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FORAMINIFERA OF THE MIDWAY FORMATION IN TEXAS

By

HELEN JEANNE PLUMMER

Bureau of Economic Geology

J. A. Udden, Director E. H. Sellards, Associate Director

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

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FORAMINIFERA OF THE MIDWAY FORMATION IN TEXAS

By

Helen Jeanne Plummer

INTRODUCTION

In June, 1925, a thesis on some foraminifera of the Midway formation in the Mexia-Corsicana area was submitted to the Department of Geology of Northwestern University and accepted for a master's degree by the Graduate Faculty upon the recommendation of Professor U. S. Grant. This preliminary study was based on rather extensive collections made during a period of field work with Mr. F. B. Plummer in northeast Texas for Rycade Petroleum Corporation. Through the courtesy of Mr. E. DeGolyer, manager of the company, release of this scientific information was at that time generously granted. This small area of tremendous economic importance offers an excellent stratigraphic section of the Midway formation from the Cretaceous contact to the overlying Wilcox, and because of the striking relationships of its lithologic units to its foraminiferal groups, this district may well be regarded as the key area for the study of the Midway formation in Texas.

Since the early study of this foraminiferal fauna as recorded in the thesis, further collections along the outcrop from northeast Texas to San Antonio have amplified somewhat the assemblage of species comprising the group and have made possible some rather broad conclusions upon the distribution of the Midway forms in the classification of foraminifera and upon the geographic extent of the faunal units observed first in the vicinity of the Mexia oil field. The results as here presented[1] must be regarded merely as a working basis for more extensive studies. Several species

[1]Manuscript submitted September, 1926; issued April, 1927.

remain to be described, and a few species here presented can well be broken up into varieties; the stratigraphic positions of many of the species and their range not only in the Midway formation but also through the Texas section can be determined more definitely by extensive studies of core samples and of more outcrop material; and the relationships of the species to lithologic units may reveal some interesting events in the depositional history of this formation.

Because so very little of the vast literature on the subject of foraminifera has been available for reference in this investigation, and because it has been impossible for the author to study old collections, some of the specific determinations here offered may later be subject to changes. It is hoped, however, that the descriptions and illustrations here presented may serve the local purpose for which the report is intended—as a guide to the identification of the Midway formation both in outcrops for the detailed mapping along the Cretaceous-Eocene contact and in well samples during drilling operations.

All holotypes and cotypes of the new species and pleisiotypes of the old species have been deposited in Walker Museum, University of Chicago. For the greater convenience of the Texas workers a duplicate set of the species is deposited at the Bureau of Economic Geology in Austin, Texas.

ACKNOWLEDGMENTS

Through the kindness of Mr. Frederick Chapman and Mr. Arthur Earland samples from the London Clay and Thanet Beds, the lowest Eocene formations in England, have been made available for comparative studies. To these same workers, to Dr. Edward Heron-Allen, and to Dr. J. A. Cushman the author is greatly indebted for advice in the determination of a few of the species, when comparison with types or topotypes of similar forms has been especially desired. Special appreciation is extended to Dr. Gabriel von Lasslo of the Hungarian Geological Survey at Budapest for

the excellent translation of some descriptions of species from his native language into English.

Several of the paleontologists in the oil-company laboratories in Houston have been generous in submitting for study their extensive collections. Mrs. Esther R. Applin and Miss Grace Newman of Rio Bravo Oil Company have furnished material from many parts of the Texas geologic section for comparative studies. Mr. P. T. Seashore of Humphreys Corporation has turned over for examination complete sets of slides made from core tests in northeast Texas. The Bureau of Economic Geology has contributed photographs of a few large species that proved rather difficult to sketch.[2] In preparing a typical columnar section of the Midway formation in the Mexia area to show the essential lithologic features, Mr. D. Gordon of Humphreys Corporation has generously given advice and lent his measured sections that have proved a valuable check on data already in hand. Special acknowledgement is due Mr. Frederick Lahee for the privilege of using as a type locality for a few upper Navarro species the outcrop seven miles north of Cameron, Milam County, from which Mr. D. M. Collingwood collected material for the author.

In the course of the study of the Midway material and in the development of the manuscript, Professor Stuart Weller and Mr. Arthur Slocum of Walker Museum have been most liberal in providing laboratory facilities, in giving much-needed advice, and in making available numerous excellent old publications. Absolute freedom in developing the problem has been accorded by Dr. E. H. Sellards of the Bureau of Economic Geology, a feature that has contributed considerably to the writer's interest in the work. Throughout more than two years of collecting, preparation, and study of the material it has been mainly through the constant coöperation, assistance, and encouragement of Mr. F. B. Plummer that the results have finally been assembled into the present form.

[2]These photographs were taken by Mr. P. T. Seashore during his associations with the Bureau.

MIDWAY FORAMINIFERAL FAUNA

GENERAL CHARACTER

The assemblage of foraminiferal species in the Midway formation comprises a very distinct group in this portion of the geologic section. The formation is underlain by the Cretaceous calcareous clays rich in Textularian and Globigerine forms and is overlain by a great thickness of almost wholly non-marine deposits of the Wilcox formation. Though the Midway fauna presents a group of forms that are distributed through the classification from the family

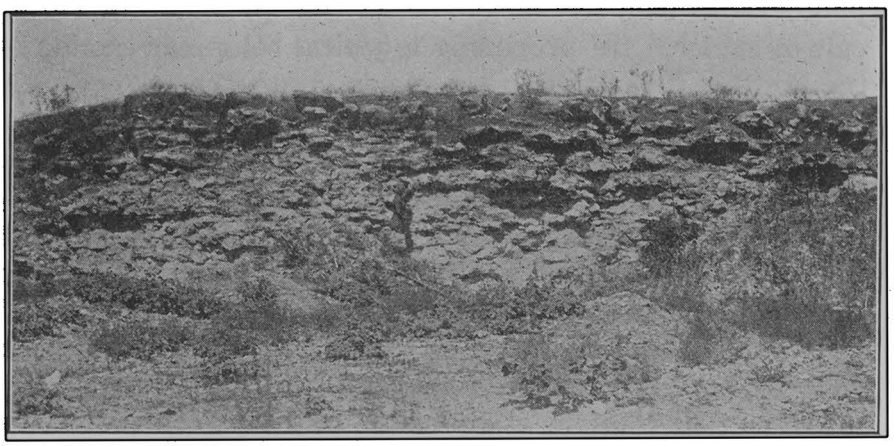


Fig. 1.—Exposure of the upper ledge of the Tehuacana limestone in a quarry about half a mile south of the town of Tehuacana.

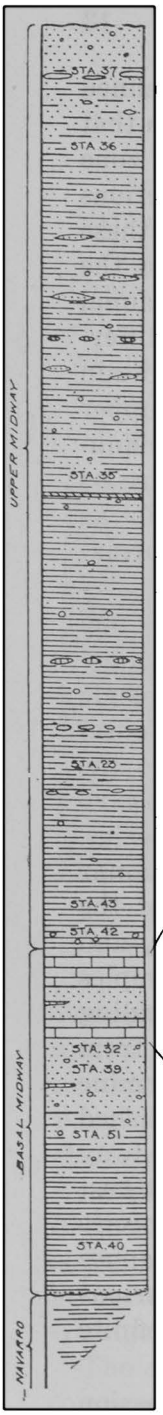
Astrorhizidae to the early part of the Nummulitidae and shows a trace of Miliolid forms, by far the most abundant are species of the families Lagenidae and Rotaliidae. The paucity of pelagic forms is indicative of a comparatively shallow sea throughout the deposition of Midway strata. Considerable fluctuation, however, strikingly evident both in the variety of its lithologic members and in the corresponding succession of its foraminiferal groups, introduces at the beginning of upper Midway times an abundance of Globigerine tests.

The foraminifera of the Midway formation as a whole comprise a distinct faunal group. Within this group, however, throughout the extent of outcrop from Bexar to

Hopkins counties are two persistent and well-defined faunules, one of which is characteristic of a basal zone that varies from 75 to 125 feet, and the other of the upper zone of 500 to 550 feet. Careful study of numerous collections of the larger fossils present corresponding evidence of these same two distinct faunal units in the formation across the state. The difference between the basal and upper faunal groups in the Midway is much more striking than the difference between the foraminiferal faunas of the Cook Mountain and Yegua formations of the Claiborne group of the upper Eocene in Texas, as recognized by Mrs. Applin (manuscript). These divisions of the Midway formation are so well defined both paleontologically and stratigraphically as to suggest the future advisability of separating the formation as at present recognized into two formations.

In the Mexia district the numerous good outcrops and presence of the conspicuous, scarp-making Tehuacana limestone (fig. 1) render the upward succession of the lithologic members of this formation very easily observed. Consequently this well-known area lent itself admirably to the preliminary investigations that revealed at once the sharp faunal break at the top of the Tehuacana limestone series, and it has become the key area in this study. The columnar section (fig. 2) presents graphically the succession of the lithologic units and their corresponding faunal zones, and figure 11 shows the localities that have furnished samples for minute examination. After a thorough understanding of the faunal changes in this restricted area, collections from the formation in both directions were examined to determine the geographic extent of the features already established locally. From a large number of widely distributed Midway outcrop samples that have been studied, the series that best presents not only the distribution of foraminiferal species in the classification, but most especially the upward changes in faunal character through the formation across various parts of the belt of outcrop, has been chosen for definite record in this paper (Pl. I).

The search for the precise nature of the faunal succession within the Midway formation northeast and southwest of



Very fine, grey to black, poorly laminated, slightly clayey silt or fine cand containing round rough-surfaced concretions.

Large, flat, rough-surfaced concretions, 3′–4′ long. This horizon carries a few fossils west of New Hope.

Grey, clayey silt becoming more and more sandy upward; shells rare.

Dark-grey, very silty clay containing sand and in places thin layers of sand between the laminae; occasional large, dark, round concretions; fossils rare.

Dark, calcareous, somewhat elongate, finely rough-surfaced concretions.

Dark-grey clays grading from slightly silty into more and more silty beds that carry partings that sparkle with fine selenite crystals. About 225′ above the limestone is a thin layer of yellowish grey aragonite characterized by radiating crystals.

Large, yellow, flat concretions, 2′–3′ long, that weather to a brilliant brown colour.

Elongate, flat, dark, calcareous, hard concretions with surfaces finely fretted by veinlets.

Compact, heavy, siltless clay with very few small round concretions.

Soft, round, small, limonite concretions some of which have hollow centers.

The compact clays of the lower part of the upper Midway section carry large assemblages of hyaline species that become less and less abundant upward as the strata become more silty. In some outcrops of silty beds the arenaceous forms are dominant, and in places *Ammodiscus incertus* is the only form of foraminiferal life.

The conspicuous and diagnostic species of this zone are *Bolivina applini, Cristellaria subaculeata* var. *tuberculata, Vaginulina legumen* var. *elegans, Vaginulina robusta, Lamarkina rugulosa, Truncatulina alleni, T. vulgaris, T. tenera, T. culter,* and *Pulvinulina exigua.*

Other diagnostic species of the upper faunule of frequent occurrence are: *Textularia eocaena, Bulimina quadrata, Frondicularia delicatissima, F. budensis, F. goldfussi, Globigerina compressa.*

Upper limestone greyish-white to yellow and brown, composed of masses of small and fragmentary shells, fish teeth, scales, and ostracods.

Fine, glauconitic, silty sand not well exposed.

Light, yellowish-grey, fossiliferous limestone containing oysters.

Few foramifera in limestone layers, but equivalents carry basal species and a few upper species.

Glauconitic, fine to medium-grained, fossiliferous quartz sand containing large, spherical concretions or even ledges of calcareous rock.

Silty, blue-grey clay weathering yellow.

Dense yellowish clay that breaks with conchoidal fracture and carries foraminiferal tests visible to the unaided eye.

Thin bed of fine yellow sand not everywhere present and may be replaced by layer of phosphatic nodules.

Discorbis newmaniae is distinctive of upper sandy layers.

The diagnostic species of basal unit are: *Cristellaria pseudocostata, Marginulina gardnerae, Vaginulina gracilis, Pulvinulina exigua* var. *limbata* and *Truncatulina elevata.*

The clays are especially marked by abundance of tests of *Cristellaria midwayensis* with its var. *carinata* and of *Nodosaria affinis.*

Vertical scale: 1 inch=100 feet

Fig. 2.—Generalized columnar section of the Midway formation in the Mexia area showing the stratigraphic position of a few representative outcrops from which samples have been studied and some of the common and diagnostic species of foraminifera that characterize the two faunal units of the formation.

the Mexia area has been a particularly fascinating problem. Outside the general area of the Mexia oil field no constant consolidated member contributes to good continuous exposures, and only by persistent sampling of scattered outcrops has the character of the upward change been revealed. Only about four miles north of the town of Mexia along Tehuacana Creek a sandy shell marl several feet in thickness overlies a slightly glauconitic sand and underlies a dark laminated clay (sta. 41). The sand is very similar to the member just below the lower Tehuacana limestone ledge farther south, but it carries no foraminifera. The fossiliferous bed is characterized mainly by an abundance of typical basal Midway species, but a very few forms that mark more especially the true upper faunal unit are present in small numbers. At the top of this bed the break is sharp and complete, for the superjacent dark clays carry only members of the true upper Midway faunule. These paleontologic features lead to the conclusion that the Tehaucana limestone a few miles to the south has merged laterally into this shell marl, in which a gradual transition from the basal to the upper zone has preceded the sudden and complete break in the sequence.

Northeastward throughout the belt of outcrop into Hopkins County the two distinct faunal units are clearly present from the study of isolated outcrops, but in only a few places has the character of the upward change been observed. The excellently exposed series of strata in the bank of a small creek 2.3 miles by road north of Cumby, Hopkins County (fig. 6, sta. 2), presents in great detail the uppermost portion of the basal zone, and the record of the foraminiferal content of the samples collected will be found in the table of distribution. The dark, gritty clays west of the road bridge at this locality present the true basal foraminiferal assemblage. The succession westward from the bridge—sandy clays, a soft limestone, calcareous sands, and glauconitic clays—presents in great detail the gradually increasing percentage of true upper Midway species through about 15 feet of section to the thin layer of phosphatic nodules in the

glauconitic clay. This well-defined horizon of black nodules cuts off sharply the very diagnostic *Cristellaria pseudocostata* of the basal faunule and marks the advent of *Vaginulina robusta* that is so typical of the upper assemblage. Upward to the top of this exposure the glauconitic clays show stronger and stronger relationships with the upper faunal zone, and undoubtedly another ten feet of section would present the compact clays that lie just above the complete break and carry the characteristically rich upper Midway faunule.

The Lone Oak area furnishes several small isolated exposures (fig. 8) across this transition, and here again a thin layer of phosphatic nodules in a glauconitic clay lies near the top of this narrow series of strata (sta. 8) that mark the close of basal Midway times. Studies in this area too late for definite record in this paper reveal the presence of the richly foraminiferal clays of the true upper Midway faunal unit only a few feet above the phosphatic nodule layer. Throughout the northeast Texas area this thin black layer is a fairly persistent feature at this horizon in the Midway formation, and care must be exercised not to confuse it with a phosphatic layer and a basal greensand that lies in a few places along the Cretaceous-Eocene contact. It is in the absence of the usual field evidence in such localities that the foraminifera become very helpful in identifying the stratigraphic position of the beds in question. This precise problem has in several places arisen in connection with glauconitic sands and clays west of an outcrop of Nacatoch sand, and microscopic examination of the material in question has always been convincing, and the amount of faulting between the abnormally related outcrops has been a simple problem. Not only does this transition zone in the top of the basal Midway unit present a mingling of the two faunules, but it carries in abundance in many places two very distinctive species that are present only very rarely in other portions of the formation and have never been seen in the basal greensand *(Polymorphina cushmani* and *Cristellaria pseudo-mamilligera)*.

Southwest of Brazos River across Milam County and the southeast corner of Williamson County numerous outcrops (stas. 52–56 and many more not recorded) prove clearly the presence of the two distinct faunal units, but no evidence of a mingling of these two groups through an intervening transition zone has been discovered. If such a zone is present in this area it is undoubtedly very narrow, as several closely spaced outcrops lead to the conclusion that the change must have been rapid, if not sudden and complete at a definite horizon.

Farther southwest along the belt of Midway outcrop that follows approximately the northwest edge of Bastrop County, the character of the change from the lower to the upper unit is clearly revealed by numerous outcrops that expose the well-known *Venericardia bulla* bed. This glauconitic fossiliferous marl, in places so rich in the shells of this beautiful pelecypod that the glauconitic material is but a binding matrix, has been followed from the vicinity of Elgin (stas. 62, 64, 65, and 66) southwest across Colorado River[3] (stas. 67 and 68) to an outcrop on Cedar Creek (sta. 69), and collections have been carefully made below, within, and above this layer. Everywhere in this area material below this fossiliferous zone presents the true basal Midway group of species. Within the *Venericardia bulla* bed itself (material extracted from the inside of the shells being preëminently superior to the matrix) foraminiferal tests are scarce, but the few forms observed show a slight mingling of the two faunules. This assemblage is specifically characterized by very frequent specimens of *Polymorphina cushmani* and *Cristellaria pseudo-mamilligera,* so diagnostic of this zone in northeast Texas. The clay immediately overlying the highly glauconitic fossiliferous bed carries only the true upper faunule. These observations indicate that this shell bed, so rich in the remains of *Venericardia bulla* Dall marks the change that terminated

[3]This outcrop is mapped in Professional Paper 126 by Alexander Deussen as locality 213 in figure 11, p. 44.

the conditions characteristic of the early Midway deposition and introduced a new set of conditions that gave rise to the more varied foraminiferal assemblage of the later Midway sea. As in all other localities where the upward succession has been clearly revealed the sharp faunal break occurs at the top of this narrow zone of transition.

The data furnished by the collection of material that has comprised this study point convincingly to the synchroneity of the conspicuous fossil bed in Bastrop County, the Tehuacana limestone, the shell marl north of Mexia, and the transition zone north of Cumby (sta. 2) and south of Lone Oak (sta. 8).

Across Caldwell and Guadaloupe counties both basal and upper zones are represented in outcrops. All avaliable outcrop material from Bexar County, however, shows only the upper faunule, and it is possible that the basal facies has in this area been overlapped or obscured by a series of strike faults. That the basal strata are here present is certain from the examination of a set of core samples. It will be interesting to carry on further detailed outcrop studies in the San Antonio district to learn the true stratigraphic relationships of the members of the Midway formation.

At a date too late for amplification of the systematic treatment of the Midway species, a large number of carefully collected samples submitted by Mr. A. E. Oldham from the Navarro and Midway formations have added some interesting data that sheds a little light on hitherto very puzzling questions. Early in this study it was observed that *Siphogenerina eleganta, Rotalia soldanii* var. *subangulata, R. aequilateralis, R. perplexa,* and *Pulvinulina partischiana* —species that in considerable frequency are diagnostic of the upper Midway zone within the formation itself—occurred very rarely in the upper strata of the Navarro in association with typical Cretaceous forms. Until recently the search for basal Midway forms that bridge the interval between the close of the Cretaceous times and the beginning of upper Midway times to prove the continuous existence

of these species within this geologic province has been fruitless. This new collection of material shows that *Siphogenerina eleganta* and *Pulvinulina partschiana* are exceedingly rare members of the true basal faunule. *Rotalia soldanii* var. *subangulata, R. aequilateralis,* and *R. perplexa* are rather frequent forms at a few places along the basal Midway outcrop, but their sutures instead of being smooth as in the upper Navarro and upper Midway strata are conspicuously elevated. A similar relationship exists between *Pulvinulina exigua* (upper Midway) and *P. exigua* var. *limbata* (basal Midway) as figured on Plate XI, figures 3 and 4. In the consideration of these four species within the Midway formation, the strong sutural elevation is a constant feature of these forms in the basal Midway strata, and the smooth sutures are constant for the upper strata. Very similarly *Cristellaria midwayensis* in the basal clays in many places exhibits a wide peripheral flange, a form known in this paper as variety *carinata.*

The constant relationship of sutural character in the four species above named and of the peripheral character in a fifth to the well-defined faunal units of the Midway formation suggests a reaction to environmental conditions. Dr. E. Heron-Allen and Mr. Arthur Earland have shown by experimentation with living forms that with the increase in the salinity of the sea water the amount of shell material secreted by the protoplasm is correspondingly increased (Jour. Roy. Mic. Soc., pp. 693–695, 1910, and Phil. Trans. Roy. Soc. London, ser. B, vol. 206, p. 262, 1915). The various observations lead to the obvious conclusion that undoubtedly the early Midway sea carried a higher percentage of calcium carbonate than did the later sea of this period, and this condition may possibly explain in some measure the greater abundance of large fossils in the basal strata of the formation, as well as the characteristically thinner-shelled foraminiferal remains of the upper unit. The above-cited interesting experiment on recent forms proves to the biologist that superficial differences in shell ornamentation do not constitute real specific differences.

If, however, in paleontologic studies these same minor variations are found to bear a distinct relationship to stratigraphy, it becomes imperative that they be recognized for the very purpose that they serve the geologist. Each point of view is correct in its own sphere, and it is to be regretted that they have not been brought into closer harmony, for upon a perfect fusion of these two domains of research do the broadest and most valuable interpretations depend.

The occurrence in the late Navarro sea of several Midway species, some of which in varying forms are typical of the Texas Tertiary strata in general, and the corresponding weakening of the dominant Cretaceous faunal characteristics in these topmost strata may indicate that the hiatus represented by the unconformity is not so tremendous as has previously been assumed. Though in this great stratigraphic problem of many facets the foraminiferal evidence may have little weight, it undoubtedly is worthy of some consideration, but much more detailed investigation in this small sphere will be necessary before any valuable contributions to the larger problem can be made.

BASAL MIDWAY FAUNULE

The Midway clays and sands below the Tehuacana limestone in the Mexia area (fig. 2) comprise a thickness of about 125 feet. The section is well exposed up the slope west of the small town of Tehuacana (fig. 11) from the Cretaceous contact, which is marked by a thin layer of fine yellow sand in a small creek bed, upward through heavy clays (sta. 40), sandy clays, and somewhat glauconitic sands that underlie immediately the lower ledge of the limestone near the top of the scarp. The compact clays in the lower portion of this series are poor in species but rich in numbers of foraminiferal tests that can be seen even without the aid of a hand lens. The usual washing process reduces this clay to a small residue composed almost wholly of foraminiferal remains that are typical of these basal clays and comprise the true basal faunule of the formation. North-

ward and northeastward from the Mexia area the basal members maintain similar lithologic characters and relationships and carry the same diagnostic species that are found in the corresponding strata of the Mexia area. The stratigraphic sequence, however, as already discussed is terminated upward not by the conspicuous limestone layer but by a narrow zone of faunal transition in which lies a persistent glauconitic sandy clay containing a phosphatic nodule layer. Wherever samples have been collected in relationship to this thin layer of black nodules the faunal change has been found to be most marked at this horizon within the transition zone and is sudden and complete at the top.

In the small assemblage of the common Midway foraminifera, the most abundant and conspicuous form is *Cristellaria midwayensis*. Some of the tests of this species are without the peripheral flange, the typical form that ranges throughout the formation. Others display a more or less well-developed flange, variety *carinata*, a form that is restricted to the basal faunal unit and is the dominant form of the species in the basal clays in some parts of northeast Texas. It is this flanged variety of *C. midwayensis* in the formation that has given rise to considerable difficulty in the identification of strata along the Cretaceous-Eocene contact in Texas. The underlying Navarro formation of Cretaceous age carries also in abundance a similar closely coiled and widely flanged Cristellarian species. Because many parts of the upper Navarro and basal Midway formations yield almost no forms other than their respective similar Cristellarians (figs. 4 and 5), it becomes necessary for paleontologic purposes that the distinctive characteristics of each be recognized, and on a later page this problem is discussed in further detail in the comparison of the Navarro and Midway faunas.

Nodosaria affinis, N. spinulosa, and *N. granti* are very common and even abundant species in many parts of the basal series of this formation, and though they occur in the upper strata they are in that zone much rarer. Further

these species are present, but in highly mineralized condition, in Navarro clays and must be employed with caution in making identification of the strata in which they occur. The field geologist will find the tests of *N. affinis* a very helpful guide in identifying basal Midway clays, for their abundance, their size, and their freshness render them readily visible in outcropping clays even without the aid of a hand lens. No Navarro clays possess this species in sufficient numbers or in a condition to render its tests visible except in well-washed samples with the aid of a microscope.

Another very common and abundant species that marks the entire Midway formation is *Truncatulina midwayensis*, but its variety *trochoidea*, which is locally very common, is restricted to the basal faunule.

The frequent and common species that mark most distinctly the basal Midway zone, not only in the formation itself but in the Texas geologic section, are *Cristellaria pseudo-costata, Vaginulina gracilis*, and *Marginulina gardnerae*. These reach their best development in the compact clays, but they persist through the sandy layers to the Tehuacana limestone in the Mexia area and into the transition zone in most of northeast Texas. *Cristellaria pseudo-costata* appears to be sharply cut off by the phosphatic nodule layer in the glauconitic clay and sandy clay near the top of this transition series. In some places *Vaginulina gracilis*, however, continues upward as a rare form for several feet above this thin black layer and in the topmost strata in this zone it may be found with tests of *V. robusta*. The field geologist will find *V. gracilis* of considerable aid in his detailed mapping, for its abundant long and slightly curved tests in the lower compact clays of the basal unit are readily visible to the naked eye and can not be confused with any visible similar form elsewhere in the Texas section.

The species *Truncatulina elevata* and *Pulvinulina exigua* var. *limbata* are less abundant forms in the basal faunule than are the species previously mentioned, but they are restricted to this part of the geologic section and in places are very helpful in identifying the basal Midway unit.

Upward in the basal zone as the clays become more and more sandy the foraminifera become less abundant, and in the slightly glauconitic sands at the top of the series in the Mexia area persistent search must be made in carefully washed samples to discover sufficient forms to mark the age of those beds. In most of this sandy series specimens of *Cristellaria pseudo-costata, C. midwayensis, Vaginulina gracilis,* and *Marginulina gardnerae* can be found; but a new form, *Discorbis newmanae,* not present in the lower compact clays begins to appear in the overlying sandy clays, and in the upper sands of the basal Midway unit it is in places almost the only foraminiferal species present. Since *D. newmanae* is restricted to the upper sandy facies of the basal Midway zone, it is an important and valuable form in the faunule, and in no other part of the geologic section is there another similar species that can present any confusion.

In the following list of species[4] that occur in the basal Midway faunal unit, those marked by a double asterisk are those at present regarded as restricted to this zone in the Texas geologic section; those marked by a single asterisk are restricted to the formation as a whole but occur in both faunal units. The species of this lower faunule that are restricted to the transition strata are so designated.

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[4]Throughout this bulletin in recording the average frequency of each species the following scale has been employed: very rare, rare, frequent, very frequent, common, very common, abundant, very abundant. Though the author's interpretation of the frequency of the various species may not meet precisely the experience of other students of Midway foraminifera, this record should serve as a general guide.

Foraminifera of the basal Midway unit

Haplophragmoides canariensis (d'Orbigny)	Rare
*Clavulina angularis d'Orbigny	Very frequent
Nodosaria comata (Batsch)	Common
Nodosaria pomuligera (Stache)	Frequent
Nodosaria granti n.sp.	Common
Nodosaria sagrinensis Bagg	Frequent
Nodosaria spinulosa (Montagu)	Very common
**Nodosaria pseudo-obliquestriata n.sp.	Very frequent
Nodosaria vertebralis (Batsch)	Common
Nodosaria affinis d'Orbigny	Abundant
Cristellaria gibba d'Orbigny	Very frequent
*Cristellaria midwayensis n.sp.	Very abundant
**Cristellaria midwayensis n.sp. var. carinata n.var.	Very common
*Cristellaria pseudo-mamilligera n.sp.	Very frequent (trans.)
**Cristellaria pseudo-costata n.sp.	Very common
Cristellaria earlandi n.sp.	Rare
**Marginulina gardnerae n.sp.	Common
*Vaginulina plumoides n.sp.	Very frequent
**Vaginulina gracilis n.sp.	Abundant
Frondicularia rugosa (d'Orbigny)	Frequent
**Frondicularia oldhami n.sp.	Very rare
Polymorphina lactea (Walker and Jacob)	Frequent
Polymorphina gibba d'Orbigny	Common
Polymorphina communis d'Orbigny	Rare
*Polymorphina cushmani n.sp.	Frequent (trans.)
Siphogenerina eleganta n.sp.	Very rare
Vitriwebbina laevis (Sollas)	Rare
Vitriwebbina chapmani n.sp.	Frequent
Ellipsopleurostomella attenuata n.sp.	Very rare (trans.)
Globigerina pseudo-bulloides n.sp.	Frequent
Globigerina triloculinoides n.sp.	Very rare
**Discorbis newmanae n.sp.	Very frequent
*Truncatulina midwayensis n.sp.	Abundant
**Truncatulina midwayensis n.sp. var. trochoidea n.var.	Common
**Truncatulina elevata n.sp.	Common
Truncatulina alleni n.sp.	Rare (trans.)
*Truncatulina vulgaris n.sp.	Common (trans.)
Siphonina prima n.sp.	Very rare
Anomalina ammonoides (Reuss) var. acuta n.var.	Very common

**Pulvinulina exigua H. B. Brady
var. obtusa Burrows and Holland.....Very rare
**Pulvinulina exigua H. B. Brady
var. limbata n.var.....Very frequent
Rotalia soldanii (d'Orbigny)
var. subangulata n.var.....Frequent (trans.)

UPPER MIDWAY FAUNULE

The upper Midway section of 500 to 550 feet in thickness carries in its basal portion about 75 feet of compact, fine, siltless,[5] blue clay that carries an abundance of fresh foraminiferal tests of species that are distributed through several families and many genera. Upward from this fossiliferous zone the clays become gradually more and more silty, and the foraminifera become correspondingly fewer till the upper half of the stratigraphic zone carries in most places only rare specimens of the diagnostic arenaceous species of the upper faunule, *Ammodiscus incertus, Haplophragmoides canariensis,* and *Textularia eocaena.* A considerable portion of these uppermost strata is devoid of all fossil remains.

Above the Tehuacana limestone in the Mexia area, and above its equivalent *Venericardia bulla* bed across Bastrop County, above the shell marl north of Mexia, and above the transition zone of northeast Texas very few of the common basal Midway forms persist in these heavy, dense, and richly foraminiferal clays that characterize this part of the section. *Cristellaria midwayensis* is very frequent in its typical form in the upper strata but is less conspicuous here than in the faunule of the basal strata. *Nodosaria affinis* is present but in general not common, as it is in many places in the lower clays. *N. spinulosa* continues as a comparatively rare species in the upper faunal unit. *Truncatulina midwayensis* still maintains strong development and is a very common species here as in the underlying zone. *C. midwayensis* var. *carinata, C. pseudo-costata, Vaginulina gracilis, Marginulina*

[5]In this paper the term "silt" is used for siliceous particles that are distinctly larger than the argillaceous particles of the compact clays but considerably smaller than fine sand. The silt in the upper Midway clays forms very thin partings either along planes of lamination causing the clay to break in sheets or more commonly along undulating and irregular surfaces that produce "joint clays" that break with subconchoidal fracture.

gardnerae, Discorbis newmanae, Truncatulina midwayensis var. *trochoidea, T. elevata,* and *Pulvinulina exigua* var. *limbata* have been completely annihilated by the changing conditions that gave rise to the deposition of the Tehuacana limestone and its lateral equivalents.

With this influx of large numbers of species that hitherto were not present in the early Midway sea, a few arenaceous forms appear for the first time in this formation. The family Textulariidae is represented by several species, most of which are unknown in the basal faunal zone. The family Lagenidae is represented by numerous Nodosarians and

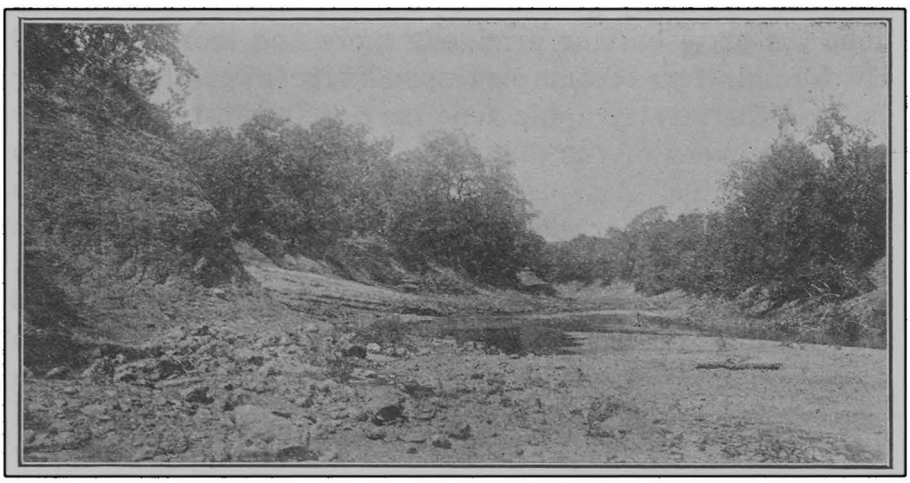

Fig. 3.—Burton's Bluff on Trinity River (sta. 16) where the silty clays of the upper Midway are exposed on the left bank of the stream. The large concretions that have been washed from the strata into the bed of the river are typical of this portion of the Midway formation.

Cristellarians, several Marginuline, Vaginuline, and Frondicularian species, some of which are common in, and diagnostic of, these upper beds, but most of which are only frequent or rare forms. The Globigerine species are more abundant and varied and point to a deeper-water deposition during the early part of the upper Midway stage. Perhaps the most conspicuous feature of practical value in distinguishing the zones is the rise of numerous common, or even abundant, members of the family Rotaliidae, which in small numbers persist upward in the upper Midway section

through the silty clays. Only patient search in clays rich in hyaline forms has revealed the existence in the Midway fauna of a representative of the family Nummulitidae and three members of the family Miliolidae.

Though *Ammodiscus incertus* is present throughout the upper Midway zone, it attains no particular value as a guide fossil till the clays have become so silty in its upper portions that this species and a few other arenaceous forms are the only fossil evidences of life during these late stages of deposition. In such strata *A. incertus* and *Textularia eocaena* are in places the only forms present, and with these species occur frequently *Haplophragmoides canariensis,* a species somewhat similar to *H. excavata* Cushman and Waters in upper Navarro clays. In some parts of the silty clays toward the top of the Midway formation *Ammodiscus incertus* attains a large size, and its very white, sparkling, finely arenaceous tests are easily detected in the washed residues barren of all other species.

Of the Textulariidae, *Textularia eocaena* is on the whole rare in the fauna but in places is of considerable aid in marking the age of the outcropping strata in the upper silty portion of the formation (fig. 3) where its occurrence with *Ammodiscus incertus* is frequent. *Clavulina angularis* reaches its best development in the upper Midway zone, but it began life in the basal strata of the formation. *Bolivina applini,* which is restricted to the upper faunal zone, is sufficiently frequent in the upper strata poor in species to be a valuable marker. In this connection it may be well to call attention to the very rare occurrence of *B. applini* in an outcrop of Taylor clays, but consultation with other workers proves this Cretaceous occurrence unique to the present date, consequently the species in unmineralized condition can probably without danger be regarded as a good upper Midway marker. *Bulimina (Ellipsobulimina) quadrata* is in a few places in the lower compact clays of the upper faunal unit abundant in both its megalospheric and microspheric forms, but it continues into the silty clays as a rare form and is diagnostic of this zone in the Texas section.

The family Lagenidae received a great impulse at the beginning of upper Midway times, and very many species flourished in small numbers for a short interval, but most of them passed out of existence as the clays became more silty and sandy toward the end of the period. *Cristellaria subaculeata* var. *tuberculata, C. turbinata, C. degolyeri, Vaginulina legumen* var. *elegans,* and *V. robusta* are the most persistent forms in the upper faunule, and in a few places *Cristellaria longiforma* is conspicuous by its numbers.

Several species in the family Rotaliidae attain a size, a frequency throughout the strata, and a geographic distribution that assign to them especially high values as horizon markers in the Texas geologic column. Of these *Truncatulina alleni*[6] and *T. vulgaris* are especially noteworthy in that in advancing upward through the formation from its base they are generally the first species to mark the change from the lower to the upper faunule in areas characterized by the zone of transition. *Rotalia soldanii* var. *subangulata* is another common or abundant form of the upper zone that makes its appearance in the lower part of the transition zone and persists upward through the silty clays in the top of the formation. *Truncatulina tenera* and *T. culter* belong strictly to the true upper faunule, and though they are abundant in only a few places they occur with sufficient constancy to possess a distinct value as guide fossils. *Pulvinulina exigua* is a very common and distinctive species, and in a few places identification of the strata has depended wholly on this form. *Pulvinulina partschiana* is very frequent and widespread in upper Midway strata, but because locally in some outcropping Navarro clays in Hunt and Hopkins counties it has recently been observed in considerable abundance in unmineralized condition, reliance in this form as a guidepost has been shaken. Though *Rotalia perplexa* is in general most common where other diagnostic hyaline species of this faunal unit are abundant, it has been observed fre-

[6]Since a few outcropping clays of the upper Navarro formation have yielded specimens of *Truncatulina alleni,* it can not be regarded as a diagnostic Midway form, though it is far more abundant in the Midway strata. However, in association with basal Midway forms it carries the significance stated above.

quently in strata poor in foraminifera and with caution serves as a guide in such places; its very rare occurrence in upper Navarro clays in Hunt County, however, detracts somewhat from its value in stratigraphic studies.

In the following list of species that belong to the Midway strata above the Tehuacana limestone in the Mexia area and its lateral equivalents elsewhere along the outcrop of the formation, those species marked with a double asterisk are at present regarded as restricted to the upper Midway faunule in the Texas geologic column; those marked by only a single asterisk are species that mark distinctly the formation as a whole but occur in both faunal units.

