, p. 392) described *O. texana* from Texas. Since that time the genus has been used by stratigraphers and petroleum geologists, in a rather cursory fashion, as a marker for what is now called the Glen Rose limestone and its presumed equivalents from Florida to Arizona and southward into Central and South America. No study of the stratigraphic and geographic distribution or systematics of the genus has been published, although several authors [1] (Carsey, 1926; Vaughan, 1932, Silvestri, 1932a; Davies, 1939; Barker, 1944; Stead, 1951, and Frizzell, 1954) have studied specimens of *Orbitolina* from North America. Three species were named, but there has been no general agreement on the validity of the named species, and both generic and specific assignments have been shifted.

The purpose of this study was to learn enough about *Orbitolina* to make it useful as a stratigraphic tool in North America. This involved learning the nature of the genus, recognizing the species, and determining their stratigraphic and geographic distribution.

The succession of evolutionary stages—or the phylogeny—of a genus may eventually provide the most reliable criterion for recognition of contemporaneity. This cannot be realized, however, until phylogenies are worked out carefully based on good stratigraphic control. The so-called phylogeny assembled by placing species or genera into a series showing progressive—or inferred progressive—morphologic change, but disregarding time, is deceptive. Compiling phylogenies from data known only from the published record is also tenuous, as the stratigraphic control is generally poor. Establishing the stratigraphic and geographic distribution of the species of *Orbitolina* in North America provides reliable basic data which can be used in constructing a phylogeny for the genus. Unfortunately the stratigraphic interval through which *Orbitolina* is found in North America is short when compared with the total range of the genus. Before a complete phylogeny can be proposed, studies similar to this should be completed in areas such as Spain and France where a succession of beds from Neocomian to Cenomanian is reported to contain *Orbitolina.*

SCOPE

The present study includes nearly all the outcrop areas of the Glen Rose limestone and its equivalents in Texas and the southern parts of New Mexico and Arizona. Thirty-two stratigraphic sections were measured throughout this outcrop area during the months of September and October 1954. In addition, samples were taken from some previously described localities. Comparative material was assembled from many places throughout the world, including the Caribbean, Central and South America, the Pacific Islands, the Near East, continental Europe, and England.

No attempt is made to settle the stratigraphic terminology for the units covered in this report. Wherever possible, the most commonly used name is applied to the units measured, and reference to the name source is made. In some areas, no name has been applied to the sedimentary rocks measured, and, therefore, the unit is not named on the stratigraphic charts. Several terms are placed in quotes in the text and on the charts. These terms, such as "*Corbula* bed" and "*Salenia* zone", are colloquial expressions understood in the area of their use but not necessarily accurate in a literal sense.

The scope of this paper is essentially limited to the material from the United States, partly because of a lack of firsthand knowledge of the stratigraphic relationships and problems elsewhere and partly because of the paucity of other samples having sufficiently accurate stratigraphic and geographic locality data.

Exceptions to the above limitation are the descriptions of two species of *Orbitolina* from France. One is *O. lenticularis*, which is the type species of *Orbitolina*, and the other is *O. concava*, to which several authors have referred the American forms.

The morphology of the genus *Orbitolina* is described and illustrated as a basis for understanding the characters that are important in recognizing and distinguishing species. The distribution of the genus and its species in the North American rocks is reviewed and the recognized species described and illustrated.

PREVIOUS STUDIES

The first published record of *Orbitolina* in North America was by Ferdinand von Roemer in his book "Texas" (Roemer, 1849, p. 392). In this book, and then later in his paper, on Cretaceous fossils from Texas (Roemer, 1852, p. 86, pl. 10, fig. 7a–d) he described and illustrated *Orbitulites texanus*, which is now known as *Orbitolina texana*. His description was based on material he collected from beds which are now assigned to the Glen Rose limestone. Since 1852 the name *Orbitolina texana* has been used in many publications where the faunal content of these beds is mentioned or described.

Dorothy Carsey was the first to describe additional species of *Orbitolina* from the United States (Carsey, 1926). She described two species, *Orbitolina whitneyi* and *Orbitolina walnutensis*. *O. whitneyi* was placed

[1] Means, J. A., 1948, A population study of the Cretaceous foraminiferal genus *Orbitolina:* Univ. of Texas master's thesis.

in synonmy with *O. texana* by Vaughan (1932, p. 609), and he said that *O. walnutensis* was so different it probably belonged to a distinct genus. *O. walnutensis* was, in fact, reassigned to the genus *Dictyoconus* by Silvestri (1932b, p. 377). Silvestri studied samples of some of the Orbitolinas from Texas and considered them to be a variety of *Orbitolina concava* (Lamarck) as he understood that species. As pointed out on page 33 Silvestri's concept of *O. concava* (Lamarck) was erroneous.

The American forms were studied again by L. M. Davies who redescribed and illustrated *O. texana*, considering it a distinct species (Davies 1939, p. 783, pl. 1, figs. 1, 3, 7, 9, 12). John A. Means, in an unpublished masters thesis completed for the University of Texas in 1948, made "a population study of the Cretaceous foraminiferal genus *Orbitolina*," in which he attempted to understand variation in the genus. His study was based on 7 samples from Texas, 1 from France and 1 from Venezuela. Unfortunately, he did not see any value in thin-section studies and relied solely on size and shape characters of the specimens. His conclusion, therefore, that *Orbitolina* has such variety within each sample that it cannot be used to discriminate horizons, is not surprising.

Orbitolina was included among the forms studied by Stead (1951) in his zonation of the Glen Rose limestone, but his study of the genus was even more superficial than that of Means. Don L. Frizzell (1954, p. 80) included *Orbitolina* in the "Handbook of Cretaceous Foraminifera of Texas" and reported it in beds of the Hensell sand member of the Travis Peak formation, the Glen Rose limestone, and the Walnut clay.

ACKNOWLEDGMENTS

A work of this nature involves a great number of people, all of whom contribute to the final product. I would like to name all who have helped, but the list would be cumbersome. Lloyd G. Henbest suggested the study, has cooperated in making material and space available, and has given advice on some of the techniques and photographic methods used. John B. Reeside, Jr., has supervised the project and helped with taxonomic problems. I was assisted in the field by William G. Melton, Jr., who helped measure the stratigraphic sections and collect the samples. Walter S. Adkins, David Amsbury, James De Cook, Roy T. Hazzard, Frank Lee, and Frank E. Lozo, Jr., gave advice and suggested localities during the fieldwork and Esther R. Applin, Franz Goerlich, Robert M. Kleinpell, Alfred R. Loeblich, Jr., Wolf Maync, Pierre Rat, Hubert G. Schenck, Robert H. Waite, and Robert A. Zeller have furnished samples from various parts of the world for the study. Carolyn Bartlett prepared the reconstruction of *Orbitolina* for figures 15 and 16.

AREAL DISTRIBUTION OF THE LOWER CRETACEOUS ROCKS IN TEXAS, NEW MEXICO, AND ARIZONA

The following discussion deals chiefly with the outcrop areas of the Trinity and does not include details of the character or distribution of the subsurface equivalents. The rocks of Trinity age crop out almost continuously in a belt that extends from Oklahoma, south to the vicinity of San Antonio, Tex., then west to Brewster County, Tex. (Fig. 1.) From there the Trinity outcrops continue intermittently through Presidio and Hudspeth Counties in Texas, Grant and Hidalgo Counties in southwestern New Mexico, and on into Cochise County in southeastern Arizona. Plates 15–17 illustrate diagrammatically the sequence of beds as measured at localities scattered throughout this outcrop area. The localities are described in more detail in the register of localities (p. 7).

Three generalized sedimentary environments can be recognized in the area of outcrop: the eastern part from Brewster County, Tex., to Oklahoma is characterized

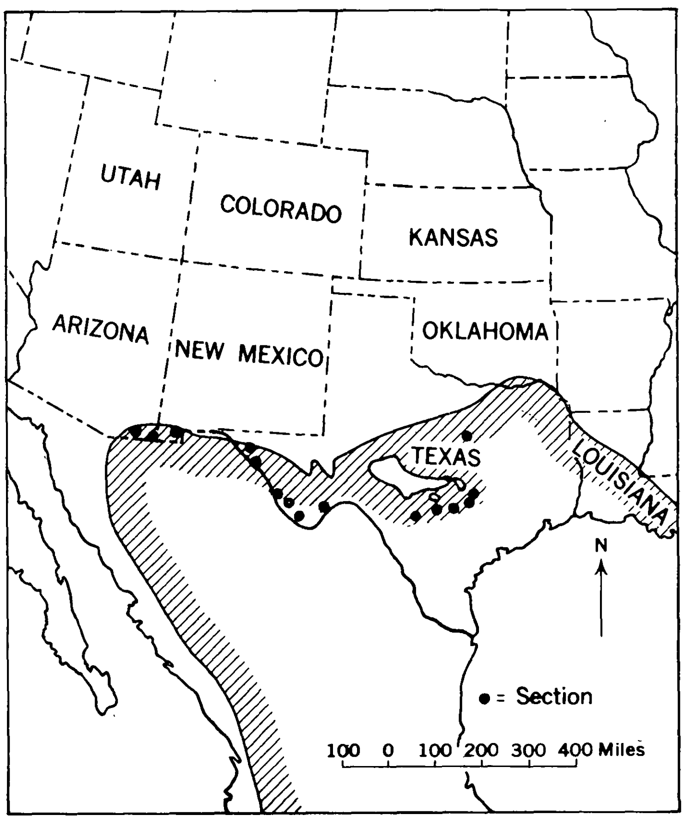

FIGURE 1.—General position of the measured stratigraphic sections in relation to the edge of the Trinity sea as shown by Adkins (1932, fig. 13).

by shelf-type sediments; the central part in southwestern Brewster County, Presidio County, and southern Hudspeth County is characterized by a rapidly sinking shelf with great thicknesses of sediments; the western part in New Mexico and southeastern Arizona is again shelf-type sedimentation with a tendency to form reef limestone.

EASTERN SHELF DEPOSITS

The Trinity sediments were deposited in a transgressing sea whose margin moved northward during Trinity time (Adkins, 1932, p. 284). The area of present outcrop represents mostly the shallow-water shelf sediments. To the south, or gulfward, the Trinity sediments of the subsurface thicken partly by increased bulk of sediment in each stratigraphic unit and partly through the addition of older beds. Imlay (1945, p. 1449) has described the Glen Rose from the subsurface of south Texas as increasing markedly in thickness basinward. He describes it as a monotonous sequence of limestones with more clastic beds toward the top and bottom of the formation. A differing view of the Glen Rose is presented by Getzenander (1956, p. 78), who considers it essentially a clastic unit similar in nature to the underlying Travis Peak formation. He states that the Glen Rose limestones are clastics derived from older Glen Rose and Travis Peak strata. He places a great deal of emphasis on the evaporites found in the Glen Rose and concludes that most of the deposition took place in an intermittently closed basin, much of the sediment being of nonmarine origin.

Along the strike of the beds in central Texas some beds appear to represent approximate time planes. For example there is a zone referred to as the "*Salenia* zone" which is immediately overlain by a limestone bed principally made of shells of a tiny pelecypod. This bed is commonly called the "*Corbula* bed." The "*Corbula* bed" and "*Salenia* zone" have been traced over large areas in central Texas and have been found to be a convenient and trustworthy marker throughout the area of their outcrop.

The Trinity group is usually subdivided into several units in central Texas. In descending order these are the Paluxy sand (restricted to the northeastern part of the outcrop area), the Glen Rose limestone, and the Travis Peak formation. Except in the northeastern area the Glen Rose limestone is overlain by the Walnut clay, the Comanche Peak limestone, and the Edwards limestone of the Fredericksburg group.

A different subdivision of the Trinity group was proposed by V. E. Barnes (1948, p. 5) as follows:

Trinity group:
- Shingle Hills formation
  - Glen Rose limestone member
  - Hensell sand member
- Travis Peak formation
  - Cow Creek limestone member
  - Sycamore sand member

Barnes (1948, p. 8) found the Hensell sand to be a clastic shoreward facies of the Glen Rose limestone.

The Glen Rose limestone is an alternating series of hard and softer calcareous beds which vary in detail from fine muds through siltstones and marls to limestones. Some of the limestones are aphanitic while other are coarse calcarenites. The alternation of hard and soft beds is irregular in the lower part of the unit, but above the "*Corbula* bed" the alternation is sufficiently regular to produce a stair-step topography on slopes.

The thickness of the Glen Rose is not constant in its area of outcrop. In Travis County it is about 500 feet thick and it thins gradually to the north. Only 200 feet of Glen Rose was measured in the type area in Somervell County. The thickness increases slightly to the west of Travis County. In Hays and Comal Counties the thickness approximates 600 feet and that thickness holds pretty well out as far as Brewster County, Tex. King (1937, p. 113) reports thicknesses up to 559 feet for the Glen Rose limestone on the rim of the Marathon basin.

AREA OF RAPID SUBSIDENCE IN WEST TEXAS

The thickness of the Trinity group increases rapidly and abruptly in southwestern Brewster County, Presidio County, and Hudspeth County. The Glen Rose limestone thickens from around 600 feet in northern and eastern Brewster County to over 1,500 feet at Fresno Peak on Solitario dome in southeastern Presidio County. In the southern part of the Quitman Mountains of Hudspeth County, Scott (1940, p. 978) reported 12,000 feet of Trinity strata. Over 2,700 feet of this section were found to contain *Orbitolina*. In central Hudspeth County the Glen Rose limestone is again thinner, including about 1,300 feet of section.

Along the northeast flank of the area of thick sections in Presidio and Hudspeth Counties the section thins rapidly. In the vicinity of Shafter in Presidio County the Glen Rose section is only about 400 feet thick and the thickness remains about the same farther north in central Presidio County.

Several names are applied to approximate Glen Rose equivalents of the Trinity in west Texas. (See fig. 2.) In the Shafter area the name Shafter is applied. In Hudspeth County, Glen Rose formation was used in the Malone mountains (C. C. Albritton, 1938, p. 1767) and Bluff formation was used nearby in the Devil Ridge area (J. F. Smith, Jr., 1940, p. 609).

The character of the sediments in the thick sections is not unlike that of the thinner sections of the Glen Rose. Soft and hard calcareous beds tend to alternate as in the Glen Rose of central Texas. Many of the limestone beds are considerably thicker than those in the central Texas Glen Rose but primarily there are just more of them. There is a large proportion of sand throughout the thicker sections, with many sandstones and sandy limestones.

STRATIGRAPHIC SECTIONS IN ARIZONA AND NEW MEXICO

The section in Arizona equivalent to the Glen Rose limestone of Central Texas is called the Mural limestone. Ransome (1904, p. 56, 65) divided the Mural limestone into 2 members; a lower member consisting of about 300 feet of thinly bedded impure limestone and an upper member consisting of about 350 feet of thick-bedded limestone, forming cliffs. Only the upper member described by Ransome was found to contain *Orbitolina.* The limestone of the upper member is not uniform. In places the lower part tends to form large reefs while the upper part remains well bedded. In places the reeflike massive limestones are continuous for distances of several miles, but in other places the reef limestone is limited laterally and transition into normal-bedded limestones takes place in a few yards. It would be inadvisable to try to correlate the Mural limestone from one locality to another solely on the basis of reef development.

The section of Trinity age in New Mexico has been regarded as extremely thick. (Lasky, 1938, p. 527.) The rocks of Trinity age were described under several formational names by Lasky (1938, p. 531–534). His section includes:

Age	*Unit*	*Thickness (feet)*
Glen Rose(?)	Skunk ranch conglomerate	3, 400
	Playas Peak formation	800–2, 000
	Corbett sandstone	1, 500–3, 000
Glen Rose	Howells Ridge formation	1, 100(?)–5, 200(?)
	Hidalgo volcanics	900—5, 000+
	Ringbone shale	0–650
Glen Rose(?)	Broken Jug limestone	5, 000(?)

The Broken Jug limestone, Howells Ridge formation, and Playas Peak formation each have limestone sequences which bear Orbitolinas and other Trinity fossils. The *Orbitolina*-bearing interval of the Broken Jug limestone as measured northwest of the King vein at Old Hachita in the northern part of the Little Hatchet Mountains is 88 feet thick. The lower limestones are silty to muddy and relatively thinbedded. In the middle are massive silty limestones. Toward the top the limestone is again thinner bedded and is a coarse calcarenite.

The *Orbitolina*-bearing beds of the Howells Ridge formation at its type locality on Howells Ridge in the Little Hatchet Mountains are 60 feet thick. The lower part is a relatively thin-bedded silty limestone and the upper part is a massive calcarenite.

The *Orbitolina*-bearing beds of the Playas Peak formation at its type locality south of Playas Peak in the Little Hatchet Mountains include 132 feet of limestone all of which is muddy to silty and relatively thick bedded.

South of the Little Hatchet Mountains, in the Big Hatchet Mountains, Robert A. Zeller has collected Orbitolinas from a section including 1,300 feet of limestones and softer beds. A study of his collections shows that the lower beds contain forms similar to those found in the lower part of the Mural limestone. The upper beds, with the exception of one collection, contain forms similar to those found in the upper part of the Mural limestone.

The limestones of the New Mexico section tend to become massive and reeflike in many places and have a topographic expression similar to that found in the Mural limestone of Arizona. Apparently, sedimentary conditions were similar in the two areas. The section reported by Lasky (1938, p. 527) is considerably thicker than the Arizona section. It is possible that the area of the Little Hatchet Mountains was subsiding more rapidly and deposition was more rapid. As the *Orbitolina*-bearing limestones are typical of the shallow shelf environment, it is not likely the water was deep during the periods of their deposition.

Another possibility is that the three limestone sequences described by Lasky as the Broken Jug limestone, Howells Ridge formation, and Playas Peak formation are more or less contemporaneous. The three limestone sequences are similar in character, and they are not found superimposed in any continuous section. The basal conglomerate of the Howells Ridge formation as exposed at the northwest end of Howells Ridge contains pebbles and cobbles reworked from Carboniferous strata, including fusulinid limestones. No Cretaceous fossiles or cobbles reworked from the Broken Jug limestone were recognized. A short distance to the south, in the Big Hatchet Mountains, where the thickness should be even greater than in the marginal area of the Little Hatchet Mountains, the section is relatively thin.

DISTRIBUTION OF *ORBITOLINA*

Orbitolina can be found in most exposures of the Glen Rose limestone and its equivalents from north-central Texas to southeastern Arizona. Plates 15–17 and figure 2 show the distribution of the *Orbitolina*-bearing beds in some of the sections measured for this study.

In the type section of the Glen Rose in Somervell County where the section is thin, only one zone containing *Orbitolina* was found. In Travis County where the Glen Rose is thicker, one zone of *Orbitolina* was found below the "*Corbula* bed" and two were found above the "*Corbula* bed." In Hays County and to the west the "*Salenia* zone" immediately under the "*Corbula* bed" has abundant *Orbitolina.* The sequence containing *Orbitolina* thickens in the western section and more beds are found which contain specimens. As many as six zones were found containing *Orbitolina* in the lower part of the Glen Rose in western Comal County. *Orbitolina* is found almost continuously through long sequences in some of the Glen Rose sections such as the upper part of the Glen Rose in Bandera and Brewster Counties in Texas.

Some sections have thick units in which no Orbitolinas are found even though the lithology gives no indication of adverse conditions. It is possible that the alternation of kinds of sediments indicate deepening and shallowing seas during the time of deposition and that the *Orbitolina* only accumulated when the depth of the sea was favorable to their proliferation. Temperature may also have had an effect on the distribution of Orbitolinas. They are generally considered to be warm-water forms, and the temperature may have varied with the depth of the water, or independently.

The species of *Orbitolina* recognized from this study are not uniformly distributed throughout the Glen Rose. Certain observations about their distribution may prove helpful for determining stratigraphic position within the Glen Rose and its equivalents when other criteria are unavailable.

The distribution of *Orbitolina texana* (Roemer) is important in that *O. texana* is never found in the upper part of the Glen Rose. Throughout its occurrence from Hudspeth County, Tex., on the west to Pinellas County, Fla. on the east it is restricted to the lower part of the Glen Rose. The highest occurrence in central Texas is the first *Orbitolina* bed below the "*Salenia* zone." It occurs in the earliest *Orbitolina*-bearing beds in central Texas. No representatives of *O. texana* were found in New Mexico or Arizona.

Orbitolina minuta Douglass, n. sp., has the most widespread distribution of any of the North American

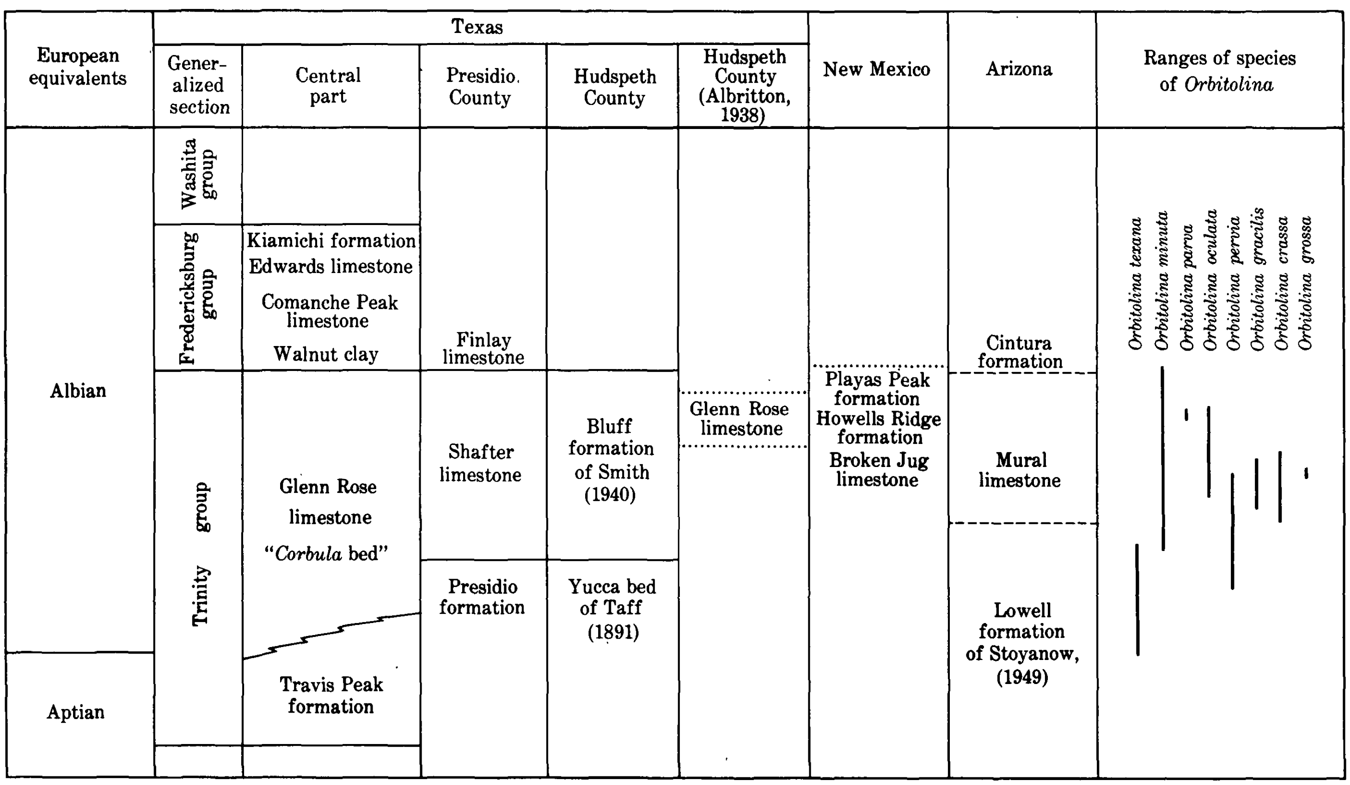

FIGURE 2.—Approximate correlation of the Lower Cretaceous formations in Texas, New Mexico, and Arizona and total known range for the species of *Orbitolina* described from these beds.

species of *Orbitolina.* In general it occurs in the upper part of the Glen Rose from the "*Salenia* zone" up. The Glen Rose can thus generally be divided into an upper and lower part on the basis of these two species. *O. minuta* has been found in two collections, f20106 and f20107, in the lower part of the Comal County section, 80–90 feet below the "*Corbula* bed." In the West, *O. minuta* has been identified in the upper part of the Bluff formation (as used by Smith (1940, p. 607)), in the Glen Rose of the Carroll Hills, in the Playas Peak type section, and in the upper part of the Mural limestone.

Other species have less widespread distribution. *O. gracilis* Douglass, n. sp., is found in the lower part of the Howells Ridge formation and in the lower part of the Broken Jug limestone. *O. crassa* Douglass n. sp., occurs in the upper part of the Broken Jug limestone and in the lower part of the Mural limestone.

The distribution of the species of *Orbitolina* forms a picture which suggests some correlations. The Brewster County section can be tied into the central Texas sections with relative ease. The highest occurrence of *O. texana* in collection f20127 is probably still below the "*Salenia* zone." The "*Corbula* bed" is not represented but its position stratigraphically would probably be at or near collection f20128, the upper collections correlating with the upper part of the Glen Rose.

The long section at Fresno Peak does not have *O. texana* represented. *O. minuta* is represented in most of the samples. The only other species of *Orbitolina* recognized was *O. oculata* Douglass, n. sp., which is also found in the upper part of the Glen Rose in Hays County, Tex., in the upper part of the Howells Ridge formation in New Mexico, and in the upper part of the Mural limestone in Arizona. It appears that the entire *Orbitolina*-bearing part of the Fresno Peak section may be younger than the lower part of the Glen Rose.

The section in Hudspeth County, Tex., contains *O. texana* in the lower part and *O. minuta* in the upper part. The lower part apparently is similar to the lower part of the Glen Rose and the upper part to the portion of the Glen Rose from the "*Salenia* zone" up. The upper part is also found in the Carroll Hills, where C. C. Albritton, Jr., (1938, p. 1767) mapped it as Glen Rose.

The Playas Peak formation in the Little Hatchet Mountains of New Mexico and the upper part of the Mural limestone of Arizona apparently also may be correlated with the upper part of the Glen Rose. The lower part of the Mural limestone cannot be correlated with the lower part of the Glen Rose on the basis of *Orbitolina.*

To the east the recognition of the upper and lower parts of the Glen Rose seems to be possible at least as far as Florida, where *O. texana* occurs below the Big Anhydrite (of local usage) and *O. minuta* is found in the younger beds.

LOCALITY DATA

U.S. Geological Survey Foraminifera locality numbers have been assigned to most of the collections studied for this report. The localities bearing these numbers are described in numerical order followed by other localities mentioned in the report.

Where several collections were taken from a single measured section, the location of the section is given, and the positions of the samples are indicated on the sections plotted on plates 15–17. The geographic locations of the collections are plotted on index maps. The samples were collected by R. C. Douglass and W. G. Melton unless otherwise specified.

FRANCE

f4440–41, Ain, France. "Aptien," Lower Cretaceous. "La Perte du Rhône, Bellegarde". U.S. National Museum Acc. 19255. This is from the type locality for *Orbitolina lenticularis* (Blumenbach).

f4862, Ballon, France. Cenomanian. "Grès vert supérieur". Collection 164 of Louis Saemann, Paris. From U.S. Military Acad. (Coll. 1199) West Point, N.Y. This is from the type locality for *Orbitolina concava* (Lamarck).

TEXAS

Section 1, collections f20064–f20068. Travis County, Tex. Glen Rose limestone exposed along and near the Bee Cave–Hamilton Pool road starting at the top of the Cow Creek limestone member of the Travis Peak formation at Hamilton Pool and ending at the top of the hill called Shingle. (See pl. 15 and fig. 3). This section includes the type Shingle Hills formation of Barnes (1948, p. 8). September 16, 1954.

Section 2, collection f20069. Travis County, Tex. The type Travis Peak formation and the overlying part of the Glen Rose limestone, as exposed in the Travis Peak cliffs downstream from the Travis Peak Post Office. The section was measured starting in the bed of the Cow Creek and continued up the hill to the first beds containing *Orbitolina.* (See pl. 15 and fig. 3.) September 19, 1954.

Section 3, collections f20070–f20076. Travis County, Tex. Upper part of the Glen Rose limestone and the overlying beds on Mount Barker. The section was measured on the west face of Mount Barker through the uppermost Glen Rose limestone, the Walnut clay, and the Comanche Peak limestone of Hill and Vaughan (1902). September 20, 1954.

FIGURE 3.—Index to localities in Travis County, Tex.

f20070, last massive limestone below the Walnut clay. Contains abundant miliolids and some megafossils.

f20071, 9 to 10 feet above f20070 from a 4-inch dense limestone and the underlying shell clay.

f20072, 12 feet above f20070 from the clay just above the road level.

f20073, 18 feet above f20070 from nodular marls.

f20074, 22–24 feet above f20070.

f20075, 27 feet above f20070 in marl above linestone bed in Walnut clay (Comanche Peak limestone of Hill and Vaughan 1902).

f20076, 36 feet above f20070 and about 12 feet below the summit of Mount Barker in a nodular marl.

f20077, Blanco County, Tex. On Austin–Marble Falls road (farm road 93) 4.0 miles west of the bridge over the Pedernales River (Cox's crossing) in small streamcut. Hensell sand of Cuyler.[2] Collection from 7–10 feet below lowest massive ledge of Glen Rose limestone. (See fig. 4.) September 21, 1954.

f20078, Travis County, Tex. Glen Rose limestone. Base of the formation, according to Cuyler.[2] Two miles east of bridge over Pedernales River at Cox's Crossing on farm road 93 in the hill south of road between two vuggy or "moth-eaten" limestones. Twelve feet above base of first vuggy limestone. (See fig. 3.) September 21, 1954.

f20079, Travis County, Tex. Glen Rose limestone, 2 miles east of bridge at Cox's Crossing of Pedernales River on ranch

[2] Cuyler, R. H., 1931, The Travis Peak formation of central Texas: Univ. of Texas Ph.D. dissertation.

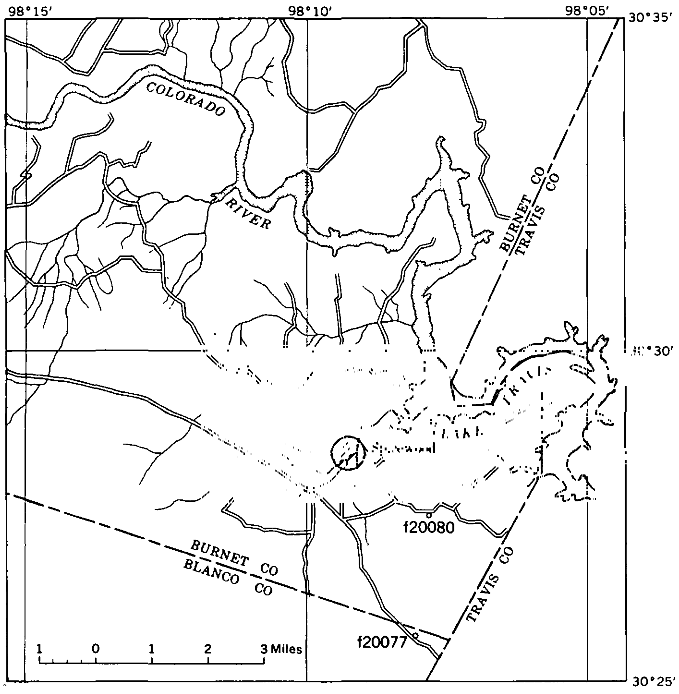

FIGURE 4.—Index to localities in Blanco and Burnet Counties, Tex.

road 93 (Austin–Marble Falls road). Collection from marl and silty limestone in roadcut about 50 yards east of f20078 on south side of road. (See fig. 3.) September 22, 1954.

f20080, Burnet County, Tex. Hensell sand unit of John Means. Two and one-fourth miles by road southeast of Spicewood, Burnet County, Tex., in calcareous siltstone 12 feet below limestone ledge of Glen Rose limestone. (See fig. 4.) Septemper 22, 1954.

f20081, Somervell County, Tex. Glen Rose limestone. In hill north of abandoned dam site on Paluxy River east of Glen Rose, Tex. *Orbitolina* in massive limestone bed starting 24 feet above river level at the dam site. Samples in ascending order through 13 feet of massive limestone. (See fig. 5.) September 23, 1954.

f20082, Bosque County, Tex. Comanche Peak limestone. One-half mile south of Hill Creek bridge on Texas highway 144 south of Glen Rose, on road to Walnut Springs. Collection from roadcut showing rudistid reef limestone at top with light chalky-looking limestone below. (See fig. 5.) September 24, 1954.

f20083, Bosque County, Tex. Comanche Peak limestone. Same general locality as f20082 but 12–16 feet stratigraphically above that collection. September 24, 1954.

Section 4, collections f20084–f20086. Hays County, Tex. Lower part of the Glen Rose limestone, including 206 feet of section below the "*Corbula* bed", starting from the lowest outcrops in the bed of the Blanco River at the bridge on the Wimberly–Fischers store road, and proceeding west and southwest. (See pl. 15 and fig. 6.) September 25, 1954.

f20089, Hays County Tex. Glen Rose limestone. "*Salenia texana* zone" at John A. Means[3] locality F-45-5. On Dripping Springs–Wimberly road about 2 miles south of Lone Man Mountain, where "*Salenia* zone" outcrops beside road at D. L. Smith Cooper Ranch. (See fig. 6.) September 26, 1954.

Section 5, collections f20090–f20096. Hays County, Tex. Upper part of the Glen Rose limestone, including 360 feet of section above the "*Corbula* bed" on the southern slope of Lone Woman Mountain on the R. B. Rainey Ranch. (See pl. 15 and fig. 6.) September 26, 1954.

Section 6, collections f20097–f20101. Comal County, Tex. Section including 235 feet of the lower part of the Glen Rose limestone along the Cranes Mill–Fischers store road, starting at the bed of the Guadalupe River at Cranes Mill Crossing and proceeding toward Fischer's store as far as the "*Corbula* bed." (See pl. 15 and fig. 7.) September 27, 1954.

Section 7, collections f20102–f20110. Comal County, Tex. Lower part of the Glen Rose limestone, including 269 feet of section. Starting at the massive limestone exposed just west of where U.S. Highway 281 crosses the Guadalupe River and proceeding south along the highway to the "*Corbula* bed." (See pl. 15 and fig. 7.) September 28, 1954.

f20111, Kendall County, Tex. Glen Rose limestone. First outcrop on north bank of Wasp Creek between the creek and A. Herbst Ranch house; 102 feet below the "*Corbula* bed". Collection taken from 8 feet of light-colored silty lime and limestone. (See fig. 8.) September 29, 1954.

f20112, Kendall County, Tex. Glen Rose limestone; 78–80 feet below "*Corbula* bed" on Herbst Ranch between Wasp Creek and the Herbst Ranch house. (See fig. 8.) September 29, 1954.

f20113, Kendall County, Tex. Glen Rose limestone; 114 feet below "*Corbula* bed." Wasp Creek where Boerne-Sisterdale road crosses the stream bed, in south bank, about 5 feet above base of stream bed. (See fig. 8.) September 29, 1954.

Section 8, collections f20114–f20117. Bandera County, Tex. Upper part of the Glen Rose limestone and the overlying Walnut clay and Comanche Peak (?) limestone, starting just below the outcrops of the "*Corbula* bed" on the county road leading into El Paraiso Ranch, and measuring up over the falls at "lovers leap." (See pl. 15 and fig. 9.) October 1, 1954.

Section 9, collections f20118–f20138. Brewster County, Tex. Section including 513 feet of Glen Rose equivalents in the west-central part of Hood Springs quadrangle. The line of section is approximately that described by R. W. Graves, Jr. (1954, p. 17). (See pl. 15 and fig. 10.) October 3 and 4, 1954.

Section 10, collections f20139–f20153. Presidio County, Tex. Section including about 1,880 feet of the Glen Rose limestone from the top of the Cow Creek (?) limestone member of the Travis Peak forma-

[3] See footnote on page 2.

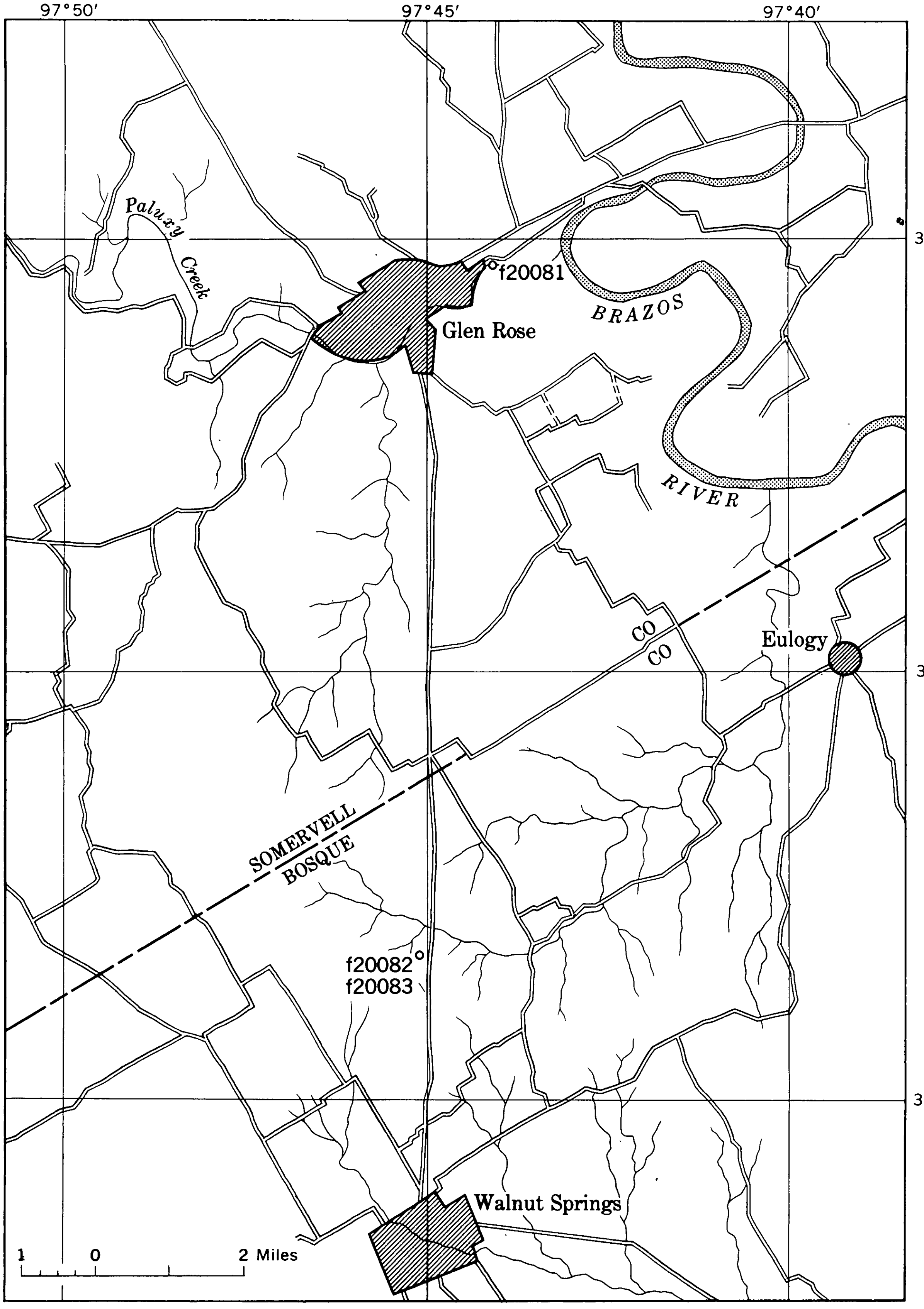

FIGURE 5.—Index to localities in Bosque and Somervell Counties, Tex.