Foraminifera of the upper Midway unit

Ammodiscus incertus (d'Orbigny)	Very frequent
Haplophragmoides canariensis (d'Orbigny)	Frequent
Textularia agglutinans d'Orbigny	Very rare
**Textularia eocaena (Gümbel)	Frequent
**Textularia carinata d'Orbigny var. expansa n.var.	Rare
Bolivina applini n.sp.	Very frequent
Pleurostomella alternans Schwager	Very rare
*Clavulina angularis d'Orbigny	Common
**Bulimina quadrata n.sp.	Frequent
Bulimina aculeata d'Orbigny	Frequent
Lagena apiculata (Reuss)	Very rare
**Nodosaria laevigata d'Orbigny var. occidentalis Cushman	Very rare
Nodosaria radicula (Linnaeus)	Very frequent
Nodosaria soluta (Reuss)	Very rare
Nodosaria pauperata (d'Orbigny)	Frequent
Nodosaria mucronata (Neugeboren)	Rare
Nodosaria pomuligera (Stache)	Very rare
Nodosaria longiscata d'Orbigny	Frequent
Nodosaria granti n.sp.	Frequent
Nodosaria sagriensis Bagg	Very frequent
Nodosaria spinescens (Reuss)	Very rare
Nodosaria spinulosa (Montagu)	Frequent
**Nodosaria oligotoma (Reuss)	Very rare
Nodosaria vertebralis (Batsch)	Rare
Nodosaria affinis d'Orbigny	Frequent
Cristellaria rotulata (Lamarck)	Frequent
Cristellaria orbicularis (d'Orbigny)	Rare

Cristellaria gibba d'Orbigny	Frequent
*Cristellaria midwayensis n.sp.	Very frequent
Cristellaria degolyeri n.sp.	Very frequent
Cristellaria turbinata n.sp.	Common
*Cristellaria pseudo-mamilligera n.sp.	Rare
Cristellaria scitula Berthelin	Very rare
**Cristellaria sublatifrons n.sp.	Very rare
**Cristellaria trigonata n.sp.	Rare
**Cristellaria subaculeata Cushman var. tuberculata n.var.	Very common
**Cristellaria longiforma n.sp.	Frequent
Cristellaria earlandi n.sp.	Very rare
Marginulina glabra d'Orbigny	Rare
**Marginulina tumida Reuss	Very rare
**Marginulina regularis d'Orbigny	Rare
**Marginulina costata (Batsch)	Rare
Vaginulina legumen (Linnaeus)	Rare
**Vaginulina legumen (Linnaeus) var. elegans d'Orbigny	Very common
**Vaginulina robusta n.sp.	Very common
*Vaginulina plumoides n.sp.	Rare
Frondicularia archiaciana d'Orbigny var. strigillata Bagg	Frequent
**Frondicularia goldfussi Reuss	Frequent
**Frondicularia budensis (Hantken)	Frequent
**Frondicularia delicatissima n.sp.	Frequent
Polymorphina lactea (Walker and Jacob)	Rare
Polymorphina gibba d'Orbigny	Rare
Polymorphina ovata d'Orbigny	Very rare
**Polymorphina spathulata Terquem	Rare
*Polymorphina cushmani n.sp.	Very rare
Siphogenerina eleganta n.sp.	Very frequent
**Ramulina laevis Rupert Jones	Very frequent
**Ramulina sp.	Very rare
Vitriwebbina laevis (Sollas)	Frequent
Vitriwebbina chapmani n.sp.	Frequent
**Chilostomelloides eocenica Cushman	Very rare
Allomorphina trigona Reuss	Rare
**Allomorphina globulosa n.sp.	Very rare
Ellipsopleurostomella attenuata n.sp.	Very rare
Globigerina pseudo-bulloides n.sp.	Common
Globigerina triloculinoides n.sp.	Very frequent
**Globigerina compressa n.sp.	Frequent
Pullenia quinqueloba (Reuss)	Rare
**Discorbis infrequens n.sp.	Very rare
Discorbis allomorphinoides (Reuss)	Frequent

**Lamarckina rugulosa Plummer	Very frequent
*Truncatulina midwayensis n.sp.	Common
**Truncatulina welleri n.sp.	Rare
Truncatulina alleni n.sp.	Common
*Truncatulina vulgaris n.sp.	Common
**Truncatulina tenera H. B. Brady	Very frequent
**Truncatulina culter (Parker and Jones)	Very frequent
Siphonina prima n.sp.	Frequent
Anomalina ammonoides (Reuss) var. acuta n.var.	Very common
**Pulvinulina exigua H. B. Brady	Common
**Pulvinulina reticulosa n.sp.	Very rare
Pulvinulina partschiana (d'Orbigny)	Very frequent
Rotalia soldanii (d'Orbigny) var. subangulata n. var.	Common
Rotalia aequilateralis n.sp.	Rare
Rotalia perplexa n.sp.	Very frequent
**Asterigerina primaria n.sp.	Very rare
Nonionina turgida (Williamson)	Very rare
Cornuspira carinata (Costa)	Very rare
Quinqueloculina ferussacii d'Orbigny	Very rare
Triloculina laevigata Bornemann	Very rare

DEPOSITIONAL HISTORY OF THE MIDWAY FORMATION

The lithologic and paleontologic study of the Midway outcrops across Texas from Hopkins to Bexar counties has revealed rather forcibly certain details in the depositional history of the Midway sea. The broad geographic distribution of the two faunal units of the formation, so sharply separated in the Mexia area by the Tehuacana limestone, proves that the changing conditions causing the sudden annihilation of several very abundant species in the lower strata were widespread and general over this basin of deposition. Although almost everywhere some shallow-water bed separates the two divisions that are faunally so distinctive, the varying conditions of deposition along the strand line at the close of the early Midway sea are well reflected in the various types of deposits at the top of the basal Midway series in different parts of the belt of outcrop.

Because the very earliest Midway waters washed shores comprised mainly of the compact clays of the Navarro formation, the sand at the base of the Eocene series is thin and

in some places even absent. Compact, buff-grey to yellow, laminated clays and slightly sandy clays containing an abundance of a few species of foraminifera mark the first essential stage of this rather shallow early Midway sea. Upward from these first compact clays the increase in sand content from sandy clays into sands and slightly glauconitic sands throughout most of the belt of outcrop points to a gradual but rather rapid shallowing of its waters. This change is reflected faunally by a marked decrease in the abundance of foraminiferal tests in the strata above the basal clays and by the advent of a shallow-water species, *Discorbis newmanae,* in the sandy facies. The conditions that gave rise to the gradual shallowing of early Midway waters were culminated by a slight irregular warping of the sea floor as expressed in the varying character of the deposits at the top of the basal series of strata along the Midway belt in different parts of the state.

In the Mexia area the early Midway deposition closed with the Tehuacana limestone member, a series of heavy limestone beds and a few interbedded sands. The wealth of fragmentary shells, fish scales and teeth, and a few shallow-water foraminifera in the limestone indicate that it was deposited in shoal water near the shoreline. Following the formation of the Tehuacana limestone it is likely that total emergence of the sea floor in this district exposed for a brief interval the deposits of the early Midway stage to weathering and erosion.

Immediately northeastward from Mexia the Tehuacana limestone merges into a rich shell marl or highly fossiliferous sand (5 to 10 feet) in which the true basal species are dominant. Still farther northeastward across Kaufmann, Hunt, and Hopkins counties a narrow zone of shallow-water beds comprising thin sands, limestone lenses, and heavy deposits of glauconitic clays and sands marks the termination of the brief early Midway sea in northeast Texas.

The shallowing of the waters southwestward from the small area of maximum elevation in the vicinity of Mexia is reflected in a glauconitic sand containing layers and

lenses rich in *Venericardia bulla* Dall, a facies most prominent in Bastrop County.

That the return to deeper-water conditions at the end of this first Midway stage was abrupt is evidenced by the complete and sudden extermination of several distinctive and abundant species of the foraminifera and of a few of the larger fossils that mark the deposits of the basal strata of the series. Though the areas featured by the transition zone show a gradual but rapid change from the true basal faunule into the true upper faunule through five to thirty feet of section, the final break everywhere at the top of this narrow zone is sharp and complete.

The depth of the sea at the beginning of the second Midway stage greatly exceeded that at any previous time in this period. Deposits of fine, siltless, compact, dark clays carry in some abundance tests of some Globigerine species and a wealth of other foraminifera that span a large portion of the classification of this group. This condition must have been general across the Texas basin, for the character of the deposits and their foraminiferal content are practically the same everywhere immediately above the depositional break at the end of early Midway times. Thereafter, through a much longer period of deposition than that occupied by the first Midway sea, a gradual and widespread shallowing of this later embayment is reflected in deposits that upward become more and more silty and sandy, and the foraminiferal remains grow more and more scanty. Instead of the rich shell marls that marked the close of the early Midway sea, only nonfossiliferous or very slightly fossiliferous silts and nonglauconitic sands lie at the top of this marine series of the first Eocene period in Texas. Further detailed study may disclose whether the almost total lack of foraminiferal life toward the end of Midway times was due to unfavourable climatic conditions, to the peculiar character of deposition along a rapidly changing shoreline, to the salinity of the sea water or a combination of adverse factors. Locally in these uppermost beds both megascopic and microscopic fossils are present, but the

foraminifera are represented mainly by rare tests of arenaceous species and scattered emaciate hyaline tests. It seems very likely that the sea water was abnormally low in its content of calcium carbonate.

COMPARISON OF NAVARRO AND MIDWAY FAUNAS

An understanding of the faunal differences that mark the Cretaceous-Eocene contact in Texas is of vital importance in both scientific and economic work. For this reason, it is deemed relevant in connection with this treatment of the Midway foraminiferal fauna to consider briefly the major features of the underlying Navarro assemblage of forms and to discuss in some detail a few species that are essential to the correct identification of its upper strata. A recent bulletin[7] on some Cretaceous species in this state presents very clearly a number of forms that characterize the Navarro fauna as found in the compact, blue-grey, calcareous clays that make up the major portion of the formation above the Nacatoch sand in south-central Texas, and this treatise should be consulted for detailed descriptions and figures of some of its common forms. The detailed mapping of areas involving the Navarro-Midway contact, however, presents the necessity of identifying the more sparsely foraminiferal uppermost strata of the Cretaceous series. In this zone comparatively few of the many species of foraminifera belonging to the formation are present in small numbers, and they are generally conspicuous in being unmineralized.[8]

The Navarro fauna as a whole is marked by a dominance of members of the family Textulariidae and of the genus *Globigerina,* as contrasted with the relative strength of the

[7]Carsey, Dorothy O., Foraminifera of the Cretaceous of central Texas: Univ. Texas Bull. 2612, pp. 1–56, pls. 1–8, March, 1926.

[8]In describing the condition of the foraminiferal tests the term "mineralized" signifies that the original shell material has been replaced by some mineral, usually crystalline calcite. In most Cretaceous clays in Texas not only the shell matter itself has been replaced, but the tests have been filled with the same mineral. The Midway tests found in the compact clays of both faunal units are almost everywhere in their original condition, but in some sandy facies replacement by calcite is common.

families Lagenidae and Rotaliidae in the Midway fauna. Navarro strata carry also numerous diagnostic representatives of the families Lagenidae and Rotaliidae in considerable numbers distributed through several genera; but these comprise a rather small percentage of the bulk of the tests present in the well-known richly foraminiferal portions of the formation. In this connection it has been interesting to observe that the major features of upper Cretaceous microfaunas in Texas are broadly applicable to some that have been described in Europe, one of the most noteworthy being that of the calcareous marls of the upper Bavarian Alps by Egger.[9]

In the average sample of the compact, blue-grey, calcareous clay from Navarro strata the family Textulariidae is represented by myriads of minute, biserial, hyaline tests, most of which are striate or costate. These the author regards as megalospheric forms of at least four different species of *Pseudotextularia* (Pl. II, figs. 1–4). This genus is better known in its much rarer microspheric form, which presents beyond the biserial stage a number of irregularly arranged chambers either in the same plane with the early chambers thus forming a fan-shaped test, or around an axis forming a conical test.[10] The special feature that marks the abundant biserial and megalospheric forms of these species of *Pseudotextularia* from true Textularians is the character of the aperture, which is a broad, highly arched, and very faintly rimmed orifice that extends over each side of the test. Specifically the forms are sharply separated by differences in shell proportions and in the character of their costations. A careful comparative study of the apertures of these megalospheric and microspheric forms and their markings reveals too close an association to be ignored. The subject has been discussed at greater length with figures in the author's thesis early in 1925, but in this paper further details are superfluous.

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[9]Egger, J. G., Foraminiferen und Ostrakoden aus den Kreidemergeln der Oberbayerischen Alpen: Abh. bay, Akad. Wiss., vol. 21, pt. 1, pp. 1–230, pls. 1–27, 1899.

[10]Some microspheric tests of *Pseudotextularia varians* Rzehak and *P. acervulinoides* Egger have recently been figured in a paper on Mendez species from Mexico: Contrib. Cushman Lab. Foram. Res., vol. 2, pt. 1, pl. 2, figs. 4 and 5, 1926.

Many of the richly foraminiferal Navarro clays carry large numbers of *Bulimina pupoides* d'Orbigny, numerous specimens of *Clavulina triquetra* Reuss,[11] the common *Gaudryina bulletta* Carsey, and *G. pupoides* d'Orbigny. The long, slender, hyaline *Bolivina plaita* Carsey is frequent in some assemblages but rarely common.

In these same highly fossiliferous clays the wealth and variety of Globigerine forms as compared with the few simple and rarer representatives of this genus in the Midway is one of the most interesting and striking features of comparative faunal studies in Texas. This genus in the Navarro is well represented by hosts of tests of *Globigerina cretacea* d'Orbigny, frequent specimens of *G. aequilateralis* H. B. Brady, and a somewhat rare and slightly hispid form that develops in maturity a smooth and flattened final chamber. More especially, however, the Globigerine group in Navarro strata is conspicuously marked by several common, large, and ornate species. One of these presents a strongly rugulose ornamentation of its globular chambers (Pl. II, fig. 10), and others are distinctly carinate or bicarinate as are the old species *G. linneana* (d'Orbigny) and *G. marginata* (Reuss) so common in Cretaceous strata of Europe. One of these carinate species, and perhaps the most common of the series in this formation, has now been named *G. rosetta* Carsey[12] (Pl. II, fig. 9). A noteworthy feature of all these ornate Navarro species of *Globigerina* is an irregularly developed thin covering or screen that partially obscures the umbilicus around which all chambers of the final whorl open. Whereas multiple apertures characterize most of the Cretaceous species of this generic group, the Midway forms possess only the simple arched orifice on the final chamber.

Members of the families Lagenidae and Rotaliidae in the richly foraminiferal Navarro clays comprise several species of *Cristellaria, Nodosaria, Vaginulina, Frondicularia, Trun-*

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[11]Reported and figured from the Navarro by Dr. Anna Martinotti: Atti Soc. Ital. Sci. Nat., vol. 64, p. 176, pl. 6, 1925.

[12]Carsey, Dorothy O., Foraminifera of the Cretaceous of Central Texas: Univ. Texas Bull. 2612, p. 44, pl. 5, fig. 3, March, 1926.

catulina, Rotalia, and *Anomalina* that are distinctive as compared with those of the Midway strata.

Though in most parts of the Navarro formation the clays yield in large numbers the highly mineralized tests of species of the family Textulariidae and the genus *Globigerina,* the upper strata of the formation, with which the field geologist is most likely to be concerned in mapping the Cretaceous-Eocene contact, are in general lean both in individuals and in species. Here the two groups so prominent in the highly fossiliferous clays are represented by very small numbers of their tests, and at some places these diagnostic Navarro forms are totally absent. Certain species that are comparatively subordinate in the richly foraminiferal clays of the formation become near the contact important as formation markers. With sufficient amounts of these higher clays lean in fresh and unmineralized tests, the systematic student of Navarro species is able to gain a more correct knowledge of the structural details of many of the forms than can be derived from the study of the material in the middle portion of the formation, where tests are completely replaced by calcite and where delicate structural features are likely to be obscured by matrix.

In the examination of samples of upper Navarro clays the residues after washing are likely to be very small, and in this material only very few foraminiferal tests may be present to give a clue to the geologic age. Amongst the few forms, which can in many samples be detected only by patient and diligent search with a microscopic power of at least ×40, there may occur a few arenaceous tests of *Gaudryina bulletta* Carsey, a sharply trilateral species of *Gaudryina* not observed in lower clays, a few specimens of *Bolivina plaita* Carsey, *Bulimina pupoides* d'Orbigny, a minute test of the genus *Virgulina,* and even the rare and very small *Buliminella* that belongs to this zone. *Textularia globulosa* is rare in these higher beds, but the tests of the megalospheric Pseudotextularians (Pl. II, figs. 1–4) so diagnostic of Cretaceous strata in this state are much more common and their rarer microspheric tests are frequently observed. It is only rarely that at least a few tests of this

great family Textulariidae are not present in the upper Navarro clays, and absolute reliance can be placed in the identification of the formation from these.

One facies frequently encountered in this contact study is Navarro clay containing practically no distinctly diagnostic species except a form here figured as *Anomalina navarroensis* n. sp. (Pl. II, fig. 6). Because a determination of the age of such material must depend wholly on this species, it becomes necessary that it be carefully distinguished from a similar Midway form, *A. ammonoides* (Reuss) var. *acuta* n. var. (Pl. X, fig. 2). Both have about the same number of smooth and strongly punctate chambers, and the tests average about the same size. The Navarro species, however, presents almost invariably a narrowly rounded periphery, whereas without exception the Midway form is marked by a very distinct but not sharp angulation. A further check in the identification, and perhaps the more reliable, is the character of the umbilical or ventral aspects of these species: the diagnostic feature of *A. navarroensis* is a series of exceedingly minute beads or prominences around the umbilicus formed by the inward termination of the slightly limbate sutures, and in addition two or three similar protuberances may occupy the shallow umbilical excavation; in the Midway species the limbations tend to combine to form a spiral, which may be rather indistinct in shape, and the central boss on its dorsal face is entire.

Of the large group of *Globigerinae* present in the Navarro formation only two or three of the especially distinctive forms are likely to be observed in the upper strata, and even these are of comparatively rare occurrence. Tests of *G. rosetta* Carsey (Pl. II, fig. 9) occur in small numbers, and another closely allied form with straight and oblique dorsal sutures is equally common. Perhaps the most frequent species of the Globigerine group in upper Navarro clays is *G. rugosa* n. sp. (Pl. II, fig. 10). This form develops a closely coiled test with five rapidly enlarging, globular chambers that are ornamented by irregularly developed rugosities or even indistinct, discontinuous, and rugulose ridges that radiate backward over each chamber from a

central point on its periphery. The umbilical features of *G. rugosa* are precisely those that mark *G. rosetta* Carsey when observed in perfect and unmineralized condition. In none of the Tertiary strata occur any species of *Globigerina* that even faintly resemble any of these ornamented Cretaceous forms, except a very rare form in the Miocene,[13] identified as *G. marginata* (Reuss).

Of the members of the families Lagenidae present in Navarro strata near the Eocene contact, *Vaginulina webbervillensis* Carsey[14] and *Frondicularia reticulata* (Reuss),[15] though of rather rare occurrence as complete tests (Pl. II, figs. 5 and 7 are frequently observed in fragmentary condition, and their specific features are so very distinctive that only very small portions are required for identification.

Because upper Navarro clays present so commonly no other foraminiferal species other than the round, flanged species of *Cristellaria* so common throughout the formation (fig. 4), a recognition of the special distinguishing features of this form becomes imperative to avoid confusion with the similar Midway species (fig. 5). In a careful comparative study of *Cristellaria midwayensis* var. *carinata* and the similar Navarro species, which for convenient reference is here named *C. navarroensis* n. sp., a large number of outcrop samples of known geologic age have been studied. These two species in fullest development display about the same number of chambers, each carries a distinct peripheral flange, and each is marked by a central boss from which radiate sutural elevations. Even in these similar features, however, slight constant differences become easily recognized. The flange of the Midway form is less likely to be entire, as it is thinner and more fragile, and from its proportionately larger central boss radiate thicker and coarser sutural elevations than those that mark the Navarro species. The most

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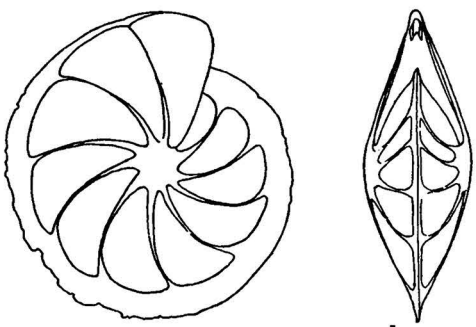
[13]Applin, E. R., Ellisor, A. E., and Kniker, H. T., Subsurface stratigraphy of the Coastal Plain of Texas and Louisiana: Bull. Am. Assoc. Pet. Geol., vol. 9, p. 98, pl. 3, fig. 7, 1925.

[14]Carsey, Dorothy O., Foraminifera of the Cretaceous of central Texas: Univ. Texas Bull. 2612, p. 39, pl. 2, fig. 7, March, 1926.

[15]Reuss, A. E., Die Foraminiferen und Entomostraceen des Kreidemergels von Lemberg: Haidinger's Naturwiss. Abh., vol. 4, p. 30, pl. 1, fig. 22, 1851.

persistent feature that separates these two similar Cristellarians is the difference in the degree of lateral compression of their tests. *C. navarroensis* is consistently so much flatter a form than *C. midwayensis* var. *carinata* that no confusion of these species is likely even from fragments of their tests. In the compact basal clays of the Midway formation the full-bodied tests of its diagnostic species are in many places so conspicuous a feature, that only an ordinary hand lens is necessary for their identification. The Navarro form is less easily observed in the field, both because mineralization of its tests has rendered them somewhat translucent and



a *b*

Fig. 4.—*Cristellaria navarroensis* n.sp., ×25, from a deep clay pit south of Corsicana (see fig. 10). *a*, Side view of the very common, closely coiled, widely flanged species of the Navarro formation, showing the fine sutural elevations radiating from a proportionately smaller central boss than that characteristic of the Midway form. *b*, Peripheral view showing the degree of lateral compression in the species.

because they are less frequent in the strata. Some of these uppermost Cretaceous clays yield only emaciate specimens of *C. navarroensis*, and these in general present fewer chambers in maximum development than does the normal healthy specimen, and its flange is likely to be much less conspicuous. Even in dealing with such pauperate tests the essential characters of the species as already discussed are sufficiently prominent to make identification certain.

Though this brief discussion has dealt very superficially with the leading diagnostic Navarro forms involved in the Cretaceous-Eocene contact studies, it is hoped that the main

differences in the two faunal assemblages have been presented with sufficient clarity to provide a working basis for identification of the two formations through microscopic examination of the strata in this stratigraphic zone. The author wishes in no way to transgress upon the field of some worker who may be occupied with a special treatise on the Navarro fauna, and consequently she has refrained so far as has been practicable from assigning new names to the species necessary to the discussion.

COMPARISON OF WILCOX AND MIDWAY FAUNAS

The only foraminiferal material from the Wilcox formation available for study by the author has come from

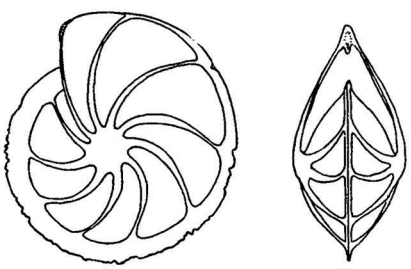


Fig. 5.—*Cristellaria midwayensis* n.sp. var. *carinata* n.var., ×25, from station 40. *a*, Side view showing the coarse sutural elevations radiating from a proportionately larger central boss than that characteristic of the Navarro form. *b*, Peripheral view showing the degree of lateral compression in this species.

Alabama and Louisiana. The fossiliferous glauconitic layers at Pendleton, Texas, on Sabine River have been carefully sampled and examined, but no trace of foraminifera has been discovered. Other marine facies of the formation from which collections have been made in Texas, notably in Bastrop County, represent shallow-water conditions that favoured accumulation of thick oyster beds but not of foraminifera.

The small faunal assemblages of the few samples collected in Alabama and Louisiana bear a close relation to the Midway fauna in being dominated by representatives of the families Lagenidae and Rotaliidae. Several species diagnostic of the Midway in Texas are present, amongst which

the most notable are *Cristellaria midwayensis* and *Siphonina prima*. The feature that especially distinguishes the Wilcox fauna is the frequency of species belonging to the family Miliolidae. Though a few species were present in large numbers during a brief interval in Comanchean times, the Wilcox period probably marks the first stage in the great progressive development of the group, which has gradually increased in species and numbers during the Tertiary epoch till in present seas they comprise a considerable portion of the recent fauna.

DESCRIPTIONS OF FIELD STATIONS

From a very large collection of outcrop samples taken from the Midway formation ninety-three have been selected between Hopkins and Bexar counties to illustrate the character of the foraminiferal fauna of the formation across this part of the state. Special care has been taken to choose several series of exposures across the Midway belt of outcrop wherever it has been possible, in order to present clearly the field data that has led to the conclusions regarding the upward faunal changes through the formation from the Cretaceous contact. An attempt has been made to describe the locations of these outcrops in such a way that with the aid of a good road map they can be readily found. Plate I presents the general distribution of the field stations along the Midway outcrop. To enable the collector to procure easily some exceptionally good and representative material in the northeast counties some detailed road maps showing these field stations have been added. The descriptions of the localities in quadrangles for which the United States Geological Survey has prepared topographic sheets should be sufficient guides to the stations here recorded.

For quick reference purposes a general statement regarding the character of the material and its foraminiferal content is added to the description of the location of each outcrop in this record.

HOPKINS COUNTY

Station 1.—Excellent exposure of dark, fossiliferous clays 2½ miles northwest of Ridgeway around the bend of a small creek that

flows northward into South Sulphur River (fig. 6). The strata in this bank are richly foraminiferal throughout the exposure and indicate by their species the true basal beds of the Midway formation.

Station 2.—Excellent exposure along small creek that flows under the bridge 2.3 miles by road north of Cumby on the road to Commerce (fig. 6). Beginning about 500 feet west of the bridge and continuing eastward as far as the strata are well exposed, a series of samples was collected from the various members of the section. The careful study of the foraminiferal groups in this series presents clearly the

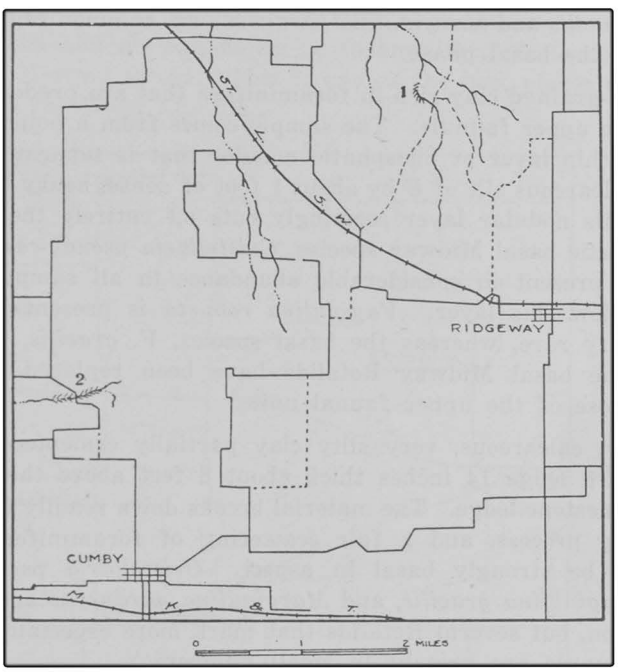


Fig. 6.—Sketch map of the area in the west edge of Hopkins County showing locations of field stations 1 and 2.

gradual transition through a thickness of about 20 feet from the true basal faunule into the upper faunule of the Midway formation. These transitional beds have nowhere else been found so well exposed as to furnish the details of this gradual upward faunal change that occurs in this formation northeast of Mexia. This zone of transition, which contains sandy clays, a thin limestone, glauconitic clays and sands, and phosphatic nodules, represents the more sudden break marked by the Tehuacana limestone in the Mexia area. The following samples were collected upward from *A* to *H* eastward along the exposure:

H.—Green, glauconitic, limy clay containing large phosphatic nodules. The washed residue consists almost wholly of glauconitic grains with a generous scattering of fresh foraminiferal tests. The species are almost wholly those of the upper Midway group, but frequent specimens of *Vaginulina gracilis* indicate that the change at this point is not quite complete.

G.—Very finely laminated, finely bedded, and somewhat silty clay so rich in foraminifera that masses of the tests are in places conspicuous along the bedding planes. This sample comes from a horizon 5½ feet above the phosphatic nodule layer. In this clay the upper Midway species are dominant, but *Vaginulina gracilis* and *Marginulina gardnerae* are common representatives of the basal phase.

F.—Fine-grained clay rich in foraminifera that are predominantly of the upper faunule. The sample comes from a point just above a thin layer of phosphatic nodules that is separated from the calcareous silt of *E* by about 1 foot of dense, heavy-bedded clay. This nodular layer seemingly cuts off entirely the very diagnostic basal Midway species, *Cristellaria pseudo-costata*, which is present in considerable abundance in all samples collected below this layer. *Vaginulina robusta* is present here but is very rare, whereas the basal species, *V. gracilis*, is frequent. The basal Midway Rotalids have been replaced entirely by those of the upper faunal unit.

E.—Grey, calcareous, very silty clay partially cemented to form a hard ledge 14 inches thick about 8 feet above the soft white limestone ledge. The material breaks down readily in the washing process, and a fair scattering of foraminifera is found to be strongly basal in aspect. *Cristellaria pseudo-costata*, *Vaginulina gracilis*, and *Marginulina gardnerae* are very common, but several Rotalids that mark more especially the upper faunule are present in small numbers.

D.—Dark, greyish-black, brittle, silty clay collected just above the 1-foot limestone ledge and about 9 feet above *C*. This gritty material contains an abundance of echinoid spines and foraminifera that are very typical of the basal Midway strata. A few emaciate specimens of upper Midway Rotalids show that the upward change from the true basal phase has begun.

C.—Grey, gritty clay just to the east of the bridge. Here the foraminiferal tests are somewhat mineralized. The species are those of the basal faunule except for *Truncatulina vulgaris*, which has been observed rarely in basal clays and may belong to that faunule as well as to the upper Midway faunule, where it is most abundant.

B.—Dark-grey, silty, very fossiliferous, and imperfectly bedded clay about 300 feet west of the bridge. The material is very rich in forms that mark these strata as strictly basal Midway.

A.—Very slightly silty, black clay with ball fracture, collected about 500 feet west of the bridge. Here is found a great abundance of forms that belong strictly to the basal Midway faunal unit.

HUNT COUNTY

Station 3.—Good exposure in deep roadside ditch on steep hill .2 of a mile east of road corner in north end of town of Commerce on highway to Paris. This grey to buff, silty clay contains many fragments of shells and an abundance of foraminiferal tests diagnostic of the basal Midway strata. This is one of the best places to study the species of the lower faunule.

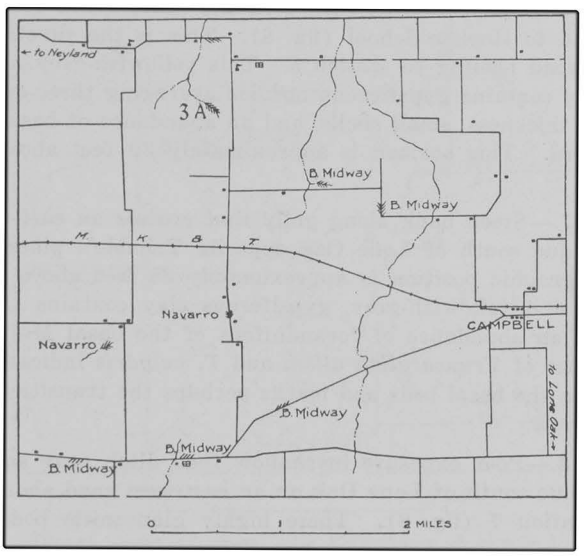


Fig. 7.—Sketch map of the Campbell area, Hunt County, showing location of field station *3A*, an outcrop of basal Midway clays, and also other exposures that yield interesting material for study.

Station 3A.—Gully in field west of north-south stretch of road about 3 miles in a straight line northwest of Campbell or 4 miles by road from that town on highway to Neyland (fig. 7). Compact, buff grey clay that reduces with difficulty in the washing process to a small residue of fine quartz particles, very few glauconitic grains, and several species of typical basal Midway foraminifera. This station has been added at a late date in the development of this paper in order to present the outcrop that furnishes excellent material for

the study of *Frondicularia rugosa* (d'Orbigny) and the rarer new species, *F. oldhami.*

Station 4.—Roadside exposure of sand and silt containing gypsiferous nodules, along the Quinlan-Greenville highway about 1.7 miles by road northeast of Quinlan depot. These beds contain poorly preserved shells and a scattering of basal Midway foraminifera.

Station 5.—Exposure of sandy clay in gully on south side of an east-west road about .7 of a mile west of its junction with the Lone Oak-Hooker School road at a point 1½ miles south of Lone Oak (fig. 8). The washed residue is largely a very fine quartz sand with a scattering of glauconite. The foraminiferal tests are rather weakly developed, and as is common in the sandy phases of the basal Midway strata *Discorbis newmanae* is the most abundant form.

RAINS COUNTY

Station 6.—Deep ditch at road fork 1½ miles south of Lone Oak on the road to Hooker School (fig. 8). This is the junction of the east-west road leading to station 5. This yellowish-grey and poorly bedded clay contains gypsiferous nodules averaging three-quarters of an inch in thickness, small shells, and an abundance of basal Midway foraminifera. This horizon is approximately 30 feet above that at station 5.

Station 7.—Steep bank along gully that crosses an east-west road 2½ miles due south of Lone Oak opposite Trimble's place (fig. 8). The stratigraphic position is approximately 25 feet above station 6. This grey and yellowish-grey, gypsiferous clay contains shell fragments and an abundance of foraminifera of the basal Midway zone. The presence of *Truncatulina alleni* and *T. vulgaris* indicates a position high in the basal beds and marks perhaps the transition into the upper faunule.

Station 8.—Poor exposure in shallow road ditch near small cabin 2½ miles due south of Lone Oak on an east-west road about ½ mile east of station 7 (fig. 8). These highly glauconitic beds lie just below a layer of phosphatic nodules. Foraminifera are abundant and belong mainly to the upper Midway faunule, but the presence of *Vaginulina gracilis* and *Marginulina gardnerae* indicate that these beds probably lie high in the zone of transition. It is interesting to observe here a few passage forms between *Vaginulina gracilis* and *V. robusta,* which shows that the upper Midway species has developed from the lower.

VAN ZANDT COUNTY

Station 9.—Roadside ditch on south side of creek valley 5 miles by road south of Wills Point on way to Scott. This well-laminated, yellowish-blue clay with partings of white, sandy silt yields only

some arenaceous forms that are in many parts of the higher strata of the upper Midway unit the only traces of foraminiferal life.

KAUFMAN COUNTY

Station 10.—Newly dug, 25-foot water well at side of road about .7 of a mile east of Cedarvale. The clay from the excavation is bluish-grey, thinly laminated, and silty. Only arenaceous forms are present in this material, a faunal character common to the middle and higher strata of the upper Midway unit.

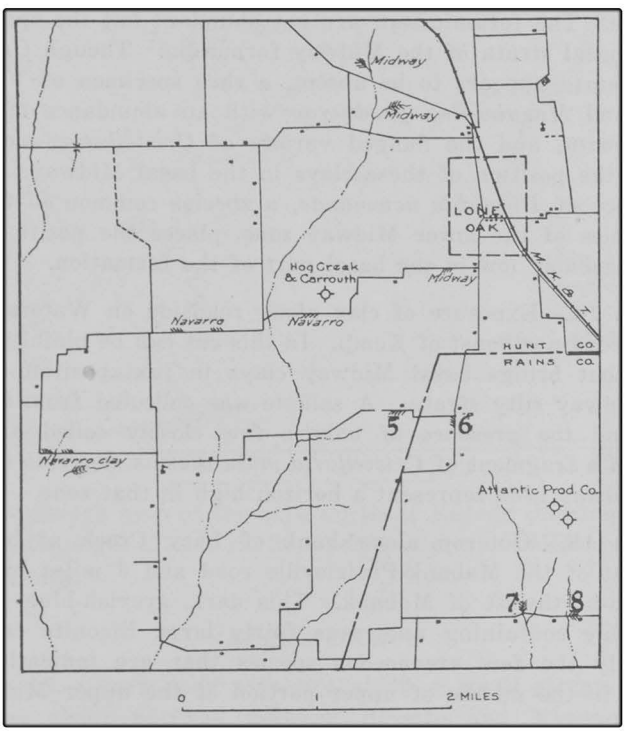


Fig. 8.—Sketch map of the Lone Oak area showing locations of field stations 5, 6, 7, and 8 and other exposures that yield interesting material for study.

Station 11.—Roadside ditch along short east-west stretch of the Kaufman-Prairieville road between Walnut and Jones creeks about 6 miles by road northwest of Prairieville and 1 mile west of a corner on which are a school, church, and cemetery. This light-grey, massive, clay contains thin seams of silt, shell fragments, and several species of foraminifera diagnostic of the upper part of the Midway formation.

Station 12.—Good exposure of silty clay along small branch about .7 of a mile east and .5 of a mile north of Prairieville just west of the north-south country road. The clay breaks with a subconchoidal fracture but contains a large proportion of silt and some fossils. For so silty a clay and a position so high in the formation the abundance of foraminifera is unusual.

Station 13.—Roadside exposure along a short east-west road 4½ miles by road northeast of Kemp on way to Kaufman. These compact clays carry a very small proportion of angular quartz sand and glauconite. The foraminifera are not abundant but the species indicate the basal strata of the Midway formation. Though *Cristellaria pseudo-costata* appears to be absent, a rare specimen of *Vaginulina gracilis* and *Marginulina gardnerae* with an abundance of *Truncatulina elevata*, and the flanged variety of *Cristellaria midwayensis* establish the position of these clays in the basal Midway. Further, the absence of *Discorbis newmanae*, a species common in the upper sandy facies of the lower Midway zone, places the position of this outcrop probably low in the basal part of the formation.

Station 14.—Exposure of clay along roadside on Waters Hill 3¾ miles by road northeast of Kemp. In this cut can be plainly observed a fault that brings basal Midway clays in juxtaposition with the upper Midway silty strata. A sample was collected from the upper strata, and the presence of only a few closely coiled arenaceous forms and a fragment of *Cristellaria midwayensis* suggests that these upper Midway beds represent a horizon high in that zone.

Station 15.—Outcrop along bank of Lacy Creek at bridge 1.3 miles west of the Mabank-Prairieville road and 3 miles in a direct line north-northwest of Mabank. This dark, greyish-blue, soft, conchoidal clay containing numerous fairly large limonite concretions yields only the few arenaceous species that are indicative of an elevation in the middle of upper portion of the upper Midway.

HENDERSON COUNTY

Station 16.—Excellent exposure in a 35-foot bank at Burton's Bluff on Trinity River at the end of a trail through the woods 1.3 miles north of Trinity Valley Store on the Kerens-Athens road about 1 mile east of the river (fig. 9). This very dark-blue to almost black, silty clay contains numerous large concretions, thin seams of selenite, and small gypsiferous nodules. Samples were collected from four horizons in this bluff and all show very few foraminifera, but the species are diagnostic of the upper Midway zone. This is the only outcrop that has yielded *Cornuspira carinata* (Costa).

Station 17.—Exposure beneath the road bridge across Trinity River on the Kerens-Athens road (fig. 9). This dark-gray to black,

hard, silty clay contains numerous poorly preserved and fragmentary shells and many hard, ferruginous concretions. The few, well-developed, and very fresh foraminiferal tests are those of the upper Midway zone.

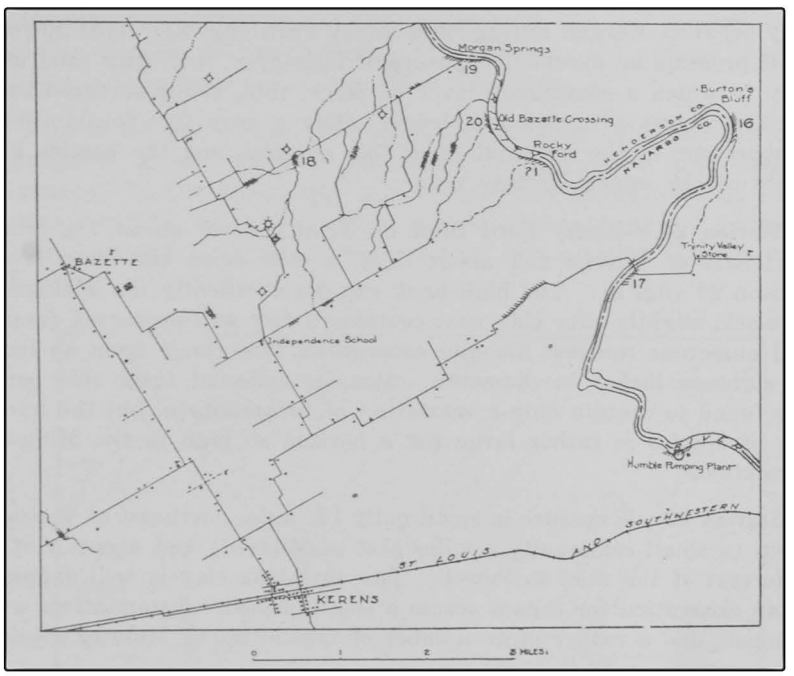


Fig. 9.—Sketch map of the area north of Kerens showing locations of field stations 16, 17, 18, 19, 20, and 21 and other Midway outcrops in the vicinity.

NAVARRO COUNTY

Station 18.—Very good exposure along a small stream north of the bridge about halfway between Bazette and Morgan Springs (fig. 9). The beds of fine-grained, dark grey-blue clay contain some shell fragments and numerous hard, ferruginous concretions that range from five to eight inches in diameter. Foraminifera are few and mostly arenaceous, but the assemblage is distinctive of a position high in the upper Midway zone.

Station 19.—Bank along Trinity River at Morgan Springs 5 miles northeast of Bazette (fig. 9). The exposure is about 800 feet long, and from 10 to 20 feet of clay outcrop beneath the terrace gravel and alluvium. The black, fissile, silty, fossiliferous clay contains many elongate limonitic concretions that measure from two to seven feet

in length and about four inches thick. Foraminifera are scarce, but the species are distinctly those of the strata high in the upper Midway unit.

Station 20.—Old Bazette Crossing on Trinity River about halfway between Morgan Springs and Rocky Ford (fig. 9). This 20-foot bluff presents an excellent exposure of light-grey, fine, silty sand and clay in which a continuous layer of large, thin, rough-surfaced concretions forms a conspicuous ledge. Only a very few foraminifera are present in the material from this outcrop, and the species are those of the upper Midway zone.

Station 21.—Rocky Ford Bluff on Trinity River about 7½ miles northeast of Kerens and about .7 of a mile down the river from station 20 (fig. 9). The high bank exposes excellently the dark-grey to black, slightly silty clay that contains a few well-preserved fossils and numerous rounded limonite concretions that range from an inch to eighteen inches in diameter. Samples collected from this bank are found to contain only a scattering of foraminifera, but the number of species is rather large for a horizon so high in the Midway formation.

Station 22.—Exposure in small gully 1¾ miles northeast of Tuckertown (a small community 2 miles east of Mildred) and about .3 of a mile east of the road to Powell. The dark-blue clay is well exposed in an excavation for a dam across a small branch. Foraminifera are common, and a rather large number of typical upper Midway species are present.

Station 23.—Shallow ditch at road corner southeast of new Corsicana reservoir on the road to Mildred (fig. 10). The dark-blue to nearly black, siltless clay that breaks with ball fracture and contains small limonite concretions, numerous small gastropods, otoliths, and a great abundance of foraminifera. This very abundance of upper Midway species indicates a position in the lower part of the upper unit. The wealth of specimens and species in the clays of this outcrop far exceeds all other material in the collection studied, and this has been chosen as the type locality for a number of new forms.

Station 24.—Road cut near top of hill on Corsicana-Navarro road just south of the junction with the Mildred road (fig. 10). In this light-grey to blue-grey, laminated clay with a few blotches of silt are numerous foraminiferal species typical of the upper Midway strata. This locality is stratigraphically about 20 feet above station 23.

Station 25.—Exposure in north side of small creek just east of the Corsicana-Angus road about 2 miles southeast of the Magnolia Refinery. Closely coiled arenaceous forms are numerous, but a fragment of *Cristellaria midwayensis* leads to a determination of Midway age.

Station 26.—Branch of small southward-flowing creek 1 mile due west of Angus on a poor country road that turns southwestward from the road that parallels the H. & T. C. track on the west. These blue-grey clays carrying both calcareous and ferruginous concretions break with subconchoidal fracture and show little silt. A rather large number of upper Midway species of foraminifera are present in these beds, but their tests are by no means abundant.

Station 27.—Exposure for some distance along bank of creek one-quarter of a mile south of the school and 1¼ miles due south of Navarro. The dark-blue clay is massively bedded and contains small, round limonite concretions from six to eight inches in diameter. Foraminifera are common in this outcrop, and a rather large number of species is represented.

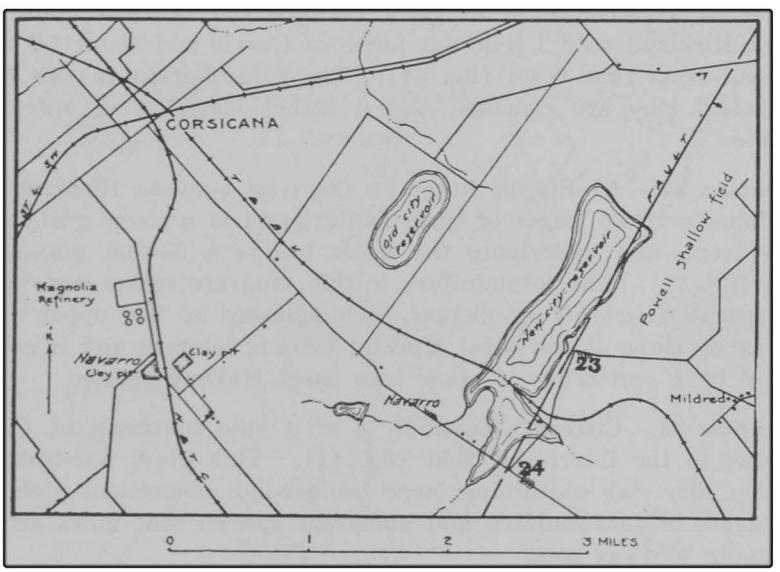


Fig. 10.—Sketch map of the area southeast of Corsicana showing location of field stations 23 and 24.

Station 28.—Road ditch exposure about 1¼ miles west-southwest of Richland in a straight line and reached by traveling 1 mile on the southwest road from that town and turning ½ mile northwest to the point where the road to Pisgah Ridge and Wortham branches off to the southwest. The exposure lies at this road junction. This fossiliferous, bluish-grey, almost siltless clay contains numerous very fresh tests of the upper Midway faunule.

Station 29.—Exposure in side of steep west-facing hill on Richland-Streetman road 1½ miles southeast of Richland where roads branch off both northeast and southwest with a short offset. This blue-grey,

fine-grained, conchoidal, concretionary clay is cut by numerous joint lines that are impregnated with limonite. The samples wash down to a very small residue of tiny ferruginous particles, shell fragments, and an abundance of typical upper Midway foraminifera. The occurrence in these beds of the high-spired *Discorbis infrequens* is interesting in proving the presence of the Discorbine type in the formation.

Station 30.—Ditch along Richland-Streetman road about 2 miles west of Streetman and about a quarter of a mile beyond the point where the road swings from due westward toward the northwest (fig. 11). This grey, almost siltless clay contains very few foraminifera, which are for the most part the closely coiled arenaceous forms, an assemblage of species that marks strata about midway in the upper zone of the formation.

Station 31.—Exposure in gully between the railroad track and Currie-Richland road 1 mile due north of Currie and about 1.2 miles by road from that town (fig. 11). The foraminifera in this grey, conchoidal clay are common, and a rather long list of species is reported.

Station 32.—At Pisgah Ridge on the road between Richland and Wortham are two ledges of limestone exposed in a steep west-facing escarpment, and underlying the lower bed is a 20-foot glauconitic sand (fig. 11). The foraminifera in this sand are rather scarce, but the species *Discorbis newmanae*, so diagnostic of the upper sands and sandy clays of the basal Midway zone, is common and is accompanied by a scattering of other true basal Midway species.

Station 33.—Cistern excavation .8 of a mile southeast of Currie on road to the Currie oil field (fig. 11). This grey, fine-textured, slightly silty clay containing large boulder-like concretions yields an abundance of foraminifera and numerous species that mark strictly the upper Midway zone.

Station 34.—Excellent exposure at the junction of an east-west road and a small northward-flowing creek 2 miles west and slightly north of Wortham (fig. 11). The well-laminated, dark greyish-blue, dense clay containing thin seams of silt yields very few species of foraminifera, but the presence of the upper Midway Rotalids marks definitely the age of the strata.

FREESTONE COUNTY

Station 35.—Exposure along north slope of hill 2 miles east of Wortham on the northeastward-trending road to Streetman (fig. 11). The fine-grained, light-grey, silty, fossiliferous, concretionary clay was sampled at two places, and the combined results are entered in

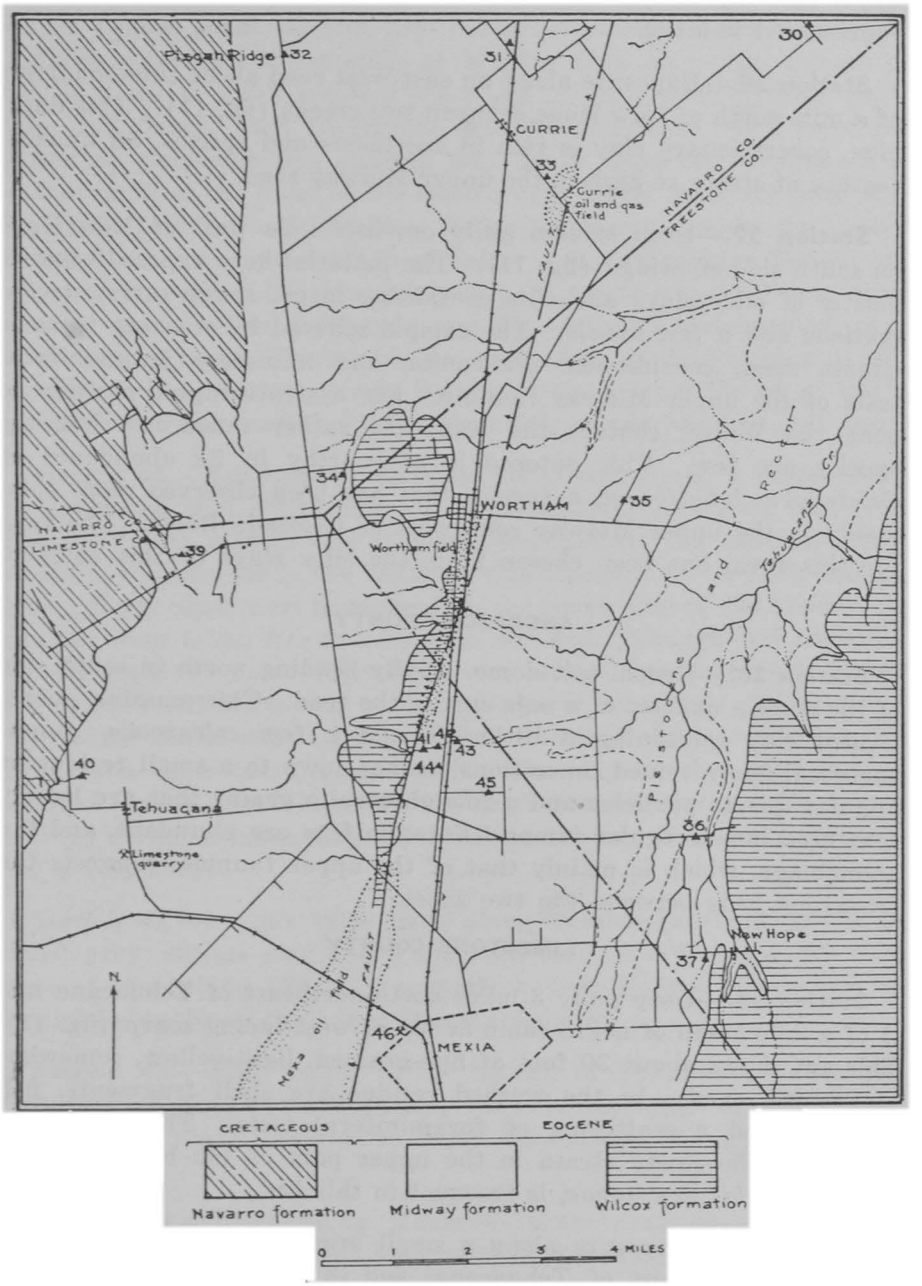


Fig. 11.—Sketch map of the Mexia-Currie area showing location of Midway outcrops from which samples have been collected and studied for their foraminiferal content.

the table showing the distribution of species. Foraminifera of the upper Midway faunal unit are abundant, and the number of species represented is large.

Station 36.—Exposure along an east-west road about three-quarters of a mile north of New Hope between two creeks (fig. 11). This dark-blue, concretionary clay is rich in specimens and species, an unusual feature of strata so high in the upper Midway zone.

Station 37.—Deep stream gully one-half mile west of New Hope on south side of bridge (fig. 11). The material here exposed consists mostly of silty clays and silts containing large, rough-surfaced concretions and a few fossils. The sample reduced by washing to some quartz sand, considerable glauconite, and numerous foraminiferal tests of the upper Midway faunule. For a stratigraphic position so near the Wilcox contact the tests are rather numerous, but the species are few. This outcrop is noteworthy in its abundance of *Cristellaria longiforma*, a species that has been observed more commonly in the upper Midway southwest of Colorado River. The type for this form has been chosen from the silty clays of this outcrop.

ANDERSON COUNTY

Station 38.—Keechi salt dome. Gully heading north in south side of the dome a quarter of a mile east of the road. This massive, poorly bedded clay containing a little silt and a few calcareous, rough-surfaced, finely veined concretions washes down to a small residue of angular quartz particles and a few glauconite grains that are loosely cemented into irregular lumps. Foraminifera are abundant, and the assemblage, which is mainly that of the upper faunule, suggests the transition beds between the two zones.

LIMESTONE COUNTY

Station 39.—Deep gully 3 miles north-northeast of Tehuacana and 1 of a mile north of negro cabin at top of west-facing scarp (fig. 11). This cut shows about 30 feet of fine-grained, light-yellow, somewhat glauconitic sand. In the washed residue are shell fragments, fish remains, and a scattering of foraminiferal tests. The significant species of the sandy strata in the upper part of the basal Midway zone, *Discorbis newmanae*, is frequent in this bed.

Station 40.—Exposure along a small branch about three-quarters of a mile northwest of Tehuacana, and .2 of a mile north of the Tehuacana-Waco road on the first road turning north (fig. 11). The freshest clay exposed along this cut is yellowish-grey, and it weathers to a deeper yellow color above. It is fine textured and contains a few gypsum nodules and seams of white powdery gypsum. Shell fragments are frequent, and the foraminifera are so large and abundant

as to be visible to the naked eye. The contact with the Navarro lies down the creek about 300 feet west of the road and is marked by a thin bed of yellow sand. Below this horizon the clays present typical Cretaceous forms. All samples of Midway clay along this exposure washed down to small residues composed of very small gypsum particles and flakes, shell fragments, and foraminifera. The material chosen to represent this outcrop was taken from the bottom of a 15-foot bank at the head of the branch east of the road, for here the clay is the freshest and furnishes the best-preserved specimens of the foraminifera. The assemblage of forms is typically basal Midway in aspect, rich in *Cristellaria midwayensis, C. pseudo-costata, Vaginulina gracilis, Marginulina gardnerae,* and *Truncatulina midwayensis* var. *trochoidea.* Though *Cristellaria pseudo-costata* exhibits a weak development of the costations across the chambers, it is on the whole quite typical. The Pulvinuline species diagnostic of the basal zone is rare.

Station 41.—Exposure of clays in Tehuacana Creek 4 miles north of Mexia and .2 of a mile west of the Mexia-Wortham road (fig. 11). The fault that carries the Wilcox down against the basal Midway strata is conspicuous in the banks of this stream cut. A dark bluish-green, sandy shell marl is exposed on the north side of the creek, and samples were taken five feet apart in the bed. Though this bed presents mainly the basal Midway species, a few upper Midway forms are present and prove that a narrow zone of transition divides these two faunal units, and is evidence that this shell marl represents the Tehuacana limestone farther south. The clay at the next station, collected but a few feet above the marl bed, carries strictly upper Midway forms, consequently the break at the top of this fossiliferous bed is very sharp.

Station 42.—In this same bank along Tehuacana Creek the dark bluish-grey. siltless clay above the shell marl at a location 300 feet west of the bridge (fig. 11) presents a very typical assemblage of species indicative of the upper Midway faunule.

Station 43.—Still higher in the section of Tehuacana Creek 200 feet east of the Mexia-Wortham road bridge (fig. 11) the dark, fossiliferous clays present a large assemblage of upper Midway species.

Station 44.—Ditch along Mexia-Wortham road about 3½ miles north of Mexia and one-half mile south of Tehuacana Creek (fig. 11). This grey, fossiliferous, slightly silty clay carries a large number of foraminiferal species that mark the lower part of the upper Midway faunal unit.

Station 45.—Roadside exposure on steep north-facing hill one-half mile east of the Mexia-Wortham road and about one-half mile south

of Tehuacana Creek (fig. 11). This compact, dark-grey, fine-grained, slightly silty clay carries a generous scattering of fresh foraminiferal tests representing numerous upper Midway species.

Station 46.—Clay pit, Mexia Brick Works, about 1 mile west of the town of Mexia (fig. 11). The pit is about 25 feet deep and 300 feet in diameter, and the bottom of the excavation furnishes very fresh, dark-blue, siltless clay that breaks with subconchoidal fracture and contains poorly preserved shell fragments. The material washes down easily to a small residue containing ferruginous flakes and an abundance of excellently preserved foraminifera that belong strictly to the upper Midway faunule and indicate a low position in this zone above the Tehuacana limestone horizon. A few samples taken in this pit show secondary Cretaceous specimens that are conspicuous by the complete mineralization of their tests. Of all the many Midway samples collected and studied, this is the only material that has furnished several specimens of *Ellipsopleurostomella attenuata*, and it has accordingly been chosen as the type locality for the species. Station 23 has yielded one specimen of this form, and material received just as this paper is about to go to press proves its existence during the deposition of the glauconitic clay in the transition zone of northeast Texas.

Station 47.—Exposure in deep ditch along Mexia-Reunion Grounds road 1.8 miles southwest of Mexia on east edge of the oil field. The beds are of medium-grained, uniformly yellow, glauconitic sand containing shells and large spherical concretions that range from six inches to three feet in diameter. The upper layers are in places cemented into a calcareous sand rock that forms the dip slope along the east side of the field. The loose sand carries very few foraminifera, but the common occurrence of *Discorbis newmanae* indicates a position high in the basal Midway zone.

Station 48.—Roadside exposure at top of hill on Mexia-Reunion Grounds road 2½ miles southwest of Mexia. This reddish-yellow or buff, sandy clay containing small ferruginous bullet-like concretions carry few foraminifera, but they are very distinctive of the upper Midway zone and probably of a position very high in the formation. The relative geographic positions of stations 47 and 48 indicate that the Mexia fault lies between them.

Station 49.—Road ditch 1½ miles northeast of Shiloah and 6 miles south of Mexia along the almost east-west road that branches from the Mexia-Shiloah highway that parallels the H. & T. C. track. This light grey, fine-grained, very silty clay containing yellow seams of ferruginous matter carries few foraminifera, but the species are significant of the upper strata and probably of a position about midway in this zone.

Station 50.—Clay pit at Groesbeck brick yard .4 of a mile northeast of the station near the H. & T. C. track. The dense, dark-grey, siltless clay in the bottom of the pit carries rather few foraminifera, but the character of the assemblage is distinctly that of the upper faunal unit.

Station 51.—At Honest Ridge School, 6 miles west of Groesbeck, is an outcrop consisting of two ledges of limestone underlain by about 25 feet of glauconitic sand, and below this sand is a sandy clay. A sample of this clay shows a generous scattering of somewhat leached foraminiferal tests of the common basal Midway species. *Discorbis newmanae*, so diagnostic of the upper sandy strata of the basal Midway zone is in this clay a rare form. It seems quite likely that the overlying sand may contain it in greater abundance, but unfortunately no higher sample was taken for this study.

MILAM COUNTY

Station 52.—Excellent exposure in west bank of Brazos River almost on the Falls County line .7 of a mile southwest of the small town of Eloise on the I. & G. N. Two low gentle folds in the bank expose the Navarro clay in the base of the bank and overlying Midway separated by less than a foot of yellowish-grey, fine-grained, cross-bedded sand. The clay between the unconformity and the terrrace material carries an abundance of the true basal Midway species.

Station 53.—Exposure along small branch 2 miles west-northwest from Baileyville is reached from that town by driving northwest 1½ miles and turning southwest for about 1¼ miles. The gully lies south of the road about .2 of a mile. The clay carries the typical basal Midway forms in abundance.

Station 54.—Bluff on west side of Brazos River about 4½ miles south of Eloise at a point where the river cuts so close to the I. & G. N. track on the east bank that jetties have been built out into the river to protect the right-of-way. The southwest bank shows a good 30-foot exposure about an eighth of a mile long. These dark-grey, fossiliferous, sandy clays carry very few foraminifera, but the species, *Cristellaria longiforma*, indicates a position in the upper zone of the formation.

Station 55.—Gully 1.3 miles northeast of Clarkson and 1,000 feet east of a negro school. The sample of this clay reduced in washing to a very small residue rich in leached and chalky specimens of foraminifera but poor in species. The forms indicate strongly the true basal strata of the Midway formation.

Station 56.—Small creek exposure just east of the Cameron-Tracy road about 1¾ miles southwest of the G. C. & S. F. station in Cameron. These clays yield an abundance of upper Midway foraminifera.

Station 57.—Along a small creek about a quarter of a mile north of a school on the north side of the Tracy-Cameron highway and about 1½ miles from Tracy by road. The outcropping clays here yield an abundance of upper Midway species of foraminifera. Rare specimens of a minute Uvigerine species occur in this assemblage, but the form is not described in this paper.

WILLIAMSON COUNTY

Station 58.—Tank near road corner at end of the northeast-trending road from Coupland and about 4 miles from that town (Bastrop quadrangle). This stiff, yellow, oxidized clay containing some sand carries numerous foraminiferal tests diagnostic of basal Midway strata. The abundance of *Discorbis newmanae* suggests a position rather high in this zone.

Station 59.—Excellent exposure in bank of small north branch of Dry Brushy Creek about 1 mile south-southeast of the tank at station 58 and about 300 feet west of the southeastward-bearing road (Bastrop quadrangle). This compact, blue-grey, siltless clay containing numerous thin-shelled pelecypods carries a fair scattering of foraminifera of the basal Midway faunule. A few rare specimens of the upper species indicate probably a transition zone at this location.

Station 60.—Very good exposure in road ditch just south of Dry Brushy Creek on the southeast-northwest road that bears stations 58 and 59, and about 4 miles due east of Coupland (Bastrop quadrangle). This compact, blue-grey, siltless clay carries few foraminifera, but the species are distinctive of the upper Midway faunul unit.

TRAVIS COUNTY

Station 61.—Road cut on south side of Wilbarger Creek about 2 miles southwest of Littig (Bastrop quadrangle, about where the 500-foot contour cuts the road). Along this exposure a fault trends diagonally across the ditch and both Navarro and Midway strata outcrop. The soft, yellowish, oxidized clay extending to the top of the slope yields a true basal Midway assemblage of species.

BASTROP COUNTY

Station 62.—Gully in west side of small branch of Wilbarger Creek close to the county line about 1¼ miles south-southeast of Littig (Bastrop quadrangle). The fine, yellow, silty, gypsiferous sand containing a few specimens of *Venericardia bulla* yields a generous scattering of basal Midway forms.

Station 63.—Ditch along Elgin-Austin road 1.4 miles northeast of Littig close to the county line (Bastrop quadrangle). The yellow, sandy, gypsiferous clay contains fragments of shells and carries an assemblage of typical basal Midway foraminifera. The species *Discorbis newmanae* is abundant, and the type has been chosen from this locality.

Station 64.—Gully close to the short northwest-southeast road about 2½ miles S. 25° E. of Littig (Bastrop quadrangle). This compact, siltless, dark-blue clay contains a layer rich in shell fragments and *Venericardia bulla* Dall. The foraminiferal assemblage of the clay above this fossiliferous layer is large and varied and belongs strictly to the upper Midway faunal unit. In the assemblage at this locality occurs *Allomorphina globulosa.*

Station 65.—About 5¼ miles due south and very slightly west of Littig where the 440-foot contour cuts a northeast-southwest road (Bastrop quadrangle) outcrops a glauconitic sand containing corals and *Venericardia bulla* Dall. The washed residue of this material yields a few species of Midway foraminifera that are not sufficiently distinctive to mark absolutely the position in the formation. As species from the clays at station 66 in the bottom of this same creek just to the north are more indicative of the basal Midway faunule, this glauconitic bed must therefore be regarded as closely associated with that zone. The evidence afforded by the examination of clays just above the *Venericardia bulla* layer at station 64 leads to the conclusion that this fossiliferous horizon divides the basal faunal unit from the upper faunal unit. It must therefore be concluded that this shell bed correlates with the Tehuacana limestone of the Mexia area, with the shell marl in Tehuacana Creek four miles north of Mexia (station 41), and with the transition zone in Hunt and Hopkins counties.

Station 66.—In the bottom of the creek about 15 feet below the glauconitic bed of station 65 and about a hundred yards farther north is a shell bed in a matrix of brown, fossiliferous, stiff clay. Midway foraminifera are present, but the species represented are few, and their general character point to deposition in the early Midway sea.

Station 67.—Excellent exposure in base of high bluff on west side of Colorado River between the Travis-Bastrop county line and the mouth of Dry Creek (Bastrop quadrangle). This dark-green to black, highly fossiliferous, clay marl below a thick covering of terrace and alluvium extends for about 150 feet along the river at moderately high water level. At the time the collection was made, only the upper five feet of the outcrop were exposed, and the samples studied have been restricted to this portion. The clay collected from the upper part of this exposure required long soaking in strong solution of sodium

carbonate and some rubbing in the washing process to eliminate the argillaceous content. The final clean residue presents an abundance of foraminiferal tests, shell fragments, and otoliths. The species of foraminifera are mostly those of the upper Midway faunule, though *Truncatulina elevata* is abundant, and specimens of *Marginulina gardnerae* occur rarely. The special interest at this locality is the presence of *Asterigerina primaria*, which is, so far as available literature indicates, the earliest geologic occurrence of this genus, at least in this country. This outcrop lies within the transition zone between the true basal beds and the true upper beds of the formation.

Station 68.—Roadside cut along the Bastrop-Austin highway about 1½ miles southeast of Elysium (a small settlement shown on the topographic sheet but not known to settlers in the district) and .3 of a mile by road southeast of a small store at the junction of the highway and a secondary northwest-bearing road (almost on the edge of the Austin quadrangle). Here very white, bleached Midway shells lie over the surface of the ground along the side of the road. The clay taken from the bottom of the ditch washes down to a mass of shell fragments, some glauconitic grains, and a little quartz sand. A fair scattering of somewhat mineralized foraminifera that belong to the upper Midway faunule characterize these clays. This location is just south of the creek along which the type specimens of *Venericardia bulla* Dall were collected.

Station 69.—Exposure in north bank of Cedar Creek 200 feet west of the bridge .4 of a mile southeast of the corner formerly occupied by Williams Store (Austin quadrangle). Compact, very fossiliferous clay at the base of the bank. Typical upper Midway foraminifera are abundant but are somewhat emaciate.

CALDWELL COUNTY

Station 70.—About 5 miles southwest of Lytton Springs from 5 to 20 feet above the basal greensand of the Midway formation. The compact and somewhat yellowish clay washes down to a small residue of loosely cemented siliceous particles, a scattering of echinoid spines, fish remains, and foraminifera that belong strictly to the basal faunule.

Station 71.—Very deep road ditch .7 of a mile northwest of Highpoint School (San Marcos quadrangle). This greyish-drab, compact, gypsiferous, and fossiliferous clay carries large numbers of basal Midway foraminifera. Farther northwest along this same road the Cretaceous-Eocene contact is marked by a yellow silty sand that can be seen in the furrows between the rows of cotton in the adjacent fields.

Station 72.—About .3 of a mile east of Highpoint School just southeast of the road corner (San Marcos quadrangle). This yellow, silty, badly oxidized clay carries an abundance of basal Midway foraminifera.

GUADALUPE COUNTY

Station 73.—About one-third of a mile southeast of Wade School (San Marcos quadrangle). This slightly buff, tough clay reduces by a special washing process[16] to a richly foraminiferal residue composed of upper Midway species is the result of this method.

Station 74.—Valley 1 mile southwest of Wade School east of road corner (San Marcos quadrangle). This resistant clay was broken down by the repeated-crystallization process and the small residue carried numerous foraminiferal species of the upper Midway zone.

Station 75.—Bottom of a 20-foot cistern 3 miles E. 20° N. of Geronimo (San Marcos quadrangle) at road corner just north of bench mark 616. This somewhat glauconitic clay carries only a few foraminifera, but the species are distinctive of the upper faunule of the Midway.

Station 76.—Bluff along east side of Cibolo Creek about half a mile south of Zeuhl (Floresville quadrangle, Military Sheet 467-S-II & IV). This shell marl with an abundance of small gastropods, pelecypods, *Dentalium* sp., otoliths, and ostracods carries also a fair scattering of foraminifera and a rather large number of species that are diagnostic strictly of the upper faunal zone.

Station 77.—About one-eighth of a mile south of station 76 in the same bluff, the highly iron-stained clay contains but a few specimens of *Ammodiscus incertus.*

Station 78.—About one-quarter of a mile south of station 76 in the same bluff only a faint trace of foraminifera occurs in the clays.

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[16]Some clays do not disintegrate completely by boiling in a concentrated solution of sodium carbonate (sal soda), so that decantation will rid the desired residue of all argillaceous matter. The material is then placed in a shallow pan, covered with a concentrated solution of sal soda, and placed in a hot oven where it remains till evaporation has been complete. The crystallization of the salt within the clay exerts enough force to loosen some of the argillaceous material which can then be poured off by decantation. The process is then repeated as many times as is necessary to clean the residue, which finally presents many contained foraminiferal tests in good condition.

BEXAR COUNTY

Station 79.—Road cut close to an acute angle in the road 2 miles southwest of Zuehl (Floresville quadrangle,[17] Military Sheet, 467-S-II & IV). An abundance of foraminifera characterize these clays, and they place these strata definitely in the upper part of the Midway formation.

Station 80.—In bank of Salitrillo Creek about 1 mile from its junction with Martinez Creek (Floresville quadrangle, Military Sheet 467-S-II & IV). A great abundance of the upper Midway forms characterize the clays of this outcrop.

Station 81.—Tank between Escondido and Salitrillo creeks about 1½ miles west of station 80 and east of the northeast-southwest road (Floresville quadrangle, Military Sheet 467-S-II & IV). An abundance of rather unusually thin-shelled and emaciate foraminiferal tests of the upper Midway faunule mark this outcrop.

Station 82.—Road cut close to Escondido Creek about 1½ miles from its confluence with Martinez Creek (Floresville quadrangle, Military Sheet 467-S-II & IV). This clay carries a generous scattering of upper Midway foraminifera.

Station 83.—Tank close to a short, almost east-west stretch of road 3 miles N. 60° E. of the town of Martinez (Floresville quadrangle, Military Sheet 467-S-II & IV). The highly iron-stained residue of tiny flakes carries few foraminifera, but they are sufficient to mark the position of the outcrop in the upper Midway zone.

Station 84.—Tank one-half mile north of Martinez close to the north-south road (Floresville quadrangle, Military Sheet 467-S-II & IV). Only a meagre scattering of foraminifera is present in these clays, but the number of species represented is large.

Station 85.—Alamo Brick Company clay pit southeast of San Antonio (San Antonio topographic sheet) on north side of the road leading southeast from the city and about one-quarter of a mile from the area broken up into city blocks; just beyond the brick yard the road forks, one branch leading to Gonzales, the other to Sutherland Springs. The compact clay from the bottom of this excellent exposure washes down to a small residue that carries charas, otoliths, small gastropods, and a large number of foraminifera of the upper Midway faunal unit. *Allomorphina trigona* is especially abundant in the clays of this outcrop, and *Chilostomelloides eocenica* is a rare form.

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[17]Military maps of areas in Texas can be purchased from the Engineer, Eighth Corps Area, Fort Sam Houston, Texas.

DESCRIPTION OF MIDWAY FORAMINIFERA

GENERAL STATEMENT

A complete treatment of the forms that comprise the Midway foraminiferal fauna would include perhaps about one hundred fifty species and varieties. As this paper is not intended to be an exhaustive treatise of the group, a large number of rare, and even several frequently occurring, forms have been omitted. The plan of treatment has rested on two purposes: first, to present such of those abundant and common species of the fauna as are of practical value in identifying the formation as a unit and members within the formation; and second, to present as fully as possible the distribution of forms in the classification and thus reveal the true character of the fauna as a whole. Synonymies, though by no means complete, present references to some of the figured forms that follow closely the types.

Family ASTRORHIZIDAE

Genus AMMODISCUS Reuss, 1861

AMMODISCUS INCERTUS (d'Orbigny)

Pl. XIII, figs. 1a–d

(Plesiotypes—Walker Museum Coll. 33001, Sta. 33)

Operculina incertus d'Orbigny, 1839, Foram. Cuba, p. 71, pl. 6, figs. 16, 17.

Spirillina arenacea Williamson, 1858, Rec. Foram. Gr. Brit., p. 93, pl. 7, fig. 203.

Trochammina incerta H. B. Brady, 1876, Carb. Perm. Foram., Palaeont. Soc., p. 71, pl. 2, figs. 10–14.

Ammodiscus incertus H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 330, pl. 38, figs. 1–3.

Ammodiscus incertus Sherborn and Chapman, 1889, Jour. Roy. Mic. Soc., p. 484, pl. 11, fig. 7.

Ammodiscus incertus Chapman, 1892, Jour. Roy. Mic. Soc., p. 326, pl. 6, fig. 11.

Ammodiscus incertus Burrows and Holland, 1897, Proc. Geol. Assoc., vol. 15, p. 31.

Ammodiscus incertus Flint, 1899, Rpt. U. S. Nat. Mus. for 1897, p. 278, pl. 23, fig. 2.
Ammodiscus tenuis Flint, 1899, *Ibid.*, p. 279, pl. 23, fig. 1.
Ammodiscus incertus Cushman, 1910, U. S. Nat. Mus. Bull. 71, pt. 1, p. 73, figs. 95, 96 (text).
Ammodiscus incertus Cushman, 1921, U. S. Nat. Mus. Bull. 100, vol. 4, p. 62, pl. 5, figs. 1, 2.

Test consists of a simple, very white, finely arenaceous tube coiled in plano-spiral manner. As the tube gradually increases in size the test becomes slightly concave bilaterally.

Diameter up to .6 mm.

The typical round discoidal test as it was originally formed is rare in the Midway material. It appears most commonly compressed peripherally on two sides making the outline elliptical, and many specimens are badly distorted in other ways. However, this much-described species can hardly be mistaken, in spite of its condition as a fossil. All specimens of *Ammodiscus incertus* so far found in Midway clays have been microspheric.

In the upper faunal unit of the Midway formation the microspheric tests of this species are common, and the persistence of the form upward through the silty clays almost to the Wilcox contact gives the species a very definite value in stratigraphic work. Many outcrops of the upper Midway silty strata yield no other fossils, yet the age of the material is rendered certain by the presence of the microspheric form of *A. incertus*. The species, however, occurs in Taylor and Navarro strata both in its megalospheric and microspheric form. The Cretaceous tests average much smaller, and they occur always with numerous other species diagnostic of these strata. It has been found, therefore, that it is reliable to assign upper Midway age to clays that carry only *A. incertus* or that carry this form accompanied by *Textularia eocaena* (Gümbel) and *Haplophragmoides canariensis* (d'Orbigny).

Geologically *A. incertus* has a long range. It has been described from the Carboniferous formations in many parts of the world, and in the Texas Pennsylvanian formations, notably in the clay below the Jacksboro limestone, it is

frequent. Descriptions of Cretaceous faunas show this species and its varieties to be common. In the Thanet Beds and in the London Clay it is a rare form. As a recent form it is a widely distributed species.

Family LITUOLIDAE

Genus HAPLOPHRAGMOIDES Cushman, 1910

HAPLOPHRAGMOIDES CANARIENSIS (d'Orbigny)

Pl. III, figs. 1a, b

(Plesiotype—Walker Museum Coll. 33002, Sta. 23)

Nonionina canariensis d'Orbigny, 1839, Foram. Îles Canaries, p. 128, pl. 2, figs. 33, 34.

Lituola canariensis Carpenter, Parker, and Jones, 1862, Introd. Foram., pl. 6, figs. 39–41.

Haplophragmium canariensis, H. B. Brady, 1884, Challenger, vol. 9 (Zoöl.), p. 310, pl. 35, figs. 1–5.

Haplophragmium canariensis Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 277, pl. 20, fig. 3.

Haplophragmoides canariensis Cushman, 1910, U. S. Nat. Mus. Bull. 71, pt. 1, p. 101, fig. 149 (text).

The Midway tests referred to this species are considerably flattened, deformed, and uncertain of clear analysis. The specimen figured has been squeezed peripherally, and the segments have lost some of their original tumidity. Other specimens are flattened laterally, so that the fossil is a very thin disc. The test is nautiloid and shows that six inflated chambers were originally separated by distinct sutural depressions around an excavated central area. Though the arenaceous shell wall is coarse, it is not conspicuously rough.