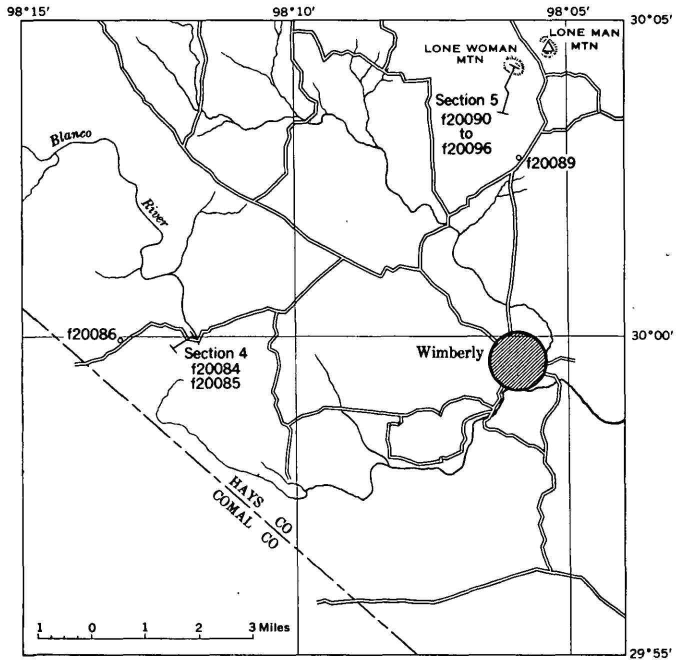

FIGURE 6.—Index to localities in Hays County, Tex.

tion to the summit of Fresno Peak on the southwest rim of Solitario dome. (See pl. 16 and fig. 11.) October 6 and 7, 1954.

Section 11, collections f20154–f20161. Presidio County, Tex. Section of the exposed Shafter and Finlay limestones in the hills 3 miles southwest of the town of Shafter. (See pl. 16 and fig. 11.) The section was started in a narrow gorge west of U.S. Highway 67 at a point where a small concrete dam had washed out. October 8, 1954.

Section 12, collections f20162–f20170. Presidio County, Tex. Shafter limestone on the T. Sheley Ranch, north of the Marfa to Ruidosa road at the break in topography between the plain and the valley of the Rio Grande. (See pl. 16.) October 9, 1954.

Section 13, collections f20171–f20177. Hudspeth County, Tex. Glen Rose limestone exposed in the Carroll Hills along the line of section 2 of C. C. Albritton (1938, p. 1770). (See pl. 16 and fig. 12.) October 10, 1954.

Section 14, collections f20178–f20183, and f20192. Hudspeth County, Tex. Bluff formation of Smith (1940, p. 609) on Yucca Mesa, approximately paralleling section 2 of Smith (1940, p. 620). (See pl. 16 and fig. 12.) October 11 and 12, 1954.

f20184, Hudspeth County, Tex. Finlay limestone. Texan Mountain just south of Sierra Blanca on Quitman Pass road. Mapped by Huffington (1943) as Finlay formation overlying Cox formation. (See fig. 12.) October 11, 1954.

Section 15, collections f20185–f20191. Hudspeth County, Tex. Section of the Bluff formation of Huffington (1943, p. 1000), just north of Quitman Pass and southeast of the county road in outcrops dipping steeply, 75°–80° E. Below—to the west—of the collections are more or less massive limestones with mulluscan shell material. They form the last outcropping ridge on the south side of the road, northeast of Quitman Pass. (See pl. 16 and fig. 12.)

Section 16, collections f20193–f20208. Hudspeth County, Tex. Glen Rose limestone of the southern Quitman Mountains, starting at the base of the limeston cliff on the east side of Mayfield Canyon and approximately following the section of Gayle Scott (1940, p. 981, pl. 55). (See pl. 16 and fig. 12.) October 14, 1954.

NEW MEXICO

Section 17, collections f20210–f20212. Grant County, N. Mex. Type Howells Ridge formation starting at the conglomerate on the east slope of Howells Ridge—the first unit of a conformable sequence overlying a faulted and contorted section of shales with intrusive rocks—and measuring to the crest of Howells Ridge. (See pl. 17, and fig. 13.) October 19, 1954.

Section 18, collections f20213–f20221. Grant County, N. Mex. Type Broken Jug limestone west of the King 500 vein, northwest of Old Hachita. Starting at the base of the massive limestone northwest of the intrusive just west of King 500 vein. This is the lowest trustworthy sequence in the Broken Jug limestone of the Eureka area. Below this horizon the beds have many intrusive rocks except for a short section at the base by the King vein. (See pl. 17 and fig. 13.) October 20, 1954.

Section 19, collection f20222–f20230. Grant County, N. Mex. Type Playas Peak formation following the line of the section measured for Lasky (1947, p. 25), starting at the fault contact between the Playas Peak formation and the Corbett sandstone, and ending at the axis of a small syncline. (See pl. 17 and fig. 13.) October 20, 1954.

f20231, Hidalgo County, N. Mex. Howells Ridge formation. In minor structure on south side of Howells Wells syncline in area between Howells fault and Copper Dick fault. Just north of the center of sec. 23, T. 28 S., R. 16 W. Collection from massive to thick-bedded blue-gray limestone with large Orbitolinas. (See fig. 13.) October 21, 1954.

f20232, Grant County, N. Mex. Howells Ridge formation. Basal conglomerate(?) of Howells Ridge formation in sec. 33, T. 27 S., R. 16 W., Grant County, N. Mex. Just south of Miss Pickle fault along line of section given by Lasky (1947) of Howells Ridge formation. Basal conglomerate is composed of rounded pebbles and cobbles of limestone, chert, quartzite, and sandstone in a limestone matrix. Many of the limestone pebbles contain crinoid columnals and those collected contain fusulinids. None of the pebbles or cobbles seen contained any Cretaceous forms. (See fig. 13.) October 22, 1954.

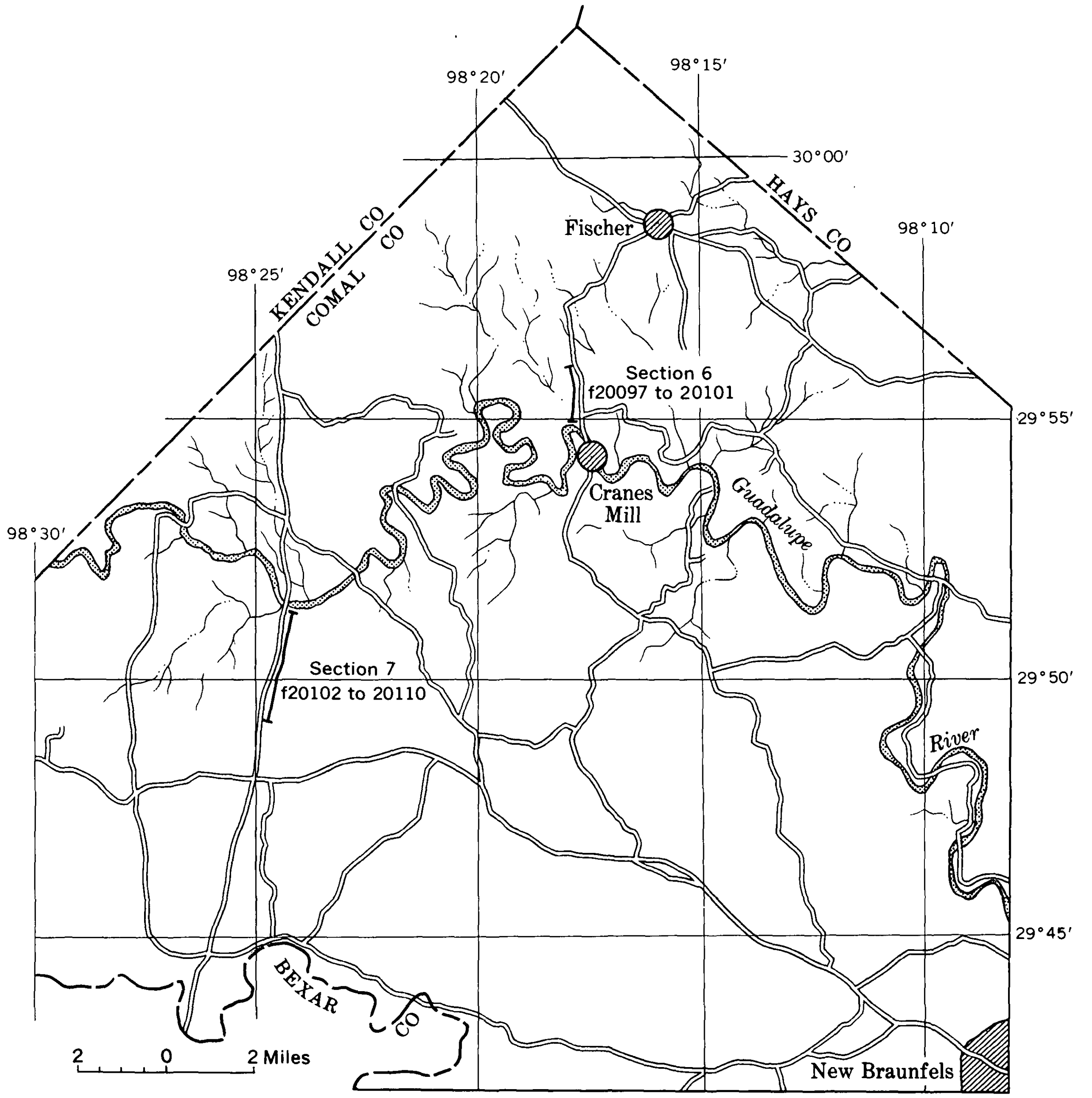

FIGURE 7.—Index to localities in Comal County, Tex.

Section 20, collections f20233, 34. Grant County, N. Mex. Section of Howells Ridge formation in the area north of Playas Peak approximately along the line of section indicated by S. G. Lasky (1947, p. 22). (Pl. 17 and fig. 13.) October 22, 1954.

Section 21, collections f20235–f20238. Grant County, N. Mex. Section of the Howells Ridge formation in the prominent hogback just north of Playas Peak. (See pl. 17 and fig. 13.) October 22, 1954.

f20239, Grant County, N. Mex. Howells Ridge formation. Limestone at top of massive limestone just below Corbett sandstone in NE¼ sec. 4, T. 28 S., R. 16 W., Grant County, N. Mex. Relation of limestone to overlying beds is uncertain, although at this particular point the relationship does not appear to be discordant. (See fig. 13.) October 22, 1954.

f20240, Hidalgo County, N. Mex. Howells Ridge formation, just below crest of high cliff at northwest end of syncline in west side of Big Hatchet Mountains in southwest corner of T. 31 S., R. 15 W., Hidalgo County, N. Mex. *Orbitolina* present locally in what looks like rock that has been squeezed in. October 23, 1954.

f20240a, Hidalgo County, N. Mex. Same as f20240 but definitely from a bed of limestone about 6 feet below crest of ridge. Just south of f20240. October 23, 1954.

ARIZONA

Section 22, collections f20241–f20245. Cochise County, Ariz. Mural limestone at Lees siding, about

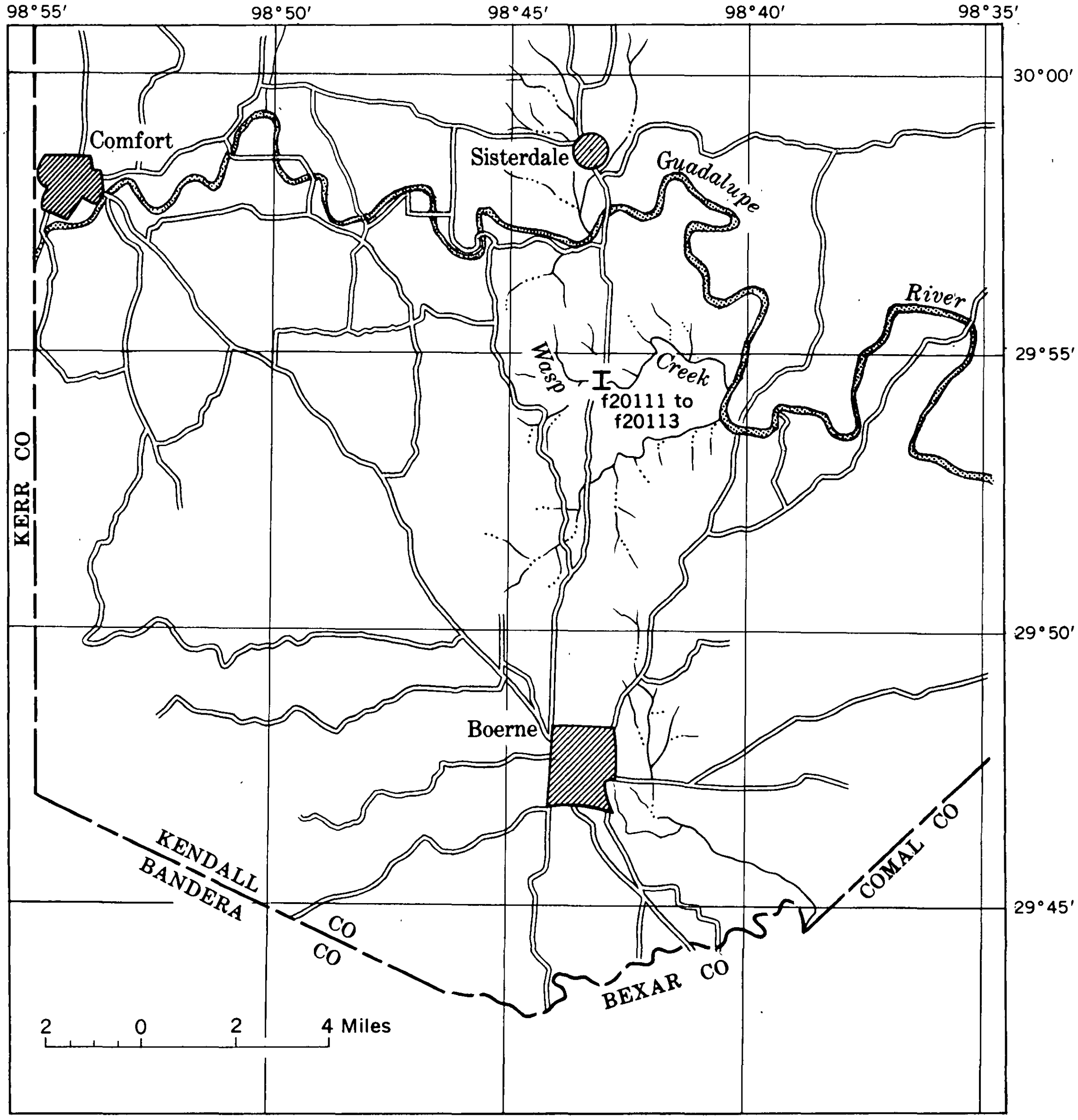

FIGURE 8.—Index to localities in Kendall County, Tex.

10 miles north-northeast of Douglas, in a quarry in T. 22 S., R. 28 E. (See pl. 17.) October 25, 1954.

Section 23, collections f20246–f20255 and f20273–f20279. Cochise County, Ariz. Mural limestone in the eastern part of the Mule Mountains north of U.S. Highway 80 and about 3 miles east of the circle in Lowell or 6 miles east of Bisbee; secs. 7 and 18, T. 23 S., R. 25 E. (See pl. 17 and fig. 14.) October 25 and 27, 1954.

Section 24, collections f20256–f20260. Cochise County, Ariz. Mural limestone in the Guadalupe Mountains near the Arizona–New Mexico border in T. 24 S., R. 32 E. (See pl. 17.) October 26, 1954.

Section 25, collections f20261–f20272. Chochise County, Ariz. Mural limestone in the 91 Hills area south of Bisbee Junction and just north of monument 91 on the international boundary, in sec. 14, T. 24 S., R. 24 E. (See pl. 17 and fig. 14.) October 27, 1954.

MISCELLANEOUS OCCURRENCES

Charente, Maritime, France. Cenomanian. Thick limestone with *Orbitolina concava* (Lamarck) at the top of the sea cliff along the seacoast near the site of old Fort Piedmont, to the south of the mouth of the Charente River. Collection by A. R. Loeblich, Jr.

Ain, France. Aptian (Urgo-Aptian facies). *Orbitolina lenticularis* (Blumenbach) at La Perte du Rhône, Bellegarde sur Valserine. Obtained by A. R. Loeblich, Jr. This is the type locality for *O. lenticularis*.

South Devon, England. Cenomanian. *Orbitolina concava* (Lamarck) from Smallacombe Gayle near Dawlish. Collected by A. G. Davis.

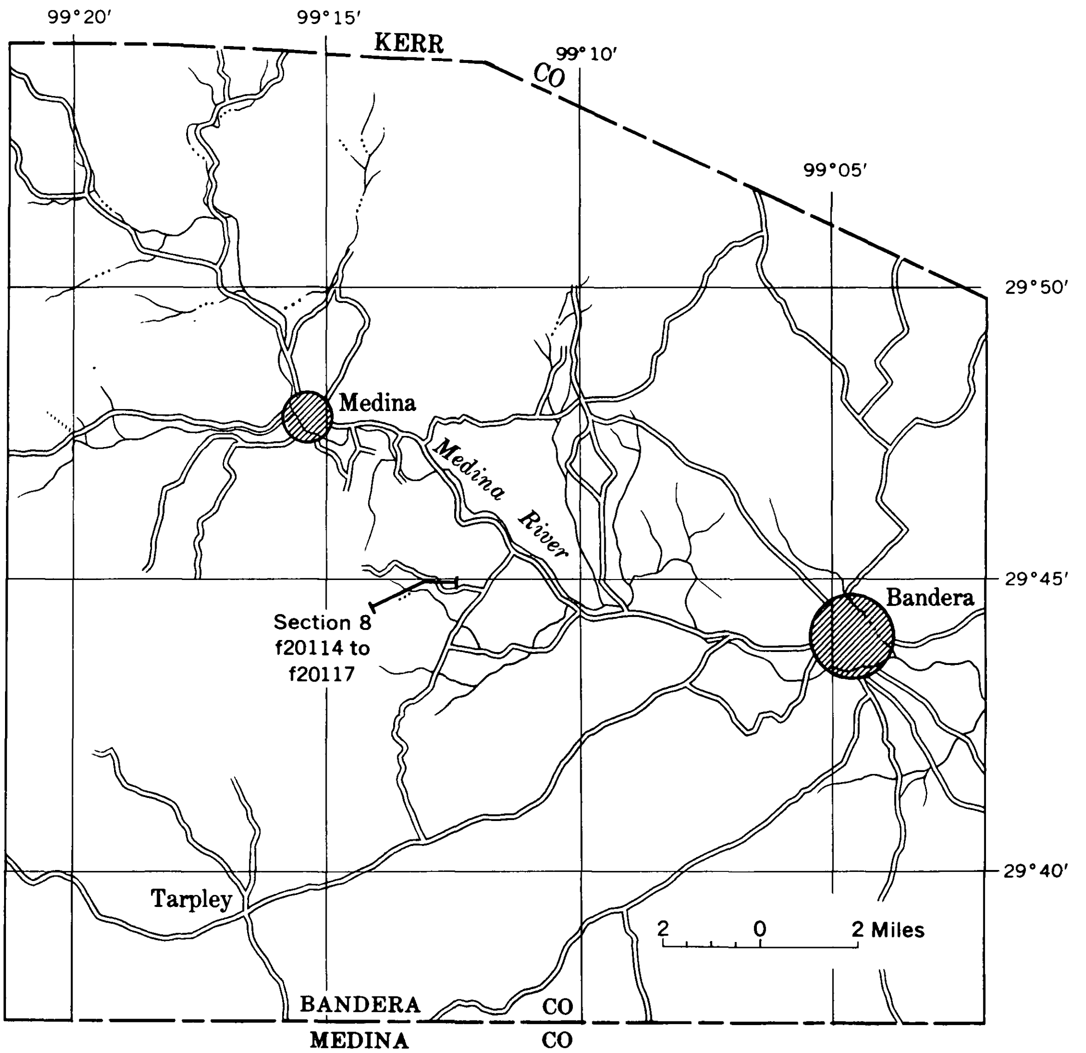

FIGURE 9.—Index to localities in Bandera County, Tex.

MORPHOLOGY OF *ORBITOLINA*

EARLY CONCEPTS AND METHODS OF DESCRIPTION

The forms now recognized as *Orbitolina* were recorded first by G. A. Deluc (1799, p. 216). He did not name them, but gave a recognizable description of the Orbitolinas from the Perte du Rhône in France. He described the size, shape, and surface structures of both sides of the test and noted a few specimens which appeared to differ from the rest in shape and organization. The internal structures were not discussed.

Orbitolina was recognized as a distinct genus by Alcide d'Orbigny (1850, p. 143). He recognized *Orbitolina* as differing from *Orbitolites* in having unequal sides, one encrusting, the other with radiating cells. This concept was partly erroneous and several of the forms included by d'Orbigny have been reassigned to other families and even to other phyla.

Early authors stressed size and shape differences in discriminating species of *Orbitolina*, and little attention was given to internal structure. Notable exceptions were Martin (1889) and H. Douvillé (1904) who made more detailed studies of the internal structures. Martin's illustrations of the internal structures of specimens from Borneo (Martin 1889, pl. 24, 25) are probably the most detailed available. More recently L. M. Davies (1939) and F. R. S. Henson (1948) have presented some details of the morphology of *Orbitolina*. The following review of the morphology of *Orbitolina* draws heavily on the previous studies, but is based, primarily, on specimens and thin sections in the available collections.

Throughout the following discussion the relationship between the internal structures of *Orbitolina* can be visualized more easily by referring to the cutaway reconstructions (figs. 15, 16).

EXTERNAL CHARACTERS

The test of *Orbitolina* occurs in a variety of forms from high conical through discoidal to reflexed conico-

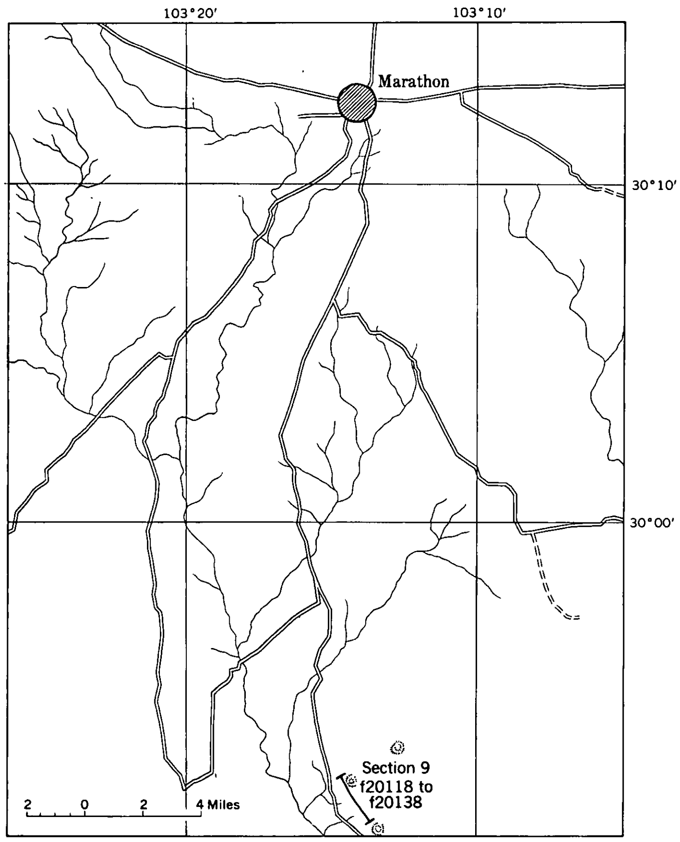

FIGURE 10.—Index to localities in Brewster County, Tex.

convex (fig. 17). Specimens range in size to about 30 mm in diameter. The size of a specimen is generally reported by giving at least two dimensions. The dimensions most commonly given are diameter and height although early authors often reported thickness.

Height is unambiguous in conical forms, but in discoidal and reflexed forms the dimension of height may not be clear. In this report height is recorded as the distance between the apex of the cone and a plane perpendicular to the axis passing through the point of maximum axial extension (fig. 18). Diameter is the maximum dimension perpendicular to the axis, and thickness (in low discoidal and reflexed forms) is the distance perpendicular to a tangent to the dorsal surface.

The apex of the cone may be one of several shapes depending on the type of embryonic apparatus developed. Figure 19 illustrates some of the more common apices. Occasionally specimens develop from twinned embryos forming peculiar shaped tests, some of which are saddle shaped or flaring, as in figures 13–15 on plate 4.

In addition to the variation in shape caused by greater or lesser convexity, as shown in figure 17, some specimens have undulating surfaces and may develop scalloped rims due to irregular growth. The dorsal surfaces of many specimens appear corrugated from the rounded outer edges of the septa or concentric lamellae.

ORIENTATION, AND TERMINOLOGY OF THIN SECTIONS

Orbitolina is considered to be a bottom-dwelling form which crept around on the substratum. Openings to the exterior are confined to the base of the cone, suggesting that it lived with the base of the more or less conical test down. This may then be considered the normal position (p. 23). The apex of the cone may then be taken as the dorsal or aboral surface and the base of the cone as the ventral or oral side.

Sections of the test cut in different planes present different aspects of structures and are not easily correlated. For comparative purposes it is important to know the position or orientation of a section. Some of the terminology used for sections by other authors is given in the glossary of special terms (p. 23). Figure 20 illustrates the nomenclature used in this report.

INTERNAL CHARACTERS

General plan of development and ontogeny. The test of *Orbitolina* is essentially a single series of shallow cuplike chambers increasing in diameter more or less regularly, forming a modified cone. At or near the apex of the cone is a proloculus from which growth started. Each succeeding chamber is subdivided internally by various partitions and plates limiting the chamber space to passages, chamberlets, and cellules.

The test starts with an embryonic apparatus (described below). A chamber is added to its base and each succeeding chamber is added to the base of the last-formed chamber, forming a uniserial, rectilinear series. The chamber is apparently not added all at once. Many specimens have a smooth lower surface, indicating deposition of the septum over the last-formed chamber. Other specimens do not have this smooth septal wall. On these the main partitions and the reticulate zone are visible. Henson (1948, p. 37) suggests that in these specimens the new chamber floor (septum) has not yet been formed.

Each successive chamber is not generally of constant height throughout. The chamber height may decrease inward from the periphery, becoming least in the area of the central complex. Some of the chambers of the low-coned forms tend to thin out completely toward the center, forming annular chambers. (See fig. 21.)

GENERAL CHARACTER OF THE THREE ZONES

Each adult chamber in *Orbitolina* is essentially a shallow cup added on to the previously developed part of the shell. The cup can be divided into three gen-

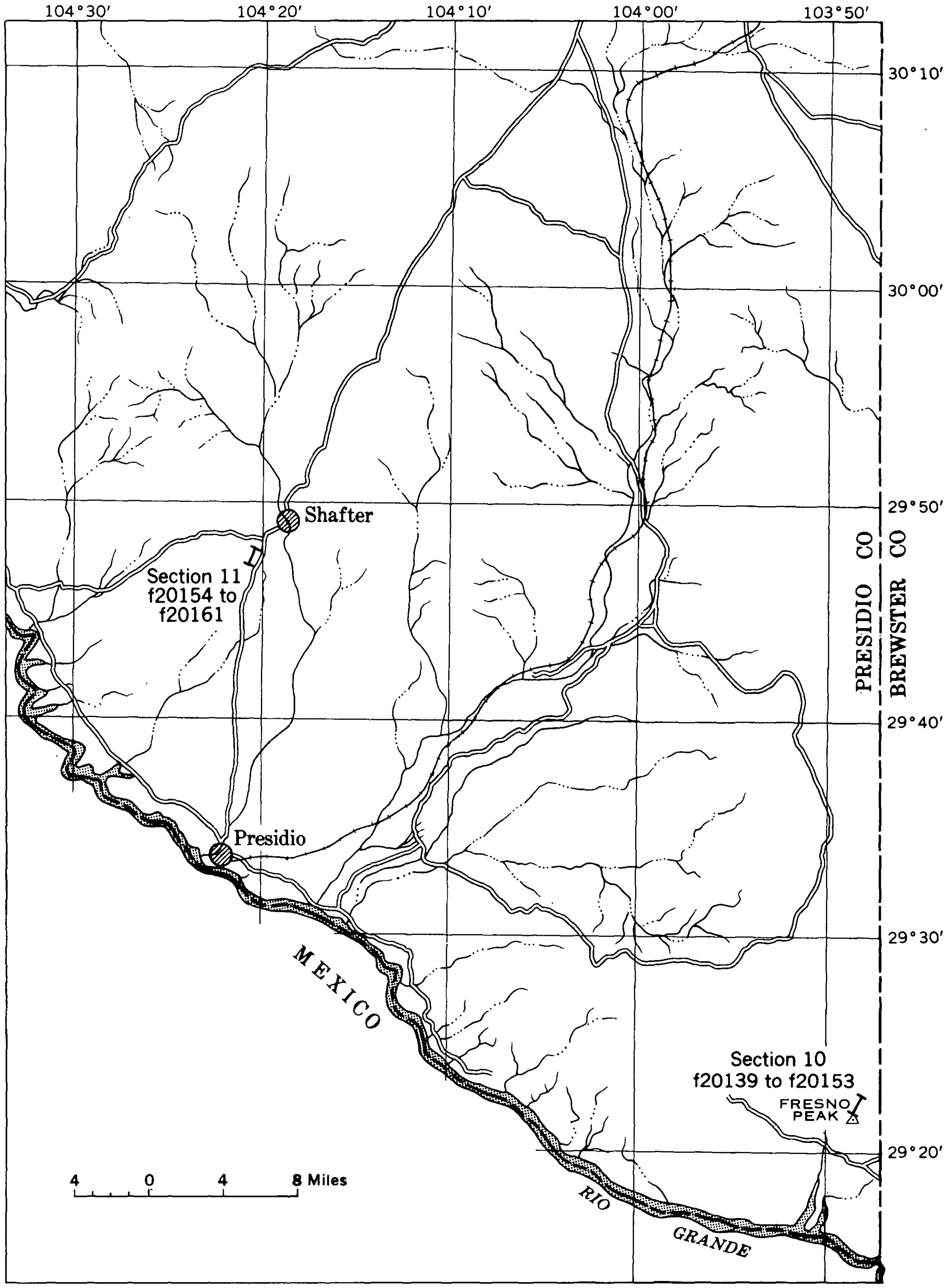

FIGURE 11.—Index to localities in Presidio County, Tex.

eral zones: a central complex with relatively unorganized structure, a radial zone in which the main elements are radially disposed, and the subdivided marginal zone.

In some specimens the central complex occupies the major portion of the shell, while in others the radial zone is better developed. The marginal zone is always a minor element in the adult chambers, but it maintains

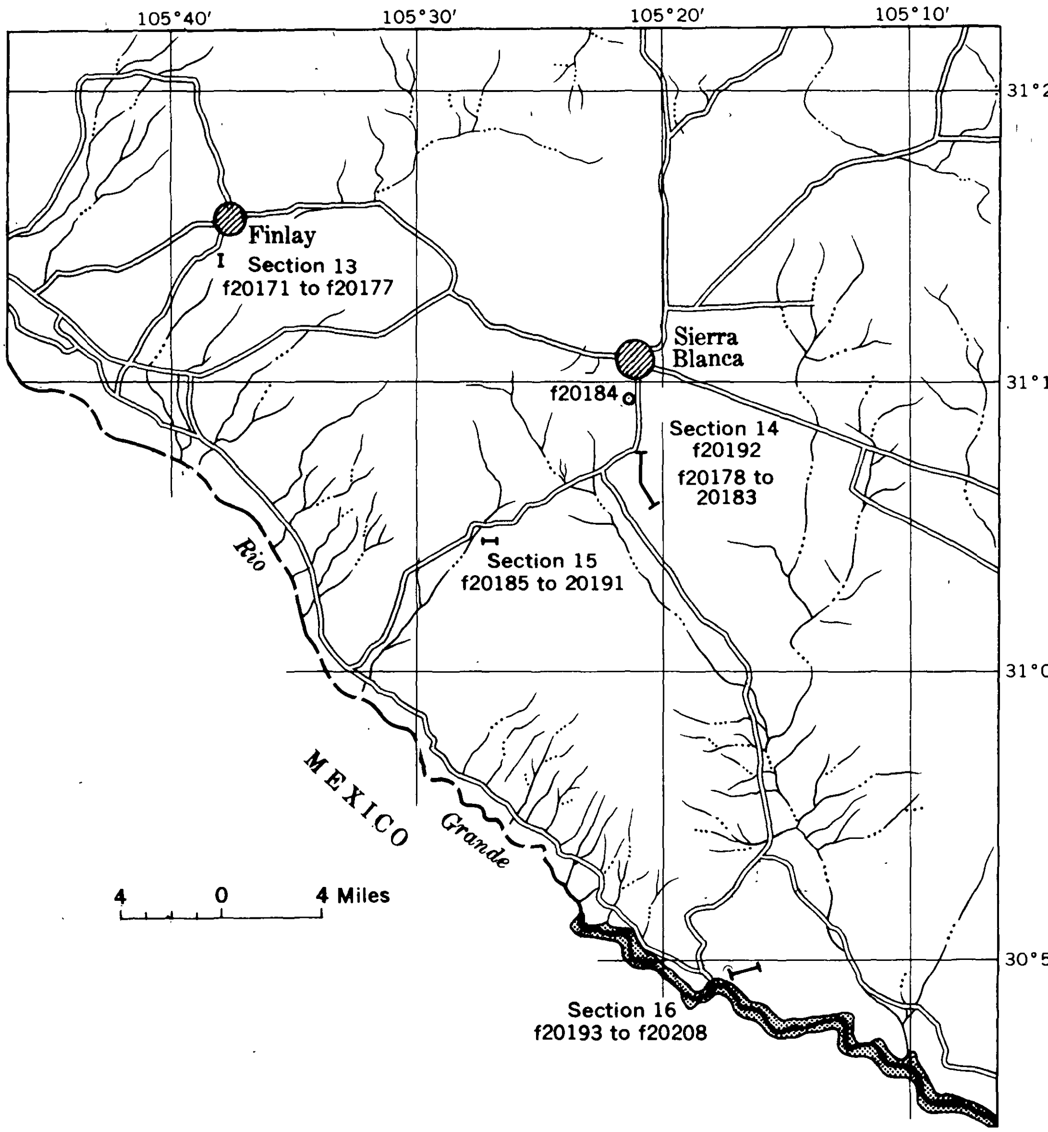

FIGURE 12.—Index to localities in Hudspeth County, Tex.

a nearly constant thickness and, therefore, occupies a large part of the early chambers.

DETAILS OF THE MARGINAL ZONE

The marginal zone includes the outer subdivided portion of each chamber. The septum (floor) of each chamber is recurved toward the apex and fused to the preceding chamber margin, thus forming the dorsal surface to the test. (Fig. 22, and pl. 8, fig. 3). The recurved edges or concentric lamellae may turn sharply and present a flattened surface, or they may be rounded, producing a corrugated dorsal surface on the test.

The marginal zone is intricately subdivided by numerous plates and partitions. As will be seen, main partitions extend through the radial zone into the marginal zone, dividing this portion of each chamber into chamberlets. The marginal chamberlets are in turn subdivided by vertical and horizontal plates into small subrectangular cellules. (Fig. 23.) The main partitions tend to alternate in position between chambers producing a pattern resembling brick work when viewed in tangential section. This character is also seen in some axial sections as a pattern of alternating shaded and clear areas developed in the marginal part of the chambers.

There may be one or more series of vertical and horizontal plates subdividing the marginal chamberlets. The primary vertical and horizontal plates tend to divide each chamberlet into four cellules. The primary vertical plates are longer along the base next to the septal floor than they are toward the top of the chamber, so that deep tangential sections in the marginal zone show primary vertical plates as incomplete.