This species has been observed mainly in the upper faunal unit of the Midway formation, and it is one of the forms that persist upward through the silty clays and clayey silts almost to the Wilcox contact. A similar species, *H. excavata* Cushman and Waters, in the upper Navarro strata exhibits a larger number of chambers in the final whorl. Consequently since the upper silty Midway beds in many places carry no foraminiferal tests other than those of *H. canari-*

ensis, careful distinction between these closely related, but stratigraphically diagnostic forms, must be made.

Family TEXTULARIIDAE

Genus TEXTULARIA Defrance, 1824

TEXTULARIA AGGLUTINANS d'Orbigny

(Plesiotype—Walker Museum Coll. 33003, Sta. 23)

Textularia agglutinans d'Orbigny, 1839, Foram. Cuba, p. 136, pl. 1, figs. 17, 18, 32–34.
Textularia agglutinans Parker and Jones, 1865, Phil. Trans., vol. 155, p. 369.
Textularia agglutinans H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 363, pl. 43, figs. 1, 2.
Textularia agglutinans Sherborn and Chapman, 1886, Jour. Roy. Mic. Soc., p. 742, pl. 14, fig. 6.
Textularia agglutinans Cushman, 1911, U. S. Nat. Mus. Bull. 71, pt. 2, p. 9, fig. 10 (text).
Textularia agglutinans Bagg, 1912, U. S. Geol. Survey Bull. 513, p. 35, pl. 7, figs. 3, 5.
Textularia agglutinans Cushman, 1918, U. S. Geol. Survey Bull. 676, p. 46, pl. 9, fig. 6.
Textularia agglutinans Cushman, 1921, U. S. Nat. Mus. Bull. 100, vol. 4, p. 106, pl. 20, fig. 8.
Textularia agglutinans Cushman, 1922, U. S. Nat. Mus. Bull. 104, pt. 3, p. 7, pl. 1, figs. 4, 5.
Textularia agglutinans Cushman, 1922, U. S. Geol. Survey Prof. Paper 129, p. 89, pl. 14, fig. 1.

Test coarsely arenaceous, short, stout, somewhat elongate, only slightly compressed; chambers few, inflated; sutures faintly depressed; aperture in a depression at base of septal face.

Length up to .6 mm.

In the Midway formation this species is marked from *Textularia eocaena* (Gümbel) by its stoutness and the roughness of its test. Its occurrence in the Midway is much too rare to be of stratigraphic value.

This much-described form has a rather long geologic range and is common in our present seas.

TEXTULARIA EOCAENA (Gümbel)

Pl. III, figs. 2a, b

(Plesiotype—Walker Museum Coll. 33004, Sta. 23)

Plecanium eocaenum Gümbel, 1868, Abh. k. bay. Akad. Wiss., vol. 10, p. 603, pl. 1, figs. 3 bis, a, b.

Test very elongate, tapering, moderately compressed, coarsely arenaceous; chambers wide, somewhat inflated, moderately rough, the final one being smoother; sutures indistinct in early part of test, somewhat depressed above; aperture an arched slit at base of last-formed chamber in a shallow depression in the septal face.

Length up to .9 mm.

The Midway form of this species resembles very closely the original figure of a form in the upper Eocene beds of the Bavarian Alps. It is distinctly more elongate than the much rarer *T. agglutinans* d'Orbigny in this same formation and is composed of whiter sand grains. *T. sturi* Karrer[18] in the Miocene strata of the Vienna Basin shows a similar elongation of test, but the lateral compression is less, and its septal face is broader and lower.

In the Texas Midway formation *T. eocaena* is a frequent species in the upper strata and occurs with considerable persistence in small numbers throughout the silty upper portion of this unit. Though outcrops of these beds in many places present only this species and *Ammodiscus incertus*, undoubtedly reliance can be placed in these arenaceous species in the identification of the formation.

This simple Textularian form in various proportions occurs very commonly in Tertiary formations.

TEXTULARIA CARINATA d'Orbigny var. EXPANSA n. var.

Pl. III, fig. 3

(Cotypes—Walker Museum Coll. 33005, Sta. 23)

Test subtriangular in outline, broad, compressed; margin sharply angular but unflanged, somewhat lobate; chambers

[18]Karrer, Felix, Ueber das Auftreten der Foraminiferen in den Mergeln der marinen Ufer-bildungen (Leythakalk) des Wiener Beckens: Sitz. k. Akad. Wiss. Wien, vol. 50, p. 703, pl. 1, fig. 1, 1864.

short, broad, finely arenaceous; sutures strongly limbate toward the axis of the test and tapering toward the margins, more coarsely arenaceous than the chambers; aperture a distinctly arched opening in a depression at the base of the septal face.

Length up to .6 mm.

From d'Orbigny's type this Midway variety differs in its lack of a peripheral flange, its broader test, and more quadrate septal face. The only perfect specimen shows a very faint spiral arrangement of the first three or four chambers and is perhaps the microspheric form. The spiral portion of the test is far too insignificant to justify its position in the genus *Spiroplecta.*

In the Midway formation this form occurs only in the upper faunal unit where it is rather rare. The upper Eocene beds of the Texas section carry a form that resembles more closely the type of this species. Other similar species occur commonly in the Tertiary formations of the Gulf Coast.

The earliest available figure of *T. carinata* d'Orbigny is in the monograph on the Miocene of the Vienna Basin. The London clay[19] carries a very common species referred to *Bigenerina capreolus* d'Orbigny, but examination of some material from that formation has failed to reveal any dimorphous tests. The general structure and appearance of the biserial portion of the true Bigenerine species resembles very closely *Textularia carinata,* and unless the form in question is sufficiently abundant to present some undoubtedly fully developed specimens, some hesitancy can perhaps be felt in making identification. The upper Eocene foraminiferal fauna of Biarritz as described by Halkyard carries the typical *T. carinata.* Gümbel figures a similar form, *Venilina haeringensis*[20] from the Eocene of the northern Alps, but it is likely that this form represents a young stage

[19]Sherborn, C. D., and Chapman, Frederick, On some microzoa from the London Clay exposed in the drainage works, Picadilly, London: Jour. Roy. Mic. Soc., ser. 2, vol. 6, p. 743, pl. 14, fig. 8, 1886.

of the true Bigenerine species that he calls *Textularia flabelliformis.*[20]

Genus BOLIVINA d'Orbigny, 1839

BOLIVINA APPLINI n. sp.

Pl. IV, fig. 1

(Cotypes—Walker Museum Coll. 33006, Sta. 46)

Test long and slender, somewhat compressed, tapering to a blunt point; periphery broadly rounded; shell wall strongly punctate; chambers smooth except for distinct striae extending from the initial extremity upward over several early chambers; sutures in early part of test faint dark lines that become more distinct upward and are finally somewhat depressed and show crenulations; aperture an elongate loop-shaped orifice extending from near the apex downward on the inner side of the last chamber.

Length up to .1 mm.

This new species resembles *B. nobilis* Hantken[21] but is distinguished from it by its sutural crenulations and the lesser amount of lateral compression.

Though nowhere abundant, *B. applini*[22] is a very frequent form in the upper Midway faunule or in the transition beds between the two faunal units. Two samples of Taylor marl have yielded specimens of exactly this same form, but it is so rare in these lower strata as to be almost negligible.

Genus PLEUROSTOMELLA Reuss, 1860

PLEUROSTOMELLA ALTERNANS Schwager

Pl. IV, figs. 2a, b

(Plesiotypes—Walker Museum Coll. 33007, Sta. 46)

Pleurostomella alternans Schwager, 1866,, Novara-Exped., Geol. Thiel, vol. 2, p. 238, pl. 6, figs. 79, 80.

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[20]Gümbel, C. W., Beiträge zur Foraminiferenfauna der nordalpinen Eocängebilde: Abh. k. bayer. Ak. Wiss., vol. 10: *Venilina haeringensis*, p. 649, pl. 2, fig. 84bis; *Textularia flabelliformis*, p. 647, pl. 2, fig. 83, 1868.

[21]Hantken, M., Die Fauna der Clavulina Szaboi Schichten, Foraminiferen: Mitth. a. d. Jahrb. k. ungar. geol. Anstalt, vol. 4, p. 65, pl. 15, fig. 4, 1875.

[22]This species has been named after Mrs. Esther R. Applin, who has been very generous in submitting numerous slides of higher Eocene faunas for examination in comparative studies.

Test elongate, tapering very bluntly toward the aboral extremity; chambers few, 7–8 in adult specimens, smooth, alternating but rarely Textularian even in the beginning of the test, inflated; sutures sharply but not deeply depressed; aperture highly arched and almost vertical with a sharply pointed tooth extending inward from each side.

Length up to .4 mm.

The main difference between *P. subnodosa* Reuss[23] and *P. alternans* lies in the character of the aperture, that of the former being simple and that of the latter toothed. One of the specimens in this collection shows a true Textularian arrangement of the first three segments; the others exhibit only the alternating obliquity of the sutures. The species has been reported from the Cretaceous formations of Europe, but the figures show the simple aperture of *P. subnodosa* and should perhaps be referred to that species.

In the upper portion of the Midway formation in Texas *P. alternans* is a rare form. Because it is present also in Taylor clays, no stratigraphic value can be attached to this species in the Gulf Coast section.

The type of this species was described from the later Tertiaries of Nicobar Islands. Halkyard reports it from the upper Eocene of Biarritz.

Genus CLAVULINA d'Orbigny, 1826

CLAVULINA ANGULARIS d'Orbigny

Pl. III, figs. 4a, b, 5a–c

(Plesiotypes—Walker Museum Coll. 33008, Sta. 23)

Clavulina angularis d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 268, No. 2, pl. 12, fig. 7.

Tritaxia ulmensis Gümbel, 1871, Sitz. k. bay. Akad. Wiss., Wien, vol. 1, p. 63, pl. 1, fig. 2.

Clavulina angularis Chapman, 1907, Jour. Linn. Soc. (Zool.), vol. 30, p. 29, pl. 4, figs. 68–73.

Clavulina angularis Halkyard, 1919, Mem. Proc. Manchester Lit. Phil. Soc., vol. 62 (1917), No. 6, p. 46.

Clavulina ulmensis Halkyard, 1919, *Idem*, pl. 3, figs. 4–6.

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[23]Reuss, A. E., Die Foraminiferen der westphälischen Kreideformation: Sitz. k. Akad. Wiss. Wien, vol. 40, p. 204, pl. 8, fig. 2, 1860.

Test elongate, tricarinate, expanding rather rapidly through the short triserial portion of the test and only very gradually throughout the uniserial portion of the more common megalospheric form, but expanding rapidly and evenly throughout the entire development of the microspheric test; sutures between last few chambers generally slightly but distinctly depressed, early sutures as faint dark bands or not evident externally; shell wall coarsely arenaceous; aperture round or subtriangular with a valvular lip on the more perfect specimens of the megalospheric forms, more sharply triangular on microspheric forms with a slight valvular extension on one side of the triangle.

The megalospheric and microspheric forms of this species have by early workers been recognized as two distinct species, and it has remained for Chapman[24] to elucidate the true relationships in his paper on Tertiary foraminifera of Victoria. In his treatment he has shown that the larger and more flaring test begins with a microspheric chamber, and that the triserial portion of the test comprises a larger number of chambers than does that of the megalospheric form. His observations on the Australian material are now found applicable to the tests of a similar character in the Midway formation in Texas.

C. angularis is most abundant in the upper faunal unit of the Midway formation, but it occurs also commonly in the basal strata. So far as is known the species is restricted to this formation. The Navarro clays carry a similar Clavuline form, but its shell wall is much smoother, the three lateral edges are sharper and more nearly entire, and the sutures are more sharply defined.

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[24]Chapman, Frederick, Tertiary foraminifera of Victoria, Australia. The Balcombian deposits of Port Phillip: Jour. Linn. Soc., Zool., vol. 30, No. 195, p. 29. pl. 4, figs. 68–73, 1907.

Genus BULIMINA d'Orbigny, 1826

BULIMINA (ELLIPSOBULIMINA) QUADRATA n. sp.

Pl. IV, figs. 4, 5

(Holotypes—Walker Museum Coll. 33009, Form B; 33010, Form A; Sta. 46)

Test of megalospheric form (Form A) almost cylindrical, stout, increasing in diameter only very slightly from the broad blunt initial end toward the broadly rounded oral extremity; microspheric form (Form B) pointed aborally through a succession of small chambers that follow the proloculum to the later mature chambers that comprise a test identical in shape with that of the much more frequent megalospheric form; chambers smooth, very little inflated, broad, and short; sutures as sharp lines in early part of test and faintly depressed above; wall thin; aperture a large vertical slit on the inner side of the last chamber and connected with all previous apertures by an inner tube that traverses the entire length of the shell.

Length up to .65 mm. in megalospheric form, average .5 mm.; up to .8 mm. in microspheric form.

The distinct features that mark this species in its more frequent megalospheric form are the shape of the test and the broad blunt chambers. The nearest established species is *B. elongata* d'Orbigny,[25] which is typically more slender and elongate. *B. ovata* d'Orbigny[25] has longer chambers and a more ellipsoid test. The chambers of *B. pupoides*,[25] which occurs in the underlying Navarro formation in Texas, shows greater inflation of its chambers, and its initial extremity is bluntly pointed. The microspheric form, which in a few places is of frequent occurrence with the numerous megalospheric tests, is distinguished by its more tapering test, but otherwise the fundamental features of the two forms are identical.

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[25]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiaire de Vienne: *B. elongata*, p. 187, pl. 11, figs. 19, 20; *B. ovata*, p. 185, pl. 11, figs. 13, 14; *B. pupoides*, p. 185, pl. 11, figs. 11, 12, 1846.

In the Midway formation *B. quadrata* is frequent in the upper faunule and is restricted to this zone in the Texas section.

It is unfortunate that a clear understanding of this species has been reached at too late a date for complete revision of the treatment here presented. Though the above description has been brought up to date, the figures were made early in the study from specimens chosen from material in which the species was very rare and the tests filled with limonitic infiltration. Figure 4 (Pl. IV) presents rather faithfully the features of the megalospheric form. The microspheric form as illustrated is not altogether typical and does not show the close affinity to the megalospheric form in the arrangement and shape of its chambers. Two very recently acquired samples collected by Mr. A. E. Oldham from the lower compact clays of the upper faunal zone have furnished numerous unfilled tests of this species in both of its forms, and the perfect transparency of the thin shell wall reveals clearly the inner tube. One of these samples was collected in the bank of a creek near the road bridge 2 miles N. 45° E. of Lone Oak on the way to Donelton (Hunt County) and about one mile due west of the Invincible-Conley No. 1 well. The other sample came from a shallow gully in a cotton field one mile due east of Honest Ridge School, which stands on the northwest side of the road leading southwest from the Nigger Creek oil field (Limestone County) and is approximately five miles from that active community.

BULIMINA ACULEATA d'Orbigny

Pl. IV, fig. 3

(Plesiotype—Walker Museum Coll. 33011, Sta. 46)

Bulimina aculeata d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 269, Modèle No. 7.

Bulimina aculeata H. B. Brady, 1884, Challenger, vol. 9, p. 406, pl. 51, figs. 7–9.

Bulimina aculeata H. B. Brady, Parker, and Jones, 1888, Trans. Zool. Soc., vol. 12, p. 220, pl. 43, fig. 8.

Bulimina aculeata Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 291, pl. 37, fig. 4.

Bulimina aculeata Cushman, 1911, U. S. Nat. Mus. Bull. 71, pt. 2, p. 86, figs. 139a, b (text).

Bulimina aculeata Cushman, 1921, U. S. Nat. Mus. Bull. 100, vol. 4, p. 161, pl. 31, fig. 5.

Bulimina aculeata Cushman, 1922, U. S. Nat. Mus. Bull. 104, pt. 3, p. 96, pl. 22, figs. 1, 2.

Test short and obtuse to elongate and subovate, tapering into a distinct apical spine in well-preserved specimens, conspicuously ornamented in the early portion of the test by numerous short spines which lie both on the edges and on the body of the chambers but which gradually disappear from the later chambers of very mature tests; chambers rather numerous, inflated, rapidly increasing in size and greatly overlapping; sutures depressed; wall thick and glassy; aperture a large curved loop on the inner border of the final chamber.

Length up to .4 mm.

This species may be confused most easily with *B. marginata* d'Orbigny,[26] which however has short spines from the edges of the chambers only, whereas *B. aculeata* presents spines also on the body of its chambers. In the Midway form of *B. aculeata* the spines become marginal on the last chambers of adult specimens, and unusually well-developed tests may show a perfectly smooth final chamber. *B. inflata* Sequenza[27] bears marginal crenulations along the edges of its chambers and *B. buchiana* d'Orbigny[28] shows similar crenulations that merge into costae that taper and disappear at the top of each chamber.

In the upper Midway *B. aculeata* is frequent. As it occurs rather rarely in Navarro clays, it has no stratigraphic value in itself.

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[26]d'Orbigny, Alcide, Tableau Méthodique de la classe des Céphalopodes: Ann. Sci. Nat., vol. 7, p. 267, No. 4, pl. 12, figs. 10–12, 1826.

[27]Seguenza, G., Prime ricerche intorno ai rhizopodi fossili delle argille Pleistoceniche dei dintorni di Catania: Atti. Accad. Gioenia Sci. Nat., ser. 2, vol. 18, p. 109, pl. 1, fig. 10, 1862.

[28]d'Orbigny, Alcide, Foraminifères du Bassin tertiare de Vienne: Paris, p. 186, pl. 11, figs. 15–18, 1846

Family LAGENIDAE

Genus LAGENA Walker and Boys, 1784

LAGENA APICULATA (Reuss)

Pl. IV, fig. 6

(Plesiotype—Walker Museum Coll. 33012, Sta. 57)

Oolina apiculata Reuss, 1850, Haidinger's Nat. Abh., vol. 4, p. 22, pl. 1, fig. 1.
Lagena apiculata Reuss, 1862, Sitz. k. Akad. Wiss. Wien, vol. 46, pl. 56, figs. 15, 16 (only).
Lagena apiculata H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 453, pl. 56, figs. 15, 16 only.
Lagena apiculata Cushman, 1919, U. S. Nat. Mus. Bull, 100, vol. 4, p. 176, pl. 52, fig. 6.

Test obtusely ovate, apiculate, smooth; aperture round, small slightly protruding.

Length .2 mm.

The type for this species differs from the Midway form only in showing a slightly more distinct tapering of the apertural extremity. From *L. globosa* this species is distinguished by its apical spine.

Lagena apiculata is a very rare form in the Midway strata, and it is included in this paper only to prove the existence of the genus in the fauna.

Genus NODOSARIA Lamarck, 1812

NODOSARIA (GL.) LAEVIGATA d'Orbigny var. OCCIDENTALIS Cushman

Pl. IV, fig. 8

(Plesiotype—Walker Museum Coll. 33013, Sta. 23)

Nodosaria (Gl.) laevigata Parker and Jones, 1865, Phil. Trans. vol. 155, p. 340, pl. 13, fig. 1.
Nodosaria (Gl.) laevigata var. *occidentalis* Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 64, pl. 12, fig. 8.

Test compact, subovate, tapering to a short apical spine at the aboral extremity; chambers few, very smooth, greatly embracing; sutures very faintly constricted; transverse; aperture round, protruding, radiate.

Length up to .5 mm.

As stated in the original description, this variety is distinguished from the type of the species by its shape and elongation. It is rather rare in the Midway fauna and has been observed only in the upper strata. It probably has no stratigraphic significance in the geologic section.

NODOSARIA (GL.) COMATA (Batsch)

Pl. IV, fig. 7

(Plesiotypes—Walker Museum Coll. 33014, Sta. 40)

Nautilus (Orthoceras) comatus Batsch, 1791, Conch. Seesandes, pl. 1, fig. 2.

Test short, ovate, apiculate; chambers few, greatly overlapping, striate; sutures transverse, only faintly depressed if at all; aperture large, round.

Length up to .7 mm.

The structure of the test is essentially that of *N. laevigata* d'Orbigny but differs in having very conspicuous but fine longitudinal striae, some of which are continuous across the sutures. Though some tests show sutural constriction, others exhibit an even contour. Some forms that have been referred to this species are now included under the name *N. comatula* by Cushman,[29] and this newer species is characterized by a test that is very similar in structure and outline to *N. radicula* (Linnaeus) but ornamented by fine longitudinal striae. A single specimen of *N. comatula* has been found in Midway clays, but it has not been included in this paper.

In the Midway formation *N. comata* is common, and in places abundant, in the basal faunule. Through the section of transition beds it is also a frequent species, but it has not been observed in true upper beds. It has been found to be far more common in the basal strata of the formation in northeast Texas than in other parts of the belt of outcrop, but this observation may result from having less material from the same stratigraphic zone southwest of the Brazos.

[29]Cushman, J. A., Foraminifera of the Atlantic Ocean: U. S. Nat. Mus. Bull. 104, pt. 4, p. 83, pl. 14, fig. 5, 1923.

NODOSARIA RADICULA (Linnaeus)

Pl. IV, figs. 9a, b

(Plesiotypes—Walker Museum Coll. 33015, Sta. 23)

Nautilus radicula Linnaeus, 1767, Syst. Nat. 12th ed., p. 285, 1164; Gmelin's ed. 13, 1788, vol. 1, pt. 6, p. 3373, No. 18.

Nodosaria radicula d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 252, No. 3, Modèle No. 1.

Nodosaria beyrichi Neugeboren, 1856, Denk. k. Akad. Wiss. Wien, vol. 12, p. 72, pl. 1, figs. 7–9.

Nodosaria radicula Jones and Parker, 1860, Quart. Jour. Geol. Soc., vol. 16, pl. 19, figs. 4, 5.

Nodosaria radicula Parker and Jones, 1865, Phil. Trans., vol. 155, p. 341, pl. 13, figs. 2–7.

Nodosaria beyrichi Hantken, 1874, Mitth. Jahrb. k. ungar. geol. Anstalt, vol. 4, p. 23, pl. 2, fig. 5. (Not *N. neugeboreni* as stated in the plate description, which must be an error.)

Nodosaria radicula H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 495, pl. 61, figs. 28–31.

Nodosaria radicula Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 309, pl. 55, fig. 1.

Nodosaria radicula Cushman, 1919, U. S. Nat. Mus. Bull. 100, vol. 4, p. 190, pl. 34, fig. 4.

Nodosaria larva Carsey, 1926, Univ. Texas Bull. 2612, p. 31, pl. 2, fig. 2.

Test elongate, stout; chambers few and somewhat overlapping, smooth, short, compact, enlarging very little; sutures transverse, slightly depressed in early part of test but increasingly more constricted toward the oral extremity; shell wall thick, glossy; aperture small, round, protruding, radiate.

Length up to 1 mm.

The Midway form of this species appears to be very typical. Both megalospheric and microspheric forms are found together in numerous samples, the former being more abundant. The megalospheric forms are characterized by the broad, blunt initial proloculum succeeded by chambers increasing only slightly in diameter till three or four have been formed, and from this point the test is evenly developed. The microspheric form is sharply pointed at its proximal extremity, the first three or four short and unconstricted chambers comprising the acute angle, from

which point the growth is identical with that of the megalospheric form.

N. radicula is a very frequent form in the upper Midway faunule. Its rare occurrence in Navarro clays detracts from its value as a diagnostic species, but its greater rarity in the lower formation and its somewhat smaller size in those strata make it possible to give the Midway form a slight value.

As a fossil *N. radicula* has been reported from the upper Triassic clays in Derbyshire, from the Miocene beds of California, and a variety is rare in the Gault of Folkestone. In the early paper on the fauna of the London Clay a form referred to this species has been figured, but it seems not to fit well the definition generally followed. In our present oceans this species is of frequent occurrence.

NODOSARIA SOLUTA (Reuss)

Pl. IV, fig. 10

(Plesiotype—Walker Museum Coll. 33016, Sta. 46)

Dentalina soluta Reuss, 1851, Zeit. deutsch. geol. Gesell., vol. 3, p. 60, pl. 3, fig. 4.

Nodosaria soluta Bornemann, 1855, Zeit. deutsch. geol. Gesell., vol 7, p. 322, pl. 12, fig. 12.

Dentalina soluta Hantken, 1875, Mitth. Jahrb. k. ungar. geol. Anstalt, vol. 4, p. 29, pl. 3, fig. 2.

Nodosaria soluta Sherborn and Chapman, 1886, Jour. Roy. Mic. Soc., p. 746, pl. 14, figs. 25, 26(?).

Nodosaria soluta Chapman, 1900, Proc. Calif. Acad. Sci., ser. 3, vol. 1, No. 8, p. 248, pl. 29, fig. 14.

Nodosaria soluta Bagg, 1912, U. S. Geol. Survey Bull. 513, p. 59, pl. 15, fig. 2; pl. 16, fig. 7.

Test elongate, faintly arcuate, apiculate; chambers few, greatly inflated, slightly pyriform, perfectly smooth, increasing rapidly in size; sutures deeply constricted; aperture protruding, round, radiate.

Length up to .7 mm.

A number of forms that have been referred to this name have now been included in *N. subsoluta,* a name created by

Cushman[30] to define tests that show a slight roughness or even hispidity over the lower portion of each chamber.

In the upper Midway faunule *N. soluta* is very rare. In some parts of the Taylor formation it is more common and better developed.

The London Clay fauna contains rare specimens of *N. soluta*. The species has been reported from formations of numerous periods in geologic history.

NODOSARIA PAUPERATA (d'Orbigny)

Pl. IV, fig. 11

(Plesiotype—Walker Museum Coll. 33017, Sta. 23)

Dentalina pauperata d'Orbigny, 1846, Foram. Foss. Vienne, p. 46, pl. 1, figs. 57, 58.

Dentalina inermis Czizek, 1847, Haidinger's Nat. Abh., vol. 2, p. 139, pl. 12, figs. 3–7.

Dentalina pauperata Bornemann, 1855, Zeit. deutsch. geol. Gesell., vol. 7, p. 324, pl. 13, fig. 7.

Nodosaria pauperata H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 500, fig. 14 (text).

Dentalina pauperata Sherborn and Chapman, 1886, Jour. Roy. Mic. Soc., p. 750, pl. 15, fig. 9.

Nodosaria pauperata Chapman, 1893, Jour. Roy. Mic. Soc., p. 588, pl. 8, fig. 32.

Nodosaria pauperata Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 51, pl. 25, fig. 7.

Nodosaria pauperata Halkyard, 1917, Mem. Proc. Manchester Lit. Phil. Soc., vol. 62, No. 6, p. 71, pl. 4, figs. 8, 9 (only).

Nodosaria pauperata Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 72, pl. 14, fig. 13.

Test elongate, subcylindrical, slightly arcuate; chambers few, enlarging very little, early ones cylindrical, later ones somewhat turgid, proloculum very rarely bulbous; sutures transverse, flush in early part of test but faintly constricted between last two or three chambers; aperture slightly eccentric, protruding, radiate.

Length up to .7 mm.

The average test of the Midway *N. pauperata* conforms to the type as illustrated by d'Orbigny in possessing but few

[30]Cushman, J. A., The foraminifera of the Atlantic Ocean; U. S. Nat. Mus. Bull. 104, pt. 4, p. 74.

chambers with an almost cylindrical early development followed by two or three somewhat inflated chambers. The Midway form differs mainly in a slightly greater elongation of the individual cylindrical chambers, which in the type are short and compact. *Nodosaria communis* (d'Orbigny) is similar in outline, but its sutures are oblique.

N. pauperata is restricted to the upper faunule in the Midway formation, and in these strata it is a frequent form. This precise form has not been observed in other formations in the Texas section.

Records show that the species has existed since Liassic times. It occurs in the English Gault, and in several Tertiary formations.

NODOSARIA MUCRONATA (Neugeboren)

Pl. IV, fig. 13

(Plesiotype—Walker Museum Coll. 33018, Sta. 23)

Dentalina mucronata Neugeboren, 1856, Denk. k. Akad. Wiss. Wein, vol. 12, p. 83, pl. 3, figs. 8–11.

Nodosaria mucronata H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 506, pl. 62, figs. 27–31.

Nodosaria mucronata H. B. Brady, Parker, and Jones, 1888, Trans. Zool. Soc. London, vol. 12, p. 223, pl. 44, fig. 10.

Nodosaria mucronata Chapman, 1893, Jour. Roy. Mic. Soc., p. 590, pl. 9, fig. 2.

Nodosaria mucronata Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 311, pl. 57, fig. 2.

Nodosaria mucronata Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 56, pl. 24, fig. 3; pl. 25, fig. 2; pl. 27, figs. 5–7; pl. 35, fig. 6.

Nodosaria mucronata Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 80, pl. 13, figs. 5–7; pl. 13, figs. 7–9.

Test elongate, tapering posteriorly; chambers few, smooth enlarging rather rapidly; sutures oblique, sharply but not deeply depressed; apertures eccentric, protruding, radiate.

Length up to .7 mm.

As a species this form has been somewhat variously figured, but the essential features of this smooth test are paucity of oblique chambers that enlarge rapidly from a small proloculum. *N. communis* (d'Orbigny) is less tapering posteriorly and has a larger number of chambers.

In the Midway formation *N. mucronata* is rare and has been observed only in the upper faunule. As it is common to Cretaceous strata, it has no stratigraphic value.

This species has been found in many formations treated in the literature but most especially in Tertiary beds.

NODOSARIA POMULIGERA (Stache)

Pl. IV, figs. 15a, b; Pl. XIV, fig. 3

(Plesiotypes—Walker Museum Coll. 33019, Sta. 67; 33020, Sta. 2-F)

Dentalina pomuligera Stache, 1864, Novara-Exped., vol. 1, p. 204, pl. 22, fig. 31.

Test elongate, tapering, slightly arcuate; chambers compact, tumid almost throughout, broadening rapidly in early portion of test, of about equal development through mature portion, and narrowing slightly toward the oral extremity in fullest development, smooth except for overlap of shell matter on the upper edge of mature chambers at some localities; sutures transverse, constricted, and marked by faint dark bands; shell wall very thick, white, opaque; aperture slightly eccentric and protruding.

Length up to 5 mm., average about 2.5 mm.

This series of compact, inflated chambers that widen rapidly at first and then maintain a rather constant size is a very distinctive form. Though sutural constrictions are in general the rule, some specimens exhibit a few cylindrical chambers in the early part of the test. *N. consobrina* and its variety *emaciata* have more elongate chambers.

The occurrence of *N. pomuligera* in the Midway is not common, though quite frequent. It occurs both in basal and upper strata but appears to die out in the lower part of the upper zone. A very similar and probably identical species occurs in both the Taylor and Navarro clays in Texas.

The original form of this species was described from the Miocene marls of Whaingaroa-Hafens, New Zealand.

NODOSARIA LONGISCATA d'Orbigny

Pl. IV, figs. 17a, b

(Plesiotypes—Walker Museum Coll. 33021, Sta. 46)

Nodosaria longiscata d'Orbigny, 1846, Foram. Foss. Vienne, p. 32, pl. 1, figs. 10–12.

Nodosaria arundinea Schwager, 1866, Novara-Exped., Geol. Theil, vol. 2, p. 211, pl. 5, figs. 43–45.

Nodosaria arundinea Sherborn and Chapman, 1886, Jour. Roy. Mic. Soc., p. 747, pl. 14, figs. 28, 29.

Nodosaria longiscata, Sherborn and Chapman, 1889, Jour. Roy. Mic. Soc., p. 486, pl. 11, figs. 17, 18.

Test very long and slender; chambers probably numerous (entire specimens impossible to procure), very elongate, smooth, cylindrical to very elongate ellipsoid; sutures transverse, only slightly to very distinctly depressed; aperture probably round and radiate.

Length unknown.

The critical remarks of Sherborn and Chapman in their papers on the London Clay have proved helpful in defining more precisely the original species from the Miocene of the Vienna Basin. Though d'Orbigny has shown a distinct angulation at the base of each chamber, examination of the original materials by these authors has shown that the specimens included under this name exhibit a variation in this detail. The main feature of the species is the very long, straight, slender test composed of very elongate chambers separated usually by distinct but not deeply constricted sutures. In the Midway material single specimens exhibit variations in shape of its chambers. *N. ewaldi* Reuss[31] of the Septarian Clays of Germany is a very closely related species and may be identical.

In the upper Midway faunule, *N. longiscata* d'Orbigny is frequent. A form identical with this occurs in Cretaceous strata in the Texas section and is seen occasionally in other formations.

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[31]Reuss, A. E., Ueber die fossilen Foraminiferen und Entomostraceen der Septarienthone der Umgegend von Berlin: Zeit. deutsch. geol. Gesell., vol. 3, p. 58, pl. 3, fig. 2, 1851.

The London Clay contains this species as a rare form. It has been observed in the Pliocene of Kar-Nicobar, Miocene of Vienna Basin, and possibly in the Oligocene of Germany.

NODOSARIA GRANTI n. sp.

Pl. V, figs. 9a–d

(Cotypes—Walker Museum Coll. 33022, Sta. 1)

Tests very long, slender, arcuate, smooth, apiculate; chambers numerous, varying from rarely compact to the more average elongate chamber that is about twice as long as broad, cylindrical to gently inflated, elliptical to ovoid; sutures transverse, unconstricted to gently constricted; wall thick, opaque, aperture round, radiate.

Length probably up to several millimeters.

Because of the exceedingly great amount of variation in the development of *N. granti*,[32] a concise description that covers completely the range of these variations is difficult to compose. The form may start either from an inflated proloculum or from one that is set off above by no sutural constriction whatever. The early portion of the test may be cylindrical or the chambers may exhibit inflation from the beginning. In general the chambers are elongate ellipsoid, but slightly pyriform chambers are frequent. The elongation of chambers marks this species from *N. consobrina* (d'Orbigny) and its variety *emaciata*. The transverse sutures separate it from *N. filiformis*. Through the courtesy of Dr. Cushman specimens of *N. cocoaensis*[33] were furnished for comparison, and this Midway form is found to be very much larger, the shell wall is very much heavier and more opaque, the chambers average much longer, and sutural constrictions are more marked.

In the basal strata of the Midway formation *N. granti* is very common and in many places very abundant. In the

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[32]This species has been named for Prof. U. S. Grant, head of the Department of Geology, Northwestern University, where this paper was accepted for an M.A. degree.

[33]Cushman, J. A., Eocene foraminifera from the Cocoa sand of Alabama: Contrib. Cush. Lab. Foram. Res., vol. 1, pt. 3, p. 66, pl. 10, figs, 5, 6, 1925.

upper faunule it is frequent, and is less strongly developed. Its occurrence in Navarro and Taylor clays renders it worthless as a formation marker in considering the species only. However, its very abundance in Midway strata is a diagnostic feature of considerable value.

NODOSARIA SPINESCENS (Reuss)

Pl. IV, fig. 12

(Plesiotype—Walker Museum Coll. 33023, Sta. 23)

Dentalina spinescens Reuss, 1851, Zeit. deutsch. geol. Gesell., vol. 3, p. 62, pl. 3, fig. 10.

Test very elongate, slender; chambers ellipsoid, about twice as long as broad, ornamented by a few short and flaring spines around the base close to the sutural constrictions; aperture large, round, somewhat phialine.

Length unknown.

The elongate, smooth chambers bearing very few spines mark this species clearly from any other in the Midway fauna, where it is rare in the upper strata. Very rarely this form is observed in Navarro and Taylor clays.

NODOSARIA SPINULOSA (Montagu)

Pl. IV, figs. 19a–c

(Plesiotypes—Walker Museum Coll. 33024, Stas. 40 and 46)

Nautilus spinulosa Montagu, 1808, Test. Brit. Supp., p. 86, pl. 19, fig. 5.

Dentalina spinulosa Sherborn and Chapman, 1886, Jour. Roy. Mic. Soc., p. 751, pl. 15, fig. 13.

Nodosaria spinulosa Bagg, 1898, U. S. Geol. Survey Bull. 88, p. 44.

Test straight or slightly arcuate, slender, apiculate; chambers numerous, elongate, gently to distinctly inflated, conspicuously ornamented by riblets that end posteriorly in downward-hanging spines in the early portion of the test, but as the chambers gradually increase in size short spines are irregularly interspersed with the riblets, and in maturity short, rib-like spines are scattered fairly well over the surface of the chambers; sutures depressed very little in

the early part of some tests to more deeply constricted above.

Length probably up to several millimeters.

In a few unessential details this species in the Midway shows some variation. The early chambers may be globular and sharply separated by deeply constricted sutures, or they may be compact and become gradually more and more inflated with growth. Some tests show distinct projecting spines on the early chambers, whereas others display on these first few chambers almost continuous costae from chamber to chamber that are broken at the sutures only irregularly till several chambers have been formed. As a species it is sharply marked from other spinose forms in having very coarse spines irregularly disposed toward the base of its chambers and merging upward into irregularly disposed costae.

In the basal faunule of the Midway formation *N. spinulosa* is very common and in places abundant. Its occurrence in the upper strata is somewhat erratic and on the whole rare. Specimens of this same species are observed rarely in Navarro clays. Though as a species it can not be regarded as a formation marker, its very abundance in the basal Midway clays at some places is sufficient to mark the age of the strata.

Samples of London clay present *N. spinulosa* in abundance. In the Cretaceous of New Jersey it is frequent. So far as known, it has not been reported from the present oceans.

NODOSARIA SAGRINENSIS Bagg

Pl. IV, fig. 16

(Plesiotypes—Walker Museum Coll. 33025, Sta. 23)

Nodosaria sagrinensis Bagg, 1912, U. S. Geol. Survey Bull. 513, p. 58, pl. 16, fig. 4.

Test straight, tapering; chambers few, short to somewhat elongate in maturity, strongly turgid, widely separated by thick bands of dense shell material, upper portions of chambers ornamented by very fine, short, interrupted and closelying striae that impart a roughness to more than half the

surface and a distinct angulation to the contour of the chambers; sutures broad, dark bands, sharply constricted, increasing into short necks between mature chambers; aperture flaring, phialine.

This species was named by Bagg from only one perfect specimen, and it is perhaps somewhat doubtful whether his name ought here to be adopted for the Midway form. He points out that the "striae suggestion seem to be on the nodes." Some of the specimens in the Midway material fall very well into this category as to ornamentation, but the average form presents exceedingly fine striae of varying degrees of intensity over the upper half of each chamber, and these end just below the center and form the angulation in the contour. Possibly if the original Pliocene material had been sufficiently rich in these forms, the true character of the markings would have been more clearly defined. *N. lepidula* Schwager[34] is somewhat similar but bears only a few, more distinct, and more flaring spines around the fullest portion of each segment. *N. antillea* Cushman[35] has a similar contour, but the chambers are smooth.

In the basal Midway beds *N. sagrinensis* is in general rare, but locally it is common. Its fullest development was reached in upper Midway times. Though it occurs in Navarro strata, it is very rare in that formation and is less well developed.

Samples from the London Clay show this same form to be very abundant, and it was described originally as *N. adolphina* (d'Orbigny),[36] a species that bears sharp flaring spines instead of the close-lying ones of the form under consideration.

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[34]Schwager, Conrad, Fossile Foraminiferen von Kar-Nicobar: Novara-Exped., Geol. Theil, vol. 2, p. 210, pl. 5, figs. 27, 28, 1886.