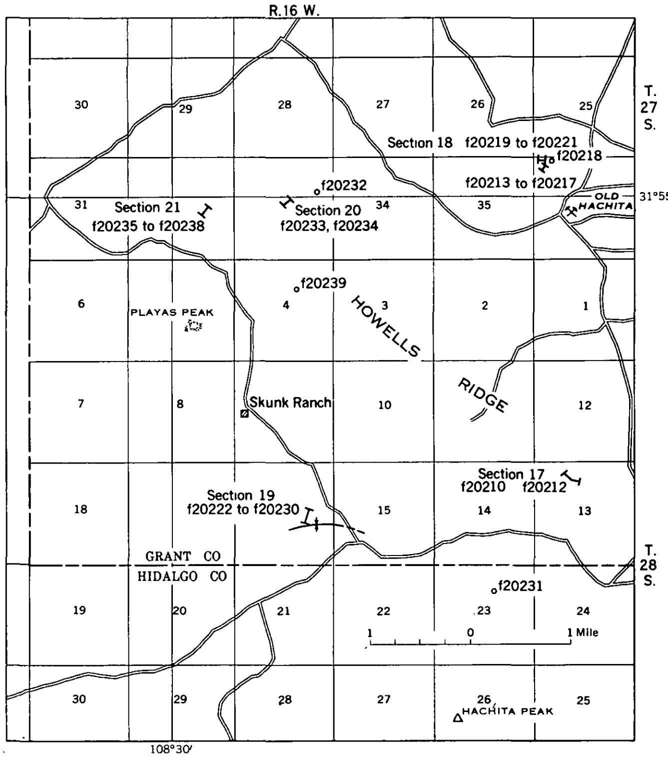

FIGURE 13.—Index to localities in New Mexico.

(Pl. 6, fig. 13.) The secondary vertical plates are probably of the same nature, as subdivisions are often apparent in the lower half of a chamberlet and do not appear in the upper half. The secondary vertical and horizontal plates tend to subdivide the cellules more finely, producing a fine grid which may be seen most easily on the dorsal surface of complete or only slightly abraded specimens.

DETAILS OF THE RADIAL ZONE

The radial zone includes the area between the marginal zone and the central complex. Within this zone each chamber is subdivided into radial passages by the main partitions. The main partitions are irregularly radial elements of shell material which extend from the central complex through the radial and marginal zones. In the marginal zone they are seen as simple wall-like partitions. As they enter the radial zone from the margin the partitions are generally thickened toward the septum of the previous chamber. (Fig. 15.) In addition, they attain a zigzag shape which continues to the central complex. The zigzag pattern is more pronounced along the unthickened lower edge of the partition (fig. 16) than at the top, where the thickening tends to even out the undulations.

The radial zone is the main living space for the protoplasm in *Orbitolina*. Although the marginal

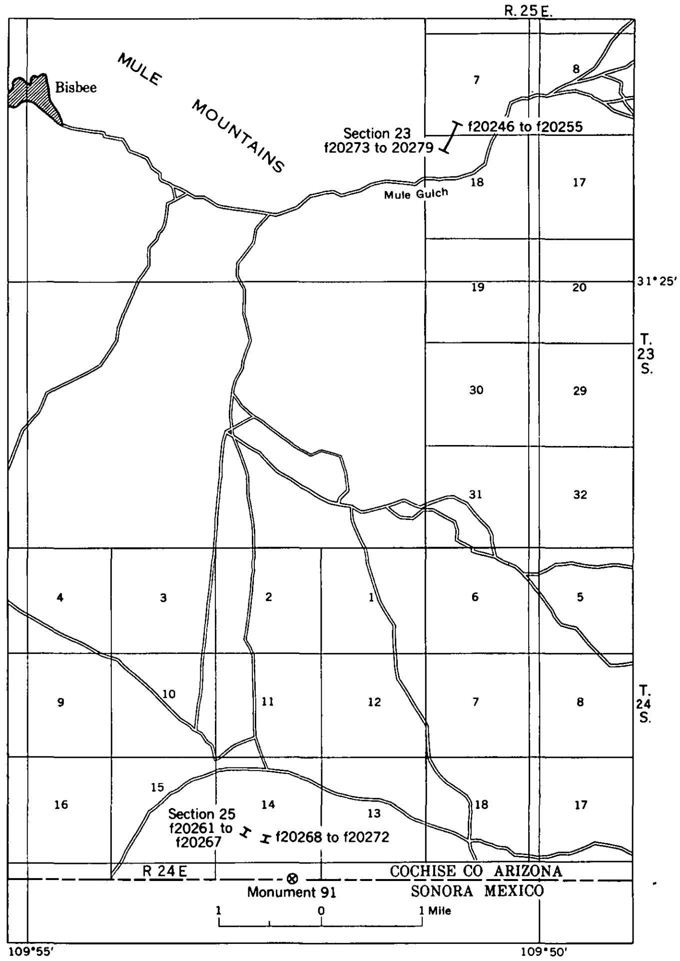

FIGURE 14.—Index to localities in Arizona.

zone is more open, it is restricted to the periphery of each chamber, and the central zone is often clogged with detrital material and so thin that little space is left. From each radial chamber passage there is communication both with adjacent passages and with the preceding and succeeding chambers (or the exterior).

Apertural pores, which provide for communication between adjacent chambers, are generally at the reentrants of the zigzag lines. The apertural pores may be seen in axial sections as breaks in the septa, as in plate 8, figure 4, but are best seen in basal sections which graze the surface of a septum, as in plate 8, figure 10. Communication between adjacent chamber passages within a given chamber is by partitional pores. These are located in the lower part of the main partitions (see pl. 6, fig. 11). Many authors have not recognized the partitional pores and have suggested no direct connection between parts of the protoplasm within a chamber. Martin, however, recognized these pores and illustrated them as part of what he called the canal system (Martin, 1889, pls. 24, 25).

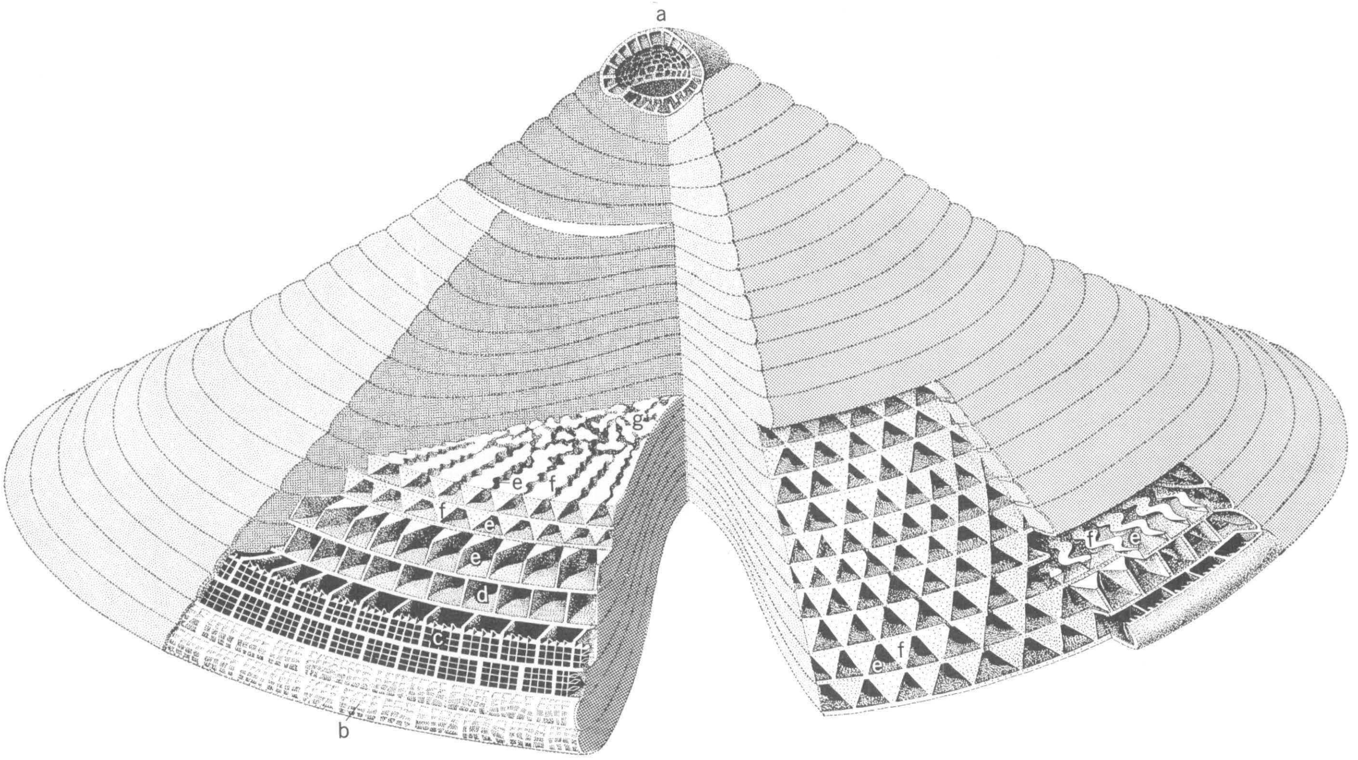

FIGURE 15.—Reconstruction *of Orbitolina* cut away in several planes to show the internal structures. *a*, megalospheric embryonic apparatus; *b*, slightly eroded surface exposing cellules, *c*, marginal zone with surface cut away, *d*, deeper cut exposing chamberlets, *e*, radial chamber passages, *f*, main partitions showing the triangular shape and zigzag nature, *g*, central complex.

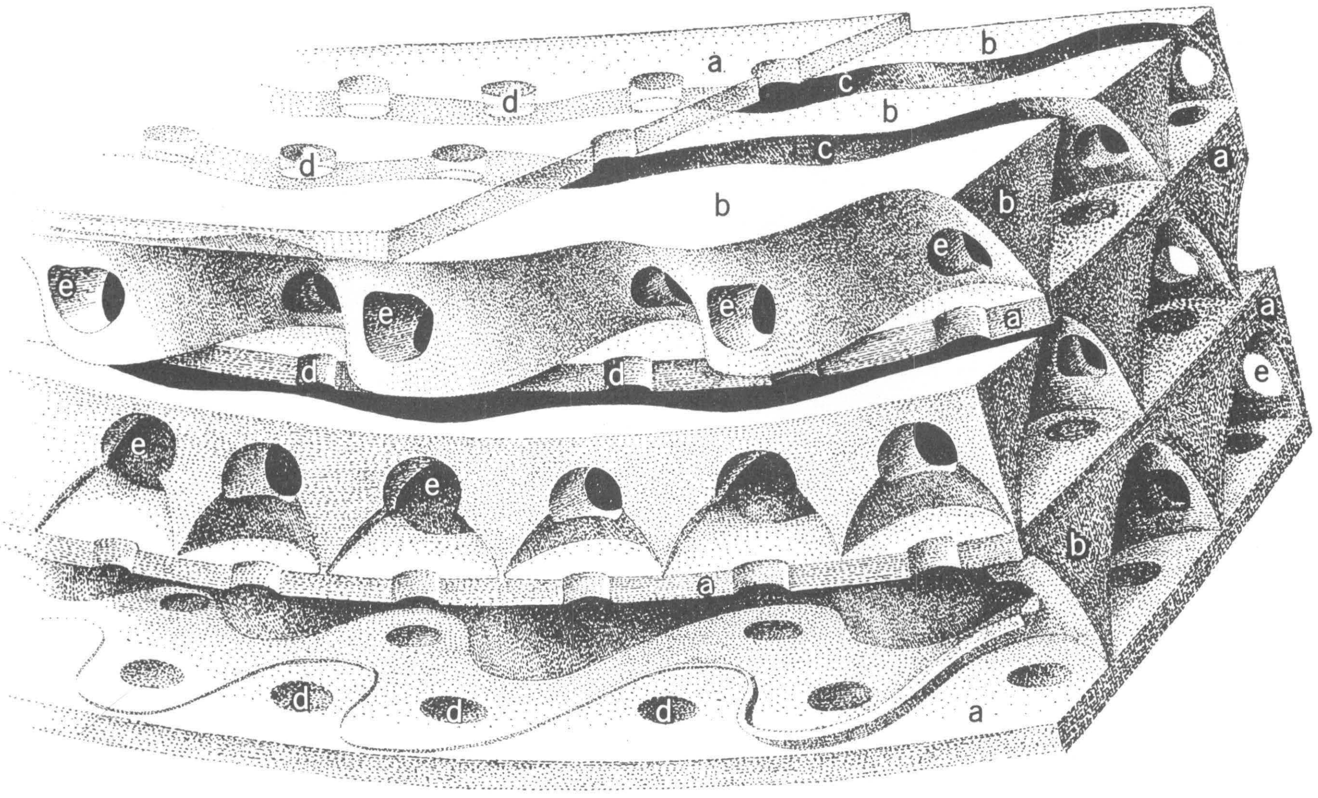

FIGURE 16.—Reconstruction of a part of the radial zone cut away in several planes. *a*, septa, *b*, main partitions, *c*, chamber passages, *d*, apertural pores, *e*, partitional pores.

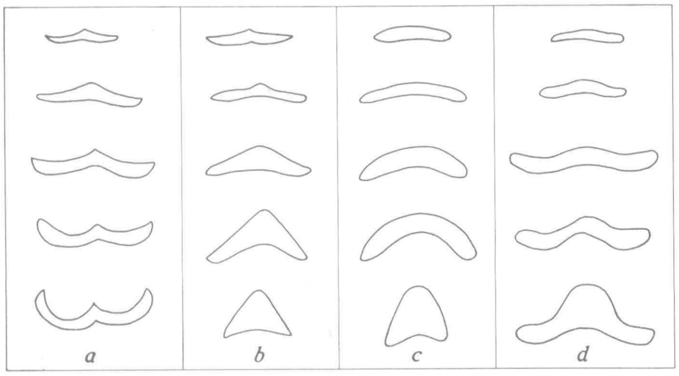

FIGURE 17.—Variation in shape of *Orbitolina* as seen in well-oriented axial sections. Column *a*, reflexed conical forms; column *b*, conical forms; column *c*, convex forms; column *d*, reflexed convex forms.

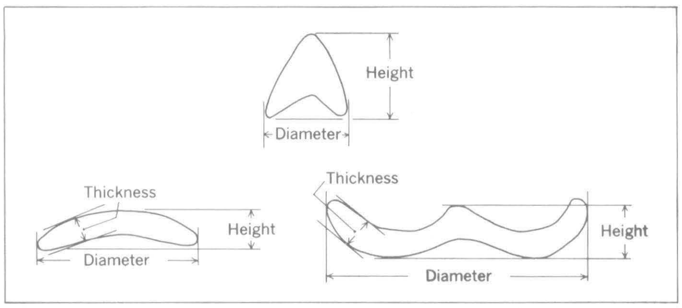

FIGURE 18.—Positions for measuring diameter, height, and thickness on conical, low convexo-concave, and reflexed specimens.

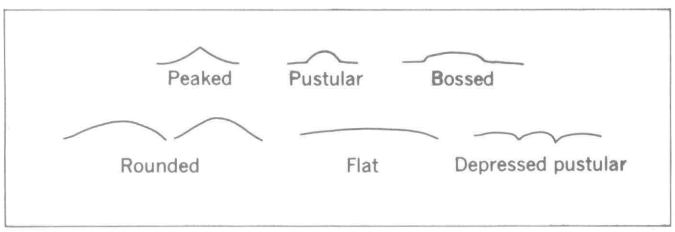

FIGURE 19.—Forms of the apex of *Orbitolina*.

DETAILS OF THE CENTRAL COMPLEX

The radial elements within each chamber tend to lose their identity toward the axis of the specimen in the area called the central complex. The central complex may occupy only the innermost portions of each chamber, or it may extend out nearly to the marginal zone leaving a restricted radial zone in between. The main partitions tend to be broken up in the central complex largely because of an increase in number and possibly in size of the partitional pores. The partitions also tend to bifurcate and become discontinuous as they are crowded toward the center of the chamber. In some specimens large amounts of detrital material are accumulated in the central complex, reducing the amount of open space for the protoplasm. The thinning of each chamber in the central zone also limits the amount of living space.

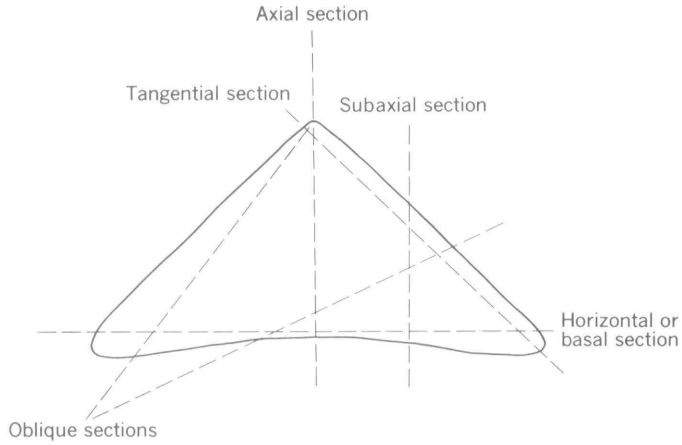

FIGURE 20.—Thin-section terminology.

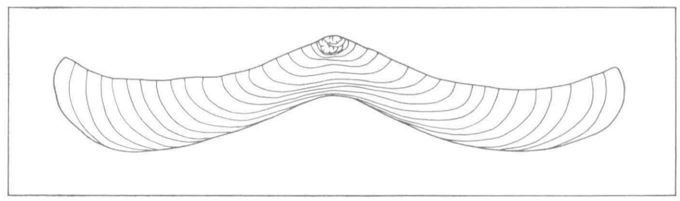

FIGURE 21.—Development of annular chambers in some Orbitolinas.

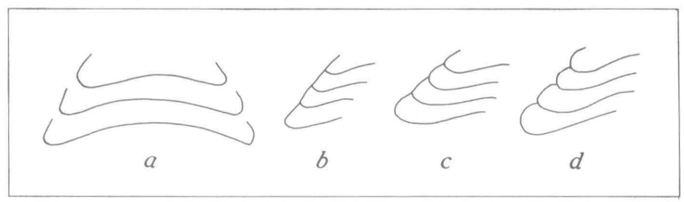

FIGURE 22.—The dorsal surface formed by the recurved edges of the septa. *a*, The chambers shown separated; *b*, concentric lamellae flush; *c*, slightly rounded; *d*, rounded, producing a corrugated dorsal surface.

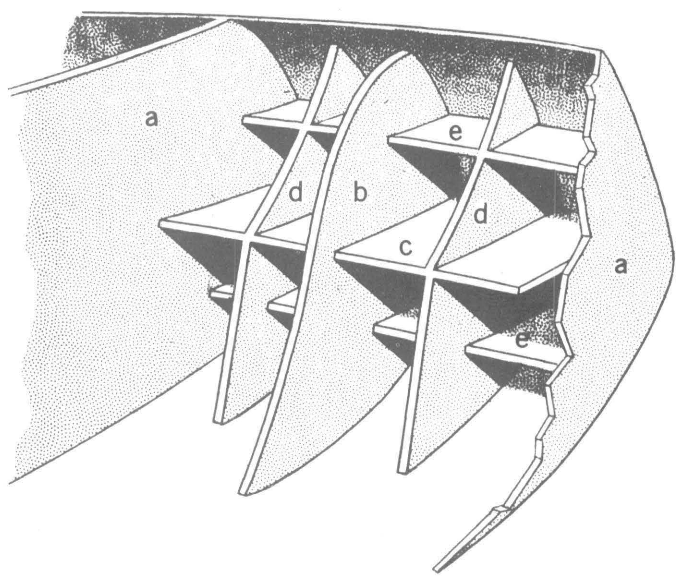

FIGURE 23.—Subdivisions of the marginal zone. *a*, main partitions, *b*, vertical primary plates, *c*, horizontal primary plate, *d*, vertical secondary plate, *e*, horizontal secondary plate.

Specimens which have calcite eyes generally have them concentrated in the area of the central complex with only scattered eyes in the radial zone.

THE EMBRYONIC APPARATUS

There are two general types of embryonic apparatus in *Orbitolina*. One is initiated with a relatively large chamber and is called megalospheric; the other is initiated with a relatively small chamber and is called microspheric.

The megalospheric embryonic apparatus has a hemispherical to spherical undivided proloculus, around the top of which is generally developed an area resembling the marginal zone of later chambers. This supraembryonic area commonly has a larger diameter than the proloculus. It is subdivided irregularly into cellules by small partitions probably homologous with the primary and secondary plates of the marginal zone. (See figs. 15, 24, and pl. 6, fig. 4.)

Most of the species studied have a second embryonic or periembryonic chamber lying immediately ventral to the proloculus. This chamber has a shallow bowl shape with about the same diameter as the supraembryonic area and may or may not be subdivided by primary and secondary plates. In some specimens this periembryonic chamber is subdivided by structures resembling the outer edges of the main partitions, which anastomose simply toward the axial area of the chamber.

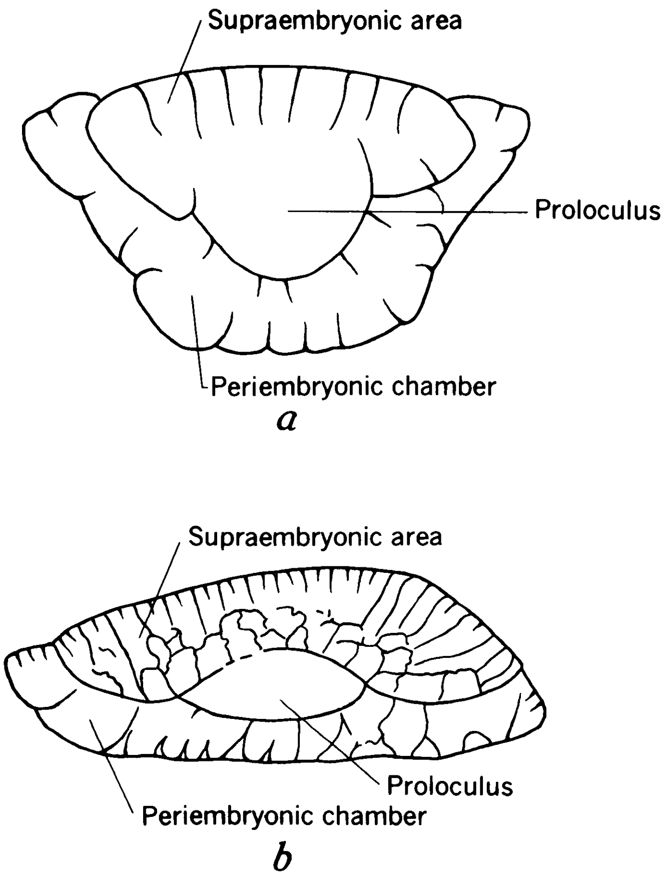

FIGURE 24.—The megalospheric embryonic apparatus in *Orbitolina*. *a*, *O. minuta* from the upper part of the Glen Rose limestone. *b*, *O. concava* from the Cenomanian of Ballon, France.

Henson (1948, p. 45–47, figs. 10, 11) described and illustrated some typical megalospheric embryos from southwestern Asia. No embryos of the type shown in his figure 11 a–c were found in the available collections. The periembryonic chambers shown surround the proloculus laterally but do not cover its ventral surface. This type of embryonic apparatus seems to be present in his illustrations of *Orbitolina* cf. *O. discoidea* (his pl. 2, figs. 1–3).

The protoplasm in the proloculus has access to the ventral periembryonic chamber by means of a pore or pores, as seen in plate 7, figure 25 and it has direct access to the supraembryonic area. Neanic chambers are added ventrally to the embryonic apparatus and generally show incipient development of the three zones found in the ephebic chambers.

The embryonic apparatus of microspheric forms is poorly known for most species. It is generally described as a trochoid spire, but its character has never been illustrated. This is due, perhaps, to the difficulty of locating the microspheric apex and of cutting a section which will contain the embryonic apparatus. Of the several thousand random sections of *Orbitolina* available in this study only a few were cut near the microspheric proloculus. On many of the free specimens, especially those of *Orbitolina texana*, the microspheric embryonic area could be seen at the apex as a small planispiral flaring coil at right angles to the axis of the cone. (See text fig. 25.) This type of coiling can be seen in some axial sections (pl. 12, fig. 16). The microspheric proloculus is apparently minute, but the best oriented sections available have not shown it clearly, so the actual size is unknown. The nepionic chambers forming the spire increase in size gradually for about one-half of a turn then flare

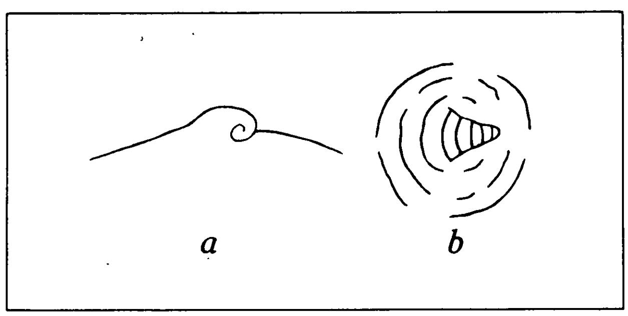

FIGURE 25.—Microspheric apex, *a*, as seen in axial section, *b*, as seen from above.

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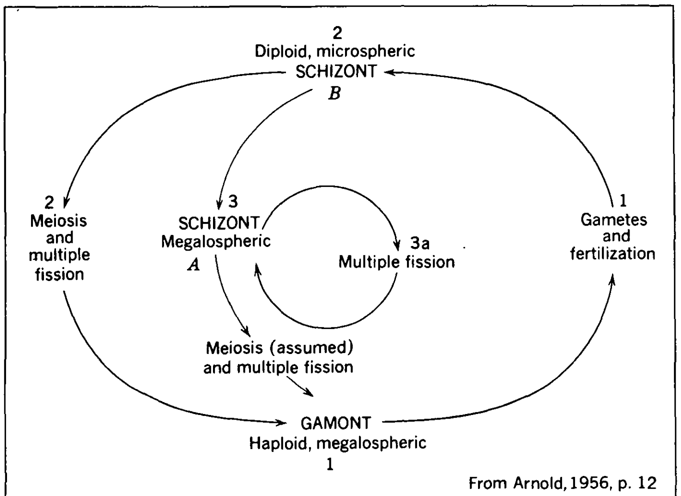
rapidly so that by little more than a full turn they have flared like the bell of a bass tuba. The neanic chambers are saucer or bowl shaped and are added ventrally; these start to develop the cone of the adult.

DIMORPHISM

The two types of embryonic apparatus described above have been ascribed to dimorphism. The summary by Le Calvez (1953, p. 182–200) of the life cycle of some living Foraminifera helps explain the differences in embryonic apparatus found in *Orbitolina.* Figure 26 adapted by Arnold (1956, p. 12) from Le Calvez shows the different methods of reproduction in some Foraminifera. From this it can be interpreted that microspheric schizonts may produce either megalospheric gamonts or megalospheric schizonts and that megalospheric schizonts must produce megalospheric gamonts before microspheric schizonts can be produced. This means that many more megalospheric than microspheric specimens should be found in a population. This is found to be the case with samples of *Orbitolina.* There are many more megalospheric specimens in any one sample than there are microspheric specimens in the sample.

There is no microspheric form known for several species of *Orbitolina.* This may be because they have not been found or recognized, but it may also be because the species is not dimorphic. Le Calvez has shown (1953, p. 195) that different species of what he considered to be the same genus may have different methods of reproduction. *Discorbis patelliformis*, for example, reproduces with alternation of generations between microspheric schizonts and megalospheric gamonts. *Discorbis orbicularis*, on the other hand, reproduces through a series of megalospheric schizonts without producing megalospheric gamonts or microspheric schizonts.



EXPLANATION
1-2-1 Dimorphic cycle; *Discorbis patelliformis*
1-2-3-1 Holotrimorphic cycle; *Rotalia beccarii flevensis*
1-2-3-1; 1-2-1; 3-3 Paratrimorphic cycle; *Elphidium crispum*
3-3 Apogamic cycle; *Discorbis orbicularis*

FIGURE 26.—Diagram of various types of life cycles exhibited by the Foraminifera.

Dimorphism has been implied for some species of *Orbitolina* solely on the basis of shape or size differences. Since there is a tendency for microspheric specimens to be larger and flatter than their megalospheric counterparts, some workers have been led to believe that the generations can be distinguished by size and shape alone. Douvillé (1912, p. 572) has listed several species placing them in either microspheric or megalospheric generations based on dimensional characters. These criteria are not to be trusted, as megalospheric forms exhibit the full range of variation in shape. The embryonic apparatus itself must be studied to determine the generation to which a specimen belongs.

BUILDING MATERIALS

The wall in *Orbitolina* is agglutinate in the sense that it is composed of a cementing medium—generally calcareous—and incorporates variable amounts of detrital material. Several authors (Cayeux, 1916, p. 368; Cushman, 1948, p. 211; Le Calvez, 1955, p. 150, 151) considered the test arenaceous with calcareous or iron oxide cement. Henson (1948, p. 37) and Sigal (1952, p. 138) considered the test calcareous microgranular. Henson did not consider it agglutinate and said many Orbitolinas contain no trace of detrital grains. He went on to point out, however, that the epidermus of most species of *Orbitolina* is finely arenaceous.

The wall can be considered in two parts. There is a thin translucent layer or epidermis which is apparently primary. This layer forms the outer cone surface and continues along the septal face. It was called the couche vitreuse or couche superficielle by Douvillé (1904, p. 654) or the epidermide or periostraco by Silvestri (1932, p. 155). This layer is generally an accumulation of fine angular quartz grains in a calcareous cement. Upon this "layer" are deposited the other elements of the test. Henson (1948, p. 37) reported occasional specimens having a thin film of clear calcite over the oral face. These may be specimens in which the primary wall has been deposited and the other elements have not yet accumulated.

In the marginal zone fine granular calcite, usually opaque, is added to the inner side of the primary wall. Rarely there are coarser irregular grains. In the radial and central zone the primary wall is thickened by additions of fine and coarse clastic material in a calcareous matrix. The amount and coarseness of the material varies from one population to the next and is, at least in part, dependent on the bottom material available while the test is being built. *Orbitolina concava* from France, which at the type locality occurs in a greensand, has a large proportion of sand grains incorporated in the test (pl. 3) compared with some of the Texas forms from marl or limestone (pl. 6). The materials in the radial and central zone may be fragments of calcite or other minerals, or parts of other organisms such as smaller foraminifers.

CALCITE EYES

In some samples there are regular round, oval- or kidney-shaped clear objects referred to as calcite eyes. These may be irregularly distributed through the inner two zones or concentrated in the central complex. The origin of the calcite eyes is unknown. Henson (1948, p. 46) suggested that they may be "pathological or secondary (parasite borings, * * *)". It is hard to visualize them as borings as they are never elongate beyond ovoid. (Pl. 10, fig. 18, pl. 13, fig. 16.) That they are open spaces or "cells" during the life of the organism is indicated by the fact that they are filled with the same material—generally clear crystalline calcite—as the radial passages, indicating that filling took place after burial. They have a discrete wall similar to the inner lining in the marginal zone. Some show crystallization of the calcite from the margins inward as in geodes. Specimens containing calcite eyes are limited to certain stratigraphic horizons.

LIVING HABIT AND ITS INFLUENCE ON THE TEST

The embryonic apparatus in both generations of *Orbitolina* may be free floating, but as chambers are added the specimens probably become bottom dwellers. Building materials for the wall are picked up from the substratum and incorporated in the calcareous matrix of the test. Species of *Orbitolina* tolerate a wide variety of bottom sediments from coarse sand through silt and mud to pure lime clay. Abundant specimens are found in both sands and aphanitic limestones. The species are more or less selective in the materials incorporated from the sediments, as species with characteristically fine-grained walls are found in both fine and coarse sediments, whereas other species tend to accumulate coarse materials, even in fine-grained limestone environments. The greatest factor controlling the debris content of the test seems to be amount of secreted, as opposed to acquired, building material.

Small tests, and the neanic chambers of larger tests, tend to be conical. They were probably dragged around with relative ease by the protoplasm. With increase in the size of the test, its support must have been progressively more difficult. The larger tests tend to flatten out and even curl up at the margin, exposing the radial zone laterally. The pseudopodia would then be free to extend and collect food without much lifting of the test. Some of the larger specimens develop and extend the radial zone laterally almost to the exclusion of the central zone and some thus develop annular chambers in which the central zone no longer develops across the entire ventral surface. Tests developing a diameter of 20 to 30 mm were probably not very motile.

GLOSSARY OF SPECIAL TERMS, WITH A SYNONYMY OF TERMS USED BY OTHER AUTHORS

Apertural pores: Circular openings through the septa allowing communication between chambers and between the last formed chamber and the outside. Apertures, of authors; perforations, of Davies, Henson; perforations obliques, of H. Douvillé; Poren des Canalsystems [part], of Martin.

Axial section: (See sections).

Basal sections: (See sections).

Calcite eyes: Rounded bodies of clear calcite occurring sporadically in the radial zone and central complex. Fremdkorperchen (Martin), of Cotter [part].

Cellules: Subdivisions of the marginal chamberlets in the outer part of the marginal zone formed by the primary and secondary plates. Cortical chambers [part], of Davies; cortical layer [part], of Glaessner; mesh structure, of Cotter; meshwork of cellules, of Maync; primary and secondary cells, of Henson; reseau superficiel and reseau poutrellaire, of H. Douvillé; reticular subseptal structure, of Carter; subepidermal cells [part], of Henson.

Central complex: The core or central zone in which the passages of the radial zone tend to bifurcate and anastomose in a reticulate or labyrinthic complex. Central or reticulate zone, of Henson; umbilical region [part], of Davies.

Chamber passages: Essentially radial tubular passages of the radial zone which are centrally directed extensions of the marginal chamberlets. Chamberlets, of Cushman; chambers, of Davies; columnar chamber structure, of Carter; logettes, of Douvillé; radial chamberlets, of Glaessner; sillons rayonnantes, of Douvillé; tubular cavities, of Galloway.

Chambers (or primary chambers): The primary cuplike subdivisions of the test, separated from each other by the septa. Callotes, of Douvillé; chambers, of authors; cups, of Davies; kammern, of Martin; loges, of Douvillé; primary chambers, of Henson.

Concentric lamellae: The areas on the dorsal surface between septal sutures, formed by the upturned edges of the septa. Concentric lamellae, of Cotter [part], Sahni [part]; concentric rings, of Carter; concentrischer Wulste, of Martin.

Epidermis (or primary wall): The thin often translucent layer forming the outer cone surface and continuing along the septal face. Couche superficielle or couche vitreuse, of Douvillé; epidermal layer, of Cushman, Maync; epidermide, of Silvestri; epitheca, of Galloway; Epithek, of Martin; first layer, of Galloway; periostraco, of Silverstri; wall, of Cushman, Galloway.

Main partitions: Radial structures extending from the marginal zone toward the center of the chamber. In the marginal zone they are simple transverse partitions; in the radial zone they become sinuous or zigzagging structures generally thickened toward the top along the base of the preceding septum. Cloisons rayonnantes, of Douvillé; interseptal partitions, of Henson; main partitions, of Glaessner, Henson; radial partitions, of Henson; ridges of Davies; Scheidewande 2 ter Ordnung, of Martin; secondary septa, of Glaessner; septa, of Carter, Sahni; septula, of Glaessner; striés rayonnantes, of Douvillé; zigzag partitions, of Davies.

Marginal chamberlets: Simple subdivisions of the primary chambers in the marginal zone formed by the main partitions only. The chamberlets are bounded at top and bottom by the septa. Chamberlets of Cushman, Glaessner, Maync; chamberlets of the third layer, of Galloway; chambers of Carter, Carsey; cortical chambers, of Davies; logettes rectangularies, of Douvillé; marginal chamberlets, of Henson; marginal chambers, of Maync; peripheral chambers, of Davies; rectangular cells, of Cotter.

Marginal zone: The peripheral portion of each chamber in which the chamberlets are subdivided by the primary and secondary plates. Cortical layer, of Carter, Glaessner; epidermal layer, of Maync; first three layers, of Galloway; marginal zone, of Henson; peripheral part (area), of Davies; reseau poutrellaire, of Douvillé.

Oblique section: (See sections).

Partitional pores: Pores through the main partitions allowing intercommunication between adjacent radial passages within a chamber. Poren des Canalsystems [part], of Martin.

Periembryonic chambers: Nepionic chambers developed on the ventral side and partially surrounding the proloculus. Corona, of Silvestri; periembryonic cells, of Henson.

Primary plates: Transverse and parallel partitions, shorter than the main partitions, subdividing the marginal chamberlets. Partitions [part], of Glaessner; primary plates, of Henson; primary vertical plates, of Maync; Scheidewande 3 ter Ordnung, of Martin; secondary partitions [part], of Cushman; secondary septa, of Galloway; septa [part], of Carter, Cotter; subepidermal plates [part], of Henson; trabercole perpendicolari [part], of Silvestri.

Radial zone: The portion of each chamber between the marginal zone and the central complex in which the elements are essentially radial. Central zone [part], of Henson; radial zone, of Henson; umbilical region [part], of Davies.

Secondary plates: Transverse and parallel partitions shorter than and alternating with the primary plates. Marginal plates, of Maync; partitions [part], of Glaessner; Scheidewande 4ter Ordnung, of Martin; secondary partitions [part], of Cushman; secondary plates, of Henson; secondary subepidermal septula, of Maync; semisepta, of Maync; septa [part], of Cotter; subepidermal plates, of Maync; Tertiary septa, of Galloway; trabercole perpendicolari [part], of Silvestri.

Sections: The following terminology for thin sections is adopted:

Axial: containing the axis about which the adult test develops. Axial, of Davies, Galloway, Henson; transverse [part], of Yabe and Hanzawa; vertical, of Martin, Douvillé, Cotter [part], Galloway, Sahni.

Basal (or horizontal): more or less parallel to the septa; approximately perpendicular to the axis in conical forms. Basal, of Galloway, Henson; cross, of Galloway; horizontal, of Martin, Yabe and Hanzawa, Cotter, Davies, Cushman; median, of Barker; parallel, of Henson, Maync; transverse, of Douvillé, Cotter, Sahni, Silvestri, Barker.

Oblique: oblique to any of the other section planes may be qualified as oblique subaxial, oblique basal etc. Oblique, of authors; transverse [part], of Yabe and Hanzawa.

Subaxial: parallel to the axis but not containing it. Axial and longitudinal, of Maync; subaxial, of Henson; transverse, of Yabe and Hanzawa [part], Henson; vertical [part] of Cotter.

Tangential: more or less tangential to any specified curved surface, usually the dorsal surface. Tangential, of authors.

Septa: The floor of each chamber is a septum which turns up around the periphery to join the previous septum and to form the dorsal surface of the test. Circular lamellae [part], of Cotter; Scheidewande 1ter Ordnung, of Martin; septa, of Henson.

Septal sutures: The lines along which successive septa fuse on the dorsal surface. Anneaux d'accroissement, of Douvillé; circular lamellae [part], of Cotter; concentric lamellae [part], of Yabe and Hanzawa, Sahni; concentrischer Furchen, of Martin; growth lines, of Galloway; linee circolari, of Silvestri; sutures, of Henson.

Supraembryonic area: A circular apical area over the megalospheric proloculus in some orbitolinids. Central boss mamilla, of Sahni; supraembryonic area, of Henson.

METHODS OF STUDY

COLLECTION OF SAMPLES

The bulk of the samples on which this study is based were collected by the author from the exposed beds of Lower Cretaceous rocks in Texas, New Mexico, and Arizona. These collections were supplemented by material available in the U.S. National Museum collections and material furnished by several individuals and field parties. Wherever possible, collections were made from stratigraphic sections which had either been measured and published by other authors or were measured at the time the collections were made. The sections were measured using a Jacob's staff and Brunton compass.

The method of collecting the samples varied with the sections. In sections where *Orbitolina* was more or less limited to certain beds, each bed was collected separately. Several bags of material were collected from some of the thicker beds, each from a part of the bed and each labeled to indicate the position in the bed. Where *Orbitolina* was found distributed through long sequences of rock, collections were taken at arbitrary intervals.

HANDLING OF SAMPLES

As each collection was made, its position in the stratigraphic succession was indicated on the columnar section being plotted and its geographic location plotted on a suitable base map. Canvas sample bags were used, and each bag was labeled with a brush pen before being filled. Locality labels were prepared at the time the collections were made, and a carbon of the label was placed in the bag with the collection. The bags thus labeled were ready for easy storage in numerical sequence in the laboratory.

The samples were shipped to the laboratory in double burlap bags which are more easily available than nail kegs or wooden boxes. Bags containing about 100 pounds of samples were found to be most economically handled.

PREPARATION OF SAMPLES

On arrival at the laboratory the samples were sorted and filed in numerical order. Samples to be prepared were identified by number from the columnar sections or original locality notes and could be readily located.

The collections made, fall into two general categories: those in hard matrix such as limestone or indurated marl and those of unconsolidated or only poorly consolidated material. Different methods of preparation were used on the two kinds of material.

SAMPLES WITH SOFT MATRIX

Samples of marl or other unconsolidated material were washed, using conventional washing and seiving techniques. Simple boiling in washing soda was found satisfactory. Hydrogen peroxide was used to break down some of the more indurated marls. The action was not sufficiently effective to justify the additional expense of the hydrogen peroxide. All material not passed through a 200-mesh screen was saved for study. Washed samples were dry sieved through 9-mesh, 40-mesh, and 60-mesh screens for ease in picking, and a part of each sample was picked for Foraminifera and other microfossils.

The preparation of thin sections from isolated specimens of *Orbitolina* involved some special techniques. In the past it has been the practice to make one thin section from each specimen to be studied. Thus axial sections would be prepared from some specimens, tangential sections prepared from other specimens and basal sections prepared from still others. This practice has been continued for most specimens less than 3 mm in diameter. Dental-casting low-heat compound was found convenient for holding small specimens in making the facet to be mounted. The compound becomes plastic when heated in warm water so that the specimen can be partially imbedded. When the compound is cooled in air or cold water it become rigid and holds the specimen securely. The specimen is then ground on a glass plate or fine lap until the desired plane is reached. Reheating the compound in warm water releases the specimen and it can then be mounted on a glass slide and the section completed.

With the larger specimens (over 3 mm) it was found practical to make multiple sections. An axial, a tangential, and a partial basal section could all be prepared from each specimen. This technique allows study of most pertinent characters on each specimen. The technique involves making thin cuts with a small diamond-bonded blade. A specimen is mounted on the edge of a piece of plate glass with about one-half of the specimen overhanging the edge of the glass. (Fig. 27). The specimen is then cut at just one side of the apex with the thin diamond blade and the free chip saved. The mounted half is then ground down to the axial plane before being removed to a standard microscope slide. After mounting on the slide another saw cut is made as close to the glass as possible (fig. 27*b*, *c*), and again the free piece is saved. The axial section is readily finished on a glass plate.

The two free chips can then be used for preparing a tangential and a partial basal section (fig. 27*d*, *e*) in the usual manner. On especially large specimens, additional sections may be made from pieces left after making the basal and tangential sections if these are also cut off after mounting as with the axial section.

Most diamond blades are too thick for use in this technique, but 2-inch blades are now available which are only 0.010 inch thick. Some difficulty was encountered in keeping the specimen from cracking off the slide while being cut. Canada balsam and some plastics were found to be too brittle. Glycol thallate was

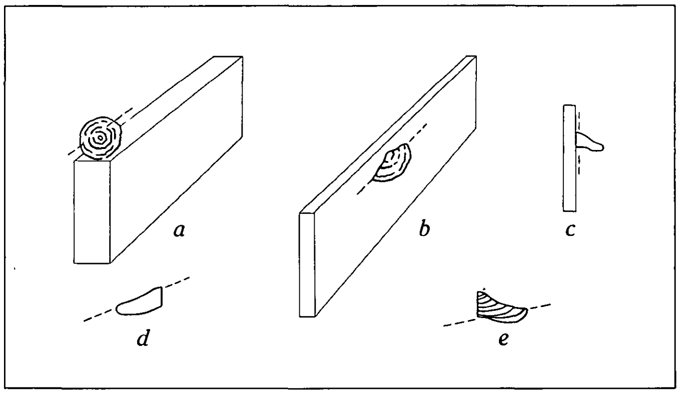


FIGURE 27.—Multiple sectioning of specimens of *Orbitolina*. *a*, Specimen mounted on a thick glass slide ready for the first cut; *b* and *c*, half the specimens mounted on a standard slide ready for the second cut; *d*, chip used for a tangential slice; *e*, chip used for a basal slice.

found to be tough enough to resist shattering and was used for mounting some specimens. In summer temperatures Glycol thallate becomes too soft for general use. Lakeside thermoplastic 70c was found to be the most useful all-weather mounting medium.

SAMPLES WITH HARD MATRIX

Samples of limestone and indurated marl were prepared for study in thin section. The sample to be studied was sawed into slices averaging a little less than one-quarter of an inch in thickness. The larger pieces were first cut with a large diamond saw into pieces that could be handled easily on a 5-inch blade. The pieces were then sliced using a 5- to 7-inch carborundum blade. The resulting slices were smooth enough, so that a minimum of grinding on a lap using 800-grit grinding powder produced a surface which could be mounted on microscope slides.

The slices were examined under the microscope for oriented sections of *Orbitolina* and other Foraminifera. The areas of interest were marked and cut out using the carborundum blade, then dried and mounted on 1- by 3-inch or larger microscope slides.

Grinding of the thin sections was greatly reduced by cutting off the excess limestone close to the glass, again using the carborundum blade. The remaining one thirty-second of an inch or so of material was quickly ground down to a thickness showing the greatest amount of detail by transmitted light. This thickness was found to vary with the sample.

Part of the material was crushed to free specimens for study of exteriors, and most samples were found to yield a few specimens with this treatment.

OBSERVATIONS ON WHOLE SPECIMENS

Many diagnostic characters can be seen on whole specimens before they are sectioned, and some of these are not easily visualized from thin sections alone. It has, therefore, been the practice to make as many observations as possible on the free specimens before preparing thin sections. Size and shape are best studied on whole specimens. Although the diameter of a specimen is represented in well-oriented axial sections, there is no way of knowing whether the dimension seen was the maximum, minimum, or mean diameter of the shell. On circular specimens there would be little or no difference, but the more irregular specimens could be misinterpreted. Many specimens are irregularly shaped with fluted margins, wavy dorsal surfaces, and other irregularities of growth. These irregularities are difficult to detect in thin section.

Details are often not easily seen on dry specimens but show up readily if the specimen is moistened or dyed lightly with a dye such as methylene blue. Light etching of the surface reveals features of the marginal layer which can often be studied more easily through the surface than in thin section. The low-temperature dental-impression compound previously mentioned was also found useful for holding specimens while cleaning the surface, etching, and staining. The character of the embryonic or supraembryonic area is often observed best on whole specimens. With the specimen held in dental compound, the apex may be abraded slowly using a thin wedge of novaculite or other fine-grained grinding stone. This can be done on the microscope stage using a minimum amount of water. Nearly continuous observation of progress is possible. The use of a light stain of methylene blue applied with the tip of a fine brush is helpful in recognizing obscure features in the embryonic apparatus as it is ground.

Broken or eroded specimens often show the character of the partitions, and chamber passages more clearly than whole specimens or thin sections and are useful in visualizing the three-dimensional relationships of the internal structures.

ETCHING

Light etching of well-preserved specimens often reveals the thin epidermal layer of granular siliceous material forming a veneer over the cellules and along the bottom or exterior surface of the septa. Deeper etching reveals the structure of the cellules and the marginal chamberlets.

Samples of limestone known to contain an abundant fauna of Foraminifera and some other microfossils were treated with dilute acids. Hydrochloric, acetic, and formic acids were tried, but residues were found to be essentially barren.

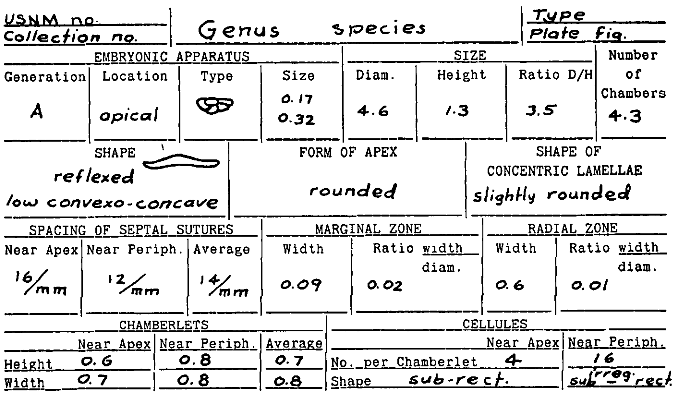
OBSERVATIONS IN THIN SECTION

Most characters of the specimens can be either seen or inferred from thin sections. The distinction between observation and inference in dealing with thin sections should be kept clearly in mind. It is difficult to visualize the shape of a specimen from an oriented axial section. It is more difficult to infer the shape from an oblique section. Low convexo-concave specimens may appear to be high biconvex forms. The accuracy of observed height and width measurements varies with the orientation in the same manner.

The single most useful section for the determination of diagnostic characters is a well-oriented axial section. Details of the marginal zone can be seen more readily in sections tangential to the dorsal surface. Details of the main partitions and chamber passages can be seen best in basal sections, and horizontal sections at the apex are useful for a study of the embryonic area. Added bits of information on the central complex and chamber passages can be gained from oblique sections, but these are the most deceptive of the sections.

RECORDING OF DATA

The large number of specimens and sections studied in a work such as this required some convenient form for recording observations. Figure 28 illustrates one side of the printed form used, showing typical notes. The reverse side of the form is used for further remarks.



USNM no. / Collection no.	Genus species	Type / Plate fig.

EMBRYONIC APPARATUS				SIZE			Number of Chambers
Generation	Location	Type	Size	Diam.	Height	Ratio D/H	
A	apical		0.17 0.32	4.6	1.3	3.5	4.3

SHAPE	FORM OF APEX	SHAPE OF CONCENTRIC LAMELLAE
reflexed low convexo-concave	rounded	slightly rounded

SPACING OF SEPTAL SUTURES			MARGINAL ZONE		RADIAL ZONE	
Near Apex	Near Periph.	Average	Width	Ratio width/diam.	Width	Ratio width/diam.
16/mm	12/mm	14/mm	0.09	0.02	0.6	0.01

CHAMBERLETS	Near Apex	Near Periph.	Average	CELLULES	Near Apex	Near Periph.
Height	0.6	0.8	0.7	No. per Chamberlet	4	16
Width	0.7	0.8	0.8	Shape	sub-rect.	sub-irreg.-rect.

FIGURE 28.—Typical data card for recording observations on specimens of *Orbitolina*.

Comparison back and forth between samples of microfossils—especially in thin section—is a difficult undertaking. Remembering what 1 specimen looked like while another is under the microscope is treacherous, and remembering what was in the sample 5 back is next to impossible. Even with the card data, comparisons were difficult. As a working aid, therefore, photographs were prepared of many of the thin sections. These photographs were made rapidly on 35 mm film at a magnification of 5 diameters. Prints from each collection in key sections were mounted in stratigraphic order. These temporary plates were used for quick reference as other samples were studied.

USE OF STATISTICAL AIDS

The use of elementary statistical procedures is helpful in defining some of the measurable characters of *Orbitolina*. Specimens were selected for measuring from most of the samples studied and measurements were tabulated for the diameter, height, diameter of the embryonic apparatus, and diameter of the proloculus. The diameter-height ratio was calculated for the specimens measured. Following the procedures outlined in Mayer, Linsley, and Usinger (1953, p. 132–147) the following characteristics were determined for the above characters of each sample: mean, standard error of the mean, standard deviation, range, and coefficient of variability. Comparison between samples was facilitated by determining the coefficient of difference and percentage of nonoverlap. Regressions and scatter diagrams were plotted for visual comparison between some samples.

PREPARATION OF ILLUSTRATIONS

Specimens, illustrating features of the morphology especially well, were noted at the time each sample was studied. From these were selected specimens to be used for illustrations. Whole specimens, which showed features particularly well, were photographed before sections were cut.

Selection of the degrees of magnification to be used in illustration was controlled by two factors. It is felt that magnification should be sufficient to show critical details clearly. At the same time it should be a magnification factor which will allow easy comparison with material in the hands of the person using the illustration. Magnifications which are simple multiples of 10 were found to be quite satisfactory.

Several kinds of equipment were used in the preparation of the photographs. One of the most satisfactory was the use of a polaroid adapter on the back of a photomicrographic camera. With this equipment the prints are obtained almost immediately and the results can be evaluated before the specimen is moved from the equipment.

Some of the drawings and sketches were prepared with the aid of a camera lucida from thin sections, and projection from photographs. The reconstructions (figs. 15, 16) were prepared from thin sections, photographs, models, and sketches of *Orbitolina texana* from Comal County, Tex.

SYSTEMATIC DESCRIPTIONS

Kingdom ANIMALIA
Phylum PROTOZOA
Class RHIZOPODA
Order FORAMINIFERA
Family ORBITOLINIDAE Martin, 1890

Genus ORBITOLINA d'Orbigny, 1850

Orbitolina d'Orbigny (1850, p. 143).

Type species.—(monotypic) *O. lenticulata* Lamarck, 1816=*Madreporites lenticularis* Blumenbach, 1805.

Diagnosis.—Test large, varying in shape from conical through discoidal to strongly reflexed convexo-concave. Dimorphic, with early microspheric chambers coiled; megalospheric form initiated with a relatively large proloculus; adult in both a rectilinear uniserial succession of shallow cuplike chambers. Chambers subdivided into radial passages by zizzag main partitions in the radial zone. Periphery subdivided into marginal chamberlets and cellules by the partitions and vertical and horizontal plates. Communication between adjacent chamber passages by partitional pores. Apertures through the septa at the reentrants of the zigzag main partions. Wall calcareous agglutinate, incorporating variable amounts of detrital material.

Description.—A detailed description of this genus has been given in the section on morphology (p. 14) of this report.

Comparison and remarks.—*Orbitolina* is easily distinguished from other genera in the family by the characters reviewed in the diagnosis. The genera which resemble *Orbitolina* most closely are *Simplorbitolina* Ciry and Rat, and *Dictyoconus* Blanckenhorn. Davies (1939 p. 781) has compared *Orbitolina* and *Dictyoconus* emphasizing the differences between the genera. He indicates that the main partitions (interseptal partitions) in *Orbitolina* are developed downward from the preceding chamber floor whereas in *Dictyoconus* the pillars are developed upward, within a chamber space. He also indicates that the protoplasm is subdivided in the umbilical part of *Orbitolina* and that it is undivided in *Dictyoconus.* Davies did not recognize any partitional pores in *Orbitolina* and accepted the view that there is no communication between radial passages in any one chamber.

The form described by Henson (1948 p. 35) as *Dictyoconus arabicus* appears to be intermediate between *Dictyoconus* and *Orbitolina.* It has many of the characters of *Dictyoconus*, but instead of pillars it has the radiating main partitions as in *Orbitolina.* The main partitions are broken up into pillarlike structures in the lower portion of each chamber by large partitional pores. The main partitions have a triangular cross section as seen in tangential section (Henson 1948 pl. 14, fig. 12). The thickened portion is toward the top as in *Orbitolina. D. arabicus* indicates a close relationship between *Orbitolina* and *Dictyoconus.*

The genus *Simplorbitolina* is known from only one species, so the knowledge of its variability is incomplete. A study of topotype material of *S. manasi* Ciry and Rat 1953, kindly provided by Pierre Rat, indicates that the main partitions of *Simplorbitolina* are broken into pillarlike structures in the lower half of the chamber in a manner similar to that in *Dictyoconus arabicus. Simplorbitolina manasi* does not have parallel (horizontal) primary or secondary plates as found in *Orbitolina* and *Dictyoconus.*

THE TYPE SPECIES OF ORBITOLINA

There has been no general agreement as to the type species of *Orbitolina.* Ellis and Messina, in the Catalog of Foraminifera, list four species which have been designated as the type at various times and by as many authors. They conclude that, "none of these designations is valid except Cushman's (1928); if Douvillé is correct, *Orbitolina* is a genus of corals * * *" Davies (1939 p. 786) presented the most widely accepted view, that *Orbitolina concava* (Lamarck) should be accepted as the type.

The genus *Orbitolina* was established in 1850 by Alcide d'Orbigny on page 143 of volume 2 of the Prodrome de Paléontologie. The entry reads:

Orbitolina, d'Orb., 1847. Ce sont des *Orbitolites* à côtés inégaux, l'un encroté, l'autre avec des loges.
342. lenticulata, d'Orb., 1847. *Orbitolites lenticulata* Lamarck, 1816; Lamouroux, 1821, pl. 72, fig. 13–16. Perte-du-Rhône (Ain), St.-Paul-de-Fenouillet (Aude).

Only one species is referred to the genus in this, the original description. The genus as described is therefore monotypic, even though five other species are referred to it in later sections of the volume. The references to d'Orb. 1847, indicate the date when the manuscript was prepared. The date of publication was 1850.

Distribution.—The genus *Orbitolina* has a wide distribution in the circumglobal equatorial belt, which is often referred to as Tethyan or Mediterranean. It is known from rocks of Barremian (Early Cretaceous) to Cenomanian (Late Cretaceous) age. (See Fig. 29.)

The species described from rocks of Barremian age include:

Orbitolina birmanica (Sahni, 1937, p. 365) from Burma.
conulus (Douvillé, 1912, p. 568) from Spain and France.
discoidea delicata (Henson, 1948, p. 54) from Arabia.
shikokuensis (Yabe and Hanzawa, 1926, p. 19) from Japan.
tibetica (Cotter, 1929, p. 352) from Tibet.

Species described from rocks of Aptian age include:

Orbitolina bulgarica janeschi (Dietrich, 1925, p. 32) from Tanganyika, Africa.
conoidea (Gras, 1852, p. 51) from France.
discoidea (Gras, 1852, p. 52) from France.
discoidea-conoidea ezoensis (Yabe and Hanzawa, 1926, p. 17) from Japan.
discoidea libanica (Henson, 1848, p. 55) from Lebanon.
japonica (Yabe and Hanzawa, 1926, p. 15) from Japan.

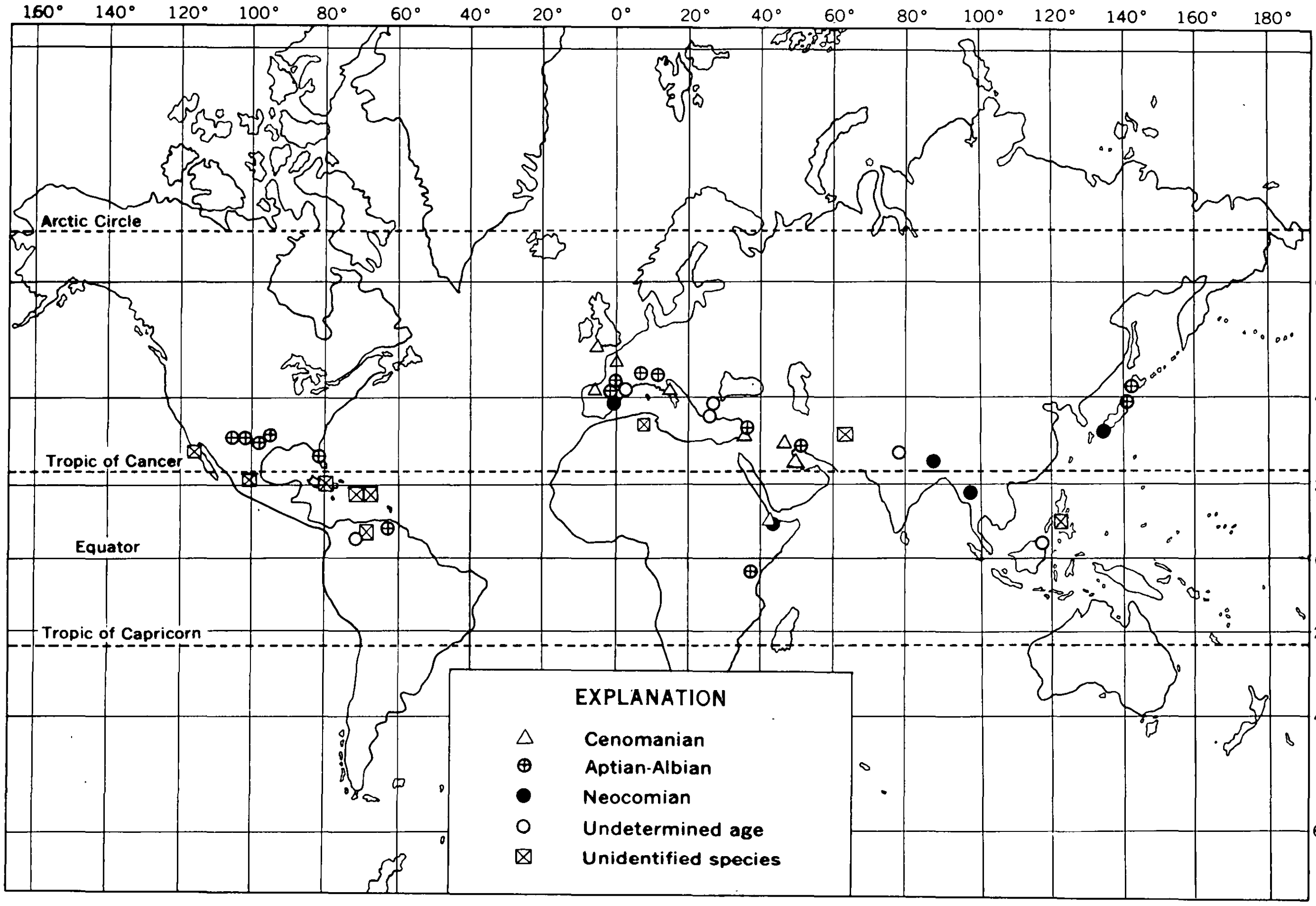


FIGURE 29.—Geographic distribution of *Orbitolina* plotted from published and unpublished occurrences.

miyakoensis (Yabe and Hanzawa, 1926, p. 18) from Japan.
kurdica (Henson, 1948, p. 48) from Iran.
lenticularis (Blumenbach, 1805) from France.
mamillata subaperta (Astre, 1930, p. 306) from Spain.
planoconvexa (Yabe and Hanzawa, 1926, p. 19) from Japan.
sub-concava (Leymerie, 1881, p. 754) from France.
texana (Roemer, 1849, p. 393) from Texas.
asaguana (Hodson, 1926, p. 5) from Venezuela.
monagasana (Hodson, 1926, p. 5) from Venezuela.
thompsoni (Hodson, 1926, p. 5) from Venezuela.

Species described from rocks of Albian age include:

Orbitolina mamillata subaperta (Astre, 1930, p. 306) from Spain.

Species described from rocks of Cenomanian age include:

Orbitolina andraci (Martin, 1891, p. 59) from Spain.
anomala (Prever, 1909, p. 7) from Italy.
boehmi (Prever, 1909, p. 18) from Italy.
concava (Lamarck, 1816, p. 197) from France.
qatarica (Henson, 1948, p. 66) from Arabia.
sefini (Henson, 1948, p. 64) from Iraq and Palestine.
paronai (Prever, 1909, p. 18) from Italy.
polymorpha (Prever, 1909, p. 56) from Italy.

Other species have been described from Cretaceous rocks for which a precise age has not been determined.[4]

Material examined.—A wealth of material has been available for this study. In addition to the abundant material from the United States, part of which is described in this paper, comparative material has been available from the West Indies, Mexico, South America, England, France, Spain, the Near and Middle East, the Philippines, and Japan. Approximately six thousand thin sections have been prepared for the study, including thousands of oriented specimens and untold numbers of random cuts. All figured specimens are deposited in the U.S. National Museum.

ARTIFICIAL KEY TO THE SPECIES OF ORBITOLINA DESCRIBED IN THIS REPORT

The key is designed for identifying samples of *Orbitolina* for which the keyed characters have been studied. Dimensional characters are based on mean dimensions for the sample; so single specimens cannot be identi-

[4] While this paper was being processed for publication a monograph of the Orbitolinas found in the Indian Continent was published by M. R. Sahni as Memoire no. 3 of the Geological Survey of India. Several new species and varieties of Orbitolinas from the Indian Continent are described and illustrated from rocks of Aptian to Cenomanian age.

fied certainly. The key form embodies the principle of dual choice progressing from alternative to alternative until the identification is made (see Keen and Frizzell, 1939). The key is artificial and does not imply relationship of species within the genus.

1.	Mean diameter of proloculus less than 0.10 mm	(2)
	Mean diameter of proloculus more than 0.10 mm	(3)
2. (1)	Mean diameter of test more than 4 mm	*O. parva*
	Mean diameter less than 4 mm	*O. lenticularis*
3. (1)	Mean diameter of proloculus between 0.10 mm and 0.19 mm	(5)
	Mean diameter of proloculus 0.19 mm or more	(4)
4. (3)	Mean diameter of proloculus less than 0.30 mm	*O. texana*
	Mean diameter of proloculus more than 0.30 mm	*O. concava*
5. (3)	With calcite eyes	(8)
	Without calcite eyes	(6)
6. (5)	Mean form ratio less than 3	*O. grossa*
	Mean form ratio more than 3	(7)
7. (6)	Mean form ratio less than 5	*O. minuta*
	Mean form ratio more than 5	*O. gracilis*
8. (5)	Main partitions strongly triangular	(9)
	Main partitions plane or slightly triangular	*O. pervia*
9. (8)	Mean diameter less than 5 mm	*O. oculata*
	Mean diameter more than 6 mm	*O. crassa*

Orbitolina lenticularis (Blumenbach)

Plate 1

Madreporites lenticularis Blumenbach (1805, fig. 80, figs. 1–6).
Orbulites lenticulata Lamarck (1816, p. 197).
Lamouroux (1821, p. 45, pl. 72, figs. 13–16).
Orbitolina lenticulata (Lamarck) d'Orbigny (1850, p. 143, n. 342).
Orbitolina lenticularis (Lamarck) Pictet and Renevier (1858, p. 1).

Diagnosis.—Test small (up to 5.2 mm in diameter), convexo-concave; embryonic apparatus with a mean diameter of 0.17 mm and a proloculus with a mean diameter of 0.09 mm; marginal zone thin, radial zone poorly developed but with main partitions thick and triangular; building materials coarse, tending to obliterate most structures.

External characters.—The test is generally low convexo-concave. Some specimens have a greater convexity, but none were found which could be called conical. Other specimens had little convexity, approaching a discoidal shape. The specimens are irregularly circular in plan but do not have fluted margins or wavy dorsal slopes. The measurements for topotypes of *Orbitolina lenticularis* are summarized in table 1 and figure 30.

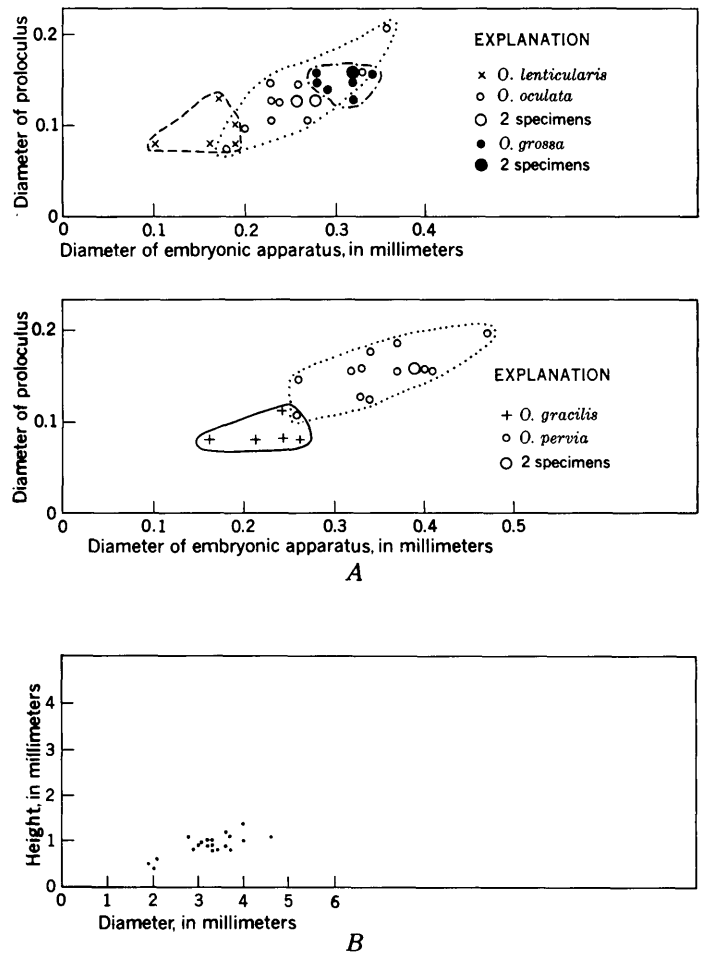


FIGURE 30.—Comparison of some species of *Orbitolina*. *a*, Comparison of the dimensions of megalospheric embryonic chambers of several species of *Orbitolina*. *b*, Dimensions of *Orbitolina lenticularis*.

TABLE 1.—*Summary data for* Orbitolina lenticularis (*Blumenbach*)

	Diameter of 23 specimens measured (mm)	Height of 23 specimens measured (mm)	D:H ratio of 23 specimens measured	Diameter of embryonic apparatus of 8 specimens measured (mm)	Diameter of proloculus of 5 specimens measured (mm)
Maximum	4.6	1.4	5.0	0.20	0.13
Minimum	1.9	.4	2.5	.10	.08
Mean	3.2	.9	3.7	.17	.09
Error of mean	±.14	±.06	±.13	±.01	±.01
Standard deviation	.66	.23	.61	.03	.02
Inferred range	1.2–5.2	0.2–1.6	1.9–5.5	.08–.26	.03–.15

The apex of most specimens is slightly rounded, though some specimens have a small indentation formed by abrasion or collapse of the embryonic chambers. One specimen was found with a subdued boss at the apex, but sectioning showed it was not caused by a supraembryonic area as in the megalospheric form of some species.

The dorsal surface of most specimens from the type locality has been eroded, removing most of the marginal zone and exhibiting the engine-turned pattern of the triangular main partitions. The best preserved specimens have an even dorsal surface with the concentric lamellae only slightly rounded or flush. The sutures tend to be evenly spaced and there are 15 to 20 per mm.

The ventral surface on most specimens is also eroded but the better preserved specimens exhibit the radiating main partitions. The ventral surface tends to be sandy with the sand grains partly obscuring the structure.

Internal characters.—The embryonic apparatus is apical. In the megalospheric generation it is initiated with a relatively small proloculus (see table 1), which is partially surrounded by the periembryonic chamber. The proloculus does not appear to be subdivided on its dorsal surface as in some species. Chambers are added to the ventral surface of the proloculus in a uniserial rectilinear series. Each chamber is a shallow saucer slightly convex upwards at the center where it is thinnest. In many of the specimens the edeges are curved up sharply so that the test develops a discoidal shape.

Marginal zone.—The marginal zone is narrow, with the maximum extention of the primary plates generally close to 0.03 mm. Only primary plates are developed through much of the test, but secondary plates are sometimes present in the late ephebic chambers. The chamberlets are rectangular and often nearly square 0.05 to 0.07 mm on a side.

Radial zones.—The radial zone includes one-third to one-half the area of each chamber, although little of it can be seen in any one section owing to the curvature of the chambers. The main partitions are thick and triangular. They zigzag rather irregularly toward the central complex. The radial passages are initially rectangular in cross section as they leave the marginal zone, but they become compressed and triangular throughout most of the radial zone.

Central complex.—The main partitions are intermittent in the central complex, with masses of partition completely surrounded by passages. The texture is generally rather coarse, as the partitions remain thick.

Building materials.—*Orbitolina lenticularis* is a sandy species in which the amount of agglutinated material apparently is much greater than the amount of secreted cementing substance. The sand grains are fine in the marginal zone, but the grains are so large and numerous in the inner two zones that the structure is difficult to decipher. The use of stain was found helpful especially on thick slices of the specimens. Thin sections tend to show little more than a mass of sand grains in a small amount of matrix.

The cementing material is mainly calcium carbonate, but many of the specimens have limonitic stains, giving the impression that iron oxide may be part of the cementing medium. The limonitic stain appears to originate with limonite pseudomorphs after pyrite, which adhere to many of the specimens and occur in the proloculus of some.

The nature of the apertural and partitional pores was not observed, owing to the coarseness of the material in the specimens, but it is assumed they are present and similar to those in other species of the genus.

Remarks.—*Orbitolina lenticularis* has been known under several names since at least 1779 when de Saussure (1779, p. 343, pl. 3, fig. 3) described and illustrated some specimens as "Lenticulaire de la Perte du Rhône." The first Linnean name given them was *Madreporites lenticularis* by Blumenbach (1805, no. 80 and fig. 80), who redescribed and illustrated some specimens from the same locality. (See pl. 1, figs. 1–6.) Eleven years later Lamarck (1816, p. 167) described more specimens of this species from the same locality and named them *Orbulites lenticulata.* They were again described by Brongniart (*in* Cuvier, 1822, p. 174, pl. 12, fig. 4) who assigned Lamarck's species to *Orbitolites.*

When d'Orbigny established the genus *Orbitolina* (1850, p. 143) he assigned this species to the new genus, using the name *Orbitolites lenticulata* Lamarck, 1816. Since the first Linnean name for this species was *Madreporites lenticularis* Blumenbach, the proper name is now *Orbitolina lenticularis* (Blumenbach).

The name *Orbitolina lenticularis* has been used for many forms throughout much of the world. Whether specimens identified with the name belong to the species or not has yet to be determined. Illustrations and descriptions of *O. lenticularis* have been so generalized and vague that comparison with other forms has been nearly impossible.

Distribution.—*O. lenticularis* has been reported from many places, including France (Blumenbach, 1805) Spain (Coquand, 1865, p. 184), Somalia (Silvestri, 1932a, p. 175), Lebanon, Syria, and Iran (Henson, 1948, p. 57), Venezuela (Dietrich, 1924, p. 183), Colómbia (Karsten, 1858, p. 114), and Texas (Douvillé, 1900a, p. 218). Whether these referred specimens are all conspecific with *O. lenticularis* is difficult to tell until they are studied in detail and compared with the type material now studied.

Specimens studied.—Three suites of specimens from the type locality at Perte du Rhône, Ain, France were available for this study. Each sample contained several hundred specimens. Most of the specimens are partly eroded or leached; so the best material was picked from each sample. Thirty-two thin sections were prepared using acids and stain, and many other specimens were partly ground and stained or the worn exterior studied.

Orbitolina concava (Lamarck) 1816

Plates 2 and 3

Orbulites concava Lamarck (1816, p. 197).
Favre (1912, pl. 1, fig. 6).
Orbitolina concava (Lamarck) d'Orbigny (1850, p. 185, n. 745).
Davies (1939, p. 787, pl. 2, fig. 15).

Diagnosis.—Test large (up to 19 mm at the type locality and over 30 mm elsewhere), convexo-concave to discoidal; embryonic apparatus largest among the species studied, with a mean diameter of 0.86 mm and a proloculus with a mean diameter of 0.33 mm; supraembryonic area complex; marginal zone thin, radial zone almost absent, with the bulk of the specimen in the central complex; building materials coarse, with little cement.

External characters.—The test is generally low convexo-concave and regularly circular in outline. Some specimens tend toward a discoidal shape, some have the late ephebic chambers reflexed. In other specimens the late ephebic chambers form a more convex or bowl-shaped test (pl. 2, figs. 7–10). The apex varies in shape from nearly flat through bossed and pustular to peaked. Most of the specimens are bossed or pustular, often with a depressed area immediately surrounding the boss. The dorsal surface is generally smooth, but the slightly rounded concentric lamellae present a subdued corrugated appearance on some specimens (pl. 2, fig. 6).