[35]Cushman, J. A., Foraminifera of the Atlantic Ocean: U. S. Nat. Mus. Bull. 104, pt. 4, p. 91. pl. 14, fig. 9, 1923.

[36]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiaire de Vienne, p. 51, pl. 2, figs. 18--20, 1846.

NODOSARIA OLIGOTOMA Reuss

Pl. IV, fig. 14

(Plesiotype—Walker Museum Coll. 33026, Sta. 23)

Nodosaria oligotoma Reuss, 1872, Palaeontographica, vol. 20, pt. 1, p. 135, pl. 33, fig. 16.

Nodosaria oligotoma Sherborn and Chapman, 1889, Jour. Roy. Mic. Soc., p. 486, pl. 11, fig. 20.

Test elongate, somewhat tapering posteriorly; chambers very few, generally 4–5 at most, somewhat elongate, ornamented by about six major thin costae alternating with faint minor costae that may be very weakly developed; sutures transverse, somewhat constricted; aperture greatly protruding, small, round.

Length up to .65 mm.

The original figure has not been available for comparison, but Sherborn and Chapman have illustrated a form of this name in the supplementary paper on the London Clay. *N. amphioxys* Reuss[37] is similar but lacks the minor costae.

In the Midway formation *N. oligotoma* is a rare form in the upper strata, but specimens are frequently observed in carefully washed samples of the siltless clays of this stratigraphic zone. So far as known, it is restricted to the upper Midway faunal zone in the Texas section.

NODOSARIA PSEUDO-OBLIQUESTRIATA n. sp.

Pl. IV, fig. 18

(Holotype—Walker Museum Coll. 33027, Sta. 3)

Test long, slender, arcuate, tapering toward the aboral extremity; chambers numerous, strongly inflated, ornamented by coarse costae that follow the length of the test somewhat obliquely; sutures strongly constricted; aperture protruding, round, somewhat eccentric.

Length up to 2 mm.

Forms similar to this new species have been described as

[37]Reuss, A. E., Die Foraminiferen, Bryozoen und Ostracoden des Pläners: Geinitz, Palaeontographica, vol. 20, p. 82, pl. 20, fig. 8, 1874.

N. obliquestriata (Reuss),[38] a name that was originally applied to tests that display slightly oblique striae across the sutures only or very weakly also over the chambers. *N. steenstrupi* (Reuss)[39] may be very close to this Midway form, but the original figure is too poor for accurate interpretation.

N. pseudo-obliquestriata is a very common form in the basal beds, to which zone in the Texas section it is probably restricted.

NODOSARIA VERTEBRALIS (Batsch)

Pl. V, fig. 10

(Plesiotype—Walker Museum Coll. 33028, Sta. 46)

Nautilus (Orthoceras) vertebralis Batsch, 1791, Conch. des Seesandes p. 3, No. 6, pl. 2, fig. 6.

Nodosaria vertebralis H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 514, pl. 63, fig. 35; pl. 64, figs. 11–14.

Nodosaria vertebralis Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 312, pl. 57, fig. 5.

Nodosaria vertebralis Bagg, 1912, U. S. Geol. Survey Bull. 513, p. 60, pl. 17, fig. 2.

Nodosaria vertebralis Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 60, pl. 32, fig. 1.

Nodosaria vertebralis Cushman, 1919, Carnegie Inst. Washington, Bull. 291, p. 35, pl. 7, figs. 3–5.

Nodosaria vertebralis Cushman, 1919, U. S. Nat. Mus. Bull. 100, vol. 4, p. 211, pl. 38, figs. 2, 3; pl. 40, fig. 2.

Nodosaria vertebralis Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 86, pl. 14, fig. 6.

Test elongate slender, straight to slightly arcuate; chambers short, compact, cylindrical; sutures marked by dark bands and constricted only between the last few chambers; surface ornamented by a few very coarse, longitudinal costae (about 8); aperture somewhat eccentric, protruding, radiate.

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[38]Reuss, A. E., Ueber die fossilen Foraminiferen und Entomostraceen der Septarienthone der Umgegend von Berlin: Zeit. deutsch. geol. Gesell., vol. 3, p. 63, pl. 3, figs. 11, 12, 1851.

[39]Reuss, A. E., Ein Beitrag zur genaueren Kenntniss der Kreidegebilde Meklenburgs: Zeit. deutsch geol. Gesell., vol. 7, p. 268, pl. 8, fig. 14a, 1855.

Length up to several millimeters.

This specific name is here assigned to those coarsely costate Nodosarian tests that show no tumidity of chamber contour till late maturity. Short forms resemble *N. raphanus* (Linnaeus), but these are probably the immature tests of *N. vertebralis*. The lines of demarcation between these strongly costate forms are not sharp in the Midway fauna. Through almost imperceptible gradations the tests referred to *N. vertebralis* pass into *N. affinis* d'Orbigny[40] and finally into a form that shows inflated chambers throughout growth and may be called *N. zippei* Reuss.[41] The specimen figured in this paper is an unusually small test that is frequent in upper Midway strata, and is chosen only because complete tests of the larger variety are so difficult to procure.

The occurrence of the large specimens of *N. vertebralis* is far more common in the basal beds, where in places it is very abundant and generally fragmentary. With it are in most outcrops the other strongly costate species closely related to this form. The Navarro carries this test rarely, but any abundance in a sample is likely to be indicative of the Midway.

As a fossil *N. vertebralis* has been reported from the London Clay, the upper Eocene at Biarritz, the Pliocene of California, Vicksburg (Oligocene) group of Mississippi, Cretaceous of New Jersey. On the whole it is rather well distributed through the geologic periods to the present.

NODOSARIA AFFINIS d'Orbigny

Pl. XIV, figs. 2a–d

(Plesiotypes—Walker Museum Coll. 33029, Sta. 67)

Nodosaria affinis d'Orbigny, 1846, Foram. Foss. Vienne, p. 39, pl. 1, figs. 36–39.

Nodosaria affinis Sherborn and Chapman, 1886, p. 748, pl. 14, fig. 33.

Nodosaria affinis Bagg, 1901, Maryland Geol. Survey, Eocene, p. 236, pl. 62, fig. 5.

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[40]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiaire de Vienne, p. 39, pl. 1, figs. 36–39, 1846.

[41]Reuss, A. E., De Versteinerungen der böhmischen Kreideformation, pt. 1, p. 25, pl. 8, figs. 1–3, 1845.

Test straight, elongate, apiculate; chambers cylindrical or only slightly inflated in earliest portion of test to more strongly globular in later development, ornamented by 9–11 strong, longitudinal costae; sutures transverse, generally slightly constricted in early part of test to deeply constricted above; aperture protruding, round, mammillate.

Length up to 7 mm.

The strongly ribbed Nodosarian forms referred in this paper to *N. affinis* display considerable variation in development in the Midway formation, and it is possible that they can be broken up into several species. However, any attempt so far to draw sharp lines of demarcation has proved futile. Most specimens exhibit a somewhat prominent proloculum, but others show a gradual increase from the very beginning. In general the sutural constrictions are evident throughout the test, becoming deeper toward the oral extremity, and even where the costae are perfectly straight across the sutures, the chambers themselves beneath this conspicuous ornamentation show at least a faint inflation. In some places this early sutural constriction is so marked that the tests may perhaps better be referred to *N. zippei.* It seems somewhat doubtful whether d'Orbigny had any real reason for his distinction between *N. affinis* and *N. bacillum* d'Orbigny and the first name is here chosen merely on the grounds of priority. Those strongly costate tests in the Midway that exhibit cylindrical chambers throughout the major portion of the test are referred to *N. vertebralis* (Batsch).

In the Midway formation *N. affinis* is very common and in places abundant, and its size renders it very easy of identification in outcrops of fresh clay. It is most abundant in the basal faunule, but locally it is very common in the upper zone. It is rather rare in Navarro and Taylor clays, where it is never visible in unwashed material, both because of its extreme rarity and because of the mineralization of its tests that renders it grey and translucent. The field geologist can well regard the form as diagnostic for his purposes, since the species as preserved in Midway strata is easily visible with an ordinary hand lens.

Nodosarian species of this type have been described from Lias to Recent under various names. Until more material from other formations in various parts of the world can be studied in comparison with the Midway forms, the significance of these variations displayed in the Midway formation seems impossible to judge.

Genus CRISTELLARIA Lamarck, 1812

CRISTELLARIA ROTULATA (Lamarck)

Pl. VII, figs. 8a, b

(Plesiotypes—Walker Museum Coll. 33030, Sta. 46)

Lenticulites rotulata Lamarck, 1804, Ann. Mus., vol. 5, p. 188, No. 3; 1806, vol. 8, pl. 62, fig. 11.

Cristellaria rotulata d'Orbigny, 1840, Mém. Soc. Géol. France, ser. 1, vol. 4, p. 26, pl. 2, figs. 16–18.

Cristellaria rotulata Parker and Jones, 1865, Phil. Trans., vol. 155, p. 345, pl. 13, fig. 19.

Cristellaria rotulata H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 547, pl. 69, figs. 13a, b.

Cristellaria rotulata Burrows, Sherborn, and Bailey, 1890, Jour. Roy. Mic. Soc., p. 559, pl. 10, fig. 17.

Cristellaria rotulata Chapman, 1896, Jour. Roy. Mic. Soc., p. 5, pl. 1, fig. 8.

Cristellaria rotulata Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 314, pl. 64, fig. 4.

Cristellaria rotulata Bagg, 1901, Md. Geol. Survey, Eocene, p. 242, pl. 63, fig. 5.

Cristellaria rotulata Bagg, 1912, U. S. Geol. Survey Bull. 513, p. 67, pl. 19, fig. 5.

Cristellaria rotulata Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 66, pl. 35, fig. 3.

Cristellaria rotulata Cushman, 1918, U. S. Nat. Mus. Bull. 103, p. 60, pl. 22, fig. 1.

Cristellaria rotulata Cushman, 1919, Proc. U. S. Nat. Mus., vol. 56. p. 614.

Cristellaria rotulata Cushman, 1921, U. S. Geol. Survey Prof. Paper 129, p. 130, pl. 32, fig. 1.

Cristellaria rotulata Cushman, 1921, U. S. Nat. Mus. Bull. 100, vol. 4, p. 223.

Cristellaria rotulata Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 108, pl. 22, fig. 2.

Test round, biconvex; peripheral margin sharply angular but not flanged; chambers 8–9 in final convolution; sutures visible as distinct lines or very slight elevations that curve very little and radiate rather acutely from the central umbonal area; apertures of all chambers usually visible on periphery in clear fresh specimens.

Diameter up to .5 mm.

C. rotulata as figured in some publications is very similar to *C. inornata* (d'Orbigny),[42] and it is this form of the species that occurs in the Midway formation. In well-developed specimens the suture lines of *C. rotulata* are slightly more curved and impinge less tangentially upon the central umbonal area; also this species averages one more chamber to the final whorl. *C. orbicularis* (d'Orbigny) in this same fauna is much smaller, its peripheral flange is better developed, and its sutures are distinctly more curved.

Where the upper strata of the Midway formation are rich in hyaline species, *C. rotulata* is very frequent; it has never been observed in the lower zone. It is doubtful whether this species possesses any stratigraphic significance.

This species has had a long geologic range. In England it has been found in strata between the Triassic and Pliocene. In the United States it is found in the New Jersey greensands, the Eocene of Maryland, and the Miocene and Pliocene of California. Today it is rather widespread in the present oceans.

CRISTELLARIA ORBICULARIS (d'Orbigny)

Pl. VII, figs. 1a, b

(Plesiotype—Walker Museum Coll. 33031, Sta. 46)

Robulina orbicularis d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 288, pl. 15, figs. 8, 9.

Cristellaria orbicularis H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 549, pl. 69, fig. 17.

Cristellaria orbicularis Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 317, pl. 63, fig. 3.

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[42]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiaire de Vienne, p. 102, pl. 4, figs 25, 26, 1846.

Cristellaria orbicularis Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 67, pl. 36, figs. 4, 5.

Cristellaria orbicularis(?) Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 101, pl. 21, fig. 7.

Test small, round, glistening; periphery faintly angular on some specimens, bounded by a narrow transparent flange; chambers 6–7, smooth, strongly curved; sutures fine, slightly elevated ridges whirling outward from a large umbonal area of very clear shell matter; aperture high on very narrow and contracted septal face.

Diameter up to .4 mm.

The test of the Midway form of this species is very translucent, and the slight sutural elevations are not easily observed. Through the large, clear umbonal area the proloculum is distinctly visible as well as some of the sutures of the inner whorl. The only similar form in the Midway fauna is *C. turbinata* which has one more chamber on the average, is less transparent, and its peripheral flange is so thin and delicate that it is on most specimens conspicuously ragged, whereas that of *C. orbicularis* (d'Orbigny) is always entire.

Where upper Midway strata carry an abundance of hyaline species, *C. orbicularis* is a very frequent form, but in general it is rare in the formation. It is doubtful that it possesses any stratigraphic value in the Texas section.

Forms referred to this species have been described in Tertiary faunas very commonly, and it is frequent in the present oceans.

CRISTELLARIA TURBINATA n. sp.

Pl. VII, figs. 4a, b; Pl. XIII, fig. 2

(Cotypes—Walker Museum Coll. 33032, Sta. 46)

Test circular, considerably compressed; peripheral margin sharp and extended into a fragile, white flange that is typically ragged; chambers 8 in final convolution, narrow, smooth; sutures strongly elevated and of about equal width from the large umbonal area to the periphery, very strongly curved; aperture at apex of narrow septal face.

Diameter up to .6 mm.

This species has the general structure of *C. vortex* (Fitchel & Moll),[43] but its chambers are much less strongly curved; it resembles somewhat *C. imperatoria* (d'Orbigny),[44] but its sutural elevations extend to the periphery instead of being confined to the area around the umbonal area, and its chambers are more moderately curved. From *C. subalata* Reuss[45] this Midway form is separated by its conspicuous peripheral flange and its narrower final chamber. The only other Midway species with which any confusion can arise is *C. orbicularis* (d'Orbigny), which has fewer chambers and an entire flange.

In unmineralized condition *C. turbinata* marks the upper faunal unit of the Midway formation, but it occurs rarely in Cretaceous strata where the tests are completely replaced by calcite.

CRISTELLARIA GIBBA d'Orbigny

(Plesiotypes—Walker Museum Coll. 33033, Sta. 23)

Cristellaria gibba d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 292, Modèle No. 17.

Cristellaria gibba d'Orbigny, 1839, Foram. Cuba, p. 63, pl. 7, figs. 20, 21.

Cristellaria gibba H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 546, pl. 69, figs. 8, 9.

Cristellaria gibba Burrows, Sherborn, and Bailey, 1890, Jour. Roy. Mic. Soc., p. 559, pl. 10, figs. 19, a, b.

Cristellaria gibba Chapman, 1896, Jour. Roy. Mic. Soc., p. 4, pl. 1, fig. 7.

Cristellaria gibba Burrows and Holland, 1897, Proc. Geol. Assoc., vol. 15, p. 44, pl. 2, figs. 5, 6.

Cristellaria gibba Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 317, pl. 64, fig. 1.

Cristellaria gibba Bagg, 1901, Md. Geol. Survey, Eocene, p. 241, pl. 63, fig. 4.

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[43]Fichtel, J. E. von, and Moll, J. P. C. von, Testacea microscopica, aliaque minuta ex generibus Argonauta et Nautilus ad naturam delineata et descripta: p. 33, pl. 2, figs. d–i, Vienna, 1798.

[44]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiaire de Vienne: p. 104, pl. 5, figs. 5, 6, Paris, 1846.

[45]Reuss, A. E., Beiträge zur Charakteristik der Kreideschichten in den Ostalpen, besonders im Gosauthale und am Wolfgangsee: Denk. k. Ak. Wiss. Wien, vol. 7, Abh. 1, p. 68, pl. 25, fig. 13, 1854.

Cristellaria gibba Earland, 1905, Jour. Quekett Mic. Club. ser. 2, vol. 9, No. 57, p. 216.
Cristellaria gibba Bagg, 1912, U. S. Geol. Survey Bull. 513, p. 66, pl. 19, fig. 4.
Cristellaria gibba Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 69, pl. 35, fig. 1.
Cristellaria gibba Cushman, 1918, U. S. Geol. Survey Bull. 676, p. 10, pl. 2, fig. 6.
Cristellaria gibba Cushman, 1919, U. S. Nat. Mus. Bull. 100, vol. 4, p. 228, pl. 45, fig. 1.
Cristellaria gibba Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 105, pl. 25, fig. 4.

Test somewhat elongate, moderately compressed; peripheral margin acutely angular but without a flange; chambers 7–9, smooth, very slightly curved; sutures visible as dark lines to narrow bands that may be very faintly elevated, curving almost imperceptably toward the periphery from the center; aperture at apex of rather long triangular septal face, protruding, radiate.

The Midway form of this species conforms very closely with the many descriptions easily available. It is frequent in the formation, especially in the upper zone, and is too similar to a Cretaceous form to be of any value as a formation marker.

This much-described species occurs widely through Cretaceous and Tertiary formations everywhere, and exists today in the present oceans.

CRISTELLARIA MIDWAYENSIS n. sp.

Pl. XIII, figs. 5a–c

(Cotypes—Walker Museum Coll. 33034, Sta. 67)

Test large, circular, very closely coiled, full bodied, though somewhat compressed; periphery distinctly angular but not flanged in its typical form; chambers 10–12 in adult form, smooth, narrow, gently curved, radiate from a conspicuous central boss and tapering somewhat toward the peripheral margin; aperture at apex of broad septal face.

Diameter up to 1.5 mm., usually less.

The figures show the typical common form of the species as it occurs throughout the Midway formation. In some places in the basal zone, however, the form develops a peripheral flange. Because the flanged form occurs only in the lower faunal unit and thus carries a slight stratigraphic value, it has been distinguished by a varietal name, *carinata.* The only other large species in the Midway fauna that exhibits strong sutural ridges is *C. degolyeri,* which is less closely coiled and has fewer chambers.

C. midwayensis is a very distinctive species in the Texas geologic section, and because of its abundance and size it is one of the most helpful in stratigraphic work. The underlying Cretaceous clays carry in abundance a similar closely coiled species (text fig. 4) that is very much more compressed laterally, bears a wide conspicuous peripheral flange, and very narrow sutural ridges swing out from a small umbonal boss. Even the widely flanged variety of this Midway species is conspicuously different from the Cretaceous species in being so very much less compressed. For the field geologist *C. midwayensis* is very usable, as it is easily visible to the naked eye in the basal clays where in many places it is very abundant.

Though in the Midway section of Texas this species is very common throughout the formation, it is much more common in the basal faunule, and as it is a shallow-water form it persists in the glauconitic clays, sands, and shell marls. Collections from outcrops of the formation in Alabama yield this form in abundance, and the Arkansas material available for study contains it very commonly. It was evidently a widespread species in Midway seas and should be of great assistance in identification of the formation across the Gulf states. The only other formation that has presented samples of *C. midwayensis* is the fossiliferous marl of the Wilcox at Nanafalia, Alabama, where it is rather rare. Because marine phases of the Wilcox are very rare in Texas, it is unlikely that any ambiguity will arise in assigning Midway age to strata carrying this species in this state.

CRISTELLARIA MIDWAYENSIS n. sp. var. CARINATA n. var.

Text figure 5, p. 41

(Cotypes—Walker Museum Coll. 33035, Sta. 3)

From the type for this species the variety differs mainly in having a conspicuous peripheral flange. This form occurs only in the basal Midway clays at a few localities, and all gradations from the flangeless form into the extreme of the variety can be found at these places.

This varietal form of the very abundant Midway Cristellarian has given rise to some confusion in the identification of its strata because of the similarity of the test to a very common species in the Navarro. The broadly flanged form of the Navarro clays *(C. navarroensis* n. sp., text fig. 4) is found everywhere to be more compressed laterally, and generally the sutural elevations are somewhat finer. In the field it is only rarely that the Cretaceous forms are visible with a hand lens because replacement of the tests by crystalline calcite has rendered them translucent.

CRISTELLARIA DEGOLYERI n. sp.

Pl. VII, figs. 7a, b

(Cotypes—Walker Museum Coll. 33036, Sta. 46)

Test somewhat longer than broad, moderately compressed; peripheral margin very sharp and bounded by a ragged flange; chambers 7–9, gently curved, smooth; sutures marked by strong elevations of clear shell matter tapering outward from a conspicuous unbonal boss; aperture at apex of an elongate septal face.

Length up to .8 mm.; usually less.

The elongation of this test marks it sharply from *C. midwayensis* var. *carinata,* and the high sutural ridges render any confusion with *C. gibba* d'Orbigny impossible. The flange on some specimens is weakly developed, but the average test shows plainly this feature in ragged condition.

In the upper Midway faunal unit *C. degolyeri*[46] is a very

[46]This species has been named for Mr. E. Degolyer, President of Amerada Petroleum Corporation, through whose permission this paper has been made available for publication.

common and persistent form in unmineralized condition. Since a few Cretaceous clays have yielded tests identical in all respects, the only feature of stratigraphic value is the condition of the test.

CRISTELLARIA PSEUDO-MAMILLIGERA n. sp.

Pl. VII, figs. 11a, b

(Cotypes—Walker Museum Coll. 33037, Sta. 40)

Test very slightly elongate, strongly compressed; periphery bounded by a rather thick keel that shows on some specimens a slight lobation; chambers 9–11 in final convolution, distinctly curved; sutures marked by conspicuous tapering elevations curving outward from an irregularly developed central boss or from a group of protuberances; aperture radiate, protruding.

Diameter up to 1.6 mm.

The general outline of the test is similar to *C. mamilligera* Karrer, but sutures of this old form are marked by a series of large beads, whereas this new species presents an irregularly developed central boss from which unbroken ridges taper along a curve toward the periphery.

Though *C. pseudo-mamilligera* has been observed as a rare species in both the basal and upper zones in general, it is very common and even abundant in the glauconitic clays and sands of the transition zone in its various phases. Since it is not present in the basal greensand of the formation, it serves as a valuable criterion in identifying the stratigraphic position of questionable glauconitic material in the formation. South of Elgin, Bastrop County, the form is found in especially large numbers in the glauconitic clay rich in *Venericardia bulla* Dall. In the upper Midway strata it is exceedingly rare.

CRISTELLARIA PSEUDO-COSTATA n. sp.

Pl. VII, figs. 9a, b

(Cotypes—Walker Museum Coll. 33038, Sta. 3)

Test much compressed, not completely involute, changing from the loosely coiled form to linear development in speci-

mens developed beyond maturity; periphery bound by a distinct, thin, transparent flange; chambers 7–8 in last whorl, ornamented by two to four irregularly developed thin costae that follow roughly the direction of coiling; sutures marked by thin, high, uneven ridges; aperture protruding from a strongly inflated septal face.

Diameter up to .7 mm.

The degree of the development of the costation is locally somewhat variable. The sutural elevations are everywhere conspicuous, but the costae that cross the chambers may be strong or almost absent. Some specimens exhibit both sets of markings so well developed, that the last chamber bears a set of four or five that radiate backward across the surface from the protruding aperture. The essential and constant characters are the loose coiling, strong lateral compression, crinkly sutural elevations, costae on the chambers more or less developed, and the peripheral flange. The original *C. costata* (Fichtel & Moll)[47] has not been available for reference, but comments in the literature indicate that it presents the two sets of costae in about equal development and a larger number of costae across the chambers than has this Midway form. Several varieties of this old species have been erected by Cushman for his recent forms in the waters about the Philippines. *C. ariminensis* (d'Orbigny)[48] bears a resemblance to this group of costate Cristellarians, but it lacks wholly the sutural elevations.

C. pseudo-costata is one of the few very distinctive sign posts in the Texas section, for it is restricted to the very narrow stratigraphic zone of the basal Midway and is a common form in that zone. The lower clays carry it most abundantly, but it is found also in the sands of the upper part of the basal section. In the shell marl along Tehuacana Creek north of Mexia it attains unusual size but is not abundant in this bed, and it ceases to exist above this horizon.

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[47]Fichtel, L. von, and Moll, J. P. C. von, Testacea microscopica aliaque minute generibus Argonauta et Nautilus ad naturam delineata et descripta: p. 47, pl. 4, figs. g, h, Vienna, 1798.

[48]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiaire de Vienne: p. 95, pl. 4, figs. 8, 9, Paris, 1846.

In Kaufman, Hunt, and Hopkins counties *C. pseudo-costata* is cut off abruptly by the phosphatic nodule layer in the transition zone that lies between the two faunal units of the formation.

CRISTELLARIA SCITULA Berthelin

Pl. VII, fig. 5

(Plesiotype—Walker Museum Coll. 33039, Sta. 23)

Cristellaria scitula Berthelin, 1880, Mém. Soc. Géol. France, ser. 3, vol. 1, p. 54, pl. 3, fig. 3.

Test elongate, much compressed; peripheral margin acutely keeled; early chambers coiled, later ones in oblique series, smooth, transparent; sutures thin dark lines not depressed; aperture protruding, marginal, radiate.

Length up to .6 mm.

The arrangement of chambers is similar to some figures of *C. crepidula,* but as the type form of this very old species is not available, and as the name has been rather promiscuously applied, no definite comparisons can be made. It appears, however, that *C. scitula* presents fewer and wider chambers.

In the Midway this species is frequent in its upper strata. Because a very similar, and perhaps identical, form is rare in Navarro clays *C. scitula* is not a safe guide fossil.

CRISTELLARIA SUBLATIFRONS n. sp.

Pl. VII, figs. 6a, b

(Holotype—Walker Museum Coll. 33040, Sta. 46)

Test elongate, smooth, tapering at both ends; peripheral margin bluntly angular; chambers few, passing from very slightly spiral to linear oblique in rapidly lengthening series, later chambers bluntly triangular but not keeled; sutures strongly oblique, smooth, distinct; aperture at apex of a long, narrow, slightly inflated septal face marked by a faint longitudinal furrow.

Length up to .5 mm.

From *C. scitula* this species differs in showing less coiling of the early chambers and in the subtriangular cross section of its mature chambers. This triangulation is, however, not so sharp as in *C. trigonata,* which presents three sharp keels and a more strongly coiled area.

In the Midway, *C. sublatifrons* is very rare and of no value in stratigraphic work, though it appears to be confined to this formation.

CRISTELLARIA TRIGONATA n. sp.

Pl. VII, figs. 3a, b

(Holotype—Walker Museum Coll. 33041, Sta. 46)

Test elongate, triangular in cross section, tapering toward the oral end; peripheral margin carnate; early chambers closely coiled; later ones sharply carinate on each side of the septal face; sutures as dark lines; aperture at the apex of a long broad septal face on mature specimens.

Length up to .7 mm.

In the Midway formation this species has been observed very rarely in the upper faunal unit, and so far no other formation has yielded this identical form.

CRISTELLARIA SUBACULEATA Cushman var. TUBERCULATA n. var.

Pl. VII, fig. 2; Pl. XIV, figs. 1a–c

(Holotype—Walker Museum Coll. 33042, Sta. 46)

Test elongate, somewhat compressed; periphery rounded on early chambers and very bluntly angular on later chambers of mature forms; chambers numerous, smooth, first six or seven plano-spiral followed by a linear succession of short, compact chambers; sutures marked by rows of distinct beadlike tubercles best developed on the coiled portion of the test and giving place to more ridgelike elevations between later chambers or even to depressions in extreme maturity; aperture protruding, radiate, peripheral.

Length up to 1.4 mm.; average 1 mm.

This new variety is very similar to Cushman's type for

the species and also to his variety *glabrata.*[49] From the former it is distinguished by the lack of the marked development of peripheral spines and the lack of a keel, and from the latter by only the lack of the keel. *C. limbata* Reuss[50] is similar in construction but displays smooth ridgelike sutural elevations and peripheral spines. *C. fragaria* (Gümbel)[51] is similarly coiled and ornamented, but the tubercles are slightly elongated parallel to the growth of the test.

C. subaculeata var. *tuberculata* is strictly an upper Midway species, which occurs very commonly in the lower portion of this zone and frequently upward into the silty clays. The size of the form makes it useful to the field geologist with a hand lens. In Alabama the species can be observed in the Midway marl at Matthews Landing near Camden on Alabama River.

Partially coiled and beaded Cristellarian forms similar to this Midway species are very common in Tertiary formations everywhere. The London Clay presents large numbers of a similar test that shows an elongation of the tubercles along the sutures and numerous smaller beads on the surfaces of the chambers between the sutures. The Thanet beds carry rather rarely similar forms. In Europe the Tertiary formations yield forms of this type in considerable abundance.

CRISTELLARIA LONGIFORMA n. sp.

Pl. XIII, figs. 4a, b

(Cotypes—Walker Museum Coll. 33043, Sta. 37)

Test elongate, stout, broad, compressed; few early chambers more or less coiled, later chambers erect and somewhat oblique; sutures very strongly limbate on each side but apparent on the margins as lines or less distinct ridges; aperture marginal, protruding, radiate.

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[49]Cushman, J. A., Foraminifera of the Atlantic Ocean, U. S. Nat. Mus. Bull. 104, pt. 4, p. 124, pl. 32, fig. 4; pl. 33, figs. 2, 3; pl. 34, fig. 3, 1923.

[50]Reuss, A. E., Die Versteinerungen der böhmischen Kreideformation; pt. 1, p. 33, pl. 13, fig. 56, 1845.

[51]Gümbel, C. W., Beiträge zur Foraminiferenfauna der nordalpinen Eocängebilde: Abh. k. bayer. Ak. Wiss., vol. 10, p. 635, pl. 1, fig. 58, 1868.

Length up to 1.7 mm.

The features of this species vary somewhat in minor details. On some specimens the early coil is more prominent than on others. Though in general the sutures are expressed on each side by separate broad limbations that disappear toward the margins and rise again at the margins less prominently, some elevations are continuous or may fade into mere lines. The distinctive features that mark *C. longiforma* are the breadth of its test from the aboral end upward, the distinct incoiling of the first 3 to 5 chambers, and the broad sutural elevations. *Vaginulina robusta,* which somewhat resembles this species, is more slender, and it presents merely a faint open coiling of its early chambers. *Cristellaria subaculeata* var. *tuberculata* has a strong incoiling, and its sutures are for the most part distinctly beaded.

In the Midway formation *C. longiforma* has been seen only in the upper faunule. It is not a common form throughout the formation as a whole, but where it occurs, it is likely to be very abundant. Because no other part of the section in Texas carries this species, it is an excellent marker. Its occurrence in northeast Texas is very rare, though in an outcrop close to the Wilcox contact east of Mexia it is abundant. In Caldwell and Bexar counties it is a frequent form in the upper clays.

CRISTELLARIA EARLANDI n. sp.

Pl. VII, fig. 10

(Holotype—Walker Museum Coll. 33044, Sta. 46)

Test very elongate, much compressed; peripheral margin narrowly rounded; chambers numerous, first six or seven closely coiled about a conspicuous and only slightly protruding boss, later ones in an erect series; sutures oblique in both the coiled and uncoiled portion of test, strongly elevated in rather even development in the coiled area but more greatly thickened on each side of the linear series; aperture marginal.

Length probably up to about 3 mm.

At only a few Midway localities has this species been observed, and no entire tests have been found. It is similar to some figures of *C. subarcuata* d'Orbigny, but the sutural limbations are so conspicuous as to require for this species a distinct name.

In the Midway formation *C. earlandi*[52] is very rare in both the basal and upper zones. A species probably identical with this occurs in the Taylor clays, but it averages somewhat smaller.

Genus MARGINULINA d'Orbigny, 1826

MARGINULINA GLABRA d'Orbigny

Pl. VI, figs. 3a–d

(Plesiotypes—Walker Museum Coll. 33045, Sta. 43)

Marginulina glabra d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 259, No. 6, Modèle No. 55.

Marginulina glabra Jones, Parker, and H. B. Brady, 1866, Crag Monog., Palaeontographical Soc., pp. 69, 233, pl. 1, fig. 26.

Marginulina glabra H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 527, pl. 65, figs. 5, 6.

Marginulina laevigata Goës, 1894, K. Svensk. Vet-Akad. Handl., vol. 20, pl. 13, figs. 703, 709.

Nodosaria aequalis Goës, 1894, *Ibid.*, figs. 711a, b.

Marginulina glabra Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 313, pl. 60, fig. 1.

Marginulina glabra Bagg, 1912, U. S. Geol. Survey Bull. 513, p. 62, pl. 21, fig. 17.

Marginulina glabra Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 79, pl. 23, fig. 3.

Marginulina glabra Cushman, 1922, U. S. Nat. Mus. Bull. 104, pt. 4, p. 127, pl. 36, figs. 5, 6.

Test short, stout, slightly curved, bluntly rounded at the base, circular in transverse section; chambers smooth and few, first three or four being inrolled; sutures not at all depressed in the coiled portion of the test but merging into

[52]This species has been named for Mr. Arthur Earland, F.R.M.S., who has for many years devoted a large portion of his energies to the study of foraminifera and has contributed largely to the recent development of the science in England.

slightly depressed sutures above; shell wall generally thick and opaque but rarely thin and transparent, very smooth; aperture radiate, protruding, marginal in youth but becoming more central with maturity.

Length up to 1 mm.

Amongst members of this general type of Marginuline forms, *M. glabra* is marked by the close incoiling of the first few chambers and the compactness of this portion of the test beyond which very few, increasingly tumid chambers are formed. In *M. subbullata* Hantken[53] the axis of the first two or three chambers is curved but not so strongly as in the typical *M. glabra.*

In the Mexia-Wortham area, *M. glabra* is a member of the upper faunule of the Midway formation. In areas farther northeast, where the depositional sequence was not broken by so great a change as evidenced by the Tehuacana limestone, the species is found in the upper part of the basal zone. So far as now known the species has not been seen in the underlying Cretaceous formations in Texas nor higher in the Tertiaries.

As a fossil *M. glabra* has been reported from the Pliocene in California and in the English Crag. The figures of similar Cretaceous forms available for comparison are too elongate to permit of identification with this species.

MARGINULINA TUMIDA Reuss

Pl. V, fig. 6

(Plesiotype—Walker Museum Coll. 33046, Sta. 23)

Marginulina tumida Reuss, 1851, Zeit. deutsch. geol. Gesell., vol. 3, p. 64, pl. 3, fig. 14.

Test elongate, tapering, and gently curving; chambers few, slightly inflated, and increasing rapidly in size; early portion of test shows tendency to coiling only by the graceful curve of its axis; sutures distinct after second chamber; surface smooth; cross section circular; aperture radiate, eccentric, and strongly protruding.

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[53]Hantken, M., Die Fauna der Clavulina Szaboi Schichten, Foraminiferen: Mitth. a. d. Jahrb. k. ungar. geol. Anstalt, vol. 4, p. 46, pl. 4, figs. 9, 10, pl. 5, fig. 9, 1875.

Length .35 mm.

Comparison with the type from the Septarian clays (Oligocene) in Germany shows the very rare Midway form to be somewhat more tapering toward the initial extremity, but structure of the test is very similar. It has been observed only in the upper Midway faunule at a very few places.

MARGINULINA GARDNERAE n. sp.

Pl. V, figs. 11a–c

(Cotypes—Walker Museum Coll. 33047, Sta. 1)

Test elongate, straight to slightly arcuate, somewhat stout, tapering bluntly toward the initial extremity; early chambers very slightly compressed, later ones round in transverse section, compact, subcylindrical, narrow; sutures evident as dark bands or faint lines, constricted only between the last two or three chambers, early sutures oblique or displaying even a suggestion of coiling, later ones transverse; aperture eccentric, protruding, radiate.

Length up to 1.5 mm.; average 1 mm.

M. gardnerae[54] is rather variable in the intensity of the coiling of its early chambers. The average specimen shows merely the Vaginuline obliquity of the sutures immediately following the proloculum, but frequent specimens exhibit a faint but true coiling. Many specimens are almost Nodosarian, but practically all tests show at least the change from oblique to transverse sutures. The faint lateral compression of the test is notable only in its early development.

In the basal unit of the Midway fauna the clays carry *M. gardnerae* in abundance. In the basal sands it is rather rare, and because tests in such material are likely to be leached, only fragments are frequent. The restriction of this species to a very narrow stratigraphic zone makes it of unusual value as a marker.

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[54]This species has been named for Dr. Julia Gardner, geologist and paleontologist for the U. S. Geological Survey.

MARGINULINA REGULARIS d'Orbigny

Pl. V, fig. 7

(Plesiotypes—Walker Museum Coll. 33048, Sta. 43)

Marginulina regularis d'Orbigny, 1846; Foram. Foss. Vienne, p. 68, pl. 3, figs. 9–12.

Vaginulina glabra Goës, 1894, K. Svensk. Vet-Akad. Handl., vol. 20, No. 9, pp. 65, 66, pl. 11, figs. 656–658.

Test elongate, gently arcuate, tapering; chambers comparatively few, full, round, very smooth, first few partially coiled; sutures slightly oblique, distinct from the beginning but becoming more and more depressed toward the oral extremity; walls fragile; aperture marginal, radiate, round, protruding.

Length up to .7 mm.

The Midway form is very close to the type as figured, perhaps the only difference being in a somewhat less sutural obliquity. *M. elongata* d'Orbigny[55] has more compact chambers; *M. pediformis* Bornemann[56] and *M. subbullata* Hantken[53] are stouter forms; *M. glabra* d'Orbigny is stouter and shows definite incoiling of the first few chambers; *M. inaequalis* Reuss[57] is more attenuate posteriorly and exhibits less coiling of the early chambers.

This species has been observed rarely in the upper strata of the Midway formation in Texas. Since it occurs also in Cretaceous clays, no stratigraphic significance can be attached to the form.

The original *M. regularis* came from the Miocene of the Vienna Basin where it is rare.

MARGINULINA COSTATA (Batsch)

Pl. V, figs. 8a–c

(Plesiotypes—Walker Museum Coll. 33049, Sta. 46)

Nautilus (Orthoceras) costatus Batsch, 1791, Conch. des Seesandes, p. 2, pl. 1, fig. 1.

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[55]d'Orbigny, Alcide, Mémoire sur les foraminifères de la Craie blanche du Bassin de Paris: vol. 4, p. 17, pl. 50, figs. 20–22, 1840.

[56]Bornemann, J. G., Die mikroskopische Fauna des Septarienthones von Hermsdorf bei Berlin: Zeit. deutsch. geol. Gesell., vol. 7, p. 326, pl. 13, fig. 13, 1855.

[57]Reuss, A. E., Die Foraminiferen der westphälischen Kreideformation: Sitz. k. Akad. Wiss. Wien., vol. 40, p. 207, pl. 7, fig. 3, 1860.

Marginulina raphanus d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 258, No. 1, pl. 10, figs. 7, 8.

Marginulina costata H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 528, pl. 65, figs. 10–13.

Marginulina costata Sherborn and Chapman, 1889, Jour. Roy. Mic. Soc., p. 487, pl. 11, fig. 28.