Many of the specimens available for this study are well preserved, retaining the fine-grained "epidermis." Where this is worn away, the finely divided marginal zone is visible, but none of the specimens display the engine-turned appearance characteristic of specimens with a well-developed radial zone. The ventral surface is relatively featureless. No radial elements are visible on the surface. A vague concentric pattern is discernable on some specimens reflecting the annular nature of some of the chambers (pl. 2, figs. 8, 10). Table 2 and figure 31 summarize the dimensional data for some topotype specimens of *Orbitolina concava.*

Internal characters.—The megalospheric embryonic apparatus is unusually large in this species. The proloculus with a mean diameter of about 0.33 mm is often irregular in shape. The area dorsal to the proloculus has more complicated subdivisions than those in most Orbitolinas. Instead of simple primary and secondary plates, there is developed in addition an area

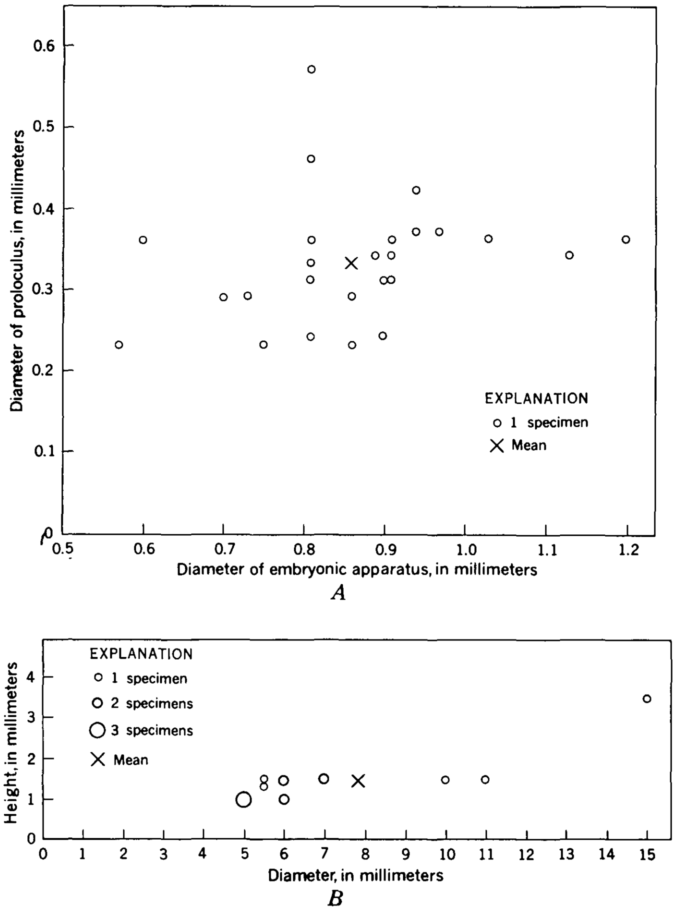


FIGURE 31.—Dimensions of some characters of *Orbitolina concava. a,* Dimensions of the megalospheric embryonic chambers of *O. concava. b,* Dimensions of *Orbitolina concava.*

TABLE 2.—*Summary data for* Orbitolina concava (*Lamarck*)

	Diameter of 15 specimens measured (mm)	Height of 15 specimens measured (mm)	D:H ratio of 15 specimens measured	Diameter of embryonic apparatus of 25 specimens meaured (mm)	Diameter of proloculus of 25 specimens measured (mm)
Maximum	17	3.5	6.7	1.2	0.57
Minimum	5	1.0	3.7	.57	.23
Mean	7.8	1.5	5.0	.86	.33
Error of mean	±.93	±.02	±.33	±.025	±.015
Standard deviation	3.6	.06	1.22	.127	.075
Inferred range	⋜18.6	1.3–1.7	1.3–8.7	.46–1.24	.10–.56

similar to the central complex. (Pl. 2, fig. 1.) The area ventral to the proloculus is also more complicated. Annular chamberlike areas develop down from the supraembryonic area and then extend over the ventral surface of the proloculus.

The neanic chambers develop ventral to the embryonic apparatus and are often the only chambers which extend across the entire ventral surface of the test. The ephebic chambers are generally annular. The marginal zone is well developed (pl. 3, figs. 4, 6, 8), with primary and short secondary plates. The primary plates are only about 0.05 mm long, however, and the marginal zone is so thin it is easily abraded away.

The radial zone is essentially absent. There is a short distance in from the marginal zone in which unthickened main partitions can be recognized, but they are soon lost in the central complex. The bulk of the test is an almost structureless central complex in which the septa and chamber layers are the only structural elements that can be traced. The test is almost entirely clastic with only minor amounts of cement. In the marginal zone the materials are fine-grained clastic materials, but the central complex is packed with coarse clastic debris. No calcite eyes were recognized.

Comparison and remarks.—*Orbitolina concava* is unlike any of the species from North America. The almost total lack of radial zone distinguishes it from most species of *Orbitolina.* In addition the large size developed by this species is unknown in America. The complicated embryonic apparatus and its relatively large size are also unduplicated by the American forms. Many specimens have been assigned to this species without a good understanding of what the name *Orbitolina concava* (Lamarck) really represents.

In 1801 Lamarck (1801, p. 376) described a form as *Orbitolites concava.* His description was brief—"Orbitolite dont la surface concave est chargée de rides rayonnantes. Sa surface convexe est parsemée de pores apparents." He did not illustrate the form, but gave a locality, "se trouve à Grignon et ailleurs." Fifteen years later Lamarck (1816, p. 197) described another form as follows,

4. Orbulite soucoupe. *Orbulites concava.*
O. uno latere convexa, subantiquata : altero *concava.*
Habite * * * Fossile de la commune de Ballon, departament de la Sarthe, à quatre lieues N.-E. du Mans. Communiquée par M. M. Menard et Desportes. Sa surface convexe offre souvent des cercles concentriques d'accroissement.

He does not cite his earlier paper, and this form is described from a different locality of entirely different geologic age. Many authors since Lamarck's time have considered both descriptions above as applying to the same form, although they are not homonyms, the one being *Orbitolites* and the other *Orbulites.* Among the more recent workers, Silvestri (1932, p. 171) heads his synonymy for *Orbitolina concava* with the Lamarck, 1801 form; Davies (1939, p. 786) regards *Orbitolites concava* Lamarck, 1801 as synonymous with *Orbulites concava* Lamarck 1816; and Henson (1948, p. 61–63) bases his discussion of *Orbitolina concava* at least in part on Lamarck's 1801 description.

Davies (1939, pl. 2, fig. 15) had access to a specimen of *Orbitolina concava* (Lamarck), 1816, from Ballon (Sarthe) but apparently did not recognize that it would not meet the 1801 description. Henson (1948, p. 62) saw specimens probably referable to *Orbitolina concava* (Lamarck) 1816 and observed that, "all have the central zone so crowded with large sand grains that no structural detail is perceptible; these at any rate do not agree with the description of the apertural face given in Lamarck's brief definition and are entirely different from Silvestri's photographs of the species." The Lamarck description he refers to is obviously the 1801 description of *Orbitolites concava.*

Silvestri (1932, p. 171) described and illustrated forms from Somalia which he referred to *Orbitolina concava* (Lamarck). He did not have topotype material of *O. concava* nor did his specimens have much in common with the specimens from Ballon, France.

The first illustrations of supposed *O. concava* Lamarck were figures by Michelin (1842, pl. 7, figs. 9a–c). These were illustrations of specimens which Lamarck may never have seen and which were from a locality in southeastern France. The first illustration of true *Orbitolina concava* (Lamarck) was presented by Favre (1912, pl. 1, fig. 6) and is reproduced on plate 2, figure 12. Only one other figure of true *O. concava* (Lamarck) 1816 has come to my attention. It is a figure by Davies (1939, pl. 2, fig. 15).

A succession of misconceptions has thus been built up regarding this species. From Lamarck's 1801 description of *Orbitolites concava*, it has been assumed that *Orbitolina concava* (Lamarck) has a pronounced radial zone. From Michelin's illustrations, an erroneous impression of the shape and character of the radial zone has developed. These erroneous conceptions were reenforced by Silvestri's illustrations of forms from Somalia, which are more or less similar to Michelin's illustrations but are completely different from Lamarck's species.

Silvestri (1932a, p. 174 and 1932b, p. 374) compared some forms from the Glen Rose limestone of central Texas with material from Somalia that he called *O. concava.* The similarities he noted led him to consider *Orbitolina texana* (Roemer) a variety of *O. concava* (Lamarck).

It should also be noted that it was *Orbulites concava* Lamarck, 1816, that was assigned to the genus *Orbitolina* by d'Orbigny. No mention was made of *Orbitolites concava* Lamarck 1801.

Distribution.—The distribution of *O. concava* (Lamarck) is unknown. The type locality is in the (Cenomanian) upper green sands of Ballon (Sarthe), France.

Specimens studied.—The description given is based on the topotype material alone, which included several hundred specimens in a sand matrix. Other material referred to *Orbitolina concava* was examined including material from other parts of France, England, Germany and the Near and Middle East.

Designation of types.—No type specimen has been designated. It is suggested that when such a designation is made it be one of the specimens in the Lamarck collection at the Museum of Natural History in Geneva.

Orbitolina texana (Roemer)

Plates 4, 5, and 6

Orbitulites texanus Roemer (1849, p. 392).
Roemer (1852, p. 86, pl. 10, figs. 7a–d).
Giebel (1853, p. 374).
Patellina texana Hill (1893, p. 20, pl. 1, figs. 2 [after Roemer], 2a–d).
?*Orbitulina texana* Hill and Vaughan (1902, p. 3).
Orbitolina texana Roemer. Taff (1891, p. 727).
Prever *in* Prever and Silvestri (1904, p. 468) [not Stanton *in* Ransome (1904, p. 70)].
Carsey (1926, p. 22, pl. 6, figs. 6a–c).
Davies (1939, p. 783, pl. 1, figs. 1, 3, 7, 9, 12).
Orbitolina whitneyi Carsey (1926, p. 22, pl. 6, fig. 9).
Orbitolina concava (Lamarck) var. *texana* (Roemer) Silvestri (1932, p. 371–381, pl. 1, figs. 1–9; pl. 2, figs. 1, 2.
? Hedberg (1937, p. 1986–1987, pl. 4, figs. 1, 2).
Orbitolina concava texana (Roemer) Barker (1944, p. 207, pl. 35, figs. 10–16).
Lozo [part] (1944, p. 553, pl. 5, figs. 1, 2).
Stead [part] (1951, p. 594, pl. 2, figs. 28–30).
Orbitolina texana (Roemer) subsp. *texana* (Roemer) Frizzell (1954, p. 80, pl. 7, figs. 32a–b).
Orbitolina texana (Roemer) var. *whitneyi* Carsey. Frizzell (1954, p. 80, pl. 7, fig. 33).

Diagnosis.—Test medium sized, up to 10 mm in megalospheric forms and nearly 12 mm in microspheric forms; shape varied, from convexo- or conico-concave to discoidal and strongly reflexed forms; embryonic apparatus largest for North American forms with a mean diameter in megalospheric forms near 0.5 mm and a proloculus with a mean diameter near 0.2 mm; marginal zone well developed; radial zone extending across most of the ephebic chamber area, main partitions strongly triangular; building materials including some coarse debris in a large amount of cement.

External characters.—The test is generally low reflexed convexo-concave, but the shape varies from strongly reflexed through discoidal to high convexo-concave. The microspheric forms tend to have the flatter or more reflexed shapes, but both microspheric and megalospheric generations exhibit a wide range of shapes. As shown in table 3 the megalospheric forms have a mean diameter of about 5 mm and the microspheric forms have a larger mean diameter. The form ratio for the microspheric forms is also greater than for the megalospheric forms. The apex in the megalospheric forms tends to be pustular. The pustule may protrude as in plate 6, figure 3, or may be depressed as in plate 6, figure 4, giving a rounded appearance to the apex. In microspheric forms, the apex tends to be rounded, with the embryonic chambers raised above the rounded surface, as in plate 6, figure 2.

The dorsal surface tends to be irregular in *Orbitolina texana.* The concentric lamellae are slightly arched in the area of the apex and are irregularly arched toward the periphery. Some of the larger forms have strongly and irregularly arched lamellae near the periphery. The margin of many specimens is slightly fluted, especially in the reflexed forms.

The ventral surface of some specimens is nearly smooth, but most specimens have the radial partitions and chamber passages clearly visible on the ventral surface.

Internal characters.—The test is initiated with one or more chambers which do not possess adult characters. In the megalospheric form of *Orbitolina texana*, there is a large initial chamber or proloculus with a mean diameter near 0.2 mm. (See table 3.) The dorsal part of the embryonic apparatus is subdivided by short plates at approximately right angles to each other producing a honey-comb structure. The second chamber is added along the ventral surface of the proloculus and is a bowl- or saucer-shaped chamber. The second chamber is subdivided throughout. The marginal zone is developed as in the ephebic chambers. The radial zone is subdivided by main partitions, but they are not thickened as in the ephebic chambers, nor are they zigzag. In the central part the main partitions anastomose, forming a simple open network.

In the microspheric form of *Orbitolina texana*, there is a small initial chamber or proloculus followed by a planispiral series of chambers coiled at right angles to the axis of the adult test. (See pl. 6, fig. 2.) The nepionic chambers increase in size gradually for about one-half a turn, then flare rapidly, becoming saucer shaped at the end of the first complete whorl. Neanic chambers are then added ventrally as in the megalosphere, followed by fully developed ephebic chambers.

Shape of the chamber.—The early postembryonic chambers are uniserial, shallow, and circular with a slightly concave base. The chambers are, therefore, thicker (or deeper) in the radial zone than in the central complex. The later chambers tend to maintain a constant thickness in the radial zone but thin in the area of the central complex. As there is variety in the shapes of grown specimens, it follows that the shape of the ephebic chambers is varied. In some specimens the late ephebic chambers maintain the same shape as the early ephebic chambers. In these, the test is a regular cone. Other specimens develop ephebic cham-

TABLE 3.—*Summary data for* Orbitolina texana (*Roemer*)

Dimensions	Sample No., generation, and number of specimens measured														
	f20113, A, 20	f20084, A, 11	f20097, A, 20	f20097, B, 20	f20098, A, 12	f20098, B, 12	f20102, A, 8	f20104, A, 20	f20108, A, 14	f20109, A, 14	f20109, B, 6	f20120, A, 21	f20122, A, 15	f20123, A, 12	f20127, A, 8
Diameter (mm):															
Maximum	7.6	....	8.0	9.3	7.0	10.9	6.5	8.4	7.4	4.7	0.9	....	....	....	....
Minimum	3.5	....	3.4	2.9	3.5	6.0	3.2	4.3	4.3	2.8	5.7	....	....	....	....
Mean	5.3	....	4.8	5.9	6.2	7.9	4.6	6.1	5.3	3.6	6.9	....	....	....	....
Error of mean	±.23	....	±.23	±.35	±.29	±.4	±.45	±.29	±.54	±.17	±.51	....	....	....	....
Standard deviation	1.2	....	1.1	1.6	1.0	1.37	1.27	1.31	1.32	.63	1.25	....	....	....	....
Inferred range	1.6–9.0	....	1.7–8.0	1.2–10.6	3.2–9.2	3.8–12.	0.8–8.4	2.2–10	1.3–9.3	1.7–5.5	3.2–10.7	....	....	....	....
Height (mm):															
Maximum	2.2	....	1.9	1.8	1.9	1.7	1.6	2.1	1.6	2.1	2.2	....	....	....	....
Minimum	1.1	....	.9	.7	1.0	.8	.8	.7	.9	1.1	1.3	....	....	....	....
Mean	1.6	....	1.3	1.0	1.5	1.2	1.1	1.4	1.4	1.6	1.7	....	....	....	....
Error of mean	±.07	....	±.01	±.06	±.09	±.08	±.09	±.08	±.11	±.08	±.09	....	....	....	....
Standard deviation	.3	....	.03	.27	.31	.28	.26	.36	.28	.28	.22	....	....	....	....
Inferred range	.7–2.5	....	.4–8.2	.2–1.8	.6–2.4	.4–2.0	.3–2.0	.2–2.5	.6–2.2	.8–2.4	.98–2.3	....	....	....	....
D:H ratio:															
Maximum	4.3	....	5.5	9.9	5.8	9.9	7.6	6.7	5.3	3.4	5.1	....	....	....	....
Minimum	2.3	....	2.8	3.3	3.2	4.5	2.4	2.4	2.5	1.7	3.4	....	....	....	....
Mean	3.3	....	3.9	6.2	4.2	6.6	4.0	4.5	4.0	2.3	4.3	....	....	....	....
Error of mean	±.12	....	±.16	±.42	±.23	±.45	±.55	±.28	±.43	±.19	±.29	....	....	....	....
Standard deviation	.6	....	.71	1.9	.8	1.55	1.55	1.26	1.06	.71	.71	....	....	....	....
Inferred range	1.6–5.0	....	1.8–6.0	.6–11.8	1.8–6.6	1.9–11.3	0–8.6	.7–8.3	.8–7.2	.2–4.4	2.2–6.4	....	....	....	....
Diameter of embryonic apparatus (mm):															
Maximum	.81	.63	.6	....	.60	....	.49	.49	.49	.40	....	0.57	0.49	0.49	0.50
Minimum	.34	.37	.3	....	.26	....	.24	.26	.27	.28	....	.33	.36	.32	.34
Mean	.5	.45	.4	....	.43	....	.37	.38	.38	.35	....	.46	.43	.39	.42
Error of mean	±.02	±.02	±.02	....	±.02	....	±.03	±.02	±.02	±.01	....	±.01	±.01	±.02	±.02
Standard deviation	.11	.18	.07	....	.08	....	.09	.08	.07	.04	....	.07	.05	.07	.06
Inferred range	.17–.88	.22–.68	.18–.62	....	.19–.67	....	.10–.64	.16–.60	.16–.60	.24–.46	....	.26–.66	.29–.58	.19–.59	.24–.60
Diameter of proloculus (mm):															
Maximum	.34	.26	.26	....	.33	....	.24	.21	.24	.21	....	.28	.27	.23	.23
Minimum	.13	.13	.13	....	.14	....	.10	.11	.13	.15	....	.13	.16	.13	.15
Mean	.20	.20	.20	....	.22	....	.17	.18	.19	.17	....	.20	.20	.18	.18
Error of mean	±.01	±.01	±.01	....	±.01	....	±.02	±.01	±.01	±.01	....	±.01	±.01	±.01	±.01
Standard deviation	.05	.04	.03	....	.05	....	.06	.03	.03	.02	....	.03	.03	.03	.03
Inferred range	.04–.36	.03–.38	.1–.3	....	.07–.37	....	.01–.33	.09–.29	.11–.27	.10–.24	....	.10–.30	.10–.30	.08–.27	.09–.27

bers in which the marginal and radial zones are well developed, but the central complex is not. Thus many of the larger specimens, especially the microspheric forms, tend to develop annular chambers in the late ephebic or gerontic stage.

The marginal edges, or concentric lamellae, are generally slightly or irregularly arched in *Orbitolina texana*, so that the dorsal surface of the test has a corrugated appearance. The chamber height increases slowly from the early chambers toward the periphery. The sutures between chambers, as exposed on the dorsal surface, are, therefore, more widely spaced toward the periphery. There are up to 20 sutures per mm near the apex and 12 to 15 sutures per mm toward the periphery.

Marginal zone.—The marginal zone is narrow. The mean extension of the primary plates is 0.06 mm with a range in the ephebic chambers of 0.05 to 0.07 mm although some large microspheric forms have plates 0.09 mm long in the late ephebic or gerontic chambers.

The chamberlets in the marginal zone are roughly square as viewed in tangential section. They are subdivided into cellules by vertical and horizontal primary plates and irregularly by secondary plates, at least in the lower half. Six to ten cellules per chamberlet are common. (See pl. 6, fig. 12.)

Radial zone.—The radial zone is well developed in *Orbitolina texana*, and it includes more than half the area of each chamber. The main partitions thicken rapidly at the inner edge of the marginal zone (pl. 6, figs. 10, 12), becoming triangular in cross section as they start the zigzag pattern of the radial zone. Plate 6, figures 9 and 10, show the development of the main partitions as seen in basal section. Apertural pores, which are relatively small, can be seen where the section grazes the floor of the chamber, passing through the septa at the reentrants in the main partitions. Some partitional pores can also be seen in plate 6, figure 9, where they are displayed as breaks in the main partitions. Abundant partitional pores are shown in plate 6, figure 11, especially where the partitions enter the central complex.

Central complex.—Free chamber space is limited in the central area of the test by the thinning of the chambers. The main partitions tend to thin and become plane instead of triangular. They become discontinuous owing to the abundance of partitional pores. No calcite eyes were recognized in this species.

Building material.—The test in this species is constructed primarily of fine-silt- to clay-size particles. Dispersed throughout the radial zone and central complex there are larger angular grains up to about 0.05 mm in diameter. The larger grains appear to be more or less pure calcite, whereas the smaller grains have a dark coloring suggesting organic material mixed in with the calcium carbonate. (See pl. 6, figs. 13, 14.)

Remarks.—Orbitolina texana was first described by Roemer (1849, p. 393) as a species of *Orbitulites.* In 1852 (p. 86, pl. 10, figs. 7a–d) he redescribed and illustrated the form, still assigning it to the same genus even though the genus *Orbitolina* had by then been proposed.

Hill and Vaughan (1902, p. 3) recognized an *Orbitolina* in the Austin area and called it *Orbitolina texana*, presumably assigning Roemer's species to d'Orbigny's genus although their citation is not clear. Roemer's species was definitely assigned to *Orbitolina* by Stanton (*in* Ransome 1904, p. 70) when it was found in the mural limestone at Bisbee, Ariz.

Orbitolina texana (Roemer) was restudied by Silvestri (1932, p. 374), who compared specimens from eastern Comal County, Tex., with Orbitolinas in his collections from Somalia (Silvestri 1932a, p. 124). He had identified the Somalian species with *O. concava* Lamarck, but the determination was based on Michelin's illustrations, which (see p. 33 of this report) are not necessarily of *O. concava* Lamarck, 1816.

Silvestri's conclusion that *O. texana* is a subspecies of *O. concava* Lamarck is, therefore, based on tenuous evidence. The topotype specimens of *O. concava* Lamarck, 1816 described in this report (p. 32) are not conspecific with *O. texana* (Roemer).

Carsey (1926, p. 22) described as a new species of *Orbitolina* a form which she called *O. whitneyi*, and she distinguished it from *O. texana* by its larger size and less conical shape. *O. whitneyi* was discussed at length by Barker (1944, p. 208), who suggested that it might represent the microspheric generation of *O. texana.* Barker was not able to obtain sections of *O. whitneyi* showing the microspheric embryo, but the specimen illustrated as figure 10 of his plate 35 has a microspheric embryonic apparatus of the type present in *O. texana* (Roemer).

Study of abundant material from the type locality of *O. whitneyi* Carsey confirms Barker's conclusions, even though Barker's material was not from the type locality (Frizzell, 1954, p. 80).

Frizzell (1954, p. 80) cited *Orbitolina texana* (Roemer) with a subspecies *texana* (Roemer) and a variety *whitneyi* Carsey. He did not recognize the different generations in *Orbitolina.*

Distribution.—Orbitolina texana (Roemer) is found throughout the lower part of the Glen Rose limestone in central Texas and as far west as Brewster County, Tex. It has also been found as far east as Pinellas County, Fla., in the subsurface lower Trinity.

The type locality, f20113, was described by Roemer (1852, p. 86) as "on the way from New Braunfels to Fredericksburg this side of the Guadalupe on Wasp Creek [translated]". The locality is in what is now Kendall County, Tex., just off the Boerne-Sisterdale road on the A. Herbst ranch.

Specimens studied.—Over 30 collections containing this species were studied. From these collections over eight hundred thin sections were prepared, including several thousand specimens. Where free specimens were available they were studied whole and then multiple sections prepared from many of the specimens. Among the specimens studied were those illustrated by Barker (1944, pl. 35, figs. 10–16).

Designation of types.—No specimen or specimens were designated as type for *Orbitulites texanus* by Roemer either in 1849 or 1852. In the 1852 paper several specimens were illustrated (Roemer, 1852, pl. 10, fig. 7a–d), but these, along with any other material on which he based his description, must all be considered syntypes. No depository for the type material was cited. The syntypes are probably among other of Roemer's specimens in the Museum of Geology and Paleontology of the institute at Bonn, Germany.

Orbitolina minuta Douglass, n. sp.

Plates 7 and 8

Orbitolina concava texana (Roemer). Stead [part] (1951, p. 594).

Orbitolina texana (Roemer) subsp. *texana* (Roemer). Frizzell [part] (1954, p. 80 [not pl. 7, fig. 32a–b]).

Name derivation: Latin, *minuta*, small.

Diagnosis.—Test small, up to about 9 mm; convexo- or conico-concave, or reflexed; embryonic apparatus consistently smaller than in *O. texana*, with a mean diameter near 0.29 mm and a proloculus with a mean diameter near 0.13 mm; marginal zone thin but finely subdivided; radial zone well developed, with strongly triangular main partitions; building materials generally fine grained in a large amount of cement.

External characters.—The test is generally low, slightly reflexed convexo-concave, but the shape varies from low to high convexo-concave, with some specimens high conico-concave. There is no marked difference in shape between the microspheric and megalospheric generations in this species. Table 4 summarizes the measurements and inferred limits on some of the representative samples of this species. The megalospheric forms have a mean diameter near 5 mm in most of the samples although the mean diameter varies from about 3 mm to 6.5 mm. The mean form ratio in most of the samples is close to 3.5 mm.

The apex on most of the specimens of this species is rounded, but a few of the specimens have a subpustular apex. No raised microsphere was found and all specimens in which no megalosphere was found had a flat to rounded apex.

The dorsal surface tends to be regular in this species. The concentric lamellae are nearly flush on some of the specimens while on others they are slightly or irregularly arched. As in most species, the irregularity tends to increase toward the periphery. The ventral surface of some specimens is smooth except for scattered larger grains of building material. Most of the specimens, however, show some stage of development of the radial partitions, generally as low broad ridges radiating from the central zone.

Internal characters.—The embryonic apparatus is apical and central. The megalospheric form has an initial chamber which in most samples has a mean diameter near 0.12 mm. (See table 4.) The dorsal part of the embryonic apparatus is subdivided by short partitions producing a honey comb structure. (See pl. 7, figs. 5–9, 24, 25.) The second chamber is added along the ventral surface of the first and is subdivided throughout. The subdivisions of the second chamber are similar to those in ephebic chambers except that there is no thickening of the main partitions and in the central zone the partitions simply anastomose, forming an open network.

The postembryonic chambers are uniserial shallow saucer shaped, with a slightly concave base. Each chamber is deepest in the radial zone and thins toward the axis, although this tendency is not as strong in *O. minuta* as it is in species such as *O. texana*. Only rarely is the central complex so diminished as to produce annular chambers. The chamber height increases slowly from the apex toward the periphery of the test. There are about 20 chambers per mm near the apex and about 15 per mm near the periphery.

The marginal zone is narrow. The mean extension of the primary plates in the ephebic chambers is 0.056 mm with an observed range of 0.03–0.08 mm. The

TABLE 4.—*Summary data for* Orbitolina minuta *Douglass, n. sp.*

[Generation A]

Dimensions	Sample No. and number of specimens measured															
	f20101, 20	f20106, 15	f20107, 20	f20110, 20	f20090, 6	f20095, 9	f20114, 20	f20115, 20	f20128, 9	f20129, 9	f20132, 8	f20134, 11	f20138, 14	f20246, 15	f20247, 12	f20252, 8
Diameter (mm):																
Maximum	6.3	5.5	4.1	7.0	4.0	6.4	8.6	7.0	--------	--------	--------	--------	8.4	--------	--------	--------
Minimum	4.0	3.4	2.8	3.6	2.1	3.7	5.0	4.2	--------	--------	--------	--------	2.8	--------	--------	--------
Mean	4.8	4.5	3.3	4.8	2.9	4.8	6.5	5.3	--------	--------	--------	--------	4.9	--------	--------	--------
Error of mean	±.17	±.18	±.09	±.18	±.21	±.26	±.23	±.16	--------	--------	--------	--------	±.32	--------	--------	--------
Standard deviation	.78	.69	.42	.82	1.53	.84	1.03	.73	--------	--------	--------	--------	1.5	--------	--------	--------
Inferred range	2.5–7.1	2.4–6.6	2.0–4.6	2.3–7.3	1.3–4.4	2.3–7.3	3.4–9.6	3.1–7.5	--------	--------	--------	--------	0.4–9.4	--------	--------	--------
Height (mm):																
Maximum	2.5	1.6	1.7	1.8	1.7	2.3	2.2	1.9	--------	--------	--------	--------	1.7	--------	--------	--------
Minimum	.8	1.0	.7	.9	.6	1.0	.9	.9	--------	--------	--------	--------	1.0	--------	--------	--------
Mean	1.2	1.3	1.0	1.4	1.0	1.6	1.6	1.4	--------	--------	--------	--------	1.4	--------	--------	--------
Error of mean	±.09	±.06	±.05	±.06	±.17	±.05	±.12	±.05	--------	--------	--------	--------	±.06	--------	--------	--------
Standard deviation	.42	.22	.22	.26	1.09	.17	.54	.23	--------	--------	--------	--------	.26	--------	--------	--------
Inferred range	0–2.5	.7–2.0	.34–1.7	.6–2.2	0–2.2	1.1–2.1	0–3.2	.7–2.1	--------	--------	--------	--------	.6–2.2	--------	--------	--------
D:H ratio:																
Maximum	6.3	5.0	4.7	6.3	3.8	4.3	7.8	5.0	--------	--------	--------	--------	5.3	--------	--------	--------
Minimum	2.4	2.4	2.4	2.6	2.5	2.5	2.9	3.2	--------	--------	--------	--------	2.6	--------	--------	--------
Mean	4.3	3.7	3.4	3.7	3.2	3.2	4.4	3.9	--------	--------	--------	--------	3.4	--------	--------	--------
Error of mean	±.26	±.23	±.14	±.19	±.26	±.06	.29	±.11	--------	--------	--------	--------	±.15	--------	--------	--------
Standard deviation	1.16	.91	.62	.84	.63	.2	1.32	.49	--------	--------	--------	--------	.7	--------	--------	--------
Inferred range	.8–7.8	1.0–6.4	1.5–5.3	1.2–6.2	1.3–5.1	2.6–3.8	.4–8.4	2.4–5.4	--------	--------	--------	--------	1.3–5.5	--------	--------	--------
Diameter of embryonic apparatus (mm):																
Maximum	.34	.49	.33	--------	.29	.33	.50	.34	0.33	0.47	0.36	0.31	.44	0.36	0.33	0.33
Minimum	.21	.24	.21	--------	.21	.24	.18	.18	.24	.16	.20	.20	.21	.24	.21	.24
Mean	.29	.32	.28	--------	.26	.27	.33	.24	.28	.28	.26	.25	.29	.28	.29	.28
Error of mean	±.01	±.02	±.01	--------	±.01	±.01	±.02	±.01	±.01	±.03	±.02	±.01	±.02	±.01	±.01	±.02
Standard deviation	.04	.07	.04	--------	.03	.03	.08	.04	.04	.09	.05	.04	.07	.04	.04	.04
Inferred range	.17–.41	.11–.53	.17–.38	--------	.18–.34	.18–.36	.10–.56	.08–.40	0.17–.39	0.01–.55	0.11–.41	0.14–.36	.12–.45	0.15–.41	0.17–.41	0.15–.41
Diamter of proloculus (mm):																
Maximum	.18	.18	.16	--------	.13	.15	.16	.20	.21	.16	.16	.16	.21	.20	.18	.16
Minimum	.08	.08	.10	--------	.08	.10	.07	.10	.10	.08	.10	.10	.08	.11	.10	.11
Mean	.12	12	.14	--------	.11	.12	.12	.12	.13	.13	.12	.12	.12	.15	.13	.13
Error of mean	±.01	±.01	±.01	--------	±.01	±.01	±.01	±.01	±.01	±.01	±.01	±.01	±.01	±.01	±.01	±.01
Standard deviation	.03	.03	.02	--------	.02	.02	.03	.03	.04	.03	.02	.02	.03	.02	.02	.03
Inferred range	.03–.20	.02–.22	.08–.20	--------	.04–.18	.06–.18	.04–.20	.04–.20	.02–2.5	.05–.21	.06–.18	.05–.19	.03–.21	.08–.22	.06–.20	.05–.21

chamberlets are roughly square in tangential view. In basal view the chamberlets appear triangular, due to the rapid thickening of the main partitions as they leave the marginal zone. They are subdivided by vertical and horizontal primary plates to form irregularly rectangular cellules (pl. 8, figs. 1, 5), and are further subdivided at the very outer edge of the marginal zone by short secondary vertical and horizontal plates.

The radial zone is well developed and extends through about half the area of each chamber. The main partitions thicken away from the marginal zone and are triangular in cross section as they start the zigzag pattern of the radial zone. (See pl. 8, figs. 1, 10.) Apertural pores are common and small. They may be seen best in basal section, as in plate 8, figure 10. Figure 6 of the same plate shows the apertural pores in axial section as breaks in the septa. Partitional pores are clearly shown in axial section in plate 8, figure 4.

The central complex is relatively free from detrital material and does not include an abundance of sand grains or shell fragments. The main partitions tend to lose their identity and are riddled with partitional pores. (See pl. 8, figs. 7, 8.) The chambers tend to thin in the central area and many of the septa are discontinuous.

Comparison and remarks.—*Orbitolina minuta* is similar in many respects to *O. texana* (Roemer), and the two have not been separated formally by earlier authors. *O. minuta* can be distinguished from *O. texana* by the size of the megalosphere. (See fig. 32.) The mean diameter of the proloculus for samples of *O. minuta* is consistently smaller than the mean diameter of the proloculus for samples of *O. texana*, and no sample of the one has as much as 10 percent overlap with any sample of the other. Generally, specimens of *O. minuta* are smaller and more conical than those of *O. texana*, although individual specimens cannot be distinguished on size and shape alone.

Stratigraphically the two species occur at different horizons. *O. minuta* occurs in the upper part of the Glen Rose limestone and as low as the "*Salenia* zone," whereas *O. texana* is confined to the lower part of the Glen Rose, below the "*Salenia* zone." Two samples collected in Comal County, Tex., f20106 and f20107, contain *O. minuta* and are exceptions to this rule. These two samples were taken from between 81 and 88 feet below the top of the "*Salenia* zone."

Distribution.—*O. minuta* is found at several horizons throughout the upper part of the Glen Rose limestone in Central Texas and in correlatives of the upper part of the Glen Rose as far west as Arizona.

Specimens studied.—Over a thousand thin sections of this species, some containing many specimens, were prepared. In addition, free specimens found in the marly zones were prepared and over a hundred specimens studied in detail.

Designation of types.—Specimen f20101-2, USNM P5459, is designated the holotype. An axial section of the specimen is illustrated on plate 7 as figure 4. A basal and a tangential slice of the same specimen are mounted on two other slides. The U.S. National Mu-

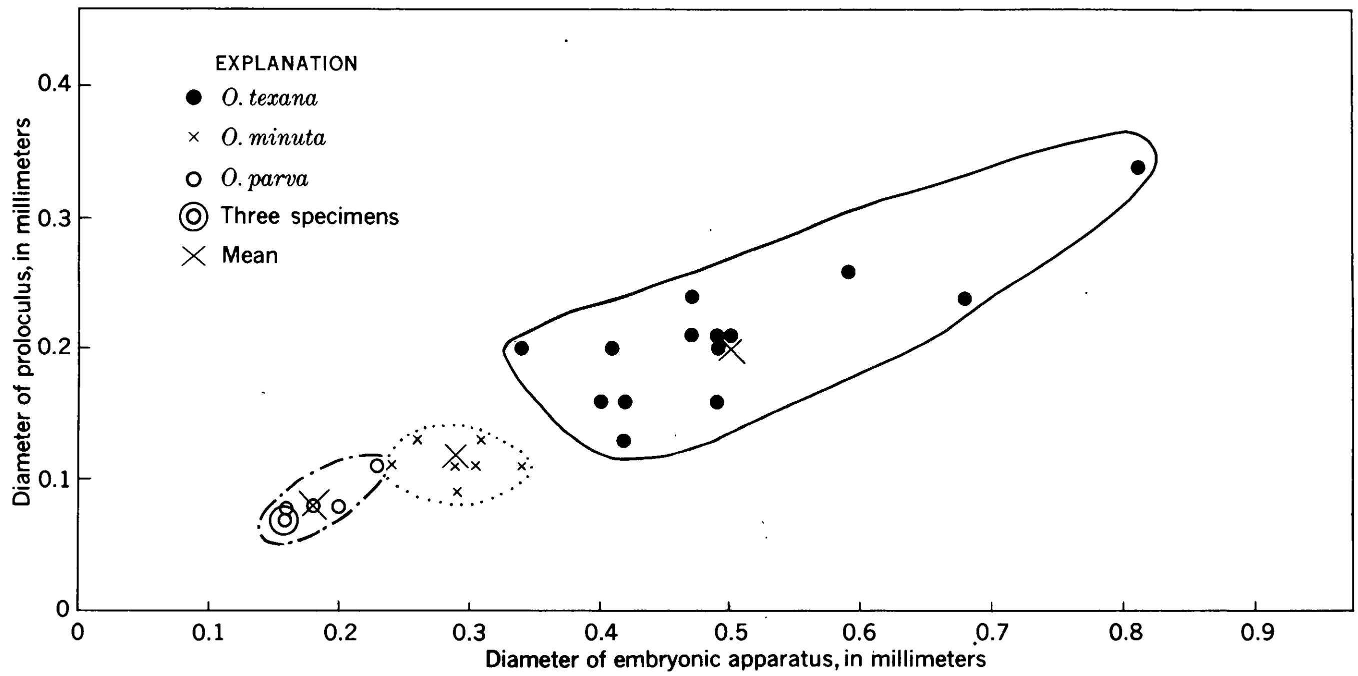


FIGURE 32.—Comparison of the megalospheric embryonic apparatus of *Orbitolina texana*, *O. minuta*, and *O. parva*.

seum numbers for the figured paratypes are given in the explanations of plates 7 and 8.