Marginulina costata, Jones, Parker, and H. B. Brady, 1896, Crag Monog., Palaeont. Soc., p. 235, pl. 1, fig. 21.

Marginulina costata Bagg, 1912, U. S. Geol. Survey, Bull. 513, p. 62, pl. 18, fig. 4.

Marginulina costata Cushman, 1919, U. S. Nat. Mus. Bull. 100, vol. 4, p. 256, pl. 41, figs. 5–8.

Test elongate, subcylindrical, tapering only very little toward the apical extremity that carries a short, stout spine; chambers few and Nodosarian generally, but slightly coiled in the microspheric form; sutures but faintly perceptible as rather broad bands, not constricted except between last two or three chambers; wall ornamented by numerous longitudinal costae, the disposition of which along the inner margin indicate the Marginuline relationships and its inherent tendency to be partially coiled in youth; aperture eccentric, protruding, round.

Length up to 2 mm.

The thin, highly elevated, delicate riblets that swing slightly toward the margin opposite that which carries the aperture marks the test of this species from all other ribbed forms in the Midway fauna. As a general rule these costae are markedly discontinuous and bifurcate frequently. *M. striatocostata,* figured by Reuss[58] from the Gault, is very similar and may be identical with this species. *M. obliquestriata* Karrer[59] also has the essential features of structure but carries a large number of striations. On the whole this species is rather well defined, and the Midway form is closely conformable with previously figured forms of this name.

M. costata in the Midway formation has been observed only in the upper faunal unit, where it is comparatively

[58]Reuss, A. E., Die Foraminiferen des norddeutschen Hils und Gault: Sitz. k. Akad. Wiss. Wien., vol. 56, p. 62, pl. 6, fig. 2, 1862.

[59]Karrer, F., Ueber das Auftreten der Foraminiferen in dem marinen Tegel des Wiener Beckens: Sitz. k. Akad. Wiss. Wien., vol. 54, p. 446, pl. 1, fig. 8, 1861.

rare. No record of its occurrence in any other part of the Texas section can be found.

This species has a long geologic range and lives today in the present oceans.

Genus VAGINULINA d'Orbigny, 1826

VAGINULINA LEGUMEN (Linnaeus)

Pl. VI, fig. 2

(Plesiotype—Walker Museum Coll. 33050, Sta. 46)

Nautilus legumen Linnaeus, 1758, Syst. Nat., ed. 10, p. 711, No. 248; ed. 12, 1767, p. 1164, No. 288.

Vaginulina legumen d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 257, Modèle No. 2.

Vaginulina legumen H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 530, pl. 66, figs. 13–15.

Vaginulina legumen Flint, 1889, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 314, pl. 60, fig. 2.

Vaginulina legumen Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 80, pl. 39, fig. 4.

Vaginulina legumen Cushman, 1919, U. S. Nat. Mus. Bull. 100, vol. 4, p. 257, pl. 41, fig. 3.

Vaginulina legumen Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 133, pl. 37, fig. 5.

Test elongate, arcuate, slender, smooth, tapering gracefully toward the apical end; chambers compact, as many as 13 in very well-developed specimens with an average of 8–9, very oblique, slightly turgid in maturity, initial chamber provided with a prominent spine; sutures oblique, slightly constricted above; aperture eccentric, radiate, all visible through the sutures of pellucid specimens.

Length up to 1.3 mm.; usually much less.

This name has been applied rather promiscuously to a variety of Vaginuline forms, till it seems to have lost much of its real significance. However, the Midway form referred to this species complies with the average description in recent literature. It is more slender and attenuate than the variety *elegans,* which occurs in abundance in this formation and presents a distinct apical spine that is absent

on the variety. As these two forms are so distinct and never pass by gradations into one another it would seem more reasonable to revert to d'Orbigny's original plan of making the variety a species, *V. elegans*. From *V. badenensis* d'Orbigny[60] this form is distinguished by less lateral compression and less oblique sutures. *V. legumen* var. *arquata* Brady[61] is more strongly arcuate and more compressed.

The Midway fauna shows *V. legumen* to have been a rare form during this period of deposition, and it existed only after the Tehuacana limestone or the equivalent glauconitic sands were laid down. Just how restricted it is in the Texas section is impossible to state at present, but it is too rare in the Midway to be of practical value as a marker.

The geological record of *V. legumen* extends back into the Triassic, and it has been reported from formations of almost every succeeding age.

VAGINULINA LEGUMEN (Linnaeus) var. ELEGANS d'Orbigny

Pl. VI, fig. 1

(Plesiotypes—Walker Museum Coll. 33051, Sta. 46)

Vaginulina elegans d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 257, No. 1, Modèle No. 54.

Vaginulina legumen var. *elegans* Cushman, 1919, U. S. Nat. Mus. Bull. 100, vol. 4, p. 258, pl. 41, fig. 4.

Vaginulina legumen var. *elegans* Cushman, 1923, U. S. Geol. Survey Prof. Paper 133, p. 30, pl. 4, fig. 8.

Test elongate, stout, very bluntly tapering toward the initial end, compressed in its early portion to less compressed in its later development; chambers smooth, 8–10 in tests of average size to as many as 13 in especially well-developed ones; proloculum nearly round but not inflated above the general contour of the test; sutures very faintly elevated to smooth, conspicuous as dark bands on pellucid

[60]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiare de Vienne: p. 65, pl. 3, figs. 6–8, Paris, 1846.

[61]Brady, H. B., Report on the Foraminifera dredged by H.M.S. *Challenger* during the years 1873–1876: Reports of the Scientific results of the Voyage of H.M.S. *Challenger*, vol. 9 (Zool.), p. 531, pl. 114, fig. 13, 1884.

specimens, very oblique in early part of test to almost transverse above, unconstricted except between last two or three; aperture eccentric, protruding, radiate, all visible through the sutural bands of very fresh tests.

Length up to 1.5 mm.; average 1 mm.

Because several different Vaginuline forms have been referred to this name, and because the original figure is not available for reference, this Midway form is perhaps not true to type. It appears to be similar in all essential characteristics to the Vicksburg species illustrated by Cushman.

In the upper Midway strata *V. legumen* var. *elegans* is very common and in places abundant. Since it is restricted to this zone it is a very helpful marker. A form very similar to this variety occurs in the Taylor and Brownstown marls.

VAGINULINA GRACILIS n. sp.

Pl. VI, figs. 5a, b

(Cotypes—Walker Museum Coll. 33052, Sta. 3)

Test long, slender, slightly arcuate, gradually tapering toward the initial end, compressed; chambers numerous, short, smooth, compact, except the primordial chamber which is bulbous in megalospheric forms; sutures oblique on early portion of test to less oblique above, expressed outwardly by distinct and narrow ridges that extend around the apertural margin; wall moderately strong; aperture marginal, protruding, radiate.

Length up to 2.5 mm.

This very conspicuous and abundant species in the strata of the basal Midway is one of the most valuable forms of this fauna in marking the narrow stratigraphic zone between the Cretaceous-Eocene contact and the Tehuacana limestone horizon. In the areas where a narrow zone of transition lies between the basal and upper beds, *V. gracilis* dies out through these few feet of section as the upper form, *V. robusta* becomes more and more abundant. The size of the test and the conspicuous transverse ridges render it particularly helpful to the field geologist with a hand lens,

for clays rich in the basal foraminifera show these tests very plainly. In the Navarro formation is a Vaginuline form of similar structure, but instead of the narrow sutural ridges, thickened elongate nodes lie along each side of the test (Pl. II, fig. 8). The mineralization of these Cretaceous tests by calcite replacement renders them almost invisible in raw clays under a hand lens, and no confusion can arise in field work.

VAGINULINA ROBUSTA n. sp.

Pl. VI, figs. 4a, b; Pl. XIII, fig. 3

(Cotypes—Walker Museum Coll. 33053, Sta. 46)

Test elongate, moderately broad, stout, somewhat compressed, tapering bluntly in megalospheric forms but very acutely in microspheric forms; chambers smooth, few, first two or three very slightly twisted followed by the usual straight linear series; sutures oblique, conspicuously marked by sharp, high ridges that on most specimens encircle the test, though a slight amount of discontinuity is frequently evident; aperture on extreme margin.

Length up to 1.4 mm.

In material rich in this species microspheric forms are not rare. Whereas the megalospheric forms begin with a very large initial chamber followed by the usual compressed chambers increasing rapidly in width up to the fifth or sixth, the early portion of the microspheric form comprises a set of about eight very small but gradually increasing chambers that form a graceful hook, and these are followed by the same broad stout series of the megalospheric form. Specimens showing development beyond the average adult stage exhibit a decrease in size of subsequent chambers and a marked decrease in sutural limbation, and the final suture may even be depressed. Frequent specimens show a tendency to a development of beads along the sutural ridges, especially the tests found in the upper part of the transition zone in Hunt and Hopkins counties.

The respective characteristics of *V. robusta* and *V. gracilis* are so definite and constant that identification even from

small fragments is unlikely to be doubtful. *V. spinigera* H. B. Brady[62] is of a structure similar to that of *V. robusta*, but its early portion is more distinctly coiled, and it bears the strong basal spines. *V. bradyi* Cushman[63] carries a single basal spine, and its early chambers are more strongly coiled. In the underlying Cretaceous strata in Texas a form of similar outline and structure is of rare occurrence, but its sutural limbations consist of distinct, blunt nodes on each side of the test instead of the high narrow ridges so diagnostic of the Texas Midway species.

In upper Midway strata *V. robusta* is one of the most valuable of diagnostic forms. Because of its size, it is easily observed in the washed residues, and because of its abundance in these strata considerable dependence can be placed upon it. It is only rarely visible in the raw clays with a hand lens. So far as known no similar form occurs in any other portion of the Texas geologic section.

VAGINULINA PLUMOIDES n. sp.

Pl. VI, fig. 6

(Holotype—Walker Museum Coll. 33054, Sta. 23)

Test very thin, wing shaped, acuminate posteriorly and anteriorly, spreading rapidly upward; chambers very oblique and somewhat curved, ornamented by very fine delicate striae parallel to the direction of growth; aperture protruding.

Length up to .8 mm.

The fine striations across the chambers vary in their degree of development, and some specimens are almost devoid of these markings. The outline of *V. plumoides* is similar to that of *V. intumescens* Reuss[64] but its surface

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[62]Brady, H. B., Report on the Foraminifera dredged by H.M.S. *Challenger* during the years 1873–1876: Reports of the Scientific Results of the Voyage of H.M.S. *Challenger*, vol. 9 (Zool.), p. 531, pl. 67, figs. 13, 14, 1884.

[63]Cushman, J. A., New species and varieties of foraminifera from the Philippines and adjacent waters: Proc. U. S. Nat. Mus., vol. 51, p. 661 (new name for a form designated by Brady as *V. brukenthali* Neugeboren in the *Challenger* report); Foraminifera of the Philippines and adjacent seas: U. S. Nat. Mus. Bull. 100, vol. 4, p. 260, pl. 42, figs. 3, 4, 1921.

[64]Reuss, A. E., Die Foraminiferen des norddeutschen Hils und Gault: Sitz. k. Akad. Wiss. Wien., vol. 46, p. 49, pl. 4, fig. 2, 1862.

markings are much finer and less continuous longitudinally, and its chambers are very much narrower.

The Midway formation carries *V. plumoides* throughout the extent of its section, and since it is restricted to this stratigraphic zone in the Texas column, it becomes one of the formation markers.

Genus FRONDICULARIA Defrance, 1824

FRONDICULARIA ARCHIACIANA d'Orbigny var. STRIGILLATA Bagg

Pl. V, figs. 2a, b

(Plesiotypes—Walker Museum Coll. 33055, Sta. 23)

Frondicularia archiaciana Reuss, 1845, Verst. böhm. Kreide, pt. 1, p. 31, pl. 13, fig. 39.

Frondicularia archiaciana Chapman, 1894, Jour. Roy. Mic. Soc., p. 155, pl. 3, fig. 6.

Frondicularia archiaciana var. *strigillata* Bagg, 1898, U. S. Geol. Survey Bull. 88, p. 47, pl. 3, fig. 5.

Test lanceolate, complanate, very elongate, compressed and leaf-like in its markings, anteriorly acute, posteriorly blunt but provided with a large spine; chambers up to about 10, large, limbate at the lateral edges, equally compressed except for the primordial chamber which is spherical and conspicuously ornamented by two or three longitudinal costae; surface distinctly marked by fine longitudinal and discontinuous striae; sutures strongly limbate near central depression that extends from the initial chamber to the aperture, which is small, protruding, radiate, and tubular.

Length up to 2 mm.

This variety as introduced by Bagg in his bulletin on the Cretaceous foraminifera of New Jersey is based on the longitudinal costations and striations. Comparison with the type of the species as shown by d'Orbigny in his monograph on the chalk of the Paris Basin reveals a difference in the width of the successive chambers, those of this variety having shorter chambers that comprise consequently a more compact test.

F. archiaciana var. *strigillata* belongs in the Texas Midway to the upper faunule where it is frequent. In

Alabama this variety is rare in the Midway marls at Matthews Landing. Because of the very common occurrence of the form in Cretaceous clays and chalks in the Texas section, it has no stratigraphic value in itself, but associations with other species in any sample renders its age certain.

The only record of the species in Tertiary formations has been found in Halkyard's report on the upper Eocene foraminifera at Biarritz. It is a very common form in the Gault of England, France, and Germany, and the type for the species came from the Craie Blanche of the Paris Basin. Brady has referred to *F. archiaciana* a form[65] that he found in a dredging from Torres Strait, but this has recently been changed to *F. compta* H. B. Brady var. *villosa* Heron-Allen and Earland.[66] Just which forms recorded in the literature belong to this variety can not be satisfactorily stated.

FRONDICULARIA GOLDFUSSI Reuss

Pl. V, fig. 3

(Plesiotypes—Walker Museum Coll. 33056, Sta. 46)

Frondicularia goldfussi Reuss, 1860, Sitz. Akad. Wiss. Wien, vol. 40, p. 192, pl. 4, fig. 7.

Frondicularia mucronata Reuss, 1874, Palaeontographica, vol. 20, pt. 2, p. 96, pl. 21, figs. 14–16.

Test elongate oval, very thin, anteriorly acute; initial segment long, narrow, highly elevated along its axis, extended into a long apical spine; later chambers sagittate and narrow; sutures fine, narrow, gracefully curved ridges; apertures extended, radiate.

Length up to 1 mm.; average .5 mm.

Though this species is found in the Midway with as many as eight or nine chambers, the average development is only

[65]Brady, H. B., Report on the foraminifera dredged by H.M.S. *Challenger* during the years 1873–1876: Reports of the Scientific Results of the Voyage of H.M.S. *Challenger*, vol. 9 (Zool.), p. 520, pl. 114, fig. 12, 1884.

[66]Heron-Allen, E., and Earland, A., Miocene foraminifera of Filter Quarry, Moorabool River, Victoria, Australia: Jour. Roy. Mic. Soc., p. 157, pl. 10, figs. 54, 55, 1924.

four or five. *F. tenuissima* Hantken[67] is similar in structure and shape but lacks the sutural elevations. *F. alata* d'Orbigny resembles this Midway species, but in its best development it presents a distinct angulation in posterior portion of its lateral contour.

F. goldfussi is very frequent in the upper faunule of the Midway formation. Just how distinctive it is in the Texas section can not at present be stated with assurance.

In Halkyard's publication on the upper Eocene fauna of Biarritz a species has been referred to *F. goldfussi,* but since the description states that the growth of the test is almost invariably Flabelline, it is doubtful whether the form ought strictly to bear this name. The species was originally found in the upper Cretaceous in Germany.

FRONDICULARIA BUDENSIS (Hantken)

Pl. V, figs. 5a, b

(Plesiotypes—Walker Museum Coll. 33057, Sta. 46)

Flabellina budensis Hantken, 1875, Mittheil. Jahrb. k. geol. Anstalt, vol. 4, p. 44, pl. 4, fig. 17.

Test transparent, thinly and evenly compressed, elongate elliptical to ovate, rarely apiculate, aboral extremity bluntly pointed; periphery very narrowly rounded; chambers numerous, narrow, smooth, partially coiled in early portion of test followed by typical sagittate chambers; sutures very faintly depressed between later chambers; shell wall very thin and smooth; aperture central, circular, prolonged, radiate.

Length up to 1 mm.

The original form of this species was described from the *Clavulina szaboi* beds (Oligocene) of Hungary, and the figure of that form bears the precise characteristics of the Midway specimens. The general outline of the test varies somewhat according to the number of Cristellarian chambers in the development and to the degree of overlap of the sagittate chambers. *F. advena,* a name introduced by

[67]Hantken, M., Die Fauna der Clavulina Szaboi Schichten, Foraminiferen: Mitth. a. d. Jahrb. ungar. geol. Anstalt, vol. 4, p. 43, pl. 13, fig. 11, 1875.

Cushman[68] to include several forms previously described as *F. inaequalis* by Brady, Flint, and himself, is a much more elongate species with few chambers in the coiled area and a larger and more globular proloculum than is exhibited by *F. budensis.*

In the upper strata of the Midway formation this species is frequent in clays carrying a varied fauna of hyaline forms, and its occurrence is limited to this stratigraphic zone in the Texas section.

Besides the original record of *F. budensis* in the Oligocene of Hungary, the only subsequent reference to the species is in Egger's treatment[69] of a Cretaceous fauna of the upper Bavarian Alps. His figures, however, indicate a very different form, and they have consequently been omitted from the above synonymy.

FRONDICULARIA OLDHAMI, n. sp.

Text figure 12

(Cotypes—Walker Museum Coll. 33357, Sta. 3A)

Test thin, elongate, about twice as long as broad in maturity, very smooth; early chambers strongly incoiled and passing gradually from this Cristellarian structure to the series of typical sagittate chambers; sutures expressed by dark lines; aperture radiate, protruding.

Length up to 1.3 mm.

At present an insufficient number of specimens is available for a thorough understanding of this very rare Midway species discovered just as the bulletin is ready to go to press. The small sample of clay from station 3A, a shallow field ditch about 4 miles northwest of Campbell (fig. 7) has yielded only one perfect specimen (fig. 12a) and a few fragments that display the stouter early part of the test. The species is introduced into the paper at this late date

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[68]Cushman, J. A., Foraminifera of the Atlantic Ocean: U. S. Nat. Mus. Bull. 104, pt. 4, p. 141, pl. 20, figs. 1, 2, 1923.

[69]Egger, J. G., Foraminiferen und Ostrakoden aus den Kreidemergeln der Oberbayerischen Alpen: Abh. k. bayer. Akad. Wiss., Cl. II, vol. 21, p. 107, pl. 10, figs. 1, 2, pl. 12, figs. 24, 25, pl. 15, figs. 19, 20, 1899.

to complete the group of Frondicularians now known in the Midway formation, since the number of species is unusually large and interesting for a Tertiary fauna.

The only material that has furnished tests of *F. oldhami*[70] is true basal Midway clay, but no statement can be made at present regarding its stratigraphic distribution.

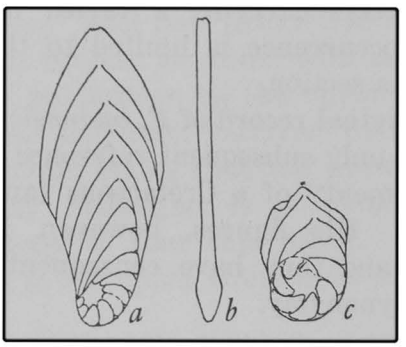

Fig. 12.—*Frondicularia oldhami* n. sp., ×25, sta. 3A. *a*, Complete mature specimen in side view. *b*, Peripheral view of same specimen. *c*, Fragment of early portion of another specimen displaying a more rapid change from the Cristellarian structure to the Frondicularian structure.

FRONDICULARIA RUGOSA (d'Orbigny)

Pl. V, fig. 1; text fig. 13

(Plesiotypes—Walker Museum Coll. 33058, Sta. 40; 33358, Sta. 3A)

Flabellina rugosa d'Orbigny, 1840, Mém. Soc. Géol. France, ser. 3, vol. 4, pt. 1, p. 23, pl. 2, figs. 4, 5, 7.

Flabellina rugosa d'Orbigny, 1846, Foram. Foss. Vienne, p. 93, pl. 21, figs. 13, 14.

Test equally compressed, thin, subrhomboid; early chambers Flabelline followed by the typical sagittate chambers, smooth or with few punctations; sutures marked by conspicuous, thin elevations; aperture protuding, radiate, central.

Length up to 1 mm.; usually less.

[70]The new specific name is given in honor of Mr. A. E. Oldham, who has taken an active interest in the development of this paper by collecting several samples on both sides of the Cretaceous-Eocene contact in northeast Texas.

A very good understanding of the structure and outline of this species as it occurs in the Texas Midway has been reached just as this bulletin is about to go to press.[71] The features as now understood are presented in text figure 13. Numerous specimens gathered from the same sample present an interesting series of variations from a few rather young forms (fig. 13a) almost precisely like d'Orbigny's type in the Craie Blanche to a broadly ovate outline (fig. 13d). This variation in outline is the direct result of the degree with which the sagittate chambers embrace the coiled early portion. The average test of this species in the Texas Midway is expressed by figure 13c.

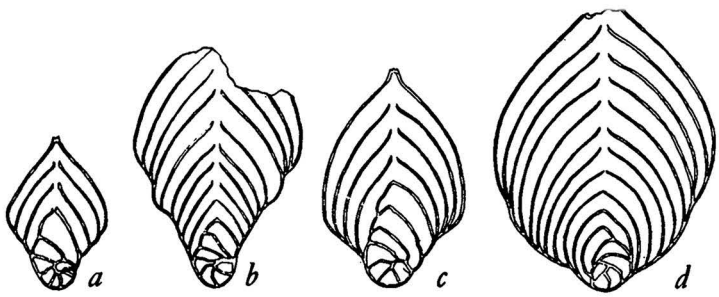

Fig. 13.—*Frondicularia rugosa* (d'Orbigny), ×25, from basal Midway clays taken from station 3A about 4 miles by road northwest of Campbell, Hunt County (see fig. 7). *a*, Rather young specimen that resembles very closely d'Orbigny's type for this species. *b*, Mature test that presents the minimum degree with which the sagittate chambers embrace the coiled portion. *c*, Average test of the species in the basal Midway clays. *d*, Specimen showing the maximum degree with which the sagittate chambers embrace the coiled portion and its resultant broadly ovate outline.

Only the basal clays of the Midway have yielded specimens of *F. rugosa*. As the tests in these beds are generally leached and in fragmentary condition, complete tests are very difficult to procure. It is too rare in this formation to possess any real stratigraphic value, and it is somewhat doubtful whether the form is restricted to this narrow zone in the Texas section. A species referred by Mrs. Applin to

[71] A sample of richly foraminiferal clay from station 3A (see fig. 7) was submitted by Mr. A. E. Oldham for examination, and it has added considerable to the previous knowledge of the Frondicularian group in the fauna.

F. rugosa occurs in the Miocene strata[72] on the salt domes along the coast, but it differs from the Midway form in outline and also from the original in some respects. Samples of Taylor clays have yielded specimens of a species identical in form and structure, but its chambers are distinctly pustulate, and it can perhaps better be referred to *F. interpunctata* (von der Marck).

F. rugosa (d'Orbigny) was originally described from the Craie Blanche (Senonian) of the Paris Basin. Later in the Vienna Basin monograph d'Orbigny discussed the genus *Flabellina* and figured this form to illustrate the characteristics of this genus, but he did not report the species as a member of the Miocene fauna treated in that publication.

FRONDICULARIA DELICATISSIMA n. sp.

Pl. V, fig. 4

(Holotype—Walker Museum Coll. 33059, Sta. 43)

Test very thin, broadly subovate, tapering rapidly toward the apertural extremity and bluntly rounded posteriorly; peripheral edges narrowly quadrate; early chambers Flabelline and irregularly coiled, later series typically sagittate; sutures delicate, thin, raised ridges from which branch a few wavy elevations especially near the apertural extremities of the sutures; shell wall coarsely punctate aperture protruding.

Length up to .95 mm., average .5 mm.

The broad oval form of the test and the finely branching character of the sutural elevations makes this form distinct from any observed in faunas already described. In most specimens the first true sagittate chamber embraces almost or wholly the coiled area, but this feature is much less exaggerated than in a common Cretaceous form of similar structure.

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[72]Applin, E. R., Ellisor, A. E., and Kniker, H. T., Subsurface stratigraphy of the Coastal Plain of Texas and Louisiana: Bull. Am. Assoc. Pet. Geol. vol. 9, p. 99, pl. 3, fig. 5, 1925.

In the Midway formation *F. delicatissima* has been observed only in the upper strata, where it is frequent. In the Texas Cretaceous available for comparative studies no similar species has been observed, but some Brownstown marl from Arkansas shows it to be common in that formation.

Genus POLYMORPHINA d'Orbigny, 1826

POLYMORPHINA LACTEA (Walker and Jacob)

Pl. VI, figs. 7a–c

(Plesiotype—Walker Museum Coll. 33060, Sta. 2B)

Serpula lactea Walker and Jacob, 1798,, Adam's Essays, ed. 2, p. 634 pl. 24, fig. 4.

Polymorphina lactea Williamson, 1858, Rec. Foram. Gr. Brit., p. 71, pl. 6, fig. 147.

Polymorphina lactea Parker and Jones, 1870, Trans. Linn. Soc., vol. 27, p. 213, pl. 39, fig. 1.

Polymorphina lactea H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 559, pl. 71, fig. 11.

Polymorphina lactea Burrows, Sherborn, and Bailey, Jour. Roy. Mic. Soc., p. 561, pl. 11, fig. 9.

Polymorphina lactea Chapman, 1896, Jour. Roy. Mic. Soc., p. 9, pl. 2, fig. 3.

Polymorphina lactea Sidebottom, 1907, Mem. and Proc. Manchester Lit. Phil. Soc., vol. 51, No. 9, p. 9, pl. 2, fig. 11.

Polymorphina lactea Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 84, pl. 34, fig. 8.

Polymorphina lactea Cushman, 1920, U. S. Geol. Survey Prof. Paper 128, p. 68, pl. 11, figs. 3, 4.

Polymorphina lactea Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 146, pl. 39, figs. 9, 11.

Test obtusely ovate, slightly unsymmetrical; chambers few (usually three), smooth, oblique, faintly inflated; sutures distinct, very little depressed; aperture round, radiate.

Length up to .2 mm.

From *P. gibba* d'Orbigny this species in the Midway is differentiated by its smaller size, faintly inflated chambers, and more oblique sutures; *P. communis* d'Orbigny is a

larger species with four or five chambers, which exhibit very distinct inflation.

Throughout the Midway *P. lactea* is a frequent form and is perhaps most common in the basal zone. Its persistence through several formations renders it valueless stratigraphically.

The geologic range of this form is very long. It is known to have existed from the Jurassic and is present in our present seas.

POLYMORPHINA GIBBA d'Orbigny

Pl. VI, figs. 8a, b

(Plesiotypes—Walker Museum Coll. 33061, Sta. 3)

Polymorphina (Globulina) gibba d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 266, No. 20; Modèle No. 63.

Globulina gibba d'Orbigny, 1846, Foram. Foss. Vienne, p. 227, pl. 13, figs. 13, 14.

Polymorphina gibba H. B. Brady, Parker, and Jones, 1870, Trans. Linn. Soc., p. 216, pl. 39, fig. 2.

Polymorphina gibba H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 561, pl. 71, fig. 12.

Polymorphina gibba Sherborn and Chapman, 1886, Jour. Roy. Mic. Soc., p. 755, pl. 16, fig. 5.

Polymorphina gibba Chapman, 1896, Jour. Roy. Mic. Soc., p. 9, pl. 2, fig. 5.

Polymorphina gibba Bagg, 1901, Md. Geol. Survey, Eocene, p. 248, pl. 63, fig. 13.

Polymorphina gibba Bagg, 1904, Md. Geol. Survey, Miocene, p. 477, pl. 133, fig. 4.

Polymorphina gibba Sidebottom, 1907, Mem. Proc. Manchester Lit. Phil. Soc., vol. 51, pt. 3, p. 10, pl. 2, figs. 15–17.

Polymorphina gibba Cushman, 1913, U. S. Nat. Mus. Bull. 71, pt. 3, p. 85, pl. 41, fig. 11.

Polymorphina gibba Cushman, 1918, U. S. Geol. Survey, Bull. 676, p. 11, pl. 2, fig. 4; p. 52, pl. 11, fig. 5.

Polymorphina gibba Cushman, 1921, U. S. Nat. Mus. Bull. 100, vol. 4, p. 267.

Polymorphina gibba Cushman, 1922, U. S. Geol. Survey Prof. Paper 129, pl. 17, fig. 3; p. 94, pl. 18, fig. 3.

Polymorphina gibba Cushman, 1923, U. S. Nat. Mus. Bull. 104, pt. 4, p. 150.

Test very broadly oval in lateral view, slightly compressed; chambers few, smooth, uninflated; sutures marked by dark lines; aperture produced, radiate.

Length up to .4 mm.

This simple form in the Midway is practically identical with d'Orbigny's form of this name in the Miocene of the Vienna Basin, but no opportunity has presented itself to make comparisons with the type, which is said to be almost globular. *P. aequalis* d'Orbigny is very similar in structure but is considerably more compressed. *P. lactea* d'Orbigny has more oblique sutures and a faint inflation of its chambers. *P. gutta* d'Orbigny is somewhat more elongate.

The best development of *P. gibba* in the Midway formation in Texas is in the basal zone, where it is very common. As very similar tests occur in Cretaceous strata in the Gulf Coast section, it is doubtful whether it has any stratigraphic significance.

It is a frequent form in all ages from the Jurassic into present times.

POLYMORPHINA COMMUNIS d'Orbigny

Pl. VI, figs. 12a, b

(Plesiotype—Walker Museum Coll. 33062, Sta. 2C)

Polymorphina (Guttulina) communis d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 266, No. 15, pl. 12, figs. 1–4.

Polymorphina communis d'Orbigny, 1846, Foram. Foss. Vienne, p. 224, pl. 13, figs. 6–8.

Polymorphina communis H. B. Brady, Parker, and Jones, 1870, Trans. Linn. Soc., vol. 27, p. 224, pl. 39, fig. 10.

Polymorphina communis H. B. Brady, Challenger, vol. 9 (Zool.), p. 568, pl. 72, fig. 19.

Polymorphina communis Chapman, 1896, Jour. Roy. Mic. Soc., p. 13, pl. 2, fig. 15.

Polymorphina communis Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 319, pl. 67, fig. 6.

Polymorphina communis Cushman, U. S. Nat. Mus. Bull. 71, pt. 3, p. 87, pl. 37, fig. 7.

Polymorphina communis Cushman, 1920, U. S. Geol. Survey Prof. Paper 128, p. 68, pl. 4, fig. 5.

Polymorphina communis Cushman, 1923, U. S. Nat. Mus. Bull. 103, pt. 4, p. 147, pl. 40, figs. 1, 2.

Test subovate, somewhat compressed, bluntly acuminate anteriorly, broadly rounded posteriorly; chambers few, tumid; sutures very oblique, depressed; shell wall heavy; aperture slightly elliptical, radiate.

Length up to .5 mm.

The Midway form corresponds very closely to d'Orbigny's original figure in all essential details, except that the sutures on the type are perhaps somewhat more deeply excavated. The strong inflation of the chambers renders confusion with any other Midway forms impossible.

The occurrence of *P. communis* in the Midway formation in Texas is confined almost entirely to the basal strata, where it is by no means common. It occurs in Cretaceous formations in Texas and in higher Tertiaries.

This species has existed from Jurassic times and occurs in marine strata of almost every age through the column since that age. It is frequent today in the present oceans.

POLYMORPHINA OVATA d'Orbigny

Pl. VI, fig. 10

(Plesiotype—Walker Museum Coll. 33063, Sta. 23)

Polymorphina ovata d'Orbigny, 1846, Foram. Foss. Vienne, p. 233, pl. 13, figs. 1–3.

Test elongate, sharply pointed at the primordial extremity and more bluntly pointed at the oral end; chambers smooth, greatly embracing and somewhat inflated; sutures slightly depressed; aperture radiate.

Length up to .5 mm.

The form as here figured is hardly normal for a fully developed specimen of this species, but as it is rare in the Midway, conditions during deposition were possibly unfavourable. It is of no stratigraphic importance as a guide fossil.

POLYMORPHINA SPATHULATA Terquem

Pl. VI, figs. 11a–c

(Plesiotypes—Walker Museum Coll. 33064, Sta. 23)

Polymorphina spathulata Terquem, 1882, Mém. Soc. Géol. France, ser. 3, vol. 2, p. 142, pl. 14 (22), fig. 32.

Test elongate oval to rhomboid, smooth, compressed; chambers little inflated if at all, irregularly alternate; shell wall thick and dense; sutures as faint lines or slight depressions; aperture protruding, radiate.

Length up to .8 mm.

This form in the Midway appears to be very close to Terquem's figure. In this formation it is rare and occurs somewhat more frequently in the upper strata.

POLYMORPHINA CUSHMANI n. sp.

Pl. VI, fig. 9; Pl. XV, figs. 1a–c

(Cotypes—Walker Museum Coll. 33065, Sta. 67; 33066, Sta. 65)

Test broadly ovoid, strongly compressed; peripheral margin narrowly rounded and somewhat lobate; sutures marked by faint depressions toward the margins but marked by irregularly disposed and broken elevations down the central axis on each side of the test; aperture extended, radiate.

Length up to 1 mm.

This species is very distinctive in its surface markings, though the shape and general structure of the test are somewhat like some old forms.

In the Midway formation *P. cushmani* is most frequent in the glauconitic sands and clays in the upper part of the transition zone, which in the belt of outcrop northeast of the Mexia area is marked by phosphatic nodules and southwest of this same area by the abundance of *Venericardia bulla*. In some outcropping clays it is of sufficient abundance to be detected with the aid of a hand lens. Because no other formation in the Texas geologic section has yielded a compressed Polymorphine test bearing strong longitudinal markings, *P. cushmani* becomes very useful as a Midway signpost. The underlying Navarro formation carries very rarely a somewhat similar large species that is much smoother and possesses fewer chambers in its fullest development.

Genus SIPHOGENERINA Schlumberger, 1883

SIPHOGENERINA ELEGANTA n. sp.

Pl. VIII, figs. 1a–c

(Cotypes—Walker Museum Coll. 33067, Sta. 46)

Test elongate; early chambers biserial merging into a succession of alternately oblique chambers that very rarely reach a Nodosarian development; very earliest portion of test marked by indistinct and irregularly developed longitudinal striations and spinulose projections that disappear rapidly upward; mature chambers very smooth and coarsely punctate; sutures sharply depressed; aperture terminal, elliptical, bounded by a short, flaring rim and connected to earlier apertures by an inner tube.

Length up to .9 mm.; average .5 mm.

Only very rarely does *S. eleganta* present one or two Nodosarian chambers. This characteristically exaggerated development of the alternate arrangement of chambers leads to the suspicion that this is the microspheric form of the species, the megalospheric form of which has not yet been observed.

In upper Midway clays this species is rather frequent, but it is in general rare in the basal strata of the formation. A few Navarro outcrops have yielded the same form, and one Taylor locality has proved its presence in that formation. It seems to have disappeared at the end of Midway times, as no record of the form has so far been found in formations of younger age in the Texas section.

Genus RAMULINA Rupert Jones, 1875

RAMULINA LAEVIS Rupert Jones

(Plesiotypes—Walker Museum Coll. 33069, Sta. 46)

Ramulina laevis Rupert Jones, 1873–74, Rep. Proc. Belfast Nat. F. Club; Appendix III, 1875, p. 88, pl. 3, fig. 19.

Ramulina laevis Balkwill and Millett, 1884, Jour. Mic., vol. 3, p. 84, pl. 4, fig. 7.

Ramulina bradyi Rzehak, 1895, Ann. k. k. Naturh. Hofmus., vol. 10, p. 223, pl. 6, fig. 5.

Ramulina laevis Chapman, 1896, Jour. Roy. Mic. Soc., p. 582, pl. 12, fig. 2.

Segments of this species are perfectly smooth, elongate, and unsymmetrical, and are free or very loosely anchored by a few irregularly developed tubercles on one side of the test.

Length of segments up to .6 mm.

The frequent tests found in the Midway material are in form identical with the figures of the specimens from the Gault of Folkestone.[73] However, Chapman makes no mention of its loosely adherent tendency, which in the material here under consideration is a rather rare feature.

In the Midway formation *R. laevis* is very frequent in the upper faunule. Whether it possesses any stratigraphic value can not at present be stated.

RAMULINA sp.

Pl. VIII, fig. 7

(Holotype—Walker Museum Coll. 33068, Sta. 36)

Only one good specimen of this form has been observed in the Midway material examined. This is very smooth and thin shelled, and a few stolon tubes branch off from the swollen portion of the test. It resembles in form the species *R. globifera* Brady[74] as figured by Chapman in his monograph on the Gault of Folkestone, but it possesses no hispidity of shell surface.

In the Midway formation fragments of this form are frequently observed, but it is too rare to be of any value as a marker and is interesting only as a species in the fauna. As further material is found, its specific identity may become clearer.

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[73]Chapman, Frederick, Foraminifera of the Gault of Folkestone: Jour. Roy. Mic. Soc., p. 582, pl. 12, fig. 2, 1896.

[74]Brady, H. B., Report on the foraminifera dredged by H.M.S. *Challenger* during the years 1873–1876: Reports of the Scientific Results of the Voyage of H.M.S. *Challenger*, vol. 9 (Zool.), p. 587, pl. 76, figs. 22–28, 1884.

Genus VITRIWEBBINA Chapman, 1892

VITRIWEBBINA LAEVIS (Sollas)

Pl. VIII, fig. 3

(Plesiotype—Walker Museum Coll. 33070, Sta. 46)

Webbina laevis Sollas, 1897, Geol. Mag., vol. 4, p. 103, pl. 6, figs. 1–3.
Vitriwebbina laevis Chapman, 1892, Geol. Mag., vol. 8, p. 53, pl. 2, fig. 4.
Vitriwebbina laevis Chapman, 1896, Jour. Roy. Mic. Soc., p. 585, pl. 12, fig. 12.
Vitriwebbina laevis Bagg, 1898, U. S. Geol. Survey Bull. 88, p. 36, pl. 2, fig. 4.

Test adherent, composed of a few smooth, hemispherical chambers; aperture protruding, small, round.

Average length of chamber .3 mm.

From *V. chapmani*[75] this species is distinguished by its smaller test and shorter chamber. It is frequent in the Midway in both faunal zones.

VITRIWEBBINA CHAPMANI n. sp.

Pl. VIII, figs. 2a, b

(Holotype—Walker Museum Coll. 33071, Sta. 85)

Test adherent, composed of strongly inflated, perfectly smooth, elongate chambers joined by narrow slender tubes, and edged by a slight flange that is so thin and merges so well into the shell on which it is adherent, that it is hardly evident unless the test has been broken away from its support.