Orbitolina parva Douglass, n. sp.

Plate 9.

Name derivation: Latin, *parva*, small, tiny.

Diagnosis.—Test small, up to about 6 mm, convexo- or conico-concave; embryonic apparatus minute, with a mean diameter of 0.18 mm and a proloculus with a mean diameter of 0.08 mm; marginal zone thin; radial zone with triangular main partitions extending across most of each chamber; building materials fine grained; no calcite eyes.

External characters.—The test is generally low, slightly reflexed convexo-concave. Some specimens are not reflexed and tend toward discoidal. Only megalospheric individuals were found. The apex in the megalospheric forms is only slightly rounded or flat. The dorsal surface is nearly smooth, as the concentric lamellae are flat or only slightly rounded. The ventral surface is concave and roughly parallels the dorsal surface. A summary of the dimension data for this species is given in table 5.

Internal characters.—The megalospheric embryonic apparatus is small, with a mean diameter of 0.18 mm. The proloculus has a mean diameter of 0.08 mm, which is the smallest for any species found in the North American material. The upper part of the embryonic apparatus is simply subdivided by plates and the lower part is almost undivided except for a few thin partitions. (Pl. 9, figs. 4–8.)

TABLE 5.—*Summary data for* Orbitolina parva *Douglass, n. sp.*

	Diameter of 4 specimens measured (mm)	Height of 4 specimens measured (mm)	D:H ratio of 4 specimens measured	Diameter of embryonic apparatus of 7 specimens measured (mm)	Diameter of proloculus of 7 specimens measured (mm)
Maximum	5.6	1.7	4.1	0.23	0.11
Minimum	3.7	.9	3.1	.16	.07
Mean	4.6	1.3	3.6	.18	.08
Error of mean	±.41	±.17	±.19	±.01	±.005
Standard deviation	.82	.33	.38	.03	.014
Inferred range	2.2–7.1	.3–2.3	2.4–4.7	.10–.26	.04–.12

The chambers are relatively thin throughout, averaging about 18 chambers per mm. They are thin toward the center of the test but are continuous, with little tendency to become annular. The marginal zone is thin, the primary plates extending about 0.05 mm and secondary plates only about half that distance. In tangential sections, such as shown in plate 9, figure 12, it can be seen that the chamberlets are divided into cellules only at the outermost edge of the marginal zone. The radial zone is well developed and includes almost all of each chamber. The main partitions thicken rapidly and zigzag in toward the central complex in a regular manner. (Pl. 9, figs. 10, 11.) Partitional and apertural pores are small and abundant. The central complex is rather limited in most chambers. Plate 9, figure 9, shows a portion of a chamber in basal section in which the main partitions lose their identity in this central area. The building materials are fine clastic grains and do not obliterate structures even in the central complex. No calcite eyes are present.

Comparison and remarks.—*Orbitolina parva* is probably closely related to *O. minuta.* The diameter of the megalospheric embryonic apparatus of *O. parva* is consistently smaller than that of *O. minuta* (see fig. 32), so much so that their statistically inferred ranges do not overlap at all.

Distribution.—This species was found at only one horizon in the Playas Peak formation in New Mexico.

Specimens studied.—Thirty-nine thin sections, containing about one hundred random cuts of specimens of *O. parva*, were studied.

Designation of types.—Specimen f20228–15, USNM P5494, is designated the holotype. It is illustrated on plate 9 as figure 2. The National Museum numbers of the figured paratypes are given in the explanation for plate 9.

Three species, *O. texana*, *O. minuta*, and *O. parva*, are closely related morphologically. They are similar in structural details of the marginal, radial, and central zones, and they build tests of about the same size and kind of detrital material. The character by which they are most easily separated is the size of the embryonic apparatus. The megalospheric embryonic apparatus shows an overall decrease in size through time for the three species. Both the total diameter of the megalospheric embryonic apparatus and the diameter of the proloculus decrease with time. *O. texana* has the largest; *O. minuta* has an intermediate size; and *O. parva* has the smallest size. (See fig. 32.) This relationship suggests phylogenetic affinity. There is a possibility that these 3 species represent a subgenus, or that the 3 taxa are really subspecies. Although considerable is now known about the Orbitolinas of North America, it would be premature to divide the genus without an adequate knowledge of the Orbitolinas from the rest of the world.

Orbitolina oculata Douglass, n. sp.

Plate 10

Name derivation: Latin, *oculata*, having eyes.

Diagnosis.—Test small, up to about 7 mm in diameter; shape conico- or convexo-concave or reflexed; embryonic apparatus with a mean diameter near 0.26 mm and a proloculus with a mean diameter near 0.13 mm; marginal zone thin, finely subdivided; radial zone with thick triangular main partitions across most of each chamber; building materials including coarse debris in the central complex; calcite eyes common.

External characters.—The test is generally low convexo-concave, irregularly reflexed. The apex is rounded or slightly pustular. The dorsal surface is smooth or may show some corrugation from slight rounding of the concentric lamellae. The ventral surface may be shallow- or deep-concave and may show little structure or may have the main partitions clearly expressed. A summary of the measurement data is given in table 6 and figure 29.

Internal characters.—The megalospheric embryonic apparatus is composed of a small proloculus with the area above subdivided by primary and secondary plates and the first ventral chamber irregularly subdivided by partitions. (See pl. 10, figs. 13–15.) The early ephebic chambers tend to maintain a constant thickness, forming a conico-convex test. The later chambers are thinner in the central area and the test becomes conico- or convexo-concave. There are about 16 chambers per mm near the apex of the test and about 12 per mm toward the periphery.

The marginal zone is narrow, the primary plates extending about 0.08 mm and the secondary plates about half that distance. The chamberlets are irregularly divided into cellules, with 6 to 8 cellules developed at the periphery of each chamberlet. (See pl. 10, fig. 16.)

The radial zone is well developed, including most of the area of each chamber. The main partitions thicken away from the marginal zone (pl. 10, figs. 16, 18, 19) and zigzag irregularly toward the central complex. Plate 10, fig. 18, is of a thin section which passes obliquely through a chamber. The uppermost thickened edges of the main partitions in the preceding chamber are visible along the left side; just to the right the section passes through the floor or septum and the apertural pores are visible in the reentrants of the relatively unthickened portion of the main partitions. The upper right hand portion is in the middle of the chamber and shows the partially thickened main partitions broken intermittently by the partitional

TABLE 6.—*Summary data for* Orbitolina oculata *Douglass, n. sp.*

Dimensions	Sample No. and number of specimens measured						
	f20092, 9	f20094, 12	f20143, 7	f20144, 7-15	f20212, 14	f20249, 8	f20255, 5
Diameter (mm):							
Maximum	5. 1	5. 3	5. 9	5. 8	7. 1	5. 2	5. 6
Minimum	2. 1	2. 9	3. 3	3. 1	3. 7	3. 7	4. 0
Mean	3. 5	4. 3	4. 7	4. 7	5. 7	4. 7	4. 8
Error of mean	±. 3	±. 12	±. 34	±. 43	±. 29	±. 18	±. 26
Standard deviation	. 9	. 4	. 9	1. 15	1. 07	. 52	. 58
Inferred range	0. 8–6. 2	3. 1–5. 5	2. 0–5. 4	1. 2–8. 2	3. 5–8. 9	3. 1–6. 3	3. 1–6. 5
Height (mm):							
Maximum	1. 6	2. 1	2. 6	2. 6	2. 3	2. 0	1. 8
Minimum	. 9	1. 1	1. 5	1. 8	1. 1	1. 4	1. 5
Mean	1. 1	1. 5	2. 0	2. 0	1. 6	1. 7	1. 7
Error of mean	±. 10	±. 10	±. 013	±. 137	±. 009	±. 08	±. 06
Standard deviation	. 3	. 36	. 36	. 356	. 32	. 224	. 12
Inferred range	. 2–2. 0	. 42–2. 58	1. 0–3. 1	. 9–3. 1	. 7–2. 6	1. 0–2. 4	1. 3–2. 1
D:H ratio:							
Maximum	4. 4	3. 8	2. 7	2. 8	4. 7	3. 3	3. 1
Minimum	2. 4	2. 3	2. 2	2. 2	2. 9	2. 2	2. 4
Mean	3. 2	2. 9	2. 4	2. 6	3. 7	2. 8	2. 8
Error of mean	±. 14	±. 19	±. 07	±. 015	±. 13	±. 15	±. 13
Standard deviation	. 41	. 65	. 19	. 405	. 5	. 41	. 29
Inferred range	2. 0–4. 4	. 05–4. 85	1. 8–3. 0	1. 4–3. 8	2. 2–5. 2	1. 6–4. 0	1. 9–3. 7
Diameter of embryonic apparatus (mm):							
Maximum	. 28	. 33	. 33	. 36	. 31	----------	----------
Minimum	. 20	. 23	. 17	. 18	. 24	----------	----------
Mean	. 24	. 28	. 23	. 26	. 27	----------	----------
Error of mean	±. 016	±. 02	±. 016	±. 012	±. 016	----------	----------
Standard deviation	. 03	. 05	. 05	. 05	. 036	----------	----------
Inferred range	. 14–. 34	. 14–. 42	. 08–. 38	. 12–. 40	. 16–. 38	----------	----------
Diameter of proloculus (mm):							
Maximum	. 13	. 16	. 18	. 21	. 15	----------	----------
Minimum	. 08	. 11	. 10	. 08	. 11	----------	----------
Mean	. 10	. 13	. 12	. 13	. 13	----------	----------
Error of mean	±. 015	±. 011	±. 008	±. 008	±. 002	----------	----------
Standard deviation	. 025	. 025	. 026	. 03	. 02	----------	----------
Inferred range	. 05–. 15	. 06–. 20	. 04–. 20	. 04–. 22	. 07–. 19	----------	----------

pores. The partitional pores are more common in the lower part of the picture area near the central complex. Calcite eyes are also visible as large rounded or kidney-shaped clear areas. The central complex of some specimens is crowded with calcite eyes, as in the specimen shown in oblique section. (Pl. 10, fig. 17.)

The building materials are varied in this species. Most of the specimens have scattered large grains in a fine, silty matrix. Some specimens are found which have a higher concentration of coarser materials.

Comparisons and remarks.—*Orbitolina oculata* is similar in many respects to *O. minuta.* The distinguishing character is the presence of calcite eyes in *O. oculata.* One's first impulse is that the presence or absence of objects of unknown purpose or origin should not be used as a specific criterion. However, the stratigraphic distribution of these forms, convinces me that the occurrence is not just by chance but is of biologic significance.

Distribution.—The distribution of samples containing *Orbitolina oculata* is shown in plates 15–17, where it can be seen that this species was found almost throughout the outcrop area. It occurs in the upper part of the Glen Rose limestone on Old Woman Mountain in Hays County, Tex.; in the Glen Rose equivalents on Fresno Peak in Presidio County, Tex.; in the top of the Howells Ridge formation in the Little Hatchet Mountains of New Mexico; and in the Mural limestone in Cochise County, Ariz.

Specimens studied.—More than three hundred thin sections containing specimens of *O. oculata* were prepared. Most of the slices have many random sections of this species. The specimens were generally well preserved in the Texas samples. The samples from New Mexico and Arizona showed poorer preservation and many were fractured and traversed by calcite veinlets.

Designation of types.—Specimen f20144–7, USNM P5510, is designated the holotype. It is illustrated on plate 10, figure 8. The National Museum numbers for the figured paratypes are given in the explanation of plate 10.

Orbitolina pervia Douglass, n. sp.

Plate 11

Name derivation: Latin, *pervia*, affording passage, open.

Diagnosis.—Test small; megalospheric specimens up to about 5 mm in diameter, and microspheric specimens to over 8 mm in diameter; megalospheric specimens conico- or convexo-concave; microspheric specimens discoidal or reflexed; marginal zone well developed; radial zone with main partitions not thickened to a triangular shape but remaining relatively thin throughout, leaving a great deal of open space; building materials rather fine throughout; calcite eyes common.

External characters.—The test is high convexo- or conico-concave but varies in shape from nearly an equilateral triangular in some megalospheric forms to low reflexed subdiscoidal in microspheric forms. The apex of the megalospheric individuals is rounded or slightly pustular. (Pl. 11, figs. 13, 15.) On microspheric forms the apex is flat to rounded; the microsphere protrudes slightly. (Pl. 11, fig. 8.) The dorsal surface of megalospheric specimens is fairly regular with the concentric lamellae flush or only slightly rounded. The later chambers in microspheric specimens develop more arching of the concentric lamellae, but they are not as strongly arched as in *O. texana.*

Internal characters.—The proloculus of the megalospheric forms has a mean diameter of 0.16 mm. It is circular in plan and convexo-plane in axial view. (Pl. 11, figs. 11, 13, 15.) The embryonic apparatus has a mean diameter of 0.36 mm. (Fig. 30.) It is subdivided over the proloculus by short primary and secondary plates. The second chamber is slightly bowl-shaped and is subdivided throughout by partitions. The microspheric forms are apparently initiated with a small planispiral series at right angles to the axis of the adult as in *O. texana.*

Ephebic chambers in the megalospheric forms are shaped like shallow saucers in which the central portion is slightly raised. Each chamber is thickest in the radial zone and thins slightly in the central zone producing a concave ventral surface on the test. The central zone of the late ephebic and gerontic chambers in microspheric forms tends to thin while the radial zone remains constant or thickens gradually. Few specimens of this species were found to have developed annular chambers. The increase in height of the chambers toward the periphery results in wider spacing of the sutures on the dorsal surface. There are about 13 sutures per mm toward the apex and as few as 9 sutures per mm at the periphery of some specimens.

The marginal zone is narrow. The primary plates extend about 0.08 mm and the secondary plates only 0.05 mm. (Pl. 11, figs. 12, 14.) Secondary horizontal plates are poorly and rarely developed, so 4 to 6 cellules per chamberlet are most common. (Pl. 11, figs. 1, 11.)

The radial zone is well developed, comprising more than half the chamber area. The main partitions do not thicken rapidly away from the marginal zone as in most species. There is some thickening but not enough to produce a consistently triangular cross section as seen in tangential view. (Pl. 11, figs. 1, 11, 17.) Oblique sections (pl. 11, figs. 2, 10) show large open areas in the radial zone. More nearly axial sections (pl. 11, figs. 3, 4, 9) show the regularity in structure of the radial zone allowed by the thinner partitions.

The central complex also tends to be more open in *O. pervia* than in many other species of *Orbitolina.* The partitions anastomose in an open network and are partly broken up by pores. (Pl. 11, figs. 5, 12.) In axial section the central complex appears denser than the radial zone, owing to the central thinning of the chambers, but in basal section the openness of the area within each chamber is apparent. Calcite eyes are common in the central zone.

The building materials in this species are rather fine throughout. Even in the central zone the coarse material is scattered and the matrix is rather fine.

Comparisons and remarks.—*Orbitolina pervia* bears some resemblance to *O. oculata.* They are not altogether dissimilar in size or shape and they both contain calcite eyes. The most distinctive character of *O. pervia* is the nature of the main partitions and therefore of the radial zone. The main partitions of *O. pervia* develop less thickening than those of any other Orbitolinas I have seen from North America. This feature gives specimens a distinctive open (pervious) look in tangential, oblique, and axial sections. Specimens described and illustrated by Henson (1948, p. 56, pl. 3, figs. 1–4) as *Orbitolina* cf. *bulgarica* (Deshayes) appear to be similar in some respects to this species but insufficient material was available to him for a precise description. Whether either *O. pervia* or Henson's specimens can be referred to *Orbitolina bulgarica* (Boué) cannot be determined without a restudy of *O. bulgarica.* For background on *O. bulgarica* (Boué) see Elliott (1952, p. 383), who has corrected the misconceptions concerning the author of this species.

Distribution.—*Orbitolina pervia* was found in collections f20124, f20125, and f20126 in the lower part of the Glen Rose limestone in the Hood Springs quadrangle, Brewster County, Tex. Some specimens in sample f20139 from Presidio County, Tex., may be referable to this species; and sample f20268 from the Mural limestone of the 91 Hills area in Cochise County, Ariz., may also contain specimens of *O. pervia.*

Specimens studied.—About one hundred thin sections were prepared, each containing several random sections of specimens assigned to this species. Many of the specimens are filled with an opaque mud which tends to obliterate the structures and make photography difficult.

Designation of types.—Specimen f20124, slide 15, USNM P5525, is designated the holotype. It is illustrated on plate 11 as figure 6. The National Museum numbers for the figured paratypes are given in the explanation of plate 11.

Orbitolina gracilis Douglass, n. sp.

Plate 12

Name derivation: Latin, *gracilis*, thin.

Diagnosis.—Test medium sized, up to nearly 8 mm in diameter; thin, conico- or convexo-concave or reflexed, with the dorsal and ventral surfaces tending to be parallel; embryonic apparatus fairly small with a mean diameter near 0.24 mm and a proloculus with a mean diameter near 0.1 mm; marginal zone thin; radial zone with thick triangular main partitions extending most of the way across each chamber; building materials medium to coarse grained, but with abundant cementing material. No calcite eyes.

External characters.—The test is low conico- or convexo-concave and may be irregularly reflexed. The test maintains a relatively uniform thickness with the dorsal and ventral surfaces roughly parallel. The apex of the megalospheric form may be rounded or the embryonic apparatus may form a raised pustular area. (See pl. 12, figs. 4, 6.) The apex of the microspheric form is rounded, with the microspheric embryonic apparatus projecting above the surface and forming a small peak. (See pl. 12, figs. 9, 11, 16.) The dorsal surface in both generations is nearly smooth, but some corruggation is caused by the slightly rounded concentric lamellae. Table 7 summarizes the dimensions for *O. gracilis.*

Internal characters.—The proloculus of the megalospheric form is small and fairly typical of the genus. (Fig. 30). The upper part of the embryonic apparatus is subdivided by primary and secondary plates and the ventral chamber is simply subdivided by relatively unthickened partitions. (Pl. 12, figs. 12–14.) The microspheric embryonic apparatus is small and coiled in a plane at right angles to the axis of growth of the adult test. (See pl. 12, figs. 9, 11, 16.)

The chambers are thin throughout, thinning even more in the central zone. They are spaced at about 20 per mm at the periphery. The chambers have remarkable continuity across the test in spite of their thinness and there is little tendency for them to become annular. The marginal zone is narrow, with the primary plates extending less than 0.06 mm and the secondary plates extending about half that distance. The chamberlets are usually subdivided into only 4 or 6 cellules. The radial zone is well developed, including most of each chamber. The main partitions thicken in the marginal zone and are already strongly triangular as they start

TABLE 7.—*Summary data for* Orbitolina gracilis *Douglass, n. sp.*

Dimensions	Sample No. and number of specimens measured			
	f20210, 14	f20211, 14	f20213, 4	f20214, 6
Diameter (mm):				
Maximum	7. 4	7. 3	----------	5. 7
Minimum	3. 7	3. 7	----------	4. 8
Mean	5. 4	5. 5	----------	4. 9
Error of mean	±. 27	±. 29	----------	±. 23
Standard deviation	1. 01	1. 08	----------	. 58
Inferred range	2. 4–8. 4	2. 2–8. 8	----------	3. 2–6. 6
Height (mm):				
Maximum	1. 7	1. 7	----------	1. 5
Minimum	. 7	. 8	----------	1. 1
Mean	1. 0	1. 1	----------	1. 3
Error of mean	±. 09	±. 07	----------	±. 08
Standard deviation	. 32	. 28	----------	. 19
Inferred range	. 09–1. 99	. 3–1. 9	----------	. 7–1. 9
D:H ratio:				
Maximum	9. 2	6. 3	----------	5. 2
Minimum	4. 1	3. 8	----------	3. 1
Mean	5. 1	5. 3	----------	4. 0
Error of mean	±. 4	±. 23	----------	±. 33
Standard deviation	1. 7	. 88	----------	. 81
Inferred range	. 2–10. 0	2. 5–8. 0	----------	1. 6–6. 4
Diameter of embryonic apparatus (mm):				
Maximum	. 32	. 40	. 28	. 23
Minimum	. 16	. 24	. 21	. 18
Mean	. 23	. 31	. 24	. 20
Error of mean	±. 015	±. 022	±. 02	±. 011
Standard deviation	. 049	. 055	. 035	. 022
Inferred range	. 09–. 38	. 15–. 47	. 13–. 35	. 13–. 27
Diameter of proloculus (mm):				
Maximum	. 15	. 16	. 16	. 11
Minimum	. 08	. 11	. 10	. 07
Mean	. 09	. 13	. 12	. 08
Error of mean	±. 008	±. 011	±. 02	±. 03
Standard deviation	. 024	. 021	. 029	. 054
Inferred range	. 02–. 16	. 07–. 19	. 03–. 21	±. 24

the zigzag pattern. (Pl. 12, figs. 15, 18.) The central complex is limited in extent and is primarily only an area in which the main partitions anastomose and lose their identity. (Pl. 12, fig. 18.) The building materials are varied, some specimens have an abundance of coarse debris and others contain mostly fine-grained material. Most of the specimens have the coarser materials.

Comparison and remarks.—*Orbitolina gracilis* is easily distinguished from the other species of *Orbitolina* in North America by its nearly uniform thickness and the thinness of the chambers. The thin shape and usually grainy nature of the test are distinctive.

Distribution.—*O. gracilis* was recognized in the Howells Ridge formation and the Broken Jug limestone in the Little Hatchet Mountains, New Mexico.

Specimens studied.—A hundred and twenty thin sections containing several hundred specimens of this species were prepared.

Designation of types.—Specimen f20211–19, USNM P5534, is designated the holotype. It is illustrated on plate 12 as figure 2. The National Museum numbers of the figured paratypes are given on plate 12.

Orbitolina crassa Douglass, n. sp.

Plate 13

Name derivation: Latin, *crassa*, fat.

Diagnosis.—Test medium sized, up to about 9 mm in diameter; low to high conico- or convexo-concave; embryonic apparatus with a mean diameter near 0.26 mm and a proloculus with a mean diameter near 0.11 mm; marginal zone thin; radial zone with triangular main partitions short in the early chambers but extending across most of each ephebic chamber; building materials fairly coarse; calcite eyes common.

External character.—Test low to high conico- or convexo-concave, with some specimens slightly reflexed. (Pl. 13, figs. 1–12.) The apex is rounded or slightly flattened. The concentric lamellae are nearly flat, producing a smooth dorsal surface. The ventral surface is concave and shows little structure. Table 8 summarizes the dimensions for seven samples of this species.

Internal character.—Only a few specimens were found in which the embryonic apparatus could be studied. No embryonic chambers of either megalospheric or microspheric generation were found in any of the Arizona specimens. A few megalospheric specimens were found in the Broken Jug limestone, and in these the embryonic apparatus had a mean diameter of 0.24 mm with a proloculus having a mean diameter of 0.11 mm. No microspheric embryos were found.

The early ephebic chambers tend to have a uniform thickness throughout, producing a biconvex test. The late ephebic chambers thin rapidly in the central area and the chambers tend to become annular in some specimens. The chambers tend to increase in height only slightly, with 10 to 11 per mm at the periphery.

TABLE 8.—*Summary data for* Orbitolina crassa *Douglass, n. sp.*

Dimensions	Sample No. and number of specimens measured						
	f20274, 6	f20275, 3	f20276, 5	f20277, 25	f20278, 4	f20219, 32	f20220, 30
Diameter (mm):							
Maximum	5. 9	5. 5	5. 7	6. 0	5. 7	8. 2	9. 3
Minimum	3. 9	4. 9	4. 4	3. 5	4. 4	4. 2	4. 0
Mean	5. 0	5. 0	5. 1	4. 8	4. 8	5. 7	6. 2
Error of mean	±. 27	±. 26	±. 26	±. 14	±. 31	±. 21	±. 21
Standard deviation	. 67	. 46	. 58	. 71	. 62	1. 18	1. 16
Inferred range	3. 0–7. 0	3. 6–6. 4	3. 4–6. 8	2. 7–6. 9	3. 0–6. 6	2. 2–9. 2	2. 7–9. 7
Height (mm):							
Maximum	2. 2	1. 9	2. 6	2. 6	2. 1	2. 7	2. 8
Minimum	1. 7	1. 7	1. 6	1. 4	1. 6	1. 3	1. 5
Mean	1. 9	1. 8	2. 0	2. 0	1. 9	1. 8	2. 1
Error of mean	±. 11	±. 13	±. 18	±. 07	±. 12	±. 06	±. 07
Standard deviation	. 22	. 22	. 40	. 34	. 24	. 33	. 38
Inferred range	1. 2–2. 6	1. 1–2. 5	. 8–3. 2	1. 0–3. 0	1. 2–2. 6	0. 8–2. 8	1. 0–3. 2
D:H ratio:							
Maximum	3. 0	3. 2	3. 3	3. 3	3. 6	4. 1	4. 5
Minimum	2. 2	2. 6	1. 8	1. 7	2. 1	1. 7	2. 1
Mean	2. 5	2. 9	2. 7	2. 5	2. 6	3. 0	2. 9
Error of mean	±. 18	±. 18	±. 31	±. 07	±. 36	±. 11	±. 11
Standard deviation	. 36	. 31	. 67	. 32	. 72	. 59	. 57
Inferred range	1. 4–3. 6	2. 0–3. 8	. 6–4. 8	1. 5–3. 5	. 4–4. 8	1. 2–4. 8	1. 2–4. 6

The marginal zone is finely subdivided with the primary plates extending about 0.08 mm and the secondary plates 0.04 mm. (See pl. 13, fig. 15.) The radial zone extends through about half the area of the early chambers and includes almost all the area of the late ephebic chambers. The main partitions thicken, becoming triangular as they leave the marginal zone. (Pl. 13, fig. 17.) They tend to lose their identity completely in the central complex. Apertural and partitional pores are abundant. (Pl. 13, fig. 18.) The central complex, where it is developed in the early chambers, is often a mass of detrital grains and calcite eyes. In the late chambers very little of the complex is developed. Building materials tend to be rather coarse in this species. There is a progressive coarsening from the margin inwards toward the central area. The primary clear layer of the wall is well preserved in many of the specimens and stands out in contrast to the agglutinated material. (Pl. 13, fig. 17). Calcite eyes are common in the central complex and also occur in the inner portions of the radial zone.

Comparison and remarks.—*Orbitolina crassa* resembles *O. grossa* in many respects. It can be distinguished most easily by the presence of calcite eyes in *O. crassa* and their absence in *O. grossa.*

Distribution.—*Orbitolina crassa* is common throughout the lower part of the Mural limestone in Arizona and it is also present in the Broken Jug limestone in New Mexico.

Specimens studied.—Two hundred thin sections, including about a thousand random cuts of specimens of *O. crassa*, were prepared.

Designation of types.—Specimen f20220-27, USNM P5551, is designated the holotype. It is illustrated on plate 13 as figure 4. The National Museum numbers of the figured paratypes are given in the explanation of plate 13.

Orbitolina grossa Douglass, n. sp.

Plate 14

Name derivation: Latin, *grossa*, big, thick.

Diagnosis.—Test medium sized, but large among the American forms, with a diameter up to nearly 9 mm and a thick convexo-concave test; embryonic apparatus with a mean diameter of 0.31 mm and a proloculus with a mean diameter of 0.15 mm; marginal zone well developed; radial zone with triangular main partitions extending across most of each chamber; building materials fairly coarse throughout; no calcite eyes.

External characters.—The test is high, irregularly reflexed, convexo-concave in adult specimens. Immature specimens tend to be convexo-plane or even biconvex. The apex of megalospheric specimens is rounded or slightly depressed pustular. (Pl. 14, figs. 6, 7.) No microspheric specimens were identified. The concentric lamellae are nearly flat, producing a smooth dorsal surface. The ventral surface is granular, showing little structure. Table 9 summarizes the dimensions for this species.

Internal characters.—The proloculus of the megalospheric forms has a mean diameter of 0.15 mm. (Fig. 30.) It is circular in plan and may be either ovoid or irregular in axial section. (See pl. 14, figs. 6, 7.) The embryonic apparatus has a mean diameter of 31 mm. It is subdivided above the proloculus by primary and secondary plates. The first chamber below the proloculus is subdivided throughout by partitions. The nature of the microspheric embryonic apparatus is unknown.

The early ephebic chambers are shaped like shallow saucers of constant depth throughout. The chambers do not thin in the central area to form a concave ventral surface until later in the ontogeny. About two-thirds of the ephebic chambers maintain a relatively constant thickness throughout so that in most specimens only the last third of the chambers give the test a concave ventral surface. There are about 10 sutures per mm toward the periphery of the test and the number remains constant except in the early ephebic chambers. (See pl. 14, figs. 1–5, 10.)

TABLE 9.—*Summary data for* Orbitolina grossa *Douglass, n. sp.*

	Diameter of 16 specimens measured (mm)	Height of 16 specimens measured (mm)	D:H ratio of 16 specimens measured	Diameter of embryonic apparatus of 8 specimens measured (mm)	Diameter of proloculus of 10 specimens measured (mm)
Maximum	8.7	3.1	3.7	0.34	0.16
Minimum	5.1	1.5	1.8	.28	.13
Mean	6.8	2.5	2.7	.31	.15
Error of the mean	±.28	±.12	±.12	±.008	±.003
Standard deviation	1.13	.48	.46	.22	.01
Inferred range	3.5–10.1	1.1–3.9	1.3–4.1	0.24–0.38	0.12–0.18

The marginal zone has primary plates extending about 0.12 mm and the secondary plates about half that distance. (See pl. 14, fig. 8.) The horizontal plates are less well developed, partly dividing the chamberlets into irregular cellules.

The radial zone is well developed, extending throughout most of each chamber. The main partitions start to thicken inside the marginal zone (see pl. 14, fig. 8), forming subtriangular chamberlets; they zigzag irregularly toward the central complex, where they lose their identity (see pl. 14, figs. 8, 9, 11). Apertural pores can be seen (pl. 14, fig. 10) passing through the septa in the radial zone.

The central complex is rather restricted in this species. In the central area the main partitions tend to stop or are broken up by partitional pores where they become crowded. The relatively constant thickness of the chambers tends to keep the central area rather open. No calcite eyes were found in this species.

The building materials are unsorted, with a fair percentage of sandy material in a finer matrix. The fine clear material of the epidermal layer of the wall stands out in contrast to the rest of the material in many of the specimens.

Comparisons and remarks.—*Orbitolina grossa* is most closely related to *O. crassa*, which it resembles in form and the shape of the chambers. *O. grossa* has a larger embryonic apparatus and proloculus than *O. crassa*, and *O crassa* has scattered to abundant calcite eyes. *O. grossa* may be related to *O. trochus* (Fritsch), as used by Silvestri (1932, p. 162). He does not illustrate any axial sections and the only embryonic apparatus illustrated (his pl. 9, fig. 3) is small, measuring only 0.10 mm in diameter.

Distribution.—*Orbitolina grossa* was found in collection f20218 from the Broken Jug limestone of the Little Hatchet Mountains in New Mexico.

Specimens studied.—Forty-nine thin sections containing over a hundred and fifty random specimens were prepared and studied. Sixteen axial or slightly subaxial sections were measured, including 10 that cut through the proloculus.

Designation of types.—Species f20218–17, USNM P5566, is designated the holotype. It is illustrated on plate 14 as figure 2. The National Museum numbers of the figured paratypes are given in the explanation of plate 14.

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Stead, F. L., 1951, Foraminifera of the Glen Rose Formation (Lower Cretaceous) of Central Texas: Texas Jour. Sci., v. 3, no. 4, p. 577–605, 3 pls. The observed range of *Orbitolina* in the central Texas section is plotted and *Orbitolina* is illustrated by exterior views.

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——— and Hanzawa, Shoshiro, 1926, Geological age of *Orbitolina*-bearing rocks of Japan: Tohoku Imp. Univ. Sci. Repts., ser. 2 (Geology), v. 9, no. 1, p. 13–20, pls. 3–6, 1 fig. Three new species and two new varieties of *Orbitolina* are described and illustrated from the Lower Cretaceous of Japan.

INDEX

[Italic numbers indicate descriptions]

PLATES 1–14

PLATE 1

FIGURES 1–26. *Orbitolina lenticularis* (Blumenbach) from the type locality at the Perte du Rhône (Ain), France (p. 30).

1–6. Blumenbach's original figures given on his plate 80 as figures 1–6, in the same order. Figures 1 and 3 are natural size, the others are enlarged probably about (× 5), although the degree of magnification is not given.

7–17. Free specimens (× 5).

18. Oblique section (× 10).

19–21. Subaxial sections (× 10).

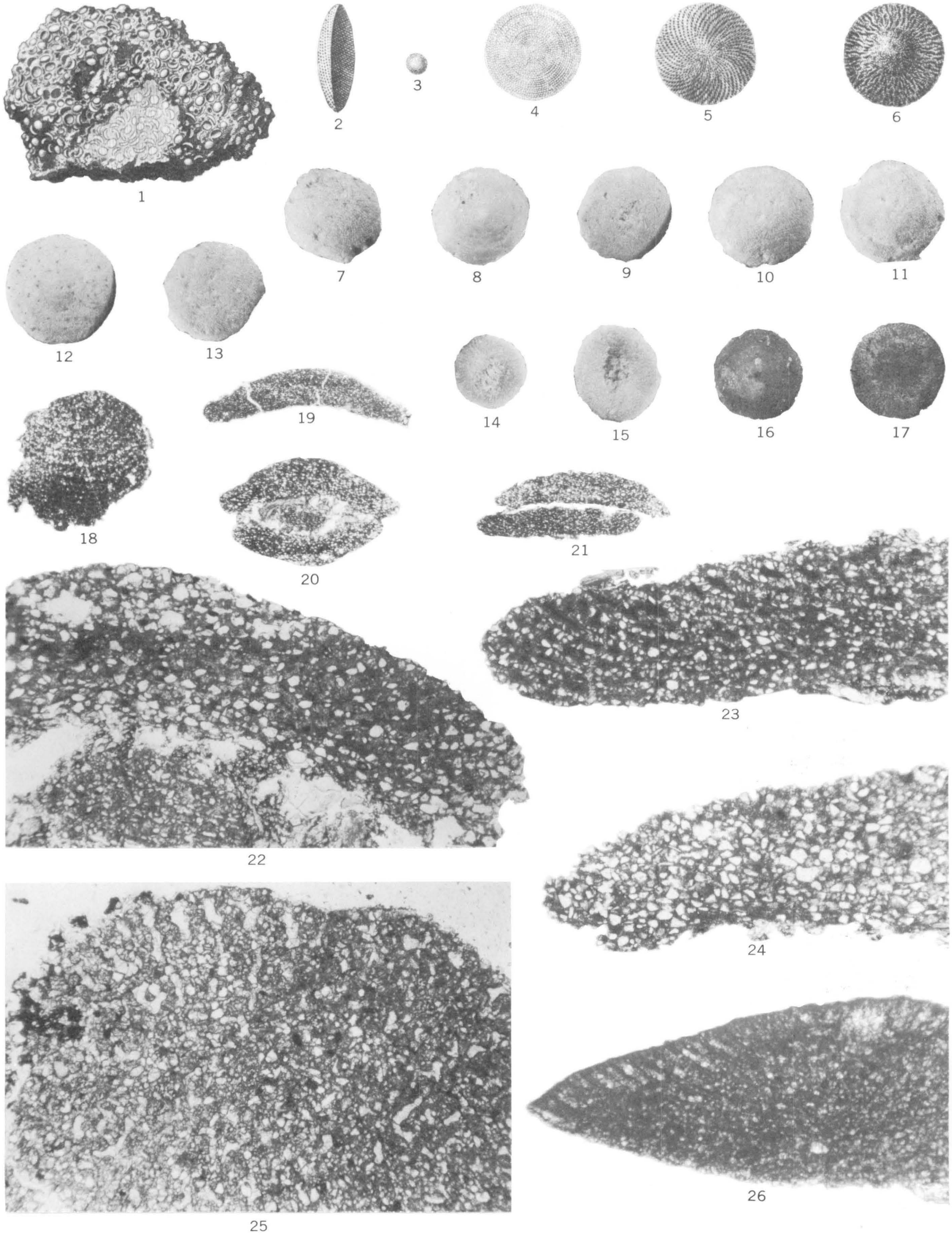
22. Enlarged portion of the upper specimen shown in figure 20 (× 50).

23. Enlarged portion of the lower specimen shown in figure 21 (× 50).

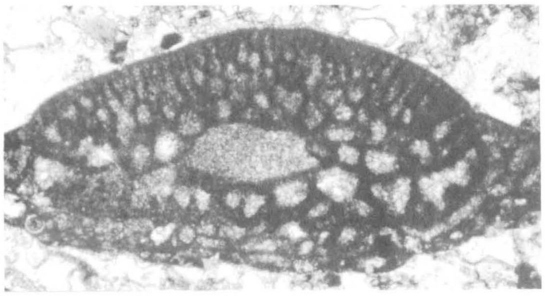
24. Enlarged portion of the upper specimen shown in figure 21 (× 50).

25. Basal section showing the main partitions in the radial zone, and the central complex (× 50).

26. Part of a small axial section with the megalospheric embryonic apparatus (× 50).



ORBITOLINA LENTICULARIS (BLUMENBACH)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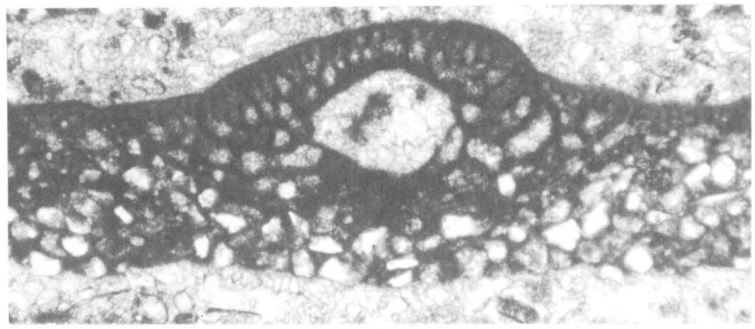
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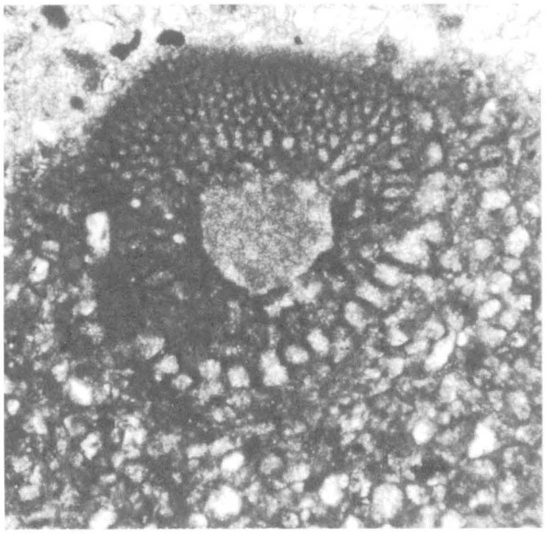
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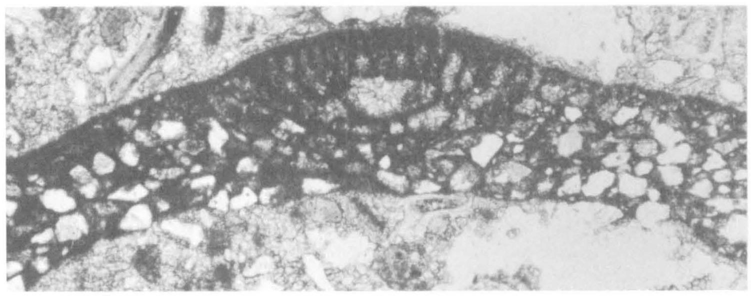
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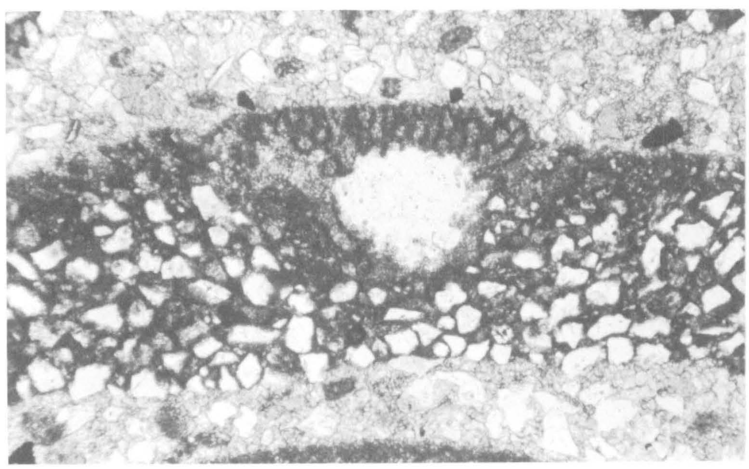
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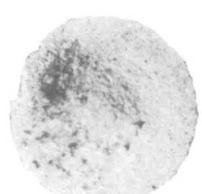
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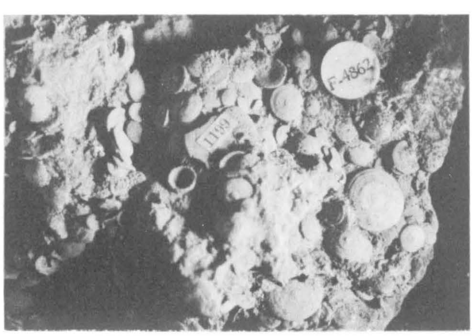

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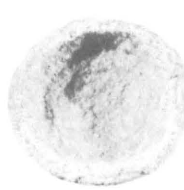
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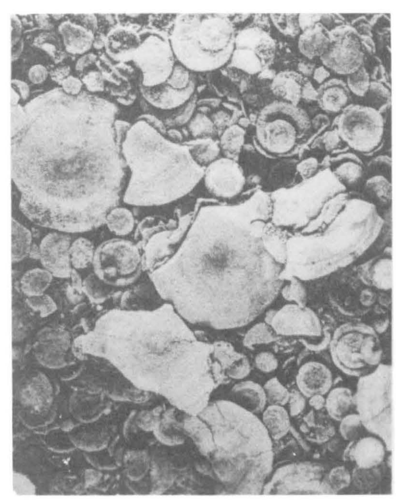
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ORBITOLINA CONCAVA (LAMARCK)

PLATE 2

FIGURES 1–12. *Orbitolina concava* (Lamarck) 1816, from the type locality at Ballon, France (p. 32).

1. Axial section of a megalospheric proloculus Sample f4862, slide 7 (× 50).
2. Axial section of a megalospheric proloculus. Sample f4862, slide 4 (× 50) (see also pl. 3, fig. 3).
3. Axial section of a megalospheric proloculus. Sample f4862, slide 6 (× 50).
4. Oblique section of a megalospheric proloculus. Sample f4862, slide 1 (× 50).
5. Axial section of a megalospheric proloculus on the same slide as figure 4 (× 50).
6. Dorsal view of a megalospheric specimen (× 5).

7–8. Dorsal and ventral views of a specimen (× 5).

9–10. Dorsal and ventral views of a specimen (× 5).

11. A sample of topotype material (× ¾).
12. Favre's illustration from Lamarck's collection of *O. concava* (Lamarck) (× 1).

PLATE 3

FIGURES 1–9. *Orbitolina concava* (Lamarck) 1816, from the type locality at Ballon, France (p. 32).

1. A thin section showing several specimens. Sample f4862, slide 6 (× 5).
2. Subaxial section. Sample f4862, slide 2 (× 5).
3. A thin section including an axial section. Sample f4862, slide 4 (× 5).
4. The marginal and short radial zone in basal section. Sample f4862, slide 3 (× 50).
5. Enlarged view of the ephebic chambers shown on the left side of the axial section in figure 3 (× 50).
6. Tangential section. Sample f4862, slide 3 (× 50).
7. Axial section through same ephebic chambers. Sample f4862, slide 7 (× 50).
8. Tangential section. Sample f4862, slide 1 (× 50).
9. Polished section with numerous unoriented sections (× 5).


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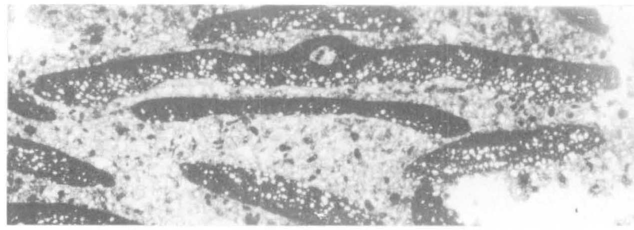
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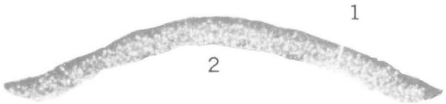
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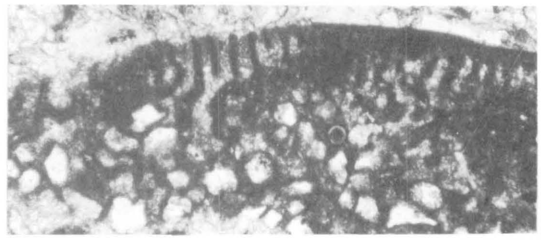
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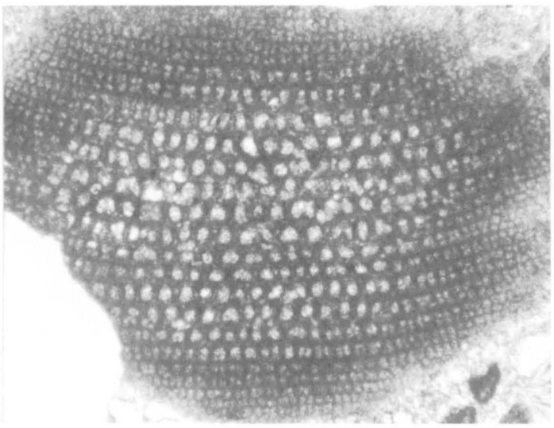
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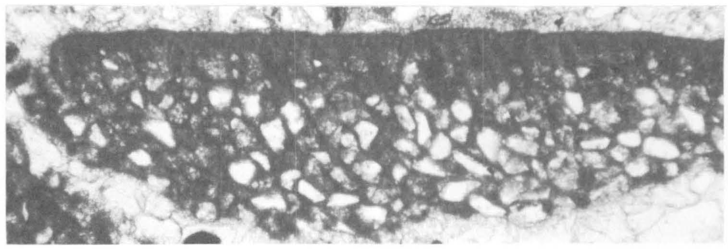
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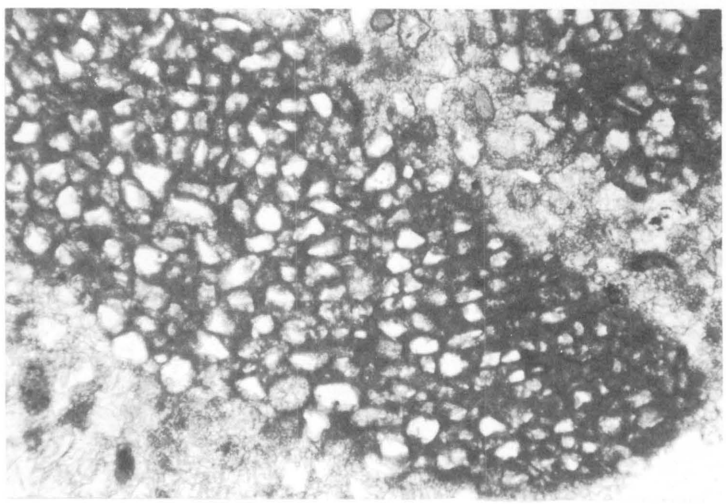
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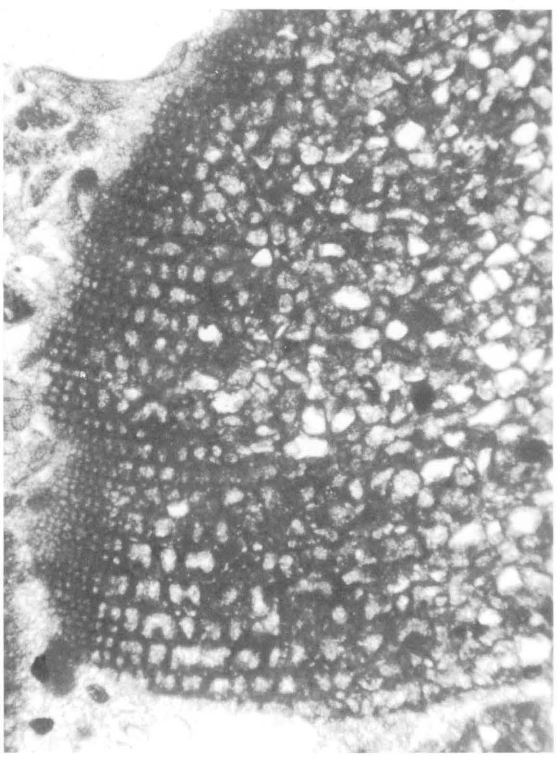
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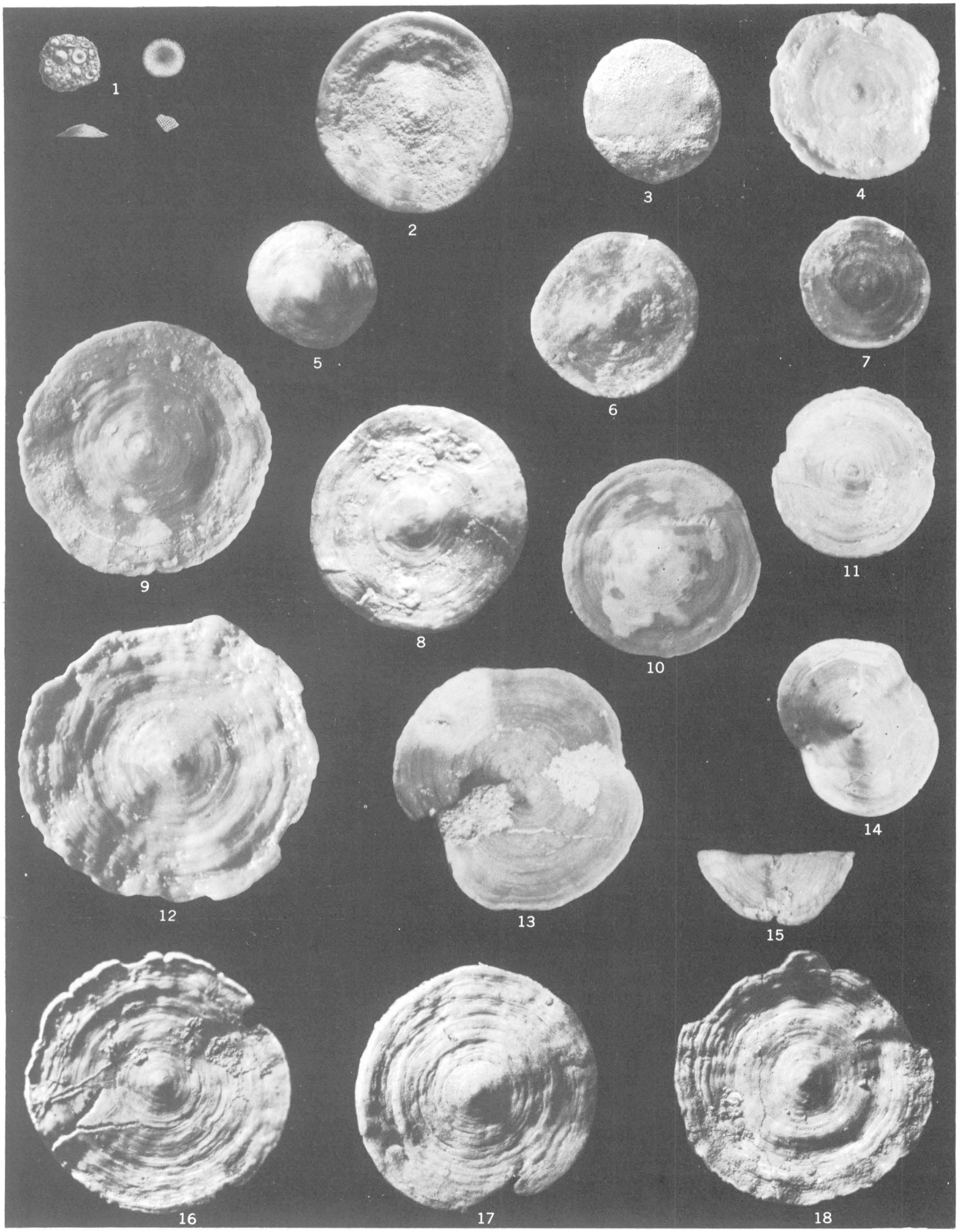
ORBITOLINA CONCAVA (LAMARCK)



ORBITOLINA TEXANA (ROEMER)

PLATE 4

FIGURES 1–18. *Orbitolina texana* (Roemer) from Texas (p. 34).

1. Roemer's original illustrations of *O. texana* reduced to (× ⅓).

2–8. Specimens from sample f20104 (× 5).

2. Eroded dorsal surface showing the marginal chamberlets.
3. Ventral view.
4. Dorsal view of a microspheric specimen.

5–8. Dorsal views of megalospheric specimens.

9–18. Specimens from a collection by A. R. Loeblich, Jr. from approximately the same position as f20104 (× 5). Specimen 13 is initiated with 4 embryos, specimen 14 has 2, and specimen 15 (shown in side view) has 2, causing irregular growth.

PLATE 5

FIGURES 1–30. *Orbitolina texana* (Roemer) from Texas (× 10) (p. 34).

1–22. Specimens from central Texas.

1. Axial section of a microspheric specimen. Sample f20097, slide B1.
2. Subaxial section of a microspheric specimen. Sample f20098, slide 5.
3. Axial section of a microspheric specimen. Sample f20098, slide 4.
4. Axial section of a microspheric specimen. Sample f20098, slide 3.
5. Axial section of a microspheric specimen. Sample f20097, slide B4.
6. Subaxial section of a microspheric specimen. Sample f20102, slide 21.
7. Axial section of a megalospheric specimen. Sample f20104, slide 9.
8. Axial section of a megalospheric specimen. Sample f20097, slide 47.
9. Axial section of a megalospheric specimen with a high pustular embryonic apparatus. Sample f20098, slide 20.
10. Axial section of a megalospheric specimen. Sample f20097, slide A1.
11. Axial section of a megalospheric specimen. Sample f20108, slide 2.
12. Axial section of a megalospheric specimen. Sample f20104, slide 2. This is the same specimen as illustrated on plate 4, as figure 7.
13. Axial section of a megalospheric specimen. Sample f20105, slide 13.
14. Axial section of a megalospheric specimen. Sample f20097, slide A5.
15. Axial section of a megalospheric specimen. Sample f20084, slide 10.
16. Slightly oblique axial section of a megalospheric specimen. Sample f20109, slide 5.
17. Axial section of a megalospheric specimen. Sample f20097, slide A3.
18. Axial section of a megalospheric specimen. Sample f20111, slide 29.
19. Oblique axial section of a megalospheric specimen. Sample f20109, slide 12.
20. Axial section of a megalospheric specimen. Sample f20098, slide 19.
21. Axial section of a megalospheric specimen. Sample f20104, slide 10.
22. Axial section of a megalospheric specimen. Sample f20104, slide 11.

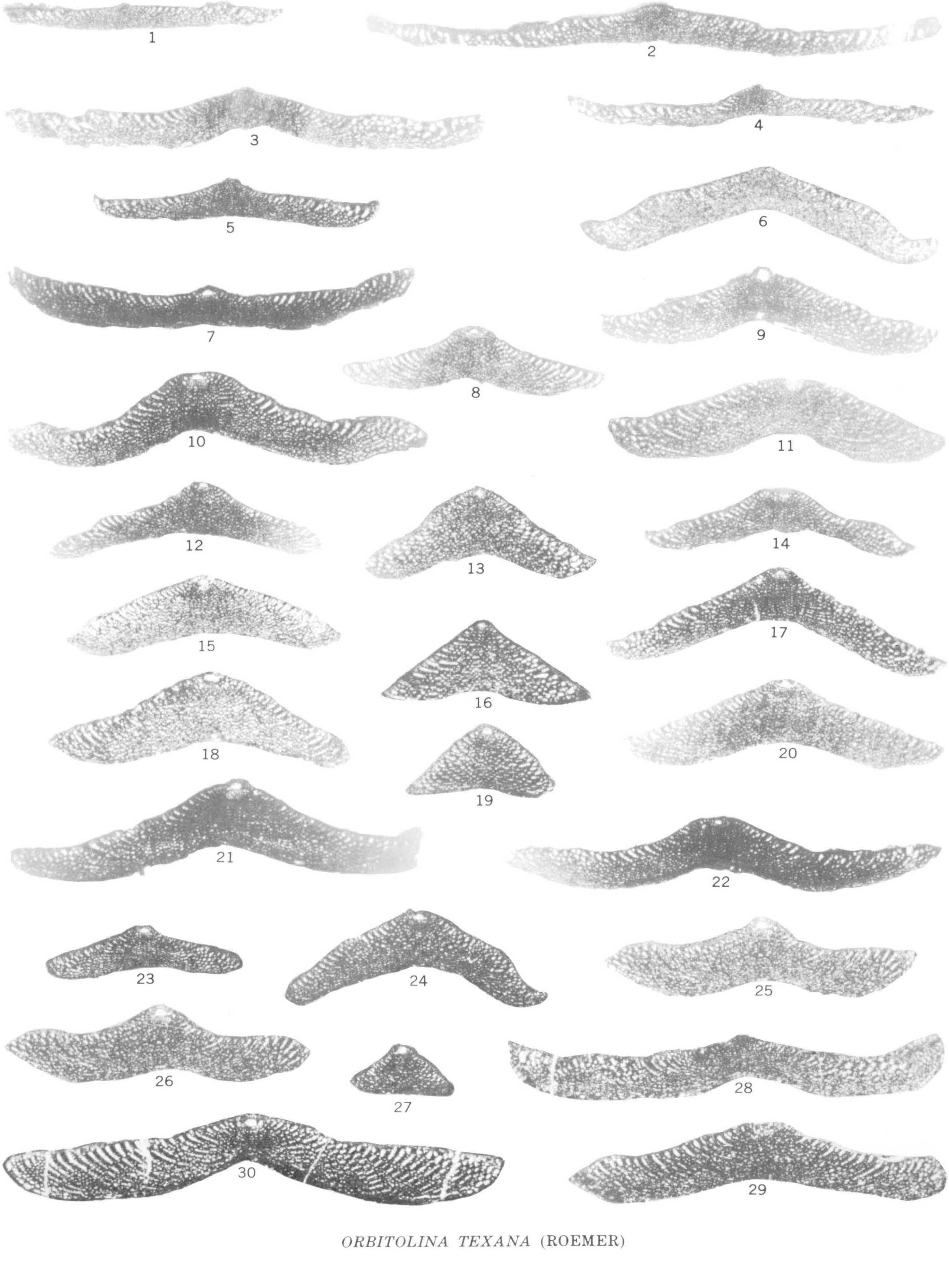
23–29. Specimens from the Hood Springs quadrangle, Brewster County, Tex.

23. Axial section of a megalospheric specimen. Sample f20120, slide 26.
24. Axial section of a megalospheric specimen. Sample f20122, slide 27.

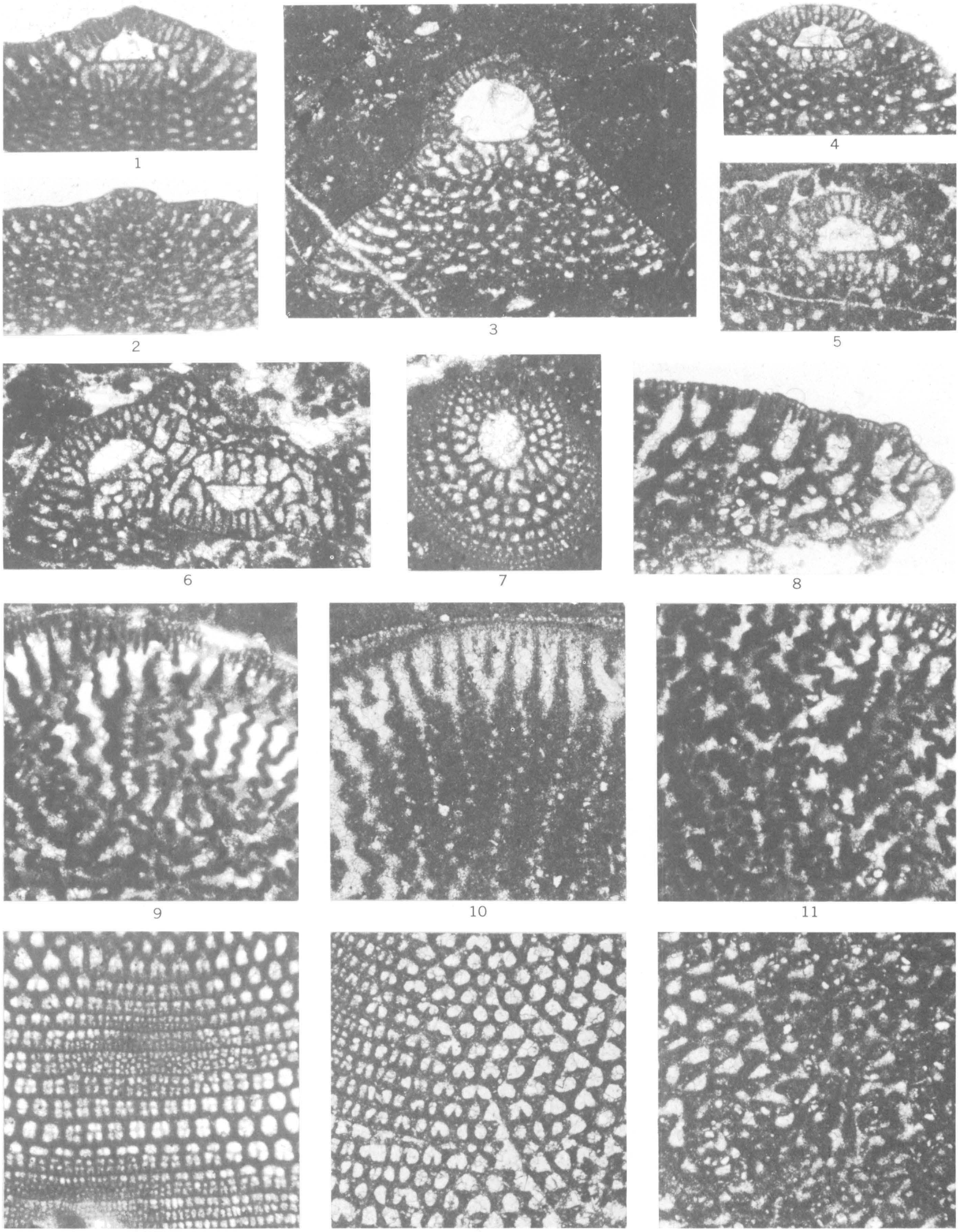
25–26. Oblique axial sections of megalospheric specimens. Sample f20123, slide 35.

27. Oblique axial section of a megalospheric specimen. Sample f20120, slide 26.
28. Axial section of a microspheric specimen. Sample f20120, slide 24.
29. Axial section of a megalospheric specimen. Sample f20122, slide 1.

30. Axial section of a megalospheric specimen from the lower part of the Shafter limestone in Presidio County, Tex. Sample f20154, slide 17.



ORBITOLINA TEXANA (ROEMER)



ORBITOLINA TEXANA (ROEMER)

PLATE 6

FIGURES 1–14. *Orbitolina texana* (Roemer) from Texas (× 50) (p. 34).

1. Axial section of the megalospheric proloculus shown in plate 5, fig. 7.
2. Axial section of the microspheric proloculus shown in plate 5, fig. 1.
3. Axial section of an exceptionally raised pustular megalosphere. Sample f20154, slide 16.
4. Axial section of the megalospheric proloculus shown in plate 5, fig. 17.
5. Axial section of the megalospheric proloculus shown in plate 5, fig. 25.
6. Double megalospheric embryonic apparatus. Sample f20192, slide 5.
7. Basal section of a megalospheric embryonic apparatus. Sample f20122, slide 29.
8. Axial section of ephebic chambers showing irregular arching of the concentric lamellae and the way in which the septa are recurved to form the dorsal surface. Sample f20113, slide A3.
9. Basal section showing the zigzag main partitions with apertural pores at the reentrants. Sample f20109, slide 7.
10. Basal section just grazing a septum showing the thickened upper portion of the main partitions and the apertural pores between them. Sample f20109, slide 5.
11. Slightly oblique basal section showing abundant partitional pores through the main partitions. Sample f20084, slide 20.
12. Tangential section showing the subdivision of the marginal chamberlets into cellules. Sample f20104, slide 5.
13. A deeper tangential section showing the triangular main partitions and the engine-turned pattern. Sample f20105, slide 1.
14. Still deeper section showing more clastic material in the main partitions. Sample f20102, slide 29.

PLATE 7

FIGURES 1–29. *Orbitolina minuta* Douglass, n. sp. from Texas, New Mexico, and Arizona (p. 36).

1–9. Specimens from central Texas.

1. Axial section of a megalospheric paratype, USNM P5456. Sample f20106, slide 9 (× 10).
2. Axial section of a microspheric paratype, USNM P5457. Sample f20101, slide 4 (× 10).
3. Axial section of a megalospheric paratype, USNM P5458. Sample f20106, slide 7 (× 10).
4. Axial view of the holotype, USNM P5459. Sample f20101, slide 2 (× 10).
5. Basal sections of two embryonic apparatuses of paratype, USNM P5460. Sample f20106, slide 24 (× 50.) The embryo on the left is cut through the proloculus. The one on the right is cut through the upper part of the embryonic apparatus showing the subdivision of this dorsal area by the platelike structures.
6. Enlarged view of the megalosphere of the specimen in figure 3 (× 50).
7. Axial section of the megalospheric embryonic chambers of a paratype, USNM P5461. Sample f20106, slide 6 (× 50).
8. Axial section of the megalospheric embryonic chambers of a paratype, USNM P5462. Sample f20106, slide 13 (× 50).
9. Axial section of the megalospheric embryonic chambers of a paratype, USNM P5463. Sample f20095, slide 51 (× 50).

10–12. Specimens from the Devils Ridge area in Hudspeth County, Tex.

10, 11. Axial sections of megalospheric paratypes, USNM P5464. Sample f20178, slide 6 (× 10).

12. Axial section of a megalospheric paratype, USNM P5465. Sample f20182, slide 2 (× 10).

13–15. Specimens from the Carroll Hills, Hudspeth County, Tex.

13. Axial section of a megalospheric paratype, USNM P5466. Sample f20175, slide 23 (× 10).
14. Axial section of a megalospheric paratype, USNM P5467. Sample f20176, slide 7 (× 10).
15. Axial section of a megalospheric paratype, USNM P5468. Sample f20172, slide 41 (× 10).

16–17. Specimens from Hood Springs quadrangle, Brewster County, Tex.

16. Oblique axial section of a megalospheric paratype, USNM P5469. Sample f20138, slide 2 (× 10).
17. Axial section of a megalospheric paratype, USNM P5470. Sample f20132, slide 4 (× 10).

18. Oblique axial section of a megalospheric paratype, USNM P5471. Sample f20154, slide 8, from the Shafter limestone, Presidio County, Tex.

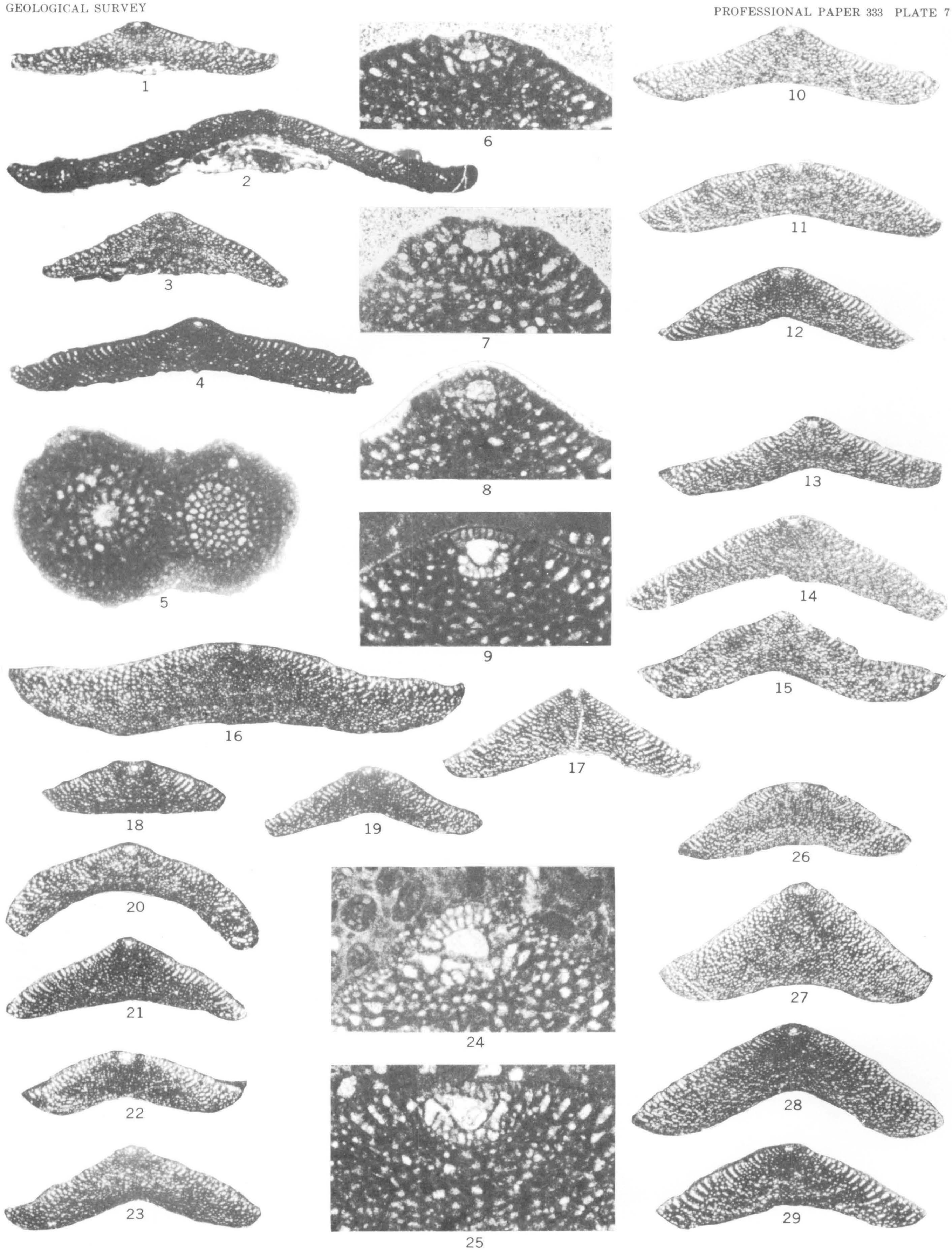
19–23. Specimens from Fresno Peak, Presidio County, Tex.

19. Axial section of a megalospheric paratype, USNM P5472. Sample f20151, slide 7 (× 10).
20. Axial section of a megalospheric paratype, USNM P5473. Sample f20145, slide 35 (× 10).
21. Axial section of a megalospheric paratype, USNM P5474. Sample f20146, slide 8 (× 10).
22. Axial section of a megalospheric paratype, USNM P5475. Sample f20148, slide 24 (× 10).
23. Axial section of a megalospheric paratype, USNM P5476. Sample f20145, slide 15 (× 10).

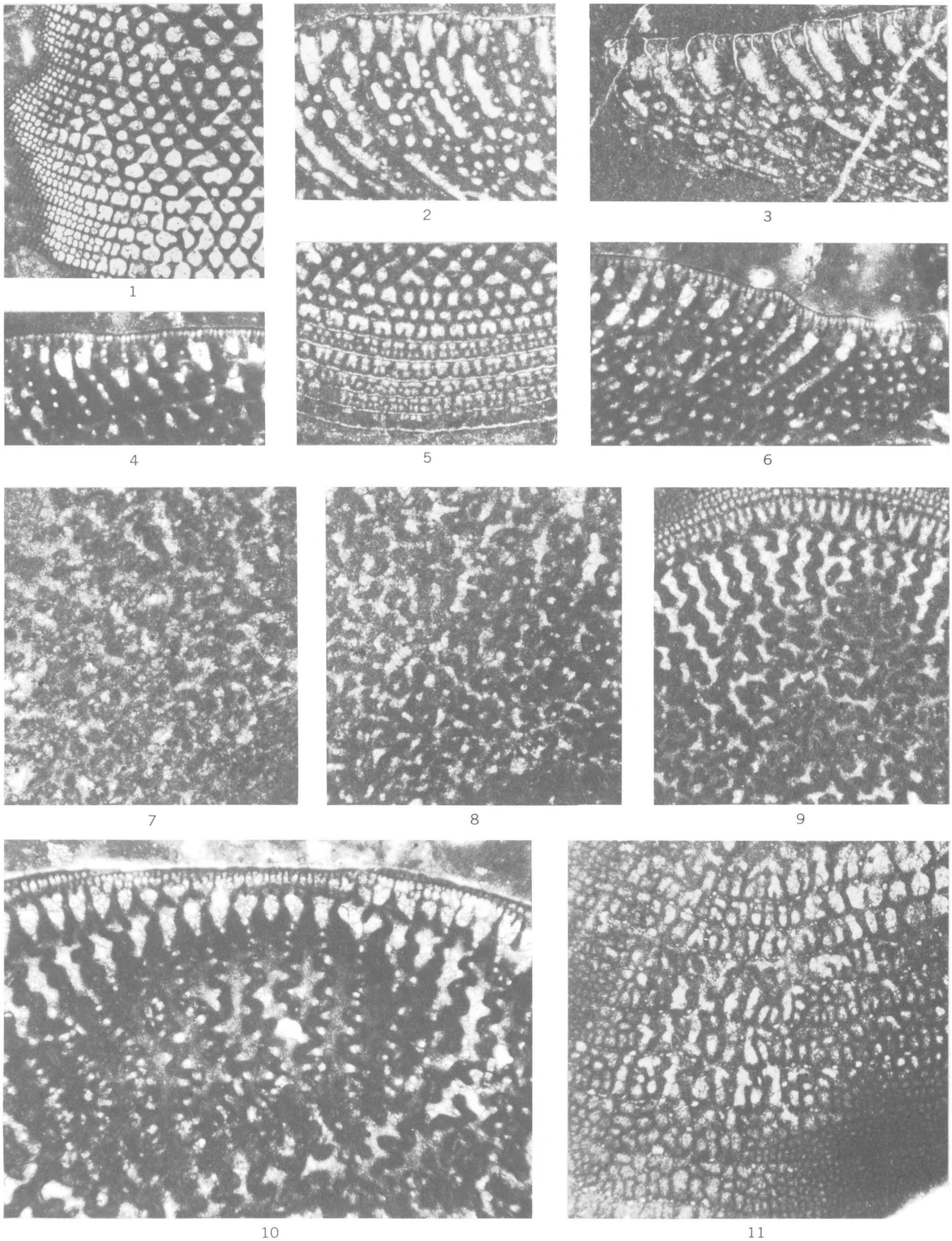
24–28. Specimens from the Playas Peak formation of New Mexico.