Average length of single chamber .7 mm.; average width .3 mm.

From *V. laevis* (Sollas) this species is differentiated by the elongation of its chambers, its larger size, and the faint flange. It is frequently observed on Nodosarian tests in both faunal zones of the formation.

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[75]This species has been named for Mr. Frederick Chapman, whose paleontologic work with both megascopic and microscopic fossils comprises a large contribution to this branch of science.

Family CHILOSTOMELLIDAE

Genus CHILOSTOMELLOIDES Cushman, 1926

CHILOSTOMELLOIDES EOCENICA Cushman

Pl. VIII, figs. 8a, b

(Plesiotype—Walker Museum Coll. 33072, Sta. 85)

Chilostomelloides eocenica Cushman, 1926, Contrib. Cushman Lab. Foram. Res., vol. 1, pt. 4, p. 78, pl. 11, fig. 20.

Test elongate ellipsoid, about twice as long as broad; shell wall very thin, smooth, and finely punctate; aperture semilunar and highly flaring, with a conspicuous lip.

Length of only perfect specimen .38 mm.

The type form described by Cushman came from the Midway formation in the Mexia area. Though numerous samples examined from this formation show badly crushed and deformed specimens that undoubtedly belong to this species, only the clay from the Alamo Brick Company pit has yielded a perfect test in these present studies. This same clay is rich in *Allomorphina trigona.* In the London clay a stouter species, now called *Chilostomelloides oviformis* (Sherborn and Chapman)[76] has been reported.

Genus ALLOMORPHINA Reuss, 1850

ALLOMORPHINA TRIGONA Reuss

Pl. VIII, figs. 5a, b

(Plesiotypes—Walker Museum Coll. 33073, Sta. 85)

Allomorphina trigona Reuss, 1850, Denk. Akad. Wiss. Wien, vol. 1, p. 380, pl. 48, fig. 14.

Allomorphina trigona H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 438, pl. 55, figs. 24–26.

Allomorphina trigona Rzehak, 1888, Ann. k. k. nat. Hofmus., vol. 3, p. 259, pl. 11, fig. 2.

Allomorphina trigona Egger, 1893, Abh. k. bay. Akad. Wiss., München, Cl. 2, vol. 18, p. 305, pl. 9, figs. 3, 4.

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[76]Cushman, J. A., The genus Chilostomella and related genera: Contrib. Cush. Lab. Foram. Res., vol. 1, pt. 4, p. 77, pl. 11, figs. 17, 21, 1926.

Test bluntly subtrigonal; periphery broadly rounded; chambers few, 3 in each whorl, considerably embracing, inflated; sutures slightly depressed; shell wall thin, very smooth, distinctly porous; aperture a narrow slit bearing a conspicuous flap at the base of the final chamber on the ventral face.

Length up to .35 mm.

The original figure has not been available for reference, but illustrations of forms of this name are sufficiently consistent to render identification quite certain. The figure of *A. cretacea* by Reuss in his paper on the chalk marls of Lemberg (Galicia) is similar in outline, but the chambers are so completely embracing that inner whorls are totally obscured by the final whorl.

The occurrence of good specimens of *A. trigona* in the Midway formation of Texas is rare, though crushed and badly deformed tests are frequent. The locality that presents the best material of this species is the clay of the Alamo Brick Company pit near San Antonio (sta. 85). A sample of Midway from near Hope, Arkansas, shows it to be a common form at that locality. The Navarro clays of Hunt County present frequent tests of this form.

Tertiary deposits in Europe show *A. trigona* rarely, and studies of dredgings reveal its presence today.

ALLOMORPHINA GLOBULOSA n. sp.

Pl. VIII, figs. 4a, b

(Holotype—Walker Museum Coll. 33074, Sta. 64)

Test bluntly ellipsoidal, last three chambers only partly embracing on superior face thus revealing the inner whorl; chambers very smooth and thin shelled; sutures not depressed; aperture a narrow slit at base of final chamber and protected by a conspicuous, somewhat flaring lip.

Length of only specimen .35 mm.

From *A. trigona* Reuss this new species differs in showing no angulation of outline and in the greater overlap of its chambers, so that the last two almost complete the final whorl. As only one specimen has been found in the Midway

material, no statement can be made regarding its distribution either geographically or stratigraphically.

Genus ELLIPSOPLEUROSTOMELLA A. Silvestri, 1903

It has been impossible to procure the publication that introduced this genus, but a very clear understanding of its fundamental features has been possible through the description of the now-discarded genus *Ellipsoidella* introduced by Heron-Allen and Earland in their monograph on the foraminifera of Selsey Bill, Sussex. These English workers created this generic name to meet the needs of a form found in the chalk flints, but later in the same monograph the name was withdrawn, because the authors discovered that Silvestri had already described such a stoloniferous Pleurostomelloid test which he called *Ellipsopleurostomella.* Since the original description for this genus is not at present available, the description of *Ellipsoidella* is here quoted as a definition:

> "Test free, cylindrical, the earlier chambers somewhat compressed and arranged in an irregularly triserial or biserial manner, the later chambers Nodosarian; aperture a terminal crescentic slit surmounted by a slightly raised and overhanging process. The interior of each chamber traversed from base to apex by a column similar in appearance, position, and structure to the internal column of *Ellipsoidina.*" Jour. Roy. Mic. Soc., 1910, p. 414, pl. 10, figs. 1–11.

In making a study of the Midway species that belongs to this genus Dr. Cushman has very kindly examined the specimens and has, upon comparison of Silvestri's original paper with the above description by Heron-Allen and Earland, confirmed the withdrawal of the name *Ellipsoidella* which duplicates the genus Ellipsopleurostomella previously erected.

ELLIPSOPLEUROSTOMELLA ATTENUATA n. sp.

Pl. VIII, figs. 6a–d

(Cotypes—Walker Museum Coll. 33075, Sta. 46)

Test long, tapering, straight or slightly uneven; chambers inflated, smooth, first two or three Textularian followed by

a Bifarine series that merges into true Nodosarian succession; sutures faint lines in early part of test and faint constrictions above; successive apertures connected by an internal column, and final aperture a somewhat curved terminal fissure one side of which arches slightly over the other.

Length up to .8 mm.

This new Midway species is more slender and tapering than *E. pleurostomelloides*,[77] and the alternating character of the earliest chambers is less conspicuous because of the lack of sutural constrictions and a very opaque shell wall. The mineral matter filling the tests renders the inner tube difficult to observe, but a rare specimen shows a few empty chambers that exhibit this important generic feature. *Ellipsoidina lorifera* Halkyard of the Eocene at Biarritz is very similar in general appearance, and early studies of some rather poor specimens of this Midway form pointed strongly to identification with this uniserial test. Continued search for further material has yielded some specimens that are more convincing, and Dr. Cushman has very kindly examined the specimens and confirmed the author's interpretation of the arrangement of the chambers.

In the Midway formation *E. attenuata* has been observed mainly in the clay that outcrops in the brick yard west of Mexia (sta. 46), where it is a rare form. At station 23 it is an exceedingly rare species of the large assemblage that characterizes this outcrop. A single specimen has been found in some material from the transition zone in northeast Texas collected too late to record formally the locality in this publication. The only other locality from which specimens have been obtained is a chalky layer in the upper part of the Taylor formation in an abandoned pit two miles southwest of the town of Taylor on the Round Rock road. These Cretaceous forms are completely replaced by crystalline calcite, and the details of structure are consequently less easily observed, but the general form is identical with

[77]Heron-Allen, E., and Earland, A., On the recent and fossil foraminifera of the shore-sands of Selsey Bill, Sussex: Jour. Roy. Mic. Soc., p. 415, pl. 10, figs. 1–11, 1910.

those of the Midway formation, and the arrangement of chambers appears the same.

Family GLOBIGERINIDAE

Genus GLOBIGERINA d'Orbigny, 1826

In assigning names to the two most common Globigerine forms in the Midway formation, it has taken considerable courage to create for them new names. The stratigraphic significance of various subordinate details in the tests of this series throughout the Texas geologic section has proved so worthy of consideration, that to meet the situation it seems imperative to break up the series in such a way that the names will bear to this stratigraphic sequence a definite relationship.

GLOBIGERINA PSEUDO-BULLOIDES n. sp.

Pl. VIII, figs. 9a–c

(Cotypes—Walker Museum Coll. 33076, Sta. 23)

Test rotaliform, very obtusely trochoid to plane dorsally, composed of about two and one-half convolutions, of which the last consists most generally of 5 (rarely 6) highly ventricose chambers increasing rapidly in size; periphery broadly rounded and lobate; shell wall thin and distinctly punctate but finely reticulate; superior face bearing a spire of small chambers only very slightly elevated, if at all, above the circumambient chambers of the final whorl; inferior face less convex and with a very distinct, though not large, umbilical depression; aperture a single, moderately large, lunate opening on the last chamber extending from the margin to the umbilicus and edged with a narrow, delicate, flaring lip.

Diameter up to .4 mm.

The general chaos existing in the literature regarding the characteristics of Globigerine forms of this type has rendered the position of this Midway species in the old synonymy rather doubtful. Careful consideration of original descriptions and those of later good authorities assign to *G. bulloides* d'Orbigny and *G. cretacea* d'Orbigny multiple

apertures. As this feature characterizes other similarly constructed Globigerine forms in lower strata of the Texas section, it seems best to reserve these old names for those tests that correspond much more closely with the original definitions. *Globigerina subcretacea* Chapman is a very low-spired form with a general arrangement of chambers like *G. pseudo-bulloides,* but again the multiple openings become a diagnostic feature.

The species *G. pseudo-bulloides,* therefore, is especially defined by the single, finely arched aperture bearing a narrow and slightly flaring lip on the more perfect and well-developed specimens. From its companion form in this formation, *G. triloculinoides,* which presents usually 3½ chambers to the last whorl and rather conspicuously reticulate surface, this species is sharply separated by having 5 chambers and a distinctly porous but less coarsely reticulate shell surface. Most of the Cretaceous species of the Texas section that bear a general resemblance to this Midway form show multiple openings, which are considerably obscured by the mineralization of the tests in these older strata. Some forms in the lower Cretaceous formations appear to be identical with *G. pseudo-bulloides* of the Midway.

This species occurs commonly throughout the Midway section, but in the richly foraminiferal strata of the lower portion of the upper zone it is very abundant. Though a similar form occurs in some parts of the Del Rio formation, no confusion can possibly arise in employing this form as a marker.

GLOBIGERINA TRILOCULINOIDES n. sp.

Pl. VIII, figs. 10a–c

(Cotypes—Walker Museum Coll. 33077, Sta. 23)

Globigerina triloba Egger, 1899, Abh. k. bay. Akad. Wiss., Cl. 2, vol. 21, pt. 1, p. 171, pl. 21, fig. 8.

Globigerina bulloides Cushman, 1920, U. S. Geol. Survey Prof. Paper 128, p. 68, pl. 11, fig. 6.

Test spiral, trochoid, composed of about 2 convolutions, the last of which is composed of 3½ very rapidly increasing and highly globose chambers; periphery very broadly

rounded and distinctly lobate; shell surface strongly reticulate; superior face rounded with a very low spire of neatly coiled tiny chambers of the preceding whorl; inferior face rounded with a very shallow umbilical depression; aperture a small arched slit on the last chamber and edged with a more or less prominent, delicately notched flap that extends from a point near the periphery to the umbilical depression.

Greatest diameter up to .35 mm.; usually less.

The somewhat similar species, *G. triloba* Reuss, shows but three visible chambers on both sides of the test, and this new name is created to include such similar structures as display plainly the chambers of the preceding convolution and but a single aperture. Cushman's *G. bulloides* of the north Pacific (U. S. Nat. Mus., Bull. 71, pt. 4, p. 5, pl. 2, figs. 7–9) has an arrangement of chambers much like that of this new species, but it has multiple apertures opening into the umbilicus. The Miocene form described by Cushman also has the characteristic structure of *G. triloculinoides,* but the apertural features have not been included in his description, and it is doubtful whether his form should be here included in the synonymy. The presence of the conspicuous apertural flap appears somewhat unusual in the Globigerine series, and its degree of development in Midway material varies somewhat from a narrow lip to the wide flap herewith figured.

In the compact, siltless clays of the lower portion of the upper Midway zone, *G. triloculinoides* is most common. It is rare in the basal beds of the formation. Since no similar form has been seen in Cretaceous strata of this section, it aids in marking the Cretaceous-Eocene contact. In higher Eocene and in Oligocene strata in Texas a much larger species of this construction occurs commonly, but the umbilical lip is less conspicuous.

GLOBIGERINA COMPRESSA n. sp.

Pl. VIII, figs. 11a–c

(Cotypes—Walker Museum Coll. 33078, Sta. 23)

Test small, rotaliform, closely coiled, somewhat compressed, equally biconvex; peripheral margin bluntly angu-

lar, lobate; chambers increasing gradually, 5 in last-formed whorl, moderately inflated, overlapping on dorsal face; sutures distinctly depressed and strongly curved on the dorsal side; shell wall thin, smooth, finely punctate; aperture a single moderately arched slit protected by a definite flaring flap at base of septal face and extending into the small but distinct umbilical depression.

Diameter up to .4 mm.; average .3 mm.

In general the structure of the test resembles *G. pseudobulloides*, but its shell surface is finer and smoother, the chambers are distinctly compressed rendering the periphery obtusely angular, the sutures curve markedly on the dorsal face, and the size of the test is smaller.

In the upper Midway *G. compressa* is common in the siltless clays that carry a fauna rich in hyaline species. No similar species occurs in Cretaceous formations. One in the Claiborne referred to *G. aequilateralis*[78] bears a resemblance in the shape of its chambers but differs in its manner of coiling.

Genus PULLENIA Parker and Jones, 1862

PULLENIA QUINQUELOBA (Reuss)

Pl. VIII, figs. 12a, b

(Plesiotypes—Walker Museum Coll. 33079, Sta. 46)

Nonionina quinqueloba Reuss, 1851, Zeit. deutsch. geol. Gesell., vol. 3, p. 47, pl. 5, fig. 31.

Pullenia sphaeroides Parker and Jones, 1865, Phil. Trans., vol. 155, p. 368, pl. 17, fig. 53.

Pullenia quinqueloba H. B. Brady, 1884, Challenger, vol. 9, (Zool.), p. 617, pl. 84, figs. 14, 15.

Pullenia quinqueloba H. B. Brady, Parker, and Jones, 1888, Trans. Zool. Soc., vol. 12, p. 226, pl. 43, figs. 22, 23.

Pullenia quinqueloba Burrows and Holland, 1897, Proc. Geol. Assoc., p. 47, pl. 2, fig. 21.

Pullenia quinqueloba Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 324, pl. 70, fig. 5.

Pullenia quinqueloba Cushman, 1914, U. S. Nat. Mus. Bull. 71, pt. 4, p. 21, pl. 13, fig. 2.

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[78]Manuscript by Mrs. Esther R. Applin.

Pullenia quinqueloba Halkyard, 1917, Mem. Proc. Manchester Lit. Phil. Soc., vol. 62, p. 104.

Pullenia quinqueloba Cushman, 1924, U. S. Nat. Mus. Bull. 104, pt. 5, p. 42, pl. 8, figs. 5–9, 11.

Pullenia quinqueloba Heron-Allen and Earland, 1924, Jour. Roy. Mic. Soc., p. 166.

Test plano-spiral, closely coiled, completely embracing, bilaterally symmetrical; peripheral margin broadly rounded; chambers 5 in last-formed whorl; shell wall very smooth and glistening; sutures faintly depressed between last two chambers; aperture a long narrow slit extending over the periphery at base of septal face.

Diameter up to .3 mm.

This well-defined species has typically five chambers in the final convolution, whereas *P. sphaeroides* (d'Orbigny) has but four and is typically less compressed.

In the Midway formation *P. quinqueloba* occurs rarely, but is persistent all along the outcrop of the upper beds. It is a rather rare form in Navarro clays in northeast Texas.

This species has existed since Cretaceous times and is very common in Tertiary formations of Europe. The type came from the Septarian clays of Germany (Oligocene). Burrows and Holland have recorded both *P. quinqueloba* and *P. sphaeroides* as rare forms in the Thanet Beds, but material at hand from bed *E* of the series at Pegwell Bay shows the former very frequent. From the London Clay a single specimen referred to *P. sphaeroides* is reported, but the figure shows about four and one-half chambers. A sample of this same formation from a recent excavation in London has been contributed by Mr. Arthur Earland, and in it numerous specimens of *P. quinqueloba* have been found. Type material furnished by Mr. Frederick Chapman from this same formation carries fewer and less typical specimens.

Family ROTALIIDAE

Genus DISCORBIS Lamarck, 1804

DISCORBIS INFREQUENS n. sp.

Pl. IX, figs. 1a–c

(Cotypes—Walker Museum Coll. 33080, Sta. 29)

Test very small, round, trochoid, the dorsal face being broadly conical and the ventral face almost flat; peripheral margin acute, very faintly lobate; chambers 3 or 4 in final whorl, narrow, strongly curved, very smooth; aperture a narrow arched opening along the edge of the final chamber between the periphery and the umbilicus.

Diameter up to .3 mm.

This exceedingly rare form in the Midway has been observed at only one locality, and it is important merely in being the only representative of the Discorbine type so far discovered in the fauna of this formation. Though the illustration shows but three chambers in the final convolution, recent additions to the author's collection show that somewhat more mature tests have 3½ and even 4 chambers.

DISCORBIS NEWMANAE n. sp.

Pl. IX, figs. 4a–c

(Cotypes—Walker Museum Coll. 33081, Sta. 63)

Test slightly oval, dorsal face being somewhat convex and the ventral face flat or slightly concave; peripheral margin sharp and thin; chambers smooth, distinctly punctate, moderately curved, increasing rather rapidly in size, usually 8 in final whorl; sutures on both sides curved and marked by tapering dark lines; aperture a distinct slit extending from a point near the margin into the small excavated umbilical depression under an apertural lip.

Greatest diameter up to .4 mm.; average .3 mm.

Because of the frequent mineralization (calcite replacement) of the tests of this species in the Midway and consequent obliteration of much significant detail, the concavity

of the ventral face, the unusually loose apertural flap projecting into the umbilicus, and the great degree of lateral compression become the most valuable features for identification of this species.

In the Midway formation in Texas, *D. newmanae*[79] has been observed only in the sandy phases of the basal zone, and in such beds it is generally very common and in some places abundant. Because of the paucity of most of the other species of the basal faunule in these sandy strata in the upper part of the zone, it becomes necessary to rely almost wholly on this species to identify the age of such beds. No other formation in the Texas geologic column has yielded this same form.

DISCORBIS ALLOMORPHINOIDES (Reuss)

Pl. IX, figs. 2a, b

(Plesiotypes—Walker Museum Coll. 33082, Sta. 36)

Valvulina allomorphinoides Reuss, 1860, Sitz. Akad. Wiss. Wien, vol. 40, p. 223, pl. 11, fig. 6.

Discorbina allomorphinoides H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 654, pl. 91, figs. 5, 8.

Discorbis allomorphinoides Cushman, 1915, U. S. Nat. Mus. Bull. 71, pt. 5, p. 2, pl. 9, fig. 1.

Discorbis allomorphinoides Cushman, 1919, Carnegie Inst. Bull. 291, p. 41.

Discorbis allomorphinoides Cushman, 1921, U. S. Nat. Mus. Bull. 100, vol. 4, p. 306, pl. 58, fig. 1.

Discorbina allomorphinoides Heron-Allen and Earland, 1924, Jour. Roy. Mic. Soc., p. 169.

Discorbis allomorphinoides Cushman, Bull. Am. Assoc. Pet. Geol., vol. 10, p. 606, pl. 20, figs. 18, 19; pl. 21, fig. 5.

Test elongate oval, somewhat more strongly convex on the dorsal side; peripheral margin very broadly rounded giving the form a very rotund appearance; chambers few, four in last whorl, enlarging rapidly; sutures faintly depressed; gently curving; shell wall very smooth and glistening; aperture opening into the umbilicus under a large, triangular umbilical flap.

[79]This species has been named for Miss Grace Newman, Paleontologist for Rio Bravo Oil Co. of Houston, Texas.

Length up to .5 mm.; average .4 mm.

The Midway species closely resembles the type in all essential features. The umbilical flap here observed is in the original Cretaceous form more rectangular, but this feature of the test is so delicate that it is easily broken, and few specimens in the material studied have exhibited its perfect shape so clearly as the specimen figured. *Rotalina subconica* as figured by Terquem in his monograph on the upper Eocene of the Paris Basin suggests a relationship to this Midway species, but the illustration is somewhat too conventional to make identification with this Tertiary species certain.

In the upper Midway clays rich in hyaline species *D. allomorphinoides* is frequent, but because of its rarity throughout the formation as a whole, it is not a valuable index fossil.

The earliest known geological occurrence of this species is the lower part of the upper Gault (Minimus clay) of Westphalia, from which it was first described by Reuss. It has since been reported from the Bowden marl (Miocene) of Jamaica,[80] the Velasco formation in Mexico,[81] and from the Miocene strata of Filter Quarry[82] in Victoria, Australia. Monographs on recent faunas show it still exists in the present oceans.

Genus LAMARCKINA Berthelin, 1880

LAMARCKINA RUGULOSA Plummer

Pl. IX, figs. 3a–c

(Paratypes—Walker Museum Coll. 33107, Sta. 23)

Lamarckina rugulosa Plummer, 1926, in Cushman, Contrib. Cushman Lab. Foram. Res., vol. 2, pt. 1, p. 8, pl. 3, figs. 6a–c.

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[80]Cushman, J. A., Fossil foraminifera from the West Indies: Carnegie Inst. Publ. 291, p. 41, 1919.

[81]Cushman, J. A., Foraminifera of the Velasco shale of the Tampico embayment: Bull. Am. Assoc. Pet. Geol., vol. 10, p. 606, pl. 20, figs. 18, 19, pl. 21, fig. 5, 1926.

[82]Heron-Allen, E., and Earland, A., Miocene foraminifera of the "Filter Quarry," Moorabool River, Victoria, Australia: Jour. Roy. Mic. Soc., p. 169, 1924.

Test very broadly elliptical, moderately compressed in average development to almost globular in extreme old age; convolutions few; chambers 5–6 in last-formed whorl, enlarging rapidly, very smooth and glistening on ventral face, highly granular on dorsal face; dorsal sutures slightly depressed and on some specimens marked by a faint ridge of smooth shell matter; ventral sutures faintly depressed; umbilicus deeply excavated; aperture a low arched opening directed into the umbilicus under a narrow and delicately fringed flap on well-preserved tests.

Diameter up to .5 mm.

Though nearly everywhere along the Midway outcrop this species exhibits a strongly granular dorsal face, in unusually shallow-water deposits this roughness is very weakly developed (sta. 67, for example).

L. rugulosa is a very frequent form in upper Midway clays, and as it has been observed in no other part of the Texas geologic section, it becomes a diagnostic fossil for a rather narrow stratigraphic zone. A sample of Wilcox from Woods Bluff, Alabama, shows a species of this same structure, but its dorsal side is smooth with distinctly depressed sutures.

Genus TRUNCATULINA d'Orbigny, 1826

TRUNCATULINA MIDWAYENSIS n. sp.

Pl. IX, figs. 7a–c; Pl. XV, figs. 3a, b

(Cotypes—Walker Museum Coll. 33083, Sta. 23)

Test almost equally biconvex, moderately compressed; peripheral margin rounded; convolutions about 2, the final one being strongly embracing; chambers usually 9 in final whorl, conspicuously punctate, gradually increasing, moderately curving; sutures broadly elevated on both sides, tapering toward the margin, and curved; aperture a slit at base of septal face under a narrow lip that extends to the umbilicus.

Diameter up to .5 mm.; usually less.

From the variety of this species, *trochoidea*, this form is distinguished by the more strongly embracing character of

its final whorl. A sharp line of demarcation is not possible, since passage forms are common, but because of the stratigraphic significance of the variety this differentiation becomes useful.

T. midwayensis is the form found throughout the Midway formation in considerable abundance, whereas the variety is abundant locally in the basal strata only. Though a somewhat similar species is frequent in parts of the Navarro, this species is distinct in being much less compressed. Because of the abundance of the species in this formation, it is a very useful marker.

TRUNCATULINA MIDWAYENSIS n. sp. var. TROCHOIDEA n. var.

Pl. IX, figs. 8a–c

(Cotypes—Walker Museum Coll. 33084, Sta. 40)

From the type this variety is distinguished by the more strongly trochoid dorsal coiling of the convolutions.

Diameter up to .6 mm.; usually less.

At some places the basal Midway strata present only this variety of the species and in considerable abundance. Forms referable to this name are very rare in upper beds of the formation. A predominance of this trochoid test is likely to be indicative of a low position in the basal zone, but it is absolutely diagnostic of the Midway formation in the Texas section and is one of its most valuable guide forms.

TRUNCATULINA ELEVATA n. sp.

Pl. XI, figs. 1a–c

(Cotypes—Walker Museum Coll. 33095, Sta. 40)

Test subconical, the dorsal face being highly elevated and the ventral face gently convex; periphery bluntly angular; chambers usually 7 in final convolution; dorsal sutures moderately oblique, almost straight, strongly elevated; ventral sutures less elevated, radiate from a distinct, thick ridge of shell matter surrounding a small excavated umbilicus; shell wall coarsely punctate; aperture a small, arched slit near this periphery.

Diameter up to .35 mm.

This species is so distinctive in the Midway fauna that no confusion can arise in its identity. Its occurrence only in the basal zone of the formation and upward through the narrow zone of transition in a few localities makes it especially valuable as a guide species. So far as known at present no similar form has been observed in any other formation in the Texas geologic column.

TRUNCATULINA WELLERI n. sp.

Pl. IX, figs. 6a–c

(Cotypes—Walker Museum Coll. 33085, Sta. 23)

Test small, equally biconvex, considerably compressed; chambers 10–11 in final whorl, strongly punctate, narrow, curved, increasing gradually in size; sutures distinct, narrow, tapering, slightly elevated, and curved in a broad gentle swing, those on the ventral side being joined in a low ridge about the small umbilical depression; aperture a low arch very close to the periphery and narrowing toward the umbilicus under a narrow lip.

Diameter up to .35 mm.; usually about .25 mm.

The superifical similarity of *T. welleri* and *Rotalia aequilateralis* may lead to some confusion where the preservation of the tests does not permit observation of apertural characters. They are about the same size in the fauna, but are distinguished by differences in wall punctations, the sutural curvatures, and number of convolutions. From *Anomalina ammonoides* var. *acuta* this species is differentiated by its smaller size, less conspicuous limbation, its lack of a central boss on the dorsal face, and an aperture that extends downward on the ventral side.

In the Midway formation, *T. welleri*[83] is comparatively rare, but in clays rich in hyaline species of the upper faunule it is frequent. In a few places it has been observed in the zone of transition between the two distinct faunal zones.

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[83]This species is named in honor of Prof. Stuart Weller, head of the Department of Paleontology and Director of Walker Museum, University of Chicago. Dr. Weller has very generously placed the facilities of his laboratories and libraries at the author's disposal during two quarters at the university and has freely given valuable suggestions during the development of this paper.

TRUNCATULINA ALLENI n. sp.

Pl. X, figs. 4a–c

(Cotypes—Walker Museum Coll. 33086, Sta. 23)

Test almost equally biconvex, the ventral side of most specimens being the more rounded; periphery subacute and bordered by a band of clear shell material, faintly lobate in its latest development; chambers 10–11 in last convolution, very coarsely punctate, previous whorls concealed by strong elevations of shell matter that follow the base of the chambers on the dorsal face; sutures on dorsal side marked by conspicuous elevations of transparent shell matter that taper and curve gently toward the periphery; sutures of the ventral face very slightly elevated and curving outward from the large smooth umbilical boss; aperture a large arched opening over the periphery and extending farther downward on the ventral side.

Diameter up to .7 mm.; average about .4 mm.

Though the dorsal face is on almost all specimens marked by strong spiral limbations as shown in the figure, some with weaker development are frequent, and these show instead of the spiral an irregular filling of shell matter. The ventral aspect of all these forms proves its identity with this species, for the large, low, smooth umbilical boss is persistent. The bilateral convexity varies somewhat from an almost flat dorsal face to a test that is nearly equally biconvex. The angular periphery, somewhat less coarse punctations, the smooth low umbilical filling, and larger number of chambers in the whorl separate it sharply from *T. vulgaris* with which it is associated in the fauna. Forms very similar to *T. alleni* have been referred to *T. ungeriana* (d'Orbigny)[84] and *T. akneriana* (d'Orbigny)[85] but they are so very different from either of these types as figured in the monograph on the Miocene of the Vienna Basin, that identity of this Midway species with either of these old forms seems impossible.

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[84]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiaire de Vienne: p. 157, pl. 8, figs. 16–18, 1846.

[85]Idem. p. 156. pl. 8, figs. 13–15, 1846.

In the Mexia area, *T. alleni*[86] occurs only in strata above the Tehuacana limestone, but elsewhere along the belt of outcrop it is observed to be one of the first forms in the top of the basal zone to indicate the transition upward into the true upper faunule. Its very rare occurrence in upper Navarro clays in Hunt and Hopkins counties deprives it of any stratigraphic value.

TRUNCATULINA VULGARIS n. sp.

Pl. X, figs. 3a–c

(Cotypes—Walker Museum Coll. 33087, Sta. 24)

Test almost equally biconvex, the ventral face being slightly the more elevated; peripheral margin broadly rounded, frequently somewhat lobate; chambers 7–9 in last whorl, last two or three distinctly turgid; sutures marked by strong elevations of clear shell material curving gently toward the periphery from a very high ridge of irregularly disposed mass of shell matter that follows the inner edge of the whorl and produces a more or less well-developed spiral on both faces; shell wall more coarsely punctate than any other species in the fauna; aperture a long, arched slit extending from the periphery toward the umbilicus under a narrow lip.

Diameter up to .6 mm.

In some parts of the formation this species shows a weaker development than does the type specimen figured. The general character of these tests is the same, but the limbations are less conspicuous and the chambers fewer. Its very coarsely porous shell renders its identity in the Midway fauna very easy.

In the Mexia area *T. vulgaris* is strictly an upper Midway species, but northeast where the change from the basal to the upper faunule is more gradual, it occurs in the top of the lower zone and continues through the narrow zone of transition. Its abundance in the Midway formation and its

[86]This species has been named for Dr. Edward Heron-Allen, F.R.S., F.R.M.S., the great English rhizopodist who has contributed very greatly in this field of science during the past three decades.

restriction to these strata make it a very useful guide form. A similar, but rare, species in Navarro clays is less compressed laterally and is marked by very little limbation.

TRUNCATULINA TENERA H. B. Brady

Pl. IX, figs. 5a–c

Plesiotypes—Walker Museum Coll. 33088, Sta. 23)

Truncatulina tenera H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 665, pl. 95, fig. 11.
Truncatulina tenera Egger, 1893, Abh. k. bay. Akad. Wiss., Cl. 2, vol. 18, p. 402, pl. 16, figs. 45–47.
Truncatulina tenera Cushman, 1915, U. S. Nat. Mus. Bull. 71, pt. 5, p. 37, pl. 16, fig. 2; pl. 23, fig. 6.
Truncatulina tenera Heron-Allen and Earland, 1916, Trans. Linn. Soc., London, ser. 2, vol. 11, pt. 13, p. 275, pl. 42, figs. 31–33.
Truncatulina tenera Halkyard, 1917, Mem. Proc. Manchester Lit. Phil. Soc., vol. 62, No. 6, p. 118.
Truncatulina tenera Cushman, 1919, U. S. Nat. Mus. Bull. 100, vol. 4, p. 318, pl. 64, fig. 2.

Test biconvex, the ventral face being very rotund and thick, the dorsal face not so high and somewhat more sharply elevated near the center; peripheral margin bluntly acute and in general somewhat lobate; chambers very smooth and finely punctate, usually 6 in the final convolution; sutures expressed by faint, slightly oblique, narrow bands on the superior face, distinctly depressed, almost straight lines below; aperture a gently curved slit under a narrow lip.

Diameter up to .4 mm.

The only difference between this Midway fossil and the original recent form of this name is in the slight obliquity of its sutures. There should be little doubt about the identification of this species, as its characteristics are distinct, and it is hardly comparable with any other form in the Texas foraminiferal faunas.

Its occurrence in the Midway formation is limited to the upper faunule, where it is frequent and in places common. As no other formation in the section carries this species, it is one of the very useful guide fossils for the upper Midway.

Its only previous record as a fossil in the literature at hand is in Halkyard's monograph on the upper Eocene foraminifera of Biarritz.

TRUNCATULINA CULTER (Parker and Jones)

Pl. X, figs. 1a–c; Pl. XV, fig. 2a, b

(Plesiotypes—Walker Museum Coll. 33089, Sta. 23)

Planorbulina culter Parker and Jones, 1865, Phil. Trans., vol. 155, p. 421, pl. 19, fig. 1.

Anomalina bengalensis Schwager, 1866, Novara-Exped., Geol. Theil, vol. 2, p. 259, pl. 7, fig. 111.

Truncatulina culter H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 668, pl. 96, fig. 3.

Truncatulina culter Egger, 1893, Abh. k. bay. Akad. Wiss., Cl. 2, vol. 18, p. 401, pl. 16, figs. 16–18.

Truncatulina culter Bagg, 1908, Proc. U. S. Nat. Mus., vol. 34, p. 157.

Truncatulina culter Heron-Allen and Earland, 1909, Jour. Roy. Mic. Soc., p. 682.

Truncatulina culter Chapman, 1910, Jour. Linn. Soc., Zool., vol. 30, p. 421.

Truncatulina culter Cushman, 1915, U. S. Nat. Mus. Bull. 71, pt. 5, p. 41, fig. 44 (text), pl. 16, fig. 1.

Truncatulina culter Cushman, 1921, U. S. Nat. Mus. Bull. 100, vol. 4, p. 320, pl. 62, fig. 4.

Test sharply convex ventrally, flat or very gently rounded dorsally; peripheral margin sharply acute and bounded by a broad thin flange; chambers moderately oblique on the dorsal face, 8–9 in the final convolution; dorsal sutures rather broad dense bands that are smooth or slightly elevated; ventral sutures limbate between early chambers of final whorl but generally depressed between last two or three, almost radiate from a small elevated umbilical filling but curved distinctly backward at the junction with the peripheral flange; aperture a slightly curved elongate opening extending transversely from the base of the last chamber near the periphery across the septal face and lying above a triangular dent near the base of the face.

Diameter up to .65 mm.; average .5 mm.

The Midway form of this species is remarkably like the original well-figured but inadequately described north

Atlantic species. One striking and constant character of all illustrations is the somewhat unusual disposition of the aperture, though not every figure has displayed the feature in precisely the form so very clearly presented by the Midway specimens.

T. culter is restricted to the upper faunule of the Midway formation where it is a very frequent form. Because of its persistence in clays that carry few species, it is valuable as a guide species.

A sample of London Clay contributed by Mr. Frederick Chapman has yielded numerous specimens of precisely this same form. Fossil records show that it has been found throughout the Tertiary, but no occurrence has placed it so close to the Cretaceous contact as it lies in the Midway formation in Texas. It is reported from the Eocene of Biarritz,[87] upper Tertiary of Selsey Bill (Sussex),[88] and in the Pliocene of Nicobar Islands.[89]

Genus SIPHONINA Reuss, 1849

SIPHONINA PRIMA n. sp.

Pl. XII, figs. 4a–c

(Cotypes—Walker Museum Coll. 33090, Sta. 46)

Test almost circular, about equally biconvex, considerably compressed laterally; peripheral angle sharply acute and delicately serrate, slightly lobate; chambers usually 5 in last-formed convolution, distinctly punctate, smooth, strongly curved; dorsal sutures marked by the serrate edges of the successive chambers and obliquely curved; ventral sutures excavated, radial from a small, shallow central depression; aperture a small, narrow, elliptical opening at the periphery on the ventral side.

Diameter up to .25 mm.

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[87]Halkyard, E., The fossil foraminifera of the blue marl of Côte des Basques, Biarritz: Mem. Proc. Manchester Lit. Phil. Soc., vol. 62, No. 6, 1917.

[88]Heron-Allen, E., and Earland, A., Recent and fossil foraminifera of the shore-sands of Selsey Bill, Sussex: Jour. Roy. Mic. Soc., p. 682, 1909.

[89]Schwager, Conrad, Fossile Foraminiferen von Kar-Nicobar: Novara-Exped., Geol. Theil, vol. 2, p. 259, pl. 7, fig. 111, 1866.

Undoubtedly from this species has developed the true lipped *Siphonina* of higher formations in the Gulf Coast section. All features of the test are identical with previously described Siphonine structures except that the aperture lacks the conspicuous tubular extension that marks various species figured commonly in the literature. Since no publication available in the preparation of this paper has reported a member of this genus so far back as the lowest Eocene, this particular species may be the primitive form of those species that occur higher in the geologic column. However, even here the Midway does not mark its earliest occurrence historically, for this same species is common and well developed in the Ripley formation, Owl Creek, Mississippi, and has been observed at one locality in the topmost Navarro clays of Texas.

In the Texas Midway formation *S. prima* is a rather frequent form, but more common in the upper faunal zone. The Wilcox clays and marls of Nanafalia, Alabama, contain this same species. Since it began its development in the upper strata of the Navarro formation, it can not be regarded as useful in stratigraphic studies.

A sample of London clay available for study has yielded a number of specimens of *S. prima* identical in every way with the Midway form. Undoubtedly this formation of south England correlates more closely with our Wilcox formation.

Genus ANOMALINA d'Orbigny, 1826

ANOMALINA AMMONOIDES (Reuss) var. ACUTA n. var.

Pl. X, figs. 2a–c

(Cotypes—Walker Museum Coll. 33091, Sta. 23)

Test involute, much compressed, almost equally biconvex but slightly more flattened above; peripheral margin subacute; chambers numerous, about 13–15 to the final convolution, narrow, and slightly curving; sutures marked by more or less distinct limbations, which on the ventral face terminate along the inner edge of the convolution in a series

of fine beads that surround a thick spiral or irregular filling of translucent shell material in the umbilical recess, and on the dorsal face merge at the center into a more or less prominently developed elevated boss; shell wall distinctly but not coarsely punctate; aperture on arched opening over the peripheral margin and extending toward the umbilicus.

Diameter up to .4 mm.; average .25 mm.

From almost every other rotaliform species within the Midway this variety is sharply distinguished by its numerous narrow chambers and its unusual degree of lateral compression. Just what the typical form of this species is can not be stated, but it is inferred from the general assemblage of descriptions for *A. ammonoides* (Reuss) that the periphery was rounded, whereas the slight angulation in our Midway form makes it distinct in the stratigraphic section in this state compared with other species that are common in upper Navarro strata. It is very close to, and perhaps identical with, a small form in Taylor strata.