24. Axial section of the megalospheric proloculus of a paratype, USNM P5477. Sample f20225, slide 22 (× 50).
25. Axial section of the megalospheric embryonic chambers of a paratype showing an apertural pore between the proloculus and the first ventral chamber, USNM P5478. Sample f20225, slide 36 (× 50).
26. Axial section of a megalospheric paratype, USNM P5479. Sample f20229, slide 27 (× 10).
27. Axial section of a megalospheric paratype, USNM P5480. Sample f20222, slide 4 (× 10).
28. Axial section of a magalospheric paratype, USNM P5481. Sample f20226, slide 35 (× 10).

29. Axial section of a megalospheric paratype from the Mural limestone, Cochise County, Ariz., USNM P5482. Sample f20252, slide 12 (× 10).



ORBITOLINA MINUTA DOUGLASS, N. SP.



ORBITOLINA MINUTA DOUGLASS, N. SP.

PLATE 8

[All figures (× 50)]

FIGURES 1–11. *Orbitolina minuta* Douglass, n. sp. from Texas, New Mexico, and Arizona (p. 36)

1. Tangential section of a paratype, USNM P5483. Sample f20095, slide 28.
2. Axial section of a portion of a paratype showing some apertural and some partitional pores, USNM P5484. Sample f20091, slide 34.
3. Axial section of a portion of a paratype showing the clear epidermal layer and how the marginal edges of the septa are recurved to form the dorsal surface of the test, USNM P5485. Sample f20178, slide 9.
4. Axial section of a portion of a paratype showing partitional and apertural pores, USNM P5486. Sample f20095, slide 14.
5. Tangential section of a paratype showing subdivisions of the chamberlets and the clear epidermal layer, USNM P5487. Sample f20222, slide 9.
6. Another portion of the specimen shown in figure 4.
7. Basal view of the central complex of a paratype, USNM P5488. Sample f20252, slide 17.
8. Basal view of the central complex of a paratype, USNM P5489. Sample f20252, slide 16.
9. Basal view of a chamber of a paratype showing the main paritions of the radial zone broken up in the central complex, USNM P5490. Sample f20226, slide 18.
10. Basal section grazing the septum in a paratype showing the thin lower edges of the zigzag main partitions, the thickened upper portion of the main partitions barely showing through from the chamber below, and the apertural pores passing through the septum, USNM P5491. Sample f20095, slide 23.
11. Tangential view of the late ephebic chambers of a microspheric paratype showing the large number of cellules per chamberlet, USNM P5492. Sample f20110, slide 2.

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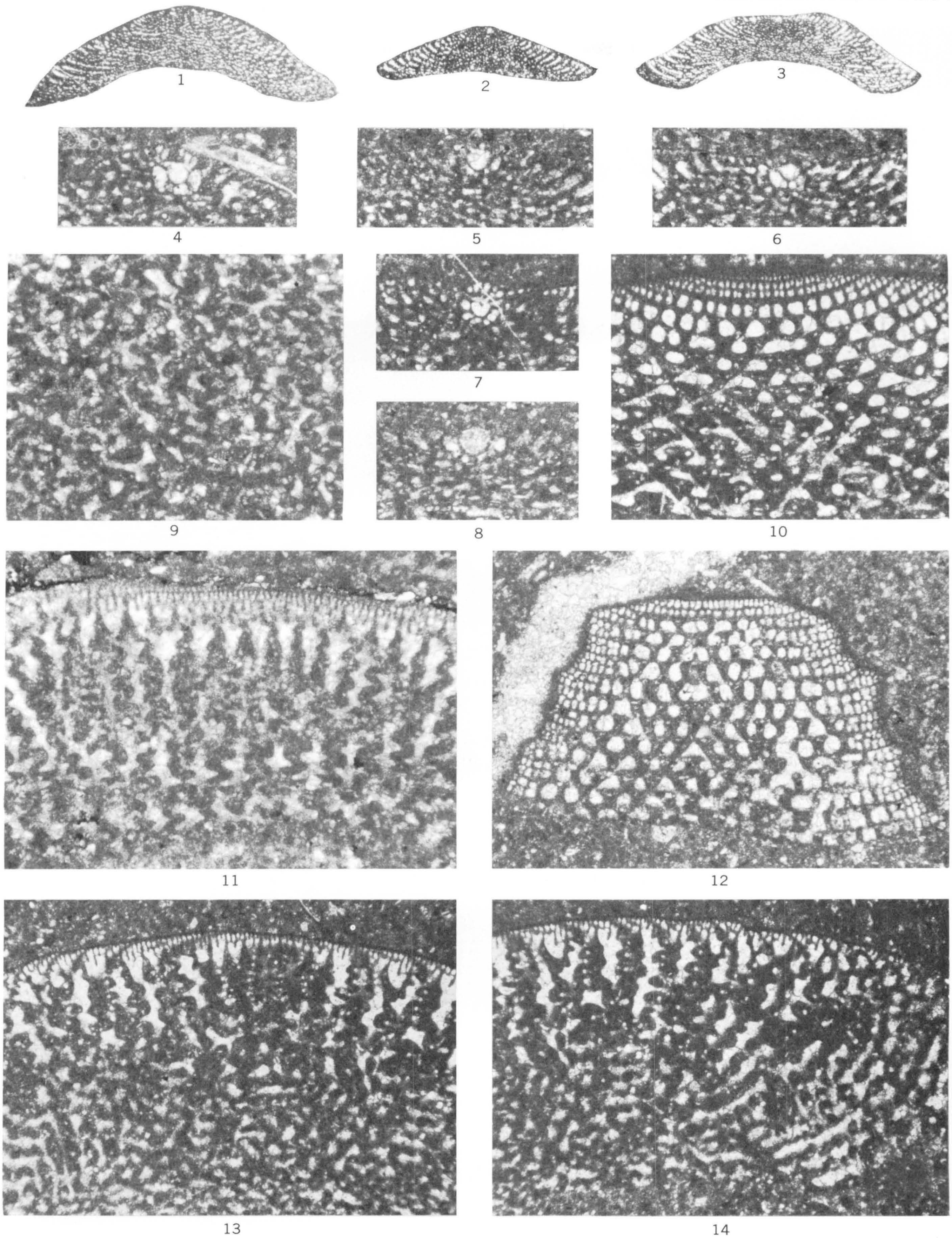
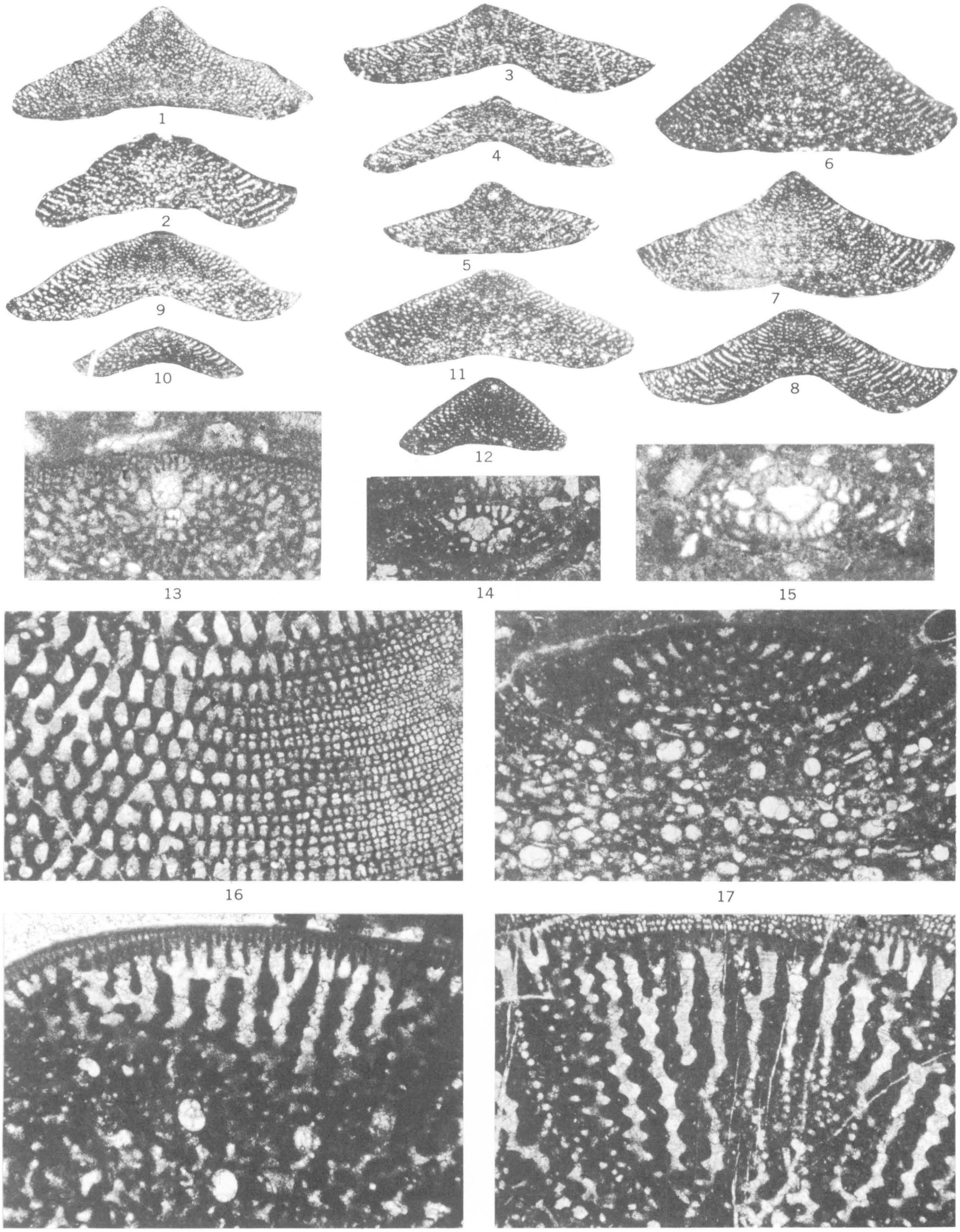
PLATE 9

FIGURES 1–14. *Orbitolina parva* Douglass, n. sp. from the Playas Peak formation in the Little Hatchet Mountains, New Mexico (p. 39.)

1. Axial section of a paratype, USNM P5493. Sample f20228, slide 11 (× 10).
2. Axial section of the holotype, USNM P5494. Sample f20228, slide 15 (× 10).
3. Axial section of a paratype, USNM P5495. Sample f20228, slide 37 (× 19).
4. Axial section of the megalospheric embryonic apparatus of a paratype, USNM P5496. Sample f20228, slide 10 (× 50).
5. Enlarged view of the embryonic chambers of the holotype (× 50).
6. Enlarged view of the embryonic chambers of the paratype illustrated in figure 3 (× 50).
7. Axial section of the megalospheric embryonic apparatus of a paratype, USNM P5497. Sample f20228, slide 4 (× 50).
8. Axial section of the megalospheric embryonic apparatus of another specimen on the same slide as the holotype (× 50).
9. Basal section in the central complex of a paratype, USNM P5498. Sample f20228, slide 31 (× 50).
10. Tangential section of a paratype, USNM P5499. Sample f20228, slide 27 (× 50).
11. Basal section through the radial zone of a paratype, USNM P5500. Sample f20228, slide 8 (× 50).
12. Tangential section of a paratype, USNM P5501. Sample f20228, slide 6 (× 50).
13. Oblique basal section of a paratype showing the finely subdivided marginal zone along the upper edge, the apertural pores where the section grazes the septum in the upper center, and a portion of the central complex toward the lower part, USNM P5502, sample f20228, slide 21 (× 50).
14. A different area on the same specimen (× 50). Showing the apertural pores as breaks in the septa.



ORBITOLINA PARVA DOUGLASS, N. SP.



ORBITOLINA OCULATA DOUGLASS, N. SP.

PLATE 10

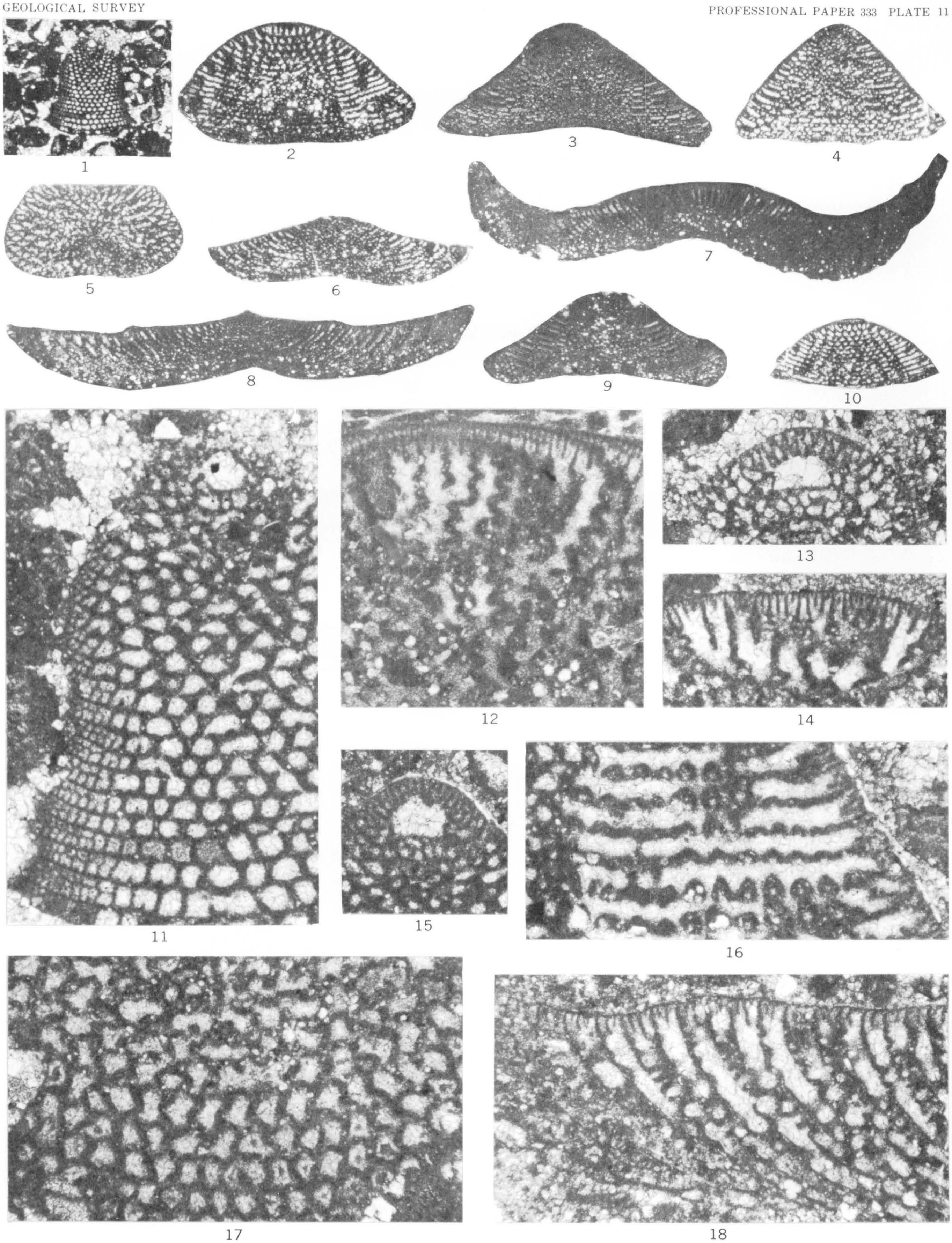
FIGURES 1–19. *Orbitolina oculata* Douglass, n. sp. (p. 39).

1. Oblique section passing through the embryonic apparatus of a paratype from the Mural limestone, Arizona, USNM P5503. Sample f20249, slide 13 (× 10).
2. Axial section of a paratype from the Cintura(?), formation Arizona, USNM P5504. Sample f20255, slide 5 (× 10).
3. Axial section of a paratype from the Howells Ridge formation, New Mexico, USNM P5505. Sample f20212, slide 20 (× 10).
4. Axial section of a paratype from the Howells Ridge formation, New Mexico, USNM P5506. Sample f20212, slide 14 (× 10).
5. Oblique section passing through the embryonic apparatus of a paratype from the Howells Ridge formation, New Mexico, USNM P5507. Sample f20212 slide 12 (× 10).
6. Oblique section of a paratype from the Glen Rose limestone, Texas, USNM P5508. Sample f20214, slide 30 (× 10).
7. Slightly oblique axial section of a paratype from the Glen Rose limestone, Texas, USNM P5509. Sample f20143, slide 5 (× 10).
8. Axial section of the holotype from the Glen Rose limestone, Texas, USNM P5510. Sample f20144, slide 7 (× 10).
9. Subaxial section of a paratype from the Glen Rose limestone, Texas, USNM P5511. Sample f20094, slide 37 (× 10).
10. Axial section of a paratype from the Glen Rose limestone, Texas, USNM P5512. Sample f20092, slide 9 (× 10).
11. Slightly subaxial section of a paratype from the Glen Rose limestone, Texas, USNM P5513. Sample f20094, slide 7 (× 10).
12. Oblique section passing through the proloculus of a paratype from the Glen Rose limestone, Texas, USNM P5514. Sample f20094, slide 14 (× 10).
13. Slightly oblique section through the proloculus of a paratype from the Glen Rose limestone, Texas, USNM P5515. Sample f20094, slide 54 (× 50).
14. Axial section of an embryonic apparatus, paratype from the Howells Ridge formation, New Mexico, USNM P5516. Sample f20212, slide 30 (× 50).
15. Axial section of an embryonic apparatus, paratype, from the Glen Rose limestone, Texas, USNM P5517 Sample f20143, slide 15 (× 50).
16. Tangential section of a paratype on the same slide as fig. 4 (× 50).
17. Portion of an oblique section of a paratype showing an abundance of calcite eyes from the Glen Rose limestone, Texas, USNM P5518. Sample f20094, slide 23 (× 50).
18. Basal section of a paratype, showing the nature of the main partition, the apertural and partitional pores, and some calcite eyes from the Glen Rose limestone, Texas, USNM P5519. Sample f20094, slide 24 (× 50).
19. Basal section of a paratype on the same slide as figure 16 (× 50).

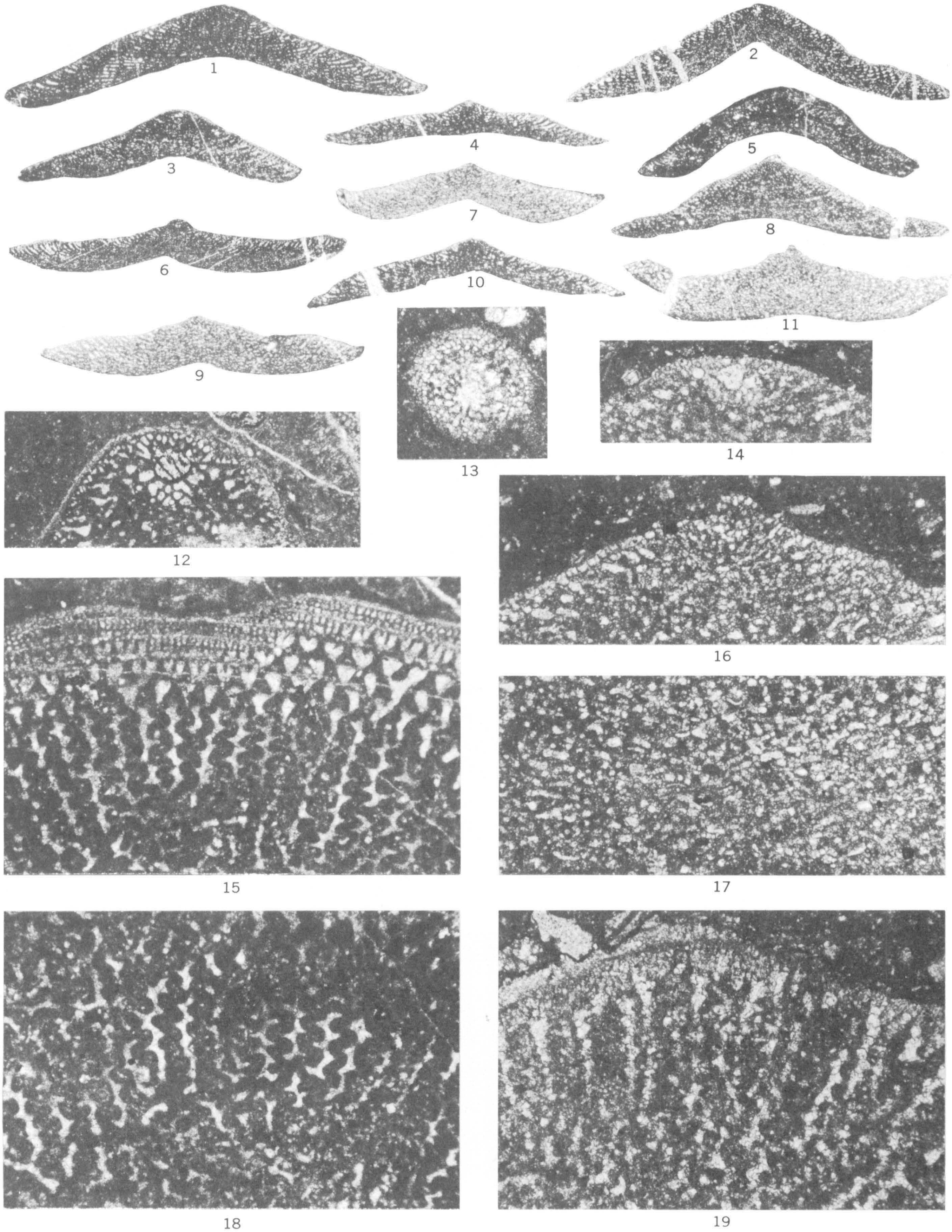
PLATE 11

FIGURES 1–18. *Orbitolina pervia* Douglass, n. sp. from the lower part of the Glen Rose limestone in Brewster County, Tex. (p. 41).

1. Deep tangential section passing obliquely through the proloculus. Paratype, USNM P5520. Sample f20124, slide 8 (× 10).
2. Oblique section showing openness of the radial zone and the distribution of calcite eyes in the central zone. Paratype, USNM P5521. Sample f20124, slide 4 (× 10).
3. Subaxial section; paratype, USNM P5522. Sample f20125, slide 13 (× 10).
4. Subaxial section; paratype, USNM P5523. Sample f20124, slide 15 (× 10).
5. Oblique basal section, showing thinness of main partitions and openness of central zone; paratype USNM P5524. Sample f20124, slide 19 (× 10).
6. Subaxial section grazing the embryonic apparatus; holotype, USNM P5525. Sample f20124, slide 15 (× 10).
7. Oblique section of a large reflexed form; paratype USNM P5525a. Sample f20126, slide 28 (× 10).
8. Axial section of a microspheric specimen; paratype, USNM P5526. Sample f20126, slide 30 (× 10).
9. Subaxial section; paratype, USNM P5527. Sample f20125, slide 10 (× 10).
10. Oblique section; paratype, USNM P5528. Sample f20124, slide 20 (× 10).
11. Enlarged portion of specimen shown in figure 1, showing the subdivisions of the marginal zone and the slight amount of thickening of the main partitions (× 50).
12. Basal section of a portion of a specimen showing the zigzag main partitions interrupted by partitional pores, especially in the central zone; paratype, USNM P5529. Sample f20126, slide 37 (× 50).
13. Embryonic apparatus of a megalospheric specimen on the same slide as the specimen illustrated as figure 10 (× 50).
14. Basal view of the marginal zone and part of the radial zone showing the character of the primary and secondary plates. Apertural pores can also be seen as circular clear areas where the septum is in the plane of the section Paratype, USNM P5530. Sample f20124, slide 11 (× 50).
15. Megalospheric embryonic chambers of a specimen on the same slide as the specimen figured as figure 6 (× 50).
16. Enlarged portion of specimen illustrated as figure 2 (× 50).
17. Deep tangential section showing the unthickened main partitions in the radial zone; paratype, USNM P5531. Sample f20124, slide 5 (× 50).
18. Part of the ephebic chambers of a specimen in axial view, illustrating the tendency to develop annular chambers; paratype, USNM P5532. Sample f20124, slide 2 (× 50).



ORBITOLINA PERVIA DOUGLASS, N. SP.



ORBITOLINA GRACILIS DOUGLASS, N. SP.

PLATE 12

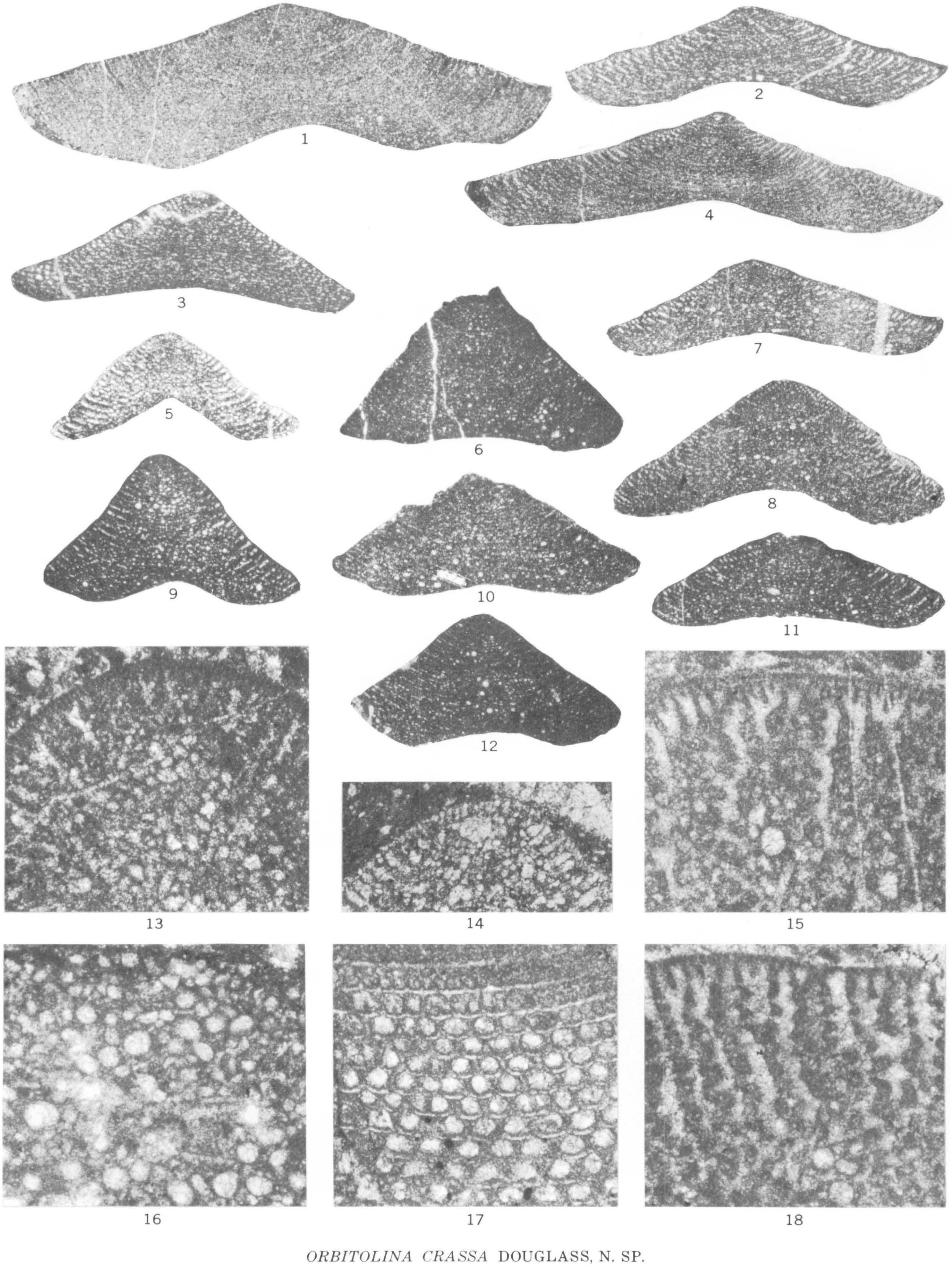
FIGURES 1–19. *Orbitolina gracilis* Douglass, n. sp. from New Mexico (p. 42).

1. Subaxial section of a paratype, Howells Ridge formation. USNM P5533. Sample f20210, slide 18 (× 10.)
2. Axial section of the holotype, Howells Ridge formation. USNM P5534. Sample f20211, slide 19 (× 10.)
3. Subaxial section of a paratype, Howells Ridge formation. USNM P5535. Sample f20211, slide 4 (× 10).
4. Axial section of a paratype, Howells Ridge formation. USNM P5536. Sample f20210, slide 8 (× 10).
5. Axial section of a microspheric paratype, Howells Ridge formation. USNM P5527. Sample f20210, slide 2 (× 10).
6. Axial section of a paratype, Howells Ridge formation. USNM P5538. Sample f20211, slide 25 (× 10).
7. Axial section of a paratype, Broken Jug limestone. USNM P5539. Sample f20213, slide 6 (× 10).
8. Axial section of a paratype, Howells Ridge formation. USNM P5540. Sample f20211, slide 4 (× 10).
9. Axial section of a paratype, Broken Jug limestone. USNM P5541. Sample f20214, slide 23 (× 10).
10. Axial section of a paratype, Howells Ridge formaticn. USNM P5542. Sample f20210, slide 6 (× 10).
11. Axial section of a microspheric paratype, Broken Jug limestone. USNM P5543. Sample f20214, slide 26 (× 10).
12. Megalospheric proloculus in slightly oblique section of a paratype, Howells Ridge formation. USNM P5544. Sample f20210, slide 26 (× 50).
13. Basal view of megalospheric embryonic chambers of a paratype, Broken Jug limestone. USNM P5545. Sample f20214, slide 27 (× 50).
14. Axial view of the megalospheric embryonic chambers of a paratype, Broken Jug limestone. USNM P5546. Sample f20213, slide 25 (× 50).
15. Basal view of a chamber of a paratype showing the triangular nature of the main partitions as they leave the marginal zone and their zigzag pattern in the radial zone. USNM P5547. Sample f20210, slide 9 (× 50).
16. Axial view of the microspheric embryonic apparatus illustrated in figure 11 (× 50).
17. Axial view of the central complex in the same specimen (× 50).
18. Basal view in another area of the specimen illustrated in figure 15 (× 50).
19. Oblique basal view of the radial zone of a paratype Broken Jug limestone. USNM P5548. Sample f20213, slide 12 (× 50).

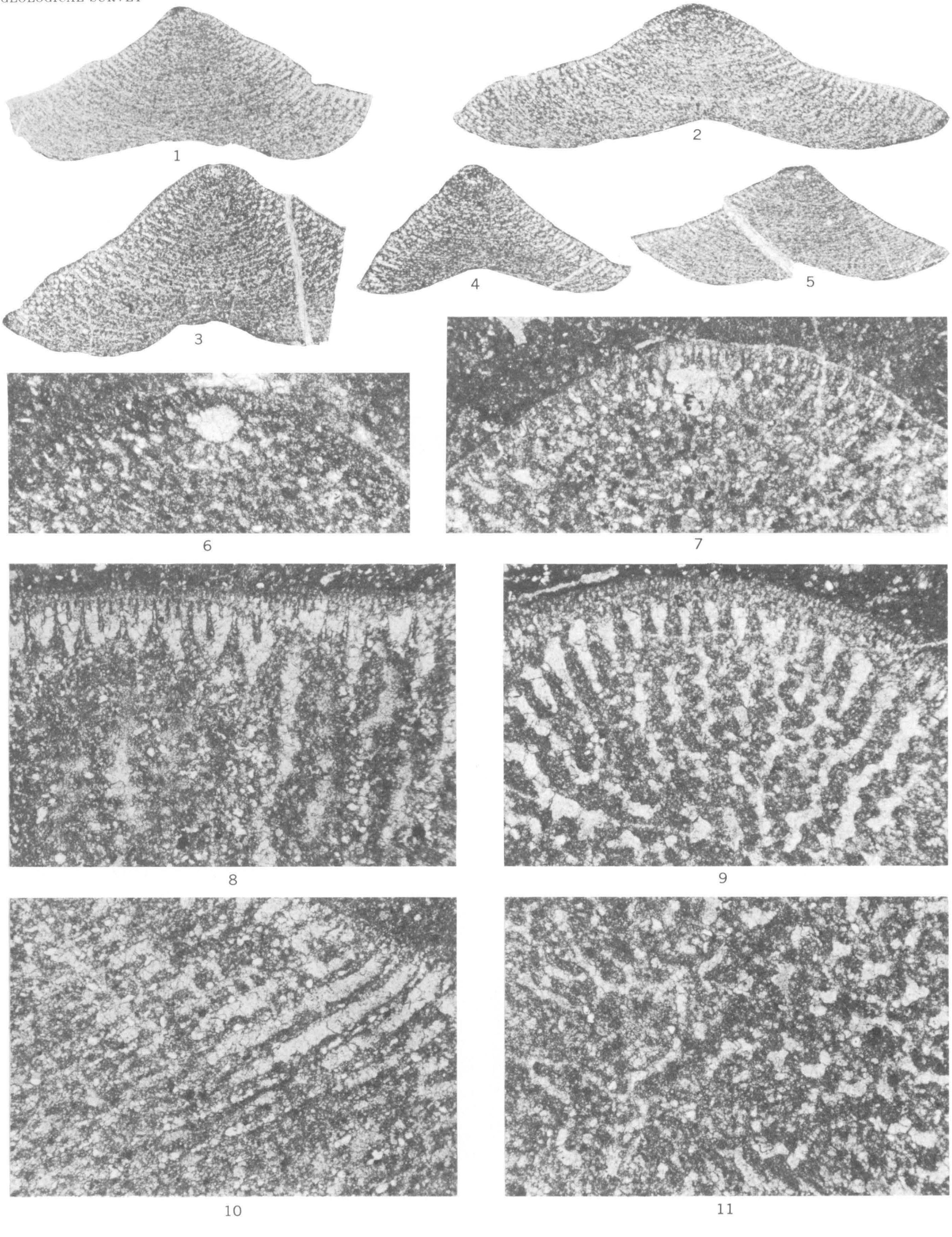
PLATE 13

FIGURES 1–18. *Orbitolina crassa* Douglass, n. sp. from Arizona and New Mexico (p. 43).

1. Axial section of a paratype from the Broken Jug limestone. USNM P5549. Sample f20220, slide 10 (× 10).
2, 3. Axial sections of two paratypes from the Broken Jug limestone. USNM P5550. Sample f20219, slide 18 (× 10).
4. Axial section of the holotype from the Broken Jug limestone. USNM P5551. Sample f20220, slide 27 (× 10).
5. Axial section of a paratype from the Broken Jug limestone. USNM P5552. Sample f20219, slide 15 (× 10).
6. Slightly oblique axial section of a paratype from the Mural limestone. USNM P5553. Sample f20278, slide 13 (× 10).
7. Axial section of a paratype from the Mural limestone. USNM P5554. Sample f20278, slide 15 (× 10).
8. Subaxial section of a paratype from the Mural limestone. USNM P5555. Sample f20277, slide 3 (× 10).
9. Subaxial section of a paratype from the Mural limestone. USNM P5556. Sample f20276, slide 11 (× 10).
10. Subaxial section on the same slide as the specimen illustrated in fig. 8 (× 10).
11. Axial section of a paratype from the Mural limestone. USNM P5557. Sample f20274, slide 12 (× 10).
12. Subaxial section of a paratype from the Mural limestone. USNM P5558. Sample f20277, slide 8 (× 10).
13. Basal section through an early ephebic chamber of a paratype showing the short radial zone and well developed central complex from the Mural limestone. USNM P5559. Sample f20274, slide 15 (×50).
14. Megalospheric embryonic apparatus of a paratype from the Broken Jug limestone. USNM P5560. Sample f20219, slide 33 (× 50).
15. Basal view of a late ephebic chamber of a paratype showing the well developed radial zone and the finely subdivided marginal zone from the Mural limestone. USNM P5561. Sample f20274, slide 16 (× 50).
16. Axial view of the central complex of a paratype showing an abundance of calcite eyes. USNM P5562. Sample f20273, slide 5 (× 50).
17. Tangential view of a paratype showing the clear primary wall layer contrasting with the agglutinate triangular cross sections of the main partitions from the Broken Jug limestone. USNM P5563. Sample f20219 slide 1 (× 50).
18. Basal view of the radial zone of a paratype showing the main partitions and abundant pores from the Mural limestone. USNM P5564. Sample f20276 slide 8 (× 50).



ORBITOLINA CRASSA DOUGLASS, N. SP.



ORBITOLINA GROSSA DOUGLASS, N. SP.

PLATE 14

FIGURES 1–11. *Orbitclina grossa* Douglass, n. sp. from the Broken Jug limestone of New Mexico (p. 44).

1. Subaxial section of a paratype. USNM P5565. Sample f20218, slide 9 (× 10).
2. Holotype. USNM P5566. Sample f20218, slide 17 (× 10).
3. Part of an axial section of a paratype. USNM P5567. Sample f20218, slide 49 (× 10).
4. Subaxial section of a paratype. USNM P5568. Sample f20218, slide 11 (× 10).
5. Broken axial section of a paratype. USNM P5569. Sample f20218, slide 18 (× 10).
6. Axial section of the embryonic chambers of a paratype. USNM P5570. Sample f20218, slide 15 (× 50).
7. Enlarged portion of the same specimen as figure 3 (× 50).
8. The marginal and radial zone in horizontal section illustrating the main partitions of the primary and secondary plates on a paratype. USNM P5571. Sample f20218, slide 27 (× 50).
9. The radial zone of a paratype in horizontal section. USNM P5572. Sample f20218, slide 33 (× 50).
10. Portion of the axial zone of a paratype illustrating the regular spacing of the chambers and the apertural pores. USNM P5572a. Sample f20218, slide 46 (× 50).
11. The central complex of the same specimen illustrated as figure 9 (× 50).

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