The Midway formation in Texas carries this variety in abundance throughout both faunal zones. The somewhat similar Navarro species, *A. navarroensis* n. sp. (Pl. II, fig. 6) is characterized by less peripheral angulation, less lateral compression, and a series of very small but distinct beadlike prominences around the umbilical center due to the abrupt termination of the sutural ridges in that area. This Navarro form is one of the most valuable for identification of the formation throughout Texas, as it persists upward through the section to the contact with the Midway in strata that are exceedingly lean in diagnostic species. It therefore becomes imperative that careful distinction be made between *A. ammonoides* var. *acuta* and *A. navarroensis*.

Genus PULVINULINA Parker and Jones, 1862

PULVINULINA EXIGUA H. B. Brady

Pl. XI, figs. 3a–c

(Plesiotypes—Walker Museum Coll. 33092, Sta. 23)

Pulvinulina exigua H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 696, pl. 103, figs. 13, 14.

Pulvinulina exigua Heron-Allen and Earland, 1909, Jour. Roy. Mic. Soc., p. 686.

Pulvinulina exigua Cushman, 1915, U. S. Nat. Mus. Bull. 71, pt. 5, p. 60, pl. 23, fig. 5.

Test small, almost equally biconvex; peripheral margin bluntly acute, very faintly lobate; chambers smooth, finely punctate, 6 in final convolution; sutures on the dorsal side very oblique, almost straight, and expressed as conspicuous, fine dark lines; ventral sutures radiate and slightly curving from a small umbilical filling that lies flush with the convexity of the inferior face; aperture a long, narrow slit extending from near the peripheral margin almost to the umbilicus.

Diameter up to .5 mm.; usually less.

The ventral aspect of *P. exigua* resembles somewhat *Truncatulina tenera* H. B. Brady, but the smaller degree of convexity of this face and the faint curvature of the sutural lines makes the distinction clear, and a comparison of the dorsal aspects of the two forms show the structure of the test entirely different. From the variety *limbata* this form is distinguished only by its smooth sutures; from the variety *obtusa* by its sharper peripheral angulation.

In the Midway formation *P. exigua* is restricted to the upper faunal zone where it is very common. No part of the Cretaceous section in Texas has in the present light of knowledge revealed this species or any variety of the form. The glauconitic strata of the Ripley formation in Mississippi yield a test of this structure, but its ventral convexity is very high, and it must be regarded as a variety. In Alabama the Wilcox marl at Nanafalia yields this species with some frequency.

PULVINULINA EXIGUA H. B. Brady var. OBTUSA Burrows and Holland

Pl. XI, figs. 2a–c

(Plesiotypes—Walker Museum Coll. 33093, Sta. 63)

Pulvinulina exigua var. *obtusa* Burrows and Holland, 1897, Proc. Geol. Assoc., vol. 15, p. 49, pl. 2, fig. 25.

From the types of this species this variety differs in having a much more broadly rounded peripheral margin, and rare specimens are almost globular.

In the Midway formation this compact variety has been observed in some sandy phases of the basal strata. At such places the other basal Midway variety is very rare or absent. The calcite replacement of the tests, so common in sandy beds, frequently obliterates details of structure in this tiny form, but the dorsal aspect of almost every specimen is significant enough for its identification. Because these varieties have been found to bear a general relationship to the lithologic character of the beds or to a definite zone in the Midway, it has been worth while to differentiate them by these varietal names.

This obtuse form was first recognized in the Thanet Beds of England where it is abundant. As the Midway corresponds rather closely in age to these strata in the London Basin, it is interesting to note the occurrence of this variety in both formations. Through the courtesy of Mr. Frederick Chapman material from the Thanet Beds has been made available for study.

PULVINULINA EXIGUA H. B. Brady var. LIMBATA n. var.

Pl. XI, figs. 4a–c

(Cotypes—Walker Museum Coll. 33094, Sta. 3)

From the type of this species this varietal form differs in having strong sutural elevations on the dorsal side and slight elevations on the ventral side.

Diameter up to .5 mm.

In the clays of the basal Midway unit this form is very frequent and in places common. As it is confined to this narrow stratigraphic unit in the Texas section, it is one of the valuable diagnostic species of the faunule.

PULVINULINA RETICULOSA n. sp.

Pl. XII, figs. 5a, b

(Cotypes—Walker Museum Coll. 33096, Sta. 23)

Test broadly elongate, greatly compressed; peripheral margin very sharply acute and conspicuously flanged; chambers rapidly increasing, very coarsely reticulate on

both sides of the test obscuring all sutures on the dorsal face and all but the last one or two on the ventral face; sutures slightly depressed between the last two or three chambers on the ventral side; aperture a narrow slit on the umbilical side.

Length up to .6 mm.

In no part of the Texas geological section has this remarkable form been observed except in the strata of the upper Midway where it is very rare.

PULVINULINA PARTSCHIANA (d'Orbigny)

Pl. XI, figs. 5a–c

(Plesiotypes—Walker Museum Coll. 33097, Sta. 23)

Rotalina partschiana d'Orbigny, 1846, Foram. Foss. Vienne, p. 153, pl. 7, figs. 28–30; pl. 8, figs. 1–3.

Pulvinulina partschiana sp. H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 699, pl. 105, fig. 3.

Pulvinulina partschiana Flint, 1899, Ann. Rpt. U. S. Nat. Mus. for 1897, p. 331, pl. 75, fig. 3.

Pulvinulina partschiana Millett, 1904, Jour. Roy. Mic. Soc., p. 502.

Pulvinulina partschiana Chapman, 1909, Proc. Roy. Soc. Victoria, n. s., vol. 22, p. 287.

Pulvinulina partschiana Cushman, 1915, U. S. Nat. Mus. Bull. 71, pt. 5, p. 64, fig. 60 (text).

Test round, almost equally biconvex, the dorsal face being somewhat the more conical; peripheral margin acute, faintly lobate, bordered by a single band of dense shell material on its dorsal side, by a double band on its ventral; chambers smooth, numerous, about 7–9 in the last whorl; sutures on dorsal side marked by broad bands very rarely elevated but commonly faintly depressed between the last two or three chambers; sutures on ventral side somewhat obliquely radial from a central opaque boss and slightly elevated; aperture a narrow slit extending from close to the periphery about halfway to the umbilical boss.

Diameter up to .5 mm.; usually less.

In some of its minor details *P. partschiana* of the Midway strata shows some variation. Though in general the ventral face is almost flat, some specimens are found to be distinctly

convex ventrally. Many young shells show no peripheral lobation or only the faintest suggestion of such a contour. Though the dorsal face on the average is not marked by elevations along its sutures, rare specimens show this feature slightly, whereas the ventral face as a rule is marked by a somewhat elevated boss and by elevated sutures, except between the last two or three chambers. The Midway forms of this species average one or two fewer chambers than d'Orbigny's type, but in other respects they agree very closely.

In the Midway formation *P. partschiana* belongs strictly to the upper faunule, where it is a frequent form and in places very common. The only higher formation in the Texas section that carries a similar species is the Claiborne, where the test is quite flat dorsally and very sharply elevated ventrally, and in these upper Eocene strata it is very rare.

In Hunt and Hopkins counties samples of upper Navarro clay have yielded locally large numbers of tests of this species that can not be distinguished from those of the upper Midway strata. In two Navarro outcrops rare specimens of a closely related species frequent in Ripley strata are characterized by a reticulate pattern in the central portion of the dorsal face, a feature that marks *P. reticulata* (Reuss)[90] of the Gault.

As a fossil *P. partschiana* has been described from the Oligocene of Germany, the Miocene of the Vienna Basin, and the Batesford limestone of Victoria (Miocene). It is also found today in the present oceans.

Genus ROTALIA Lamarck, 1804

ROTALIA SOLDANII (d'Orbigny) var. AUBANGULATA n. var.

Pl. XII, figs. 1a–c

(Cotypes—Walker Museum Coll. 33098, Sta. 23)

Test almost plano-convex, the dorsal side being flat or faintly convex, the ventral side very strongly convex, com-

[90]Reuss, A. E., Die Foraminferen des norddeutschen Hils und Gault: Sitz. k. Akad. Wiss., Wien., vol. 46, p. 83, pl. 10, fig. 4, 1862.

posed of about two convolutions; peripheral margin bluntly angular; chambers 8–9 in final whorl; sutures slightly depressed between the last two or three chambers on both sides and around the small umbilical excavation, otherwise plain or faintly elevated, moderately oblique dorsally and radiate ventrally; shell wall very finely punctate, very smooth, glistening; aperture a long narrow slit at the base of a broad septal face extending from a point below the periphery almost into the umbilicus.

Diameter up to .4 mm.; usually less.

The Midway form of this well-known species has a much less sharp peripheral angulation than the type described from the Miocene of the Vienna Basin, and the number of its convolutions are fewer. Such minor differences must here be recognized, since in the Texas section this form is present at several horizons, and some of the variations in its form and structure are of stratigraphic value. The Navarro clays carry a form of this species closely related to the Midway variety, but the number of its chambers is less and its periphery is more broadly rounded. Another very rare Navarro form of this species resembles very closely the type.

In the Mexia area where the faunal break is lithologically very sharply marked by the Tehuacana limestone, this form belongs strictly to the upper faunule of the Midway formation. In areas where the two faunal zones are less sharply divided, this species occurs low in the zone of transition.

As a fossil the species *Rotalia soldanii* (d'Orbigny) is very common the world over in upper Cretaceous strata but especially in Tertiaries. It is a frequent form today in the present oceans.

ROTALIA AEQUILATERALIS n. sp.

Pl. XII, figs. 3a–c

(Cotypes—Walker Museum Coll. 33099, Sta. 23)

Test almost equally biconvex, composed of about two and one-half convolutions that increase very slowly in width; peripheral margin narrowly rounded, faintly lobate in the

last-formed portion of the test; chambers compact, numerous, about 10 in final whorl; dorsal sutures distinct, narrow, tapering bands without elevation, strongly curved with a slight angulation, but not oblique, depressed gently between last two or three chambers only; ventral sutures elevated most markedly around the small umbilicus and tapering radially toward the margin, dark on tests filled with mineral matter; aperture a very narrow slit at base of septal face and bearing a very narrow extended lip.

Diameter up to .4 mm.; usually less.

This small and very smooth form resembles superficially *Truncatulina welleri* in this same fauna, but may be distinguished by its finer shell punctations, the angulation of its dorsal sutures, its straight and radiate ventral sutures, the larger number of convolutions, and the characteristic aperture of this type of shell. *R. cretacea* Carsey[91] of the Navarro strata is very similar but it is distinctly larger, averages about 12 chambers in the final whorl, and inclines to be somewhat more convex ventrally, whereas *R. aequilateralis* is slightly more convex dorsally.

In the Midway formation this species is found mainly in the upper faunule, but it is a very rare form in the transition zone. It is nowhere common but is frequent in the highly foraminiferal compact clays in the upper zone. Since a few typical upper Navarro samples have yielded specimens identical with those of the Midway strata, *R. aequilateralis* can not be regarded as stratigraphically diagnostic.

ROTALIA PERPLEXA n. sp.

Pl. XII, figs. 2a–c

(Cotypes—Walker Museum Coll. 33100, Sta. 23)

Test oval, about equally biconvex, considerably compressed; peripheral margin broadly rounded, somewhat lobate; chambers smooth, glistening, finely punctate, gently curving, 6 to the final whorl; dorsal sutures marked by thick, smooth or very slightly elevated, tapering bands that

[91]Carsey, Dorothy O., Foraminifera of the Cretaceous of central Texas: Univ. Tex. Bull. 2612, p. 48, pl. 5, fig. 1, 1926.

become distinctly angular at their broadest points; ventral sutures depressed, radiate from a sunken umbilicus; aperture a conspicuous round opening at the base of the septal face and protected by an arched flap that is directed into the umbilicus.

Length up to .5 mm.; average .35 mm.

The generic position of this species has been very puzzling. In its general structure and appearance it resembles *Pulvinulina hauerii* (d'Orbigny)[92] and *P. eximia* Rzehak,[93] but the apertural features of the Midway form are very different from those of the older species.

The upper Midway faunal unit carries *R. perplexa* very commonly. Because a very few outcrops of topmost Navarro clay have also been found to carry this identical species, it can not be regarded as a stratigraphically diagnostic form. The Claiborne strata in the upper Eocene of Texas is characterized by a similar test that is less compressed, larger, and presents an orifice along the base of the septal face instead of into the umbilical excavation. Material from the Wilcox marls at Nanafalia, Alabama, show *R. perplexa* to have been a frequent species during the deposition of those beds.

Genus ASTERIGERINA d'Orbigny, 1839

ASTERIGERINA PRIMARIA n. sp.

Pl. XII, figs. 8a–c

(Cotypes—Walker Museum Coll. 33101, Sta. 67)

Test round, obtusely conical, the dorsal side being distinctly elevated and the ventral side almost flat; peripheral margin sharply keeled, lobate; number of whorls about two in well-developed tests; chambers 5–6 in final convolution,

[92]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiaire de Vienne: p. 151, pl. 7, figs. 22–24, 1846.

[93]Rzehak, A., Die Foraminiferen des kieseligen Kalkes von Nieder-Hollabrunn und des Melettamergels der Umgegung von Bruderndorf in Niederösterreich: Ann. k. k. naturh. Hofmus., vol. 3, p. 263, pl. 11, fig. 7, 1888.

smooth, conspicuously punctate; dorsal sutures moderately curved faintly elevated, produced peripherally to form the marginal keel, rather strongly elevated in the early portion of the spire; ventral sutures strongly curved but partly masked by the supplementary chambers formed by the umbilical lobes over the successive apertures of the last whorl; aperture a strongly arched slit directed toward the irregularly pustulate umbilicus.

Diameter up to .3 mm.

Through the kindness of Dr. Cushman specimens of *A. carinata* d'Orbigny[94] from the Tortugas region and Miocene specimens of *A. planorbis* d'Orbigny[95] from the Vienna Basin have been made available for comparisons. The former, which is the genotype, shows in the center of its conical ventral face a single smooth umbilical boss from which the sharply angular and diamond-shape secondary chambers radiate, and near the aperture are elongate granules in faint alignment. The classical fossil species exhibits numerous conspicuous pustules in the umbilical area, and no roughness is evident near the aperture, though on some specimens the central pustulate region leans toward the apertural side. The Midway species, in the character of its ventral granulation, is more nearly like the Miocene form of d'Orbigny's. It is distinct, however, in having fewer whorls, very moderately oblique dorsal sutures, delicately curved supplementary chambers, and a strongly curved apertural slit.

In the Midway formation of Texas *A. primaria* has been observed at only one locality in Texas—an outcrop of dark greenish-grey, fossiliferous shell marl just below the *Venericardia bulla* ledge on the west side of Colorado River in Bastrop County about one-quarter of a mile south of the Travis County line (sta. 67). This shallow-water deposit, which probably marks the transition between the basal and upper faunal units, carries mainly the species of the upper

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[94]d'Orbigny, Alcide, De la Sagra, Histoire physique, politique, et naturelle de l'Ile de Cuba, Foraminifères: p. 118, pl. 5, fig. 25, pl. 6, figs. 1, 2, Paris, 1840.

[95]d'Orbigny, Alcide, Foraminifères fossiles du Bassin tertiaire de Vienne: p. 205, pl. 11, figs. 1–3, Paris, 1846.

faunule, and in this material *A. primaria* is very common. In Alabama the fossiliferous marl at Matthews Landing presents a very closely allied species in which the supplementary chambers form a more perfect star with points extending almost to the periphery.

The presence of this rather highly organized foraminifer in so old a deposit as the Midway is of special historical interest in Gulf Coast studies, for in the literature at hand no record of this genus in this country earlier than the Byram marl has been found, though it is known to occur in yet-undescribed upper Eocene formations in Texas. In the foreign publications no representative of this group earlier than the upper Eocene at Biarritz (by Halkyard) has been noted, but the lack of literature makes a definite statement regarding the geneology of this genus impossible at this time.

Family NUMMULITIDAE

Genus NONIONINA d'Orbigny, 1826

NONIONINA TURGIDA (Williamson)

Pl. XII, figs. 6a–c, 7a, b

(Plesiotypes—Walker Museum Coll. 33102, Sta. 64; 33103, Sta. 23)

Rotalina turgida Williamson, 1858, Rec. Foram. Gt. Brit., p. 50, pl. 4, figs. 95–97.

Nonionina turgida H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 731, pl. 109, figs. 17–19.

Nonionina turgida Cushman, 1914, U. S. Nat. Mus. Bull. 71, pt. 4, p. 29, pl. 15, fig. 3.

Test elongate, bilaterally symmetrical to faintly unsymmetrical; chambers 8–9, very smooth, increasing very rapidly in size, the last-formed chamber being in adult stage very large and somewhat embracing; sutures faintly depressed about the sharp, small umbilicus, radial; aperture a small arched orifice at base of the large, broad, inflated septal face.

Length up to .25 mm.

Only one perfectly symmetrical form has been found in the Midway fauna, and this corresponds almost exactly to Cushman's figure in his monograph on the north Pacific. Other specimens in the Midway show a slight tendency in the last chamber to lean to one side. The type form presented by Williamson is strongly unsymmetrical. The diagnostic feature of this species is the very large, turgid, embracing final chamber.

In the Midway formation *N. turgida* is rare and occurs in both the lower and upper faunules of the section. As this same species occurs frequently in the upper Navarro strata, it carries no stratigraphic significance in Cretaceous-Eocene contact problems, but it is interesting in being the only representative of the family Nummulitidae in the Midway fauna.

The lack of literature makes it impossible to trace the occurrence of *N. turgida* as a fossil. In the Challenger report is a statement that Reuss has described it from the Antwerp Crag (Pliocene), and that others have found it in post-Tertiary strata in Norway, Scotland, and Ireland. Figures of these forms have not been available for comparison. It is found today in both the north Atlantic and north Pacific, as well as in other parts of the present seas.

Family MILIOLIDAE

Genus CORNUSPIRA Schultze, 1854

CORNUSPIRA CARINATA (Costa)

Pl. XII, fig. 9

(Plesiotypes—Walker Museum Coll. 33104, Sta. 21)

Operculina carinata Costa, 1856, Atti Accad. Pont., vol. 7, fasc. 2, p. 209, pl. 17, fig. 1.

Cornuspira carinata H. B. Brady, 1884, Challenger, vol. 9 (Zool.), p. 201, pl. 11, fig. 4.

Cornuspira carinata Cushman, 1919, U. S. Nat. Mus. Bull. 100, vol. 4, p. 392, pl. 77, fig. 6.

Test a very gradually increasing, compressed, nonseptate, porcellanous tube coiled upon itself and only slightly

embracing; peripheral border sharply angular; surface devoid of ornamentation except for faint oblique corrugations or lines of growth.

Diameter of only specimen .5 mm.

This species has been observed at only one locality along the Midway outcrop. It occurs rarely in Navarro clays from its contact with the Taylor upward through the section. It appears to have become extinct in the Texas area at the end of the Midway period.

Genus QUINQUELOCULINA d'Orbigny, 1826

QUINQUELOCULINA FERUSSACII d'Orbigny

Pl. XII, fig. 10

(Plesiotypes—Walker Museum Coll. 33105, Sta. 23)

Quinqueloculina ferussacii d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 301, No. 18; Modèle No. 32.

Miliola (Quinqueloculina) ferussacii Parker and Jones, 1865, Phil. Trans., vol. 155, p. 411, pl. 15, fig. 36.

Miliolina ferussacii Sherborn and Chapman, 1886, Jour. Roy. Mic. Soc., p. 742, pl. 14, fig. 5.

Test small compressed, broadly elliptical in side view; 5 visible chambers that exhibit distinct angulation; aperture oval with a simple tooth.

Length of only specimen .25 mm.

This tiny form appears to have existed under unfavorable conditions, as it is very small and emaciate. It does not follow the type precisely, but the poor development of this single specimen renders a better determination impossible. It is interesting in the fauna in being the only representative of this genus.

Genus TRILOCULINA d'Orbigny, 1826

TRILOCULINA LAEVIGATA Bornemann

Pl. XII, fig. 11

(Plesiotype—Walker Museum Coll. 33106, Sta. 23)

Triloculina laevigata Bornemann, 1855, Zeit. deutsch. geol. Gesell., vol. 7, p. 350, pl. 19, fig. 5.

Test somewhat elongate ellipsoid with three very broadly rounded and strongly embracing visible chambers; wall very smooth and glistening; aperture a crescentiform slit with a large semilunar tooth.

Length of only specimen .35 mm.

In all the Midway material examined only one very perfect and well developed specimen has been found. It resembles very closely *T. circularis* Bornemann[96] which occurs rarely in the London Clay but is typically more elongate. Both these species were described from the Septarienthone (Oligocene) of Germany.

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PLATE II

NAVARRO SPECIES

In the discussion of the comparison of Navarro and Midway faunas, pp. 34 to 42, the few species presented on this plate are very informally mentioned.

Figure—

1. *Pseudotextularia* a, ×75. Megalospheric form. From bank of Walker Creek, 6 miles N. 15° E. of Cameron, Milam Co., about 5 feet below the Midway greensand. a, Front view. b, Edge view of same specimen. This species in the group of Pseudotextularians of the Navarro fauna is conspicuous for the thickness of its test and for the coarseness of its costations. (Holotype, Walker Museum Coll. 33359.)
2. *Pseudotextularia* b, ×75. Megalospheric form. Same locality as above. a, Front view. b, Edge view of same specimen. This species is marked by a greater lateral compression of its test in maturity than any other species of this group exhibits, and the distinct obliquity of its chambers is a significant feature. (Holotype, Walker Museum Coll. 33360.)
3. *Pseudotextularia* c, ×75. Megalospheric form. Same locality as above. a, Front view. b, Edge view of same specimen. In this form the mature chambers are greatly inflated and large, and they are marked very faintly by fine striae. (Holotype, Walker Museum Coll. 33361.)
4. *Pseudotextularia* d, ×75. Megalospheric form. Same locality as above. a, Front view. b, Edge view of same specimen. This species presents a gradual increase in size of chambers toward maturity, compact chambers, and distinct but fine striae. (Holotype, Walker Museum Coll. 33362.)
5. *Frondicularia reticulata* (Reuss), ×25. From a clay pit south of Corsicana (see text fig. 10). (Plesiotype, Walker Museum Coll. 33366.)
6. *Anomalina navarroensis* n. sp., ×50. From bank of Walker Creek 6 miles N. 15° E. of Cameron, Milam Co., about 5 feet below the Midway greensand. a, Dorsal view. b, Peripheral view of another specimen. c, Ventral view of a third specimen. (Cotypes, Walker Museum Coll. 33369.)
7. *Vaginulina webbervillensis* Carsey, ×25. From clay pit south of Corsicana (see text fig. 10). (Paratype, Walker Museum Coll. 33364.)
8. *Vaginulina gracilis* n. sp. var. *cretacea* n. var., ×25. From bank of Walker Creek, 6 miles N. 15° E. of Cameron, Milam Co., about 5 feet below Midway greensand. This form frequent in Navarro clays in Texas is distingished from the type for the species in the basal Midway strata by its thickened sutural nodes. (Holotype, Walker Museum Coll. 33365.)
9. *Globigerina rosetta* Carsey, ×50. Same locality as above. a, Dorsal view. b, Peripheral view of another specimen from which the umbilical covering has been broken. c, Ventral view of specimen exhibiting the ferfectly preserved umbilical covering. (Topotypes, Walker Museum Coll. 33368.)
10. *Globigerina rugosa* n. sp., ×50. Same locality as above. a, Dorsal view. b, Peripheral view of another specimen that lacks the umbilical covering. c, Ventral view of another specimen without its umbilical covering and showing the multiple apertures around the umbilicus and the earlier whorl within the test. d, Ventral view of a specimen showing the irregularly developed and loosely attached umbilical protective covering that marks this species and many other ornate Globigerine species in this fauna. (Cotypes, Walker Museum Coll. 33367.)
11. *Bulimina pupoides* d'Orbigny, ×50. From clay pit south of Corsicana (see text fig. 10). (Topotype, Walker Museum Coll. 33363.)

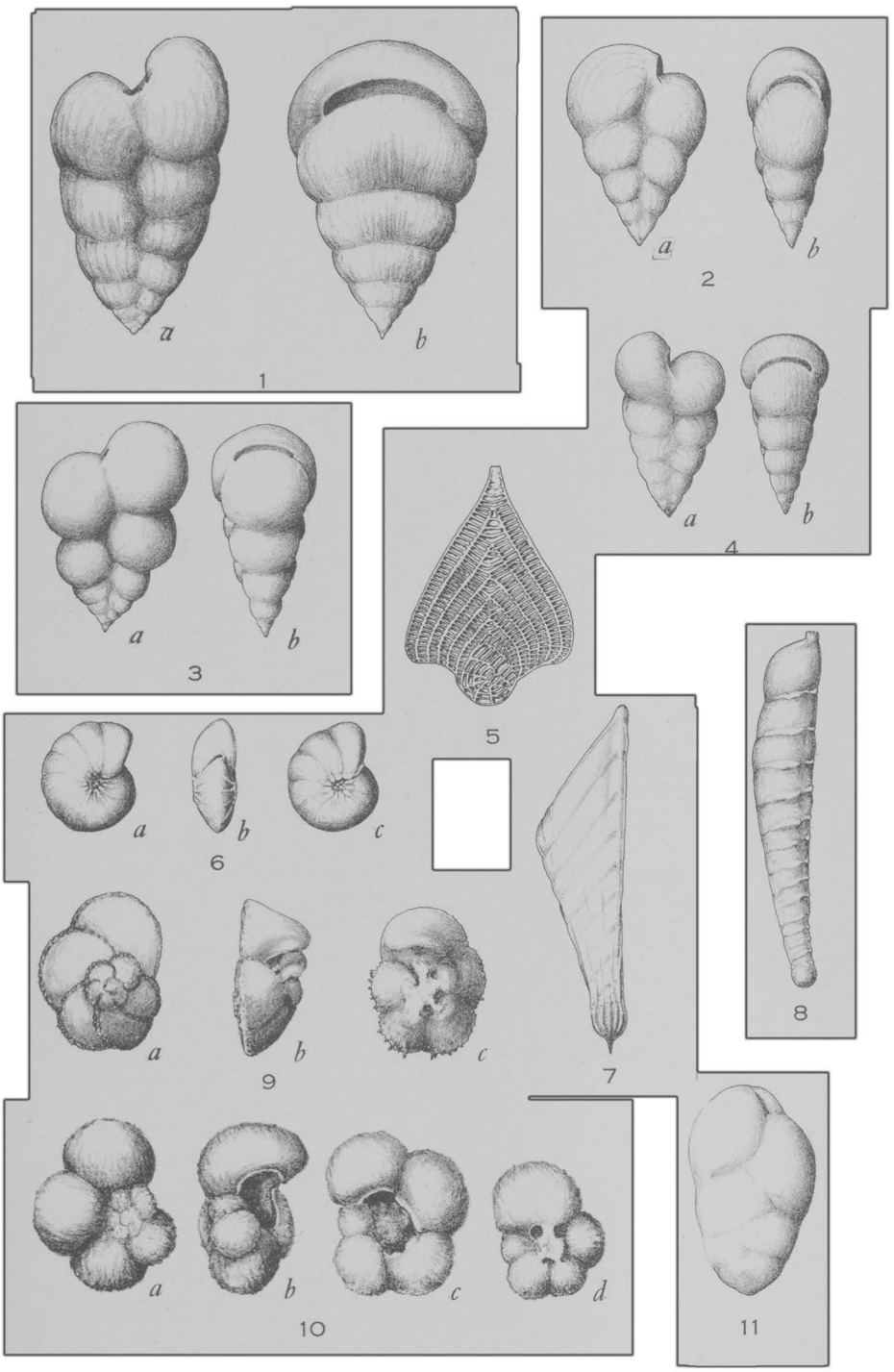
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PLATE III

Figure— PAGE

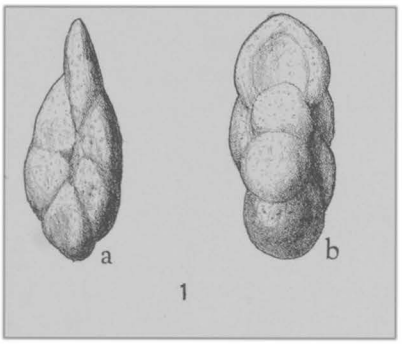
1. *Haplophragmoides canariensis* (d'Orbigny), ×50, Sta. 23. a, Side view of a specimen compressed peripherally. b, Peripheral view of same specimen 65

2. *Textularia eocaena* (Gümbel), ×50, Sta. 23. a, Side view. b, Peripheral view of same specimen 67

3. *Textularia carinata* d'Orbigny var. *expansa* n. var., ×50, Sta. 23. Side view 67

4. *Clavulina angularis* d'Orbigny, microspheric form, ×50, Sta. 23. a, Side view. b, Apertural view of another specimen 70

5. *Clavulina angularis* d'Orbigny, megalospheric form, ×50, Sta. 23. a, Side view of a specimen exhibiting globular chambers in its latest development. b, Side view of another specimen showing the more normal tricarinate form throughout the length of its test. c, Apertural view 70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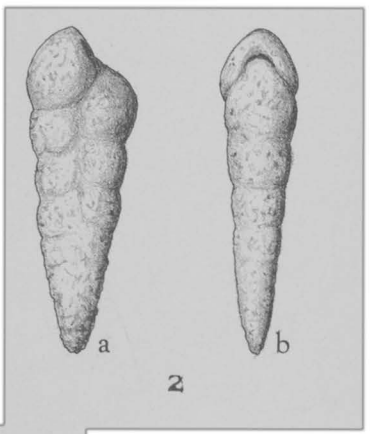
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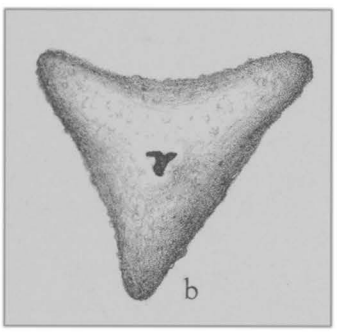
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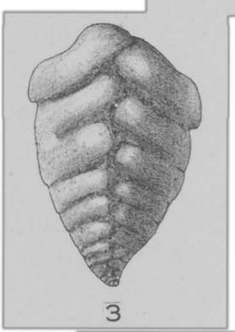
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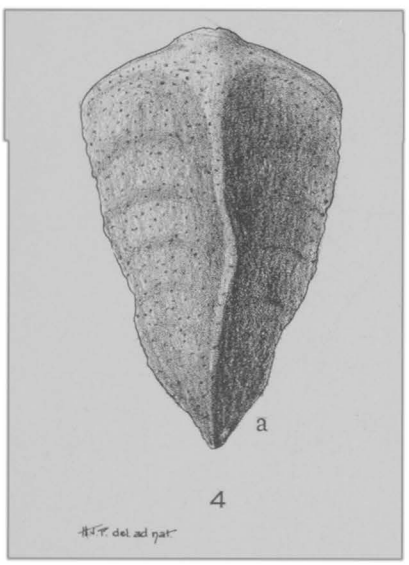
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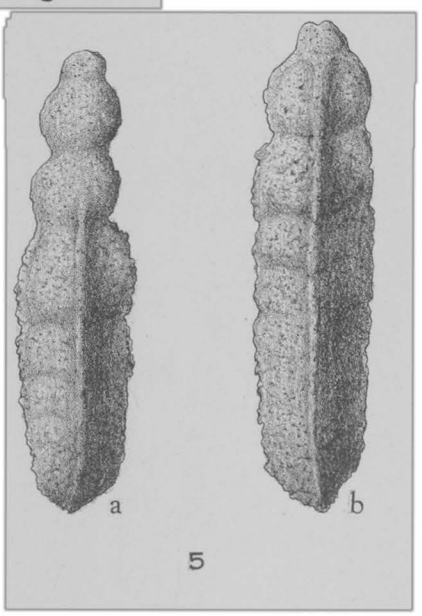
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PLATE IV

Figure— PAGE

1 *Bolivina applini* n. sp., ×50, Sta. 46 69

2. *Pleurostomella alternans* Schwager, ×50, Sta. 46. a, Side view showing arrangement of chambers. b, View of another specimen showing toothed aperture 69

3. *Bulimina aculeata* d'Orbigny, ×50. Sta. 46. Side view showing aperture 73

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9. *Nodosaria radicula* (Linnaeus), ×30, Sta. 23. a, Megalospheric form. b, Microspheric form 77

10. *Nodosaria soluta* (Reuss), ×50, Sta. 46 78

11. *Nodosaria pauperata* (d'Orbigny) ×50, Sta. 23 79

12. *Nodosaria spinescens* (Reuss), ×50, Sta. 23 84

13. *Nodosaria mucronata* (Neugeboren), ×50, Sta. 23 80

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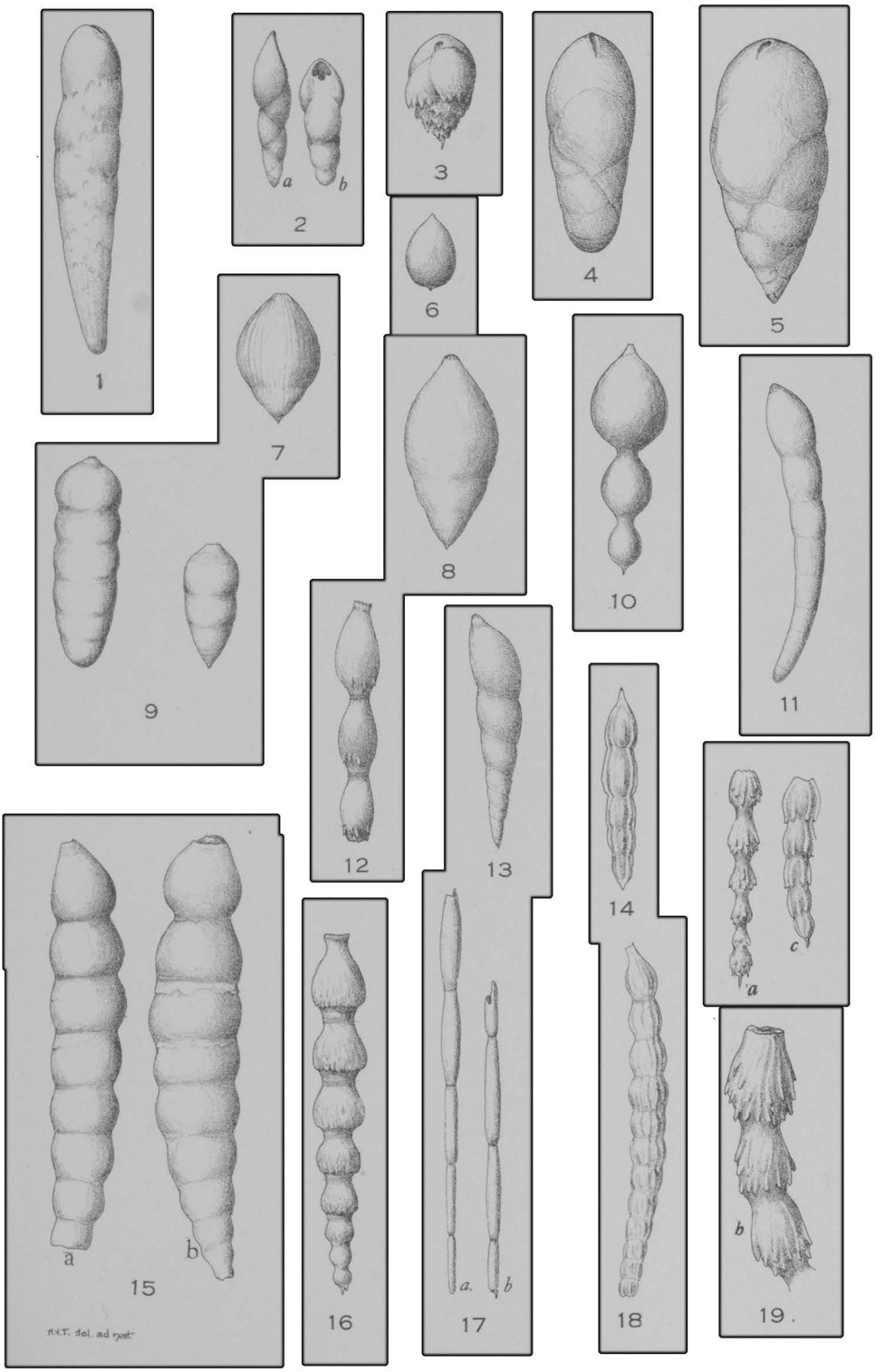
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PLATE V

Figure— PAGE

1. *Frondicularia rugosa* (d'Orbigny) ×50, Sta. 40 118
2. *Frondicularia archiaciana* (d'Orbigny) var. *strigillata* Bagg, ×25, Sta. 23. a, Side view. b, Peripheral view 114
3. *Frondicularia goldfussi* Reuss, ×25, Sta. 46 115
4. *Frondicularia delicatissima* n. sp., ×50, Sta. 43 120
5. *Frondicularia budensis* (Hantken), ×25, Sta. 46. a, Evenly elliptical form. b, Speciment showing more rapid increase in width with growth 116
6. *Marginulina tumida* Reuss, ×50, Sta. 43 105
7. *Marginulina regularis* d'Orbigny, ×50, Sta. 43 107
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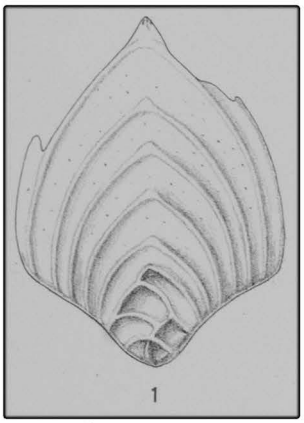

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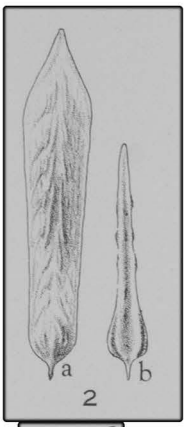

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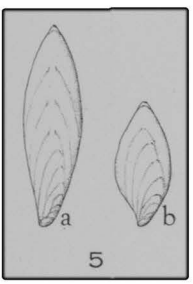

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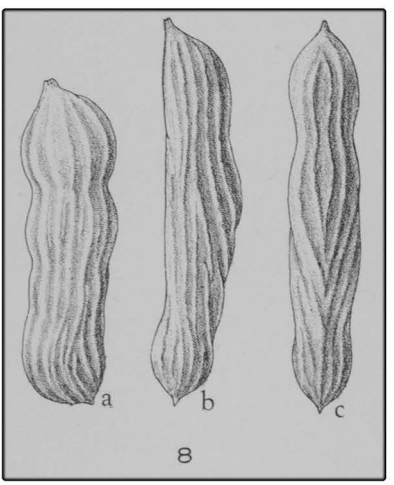

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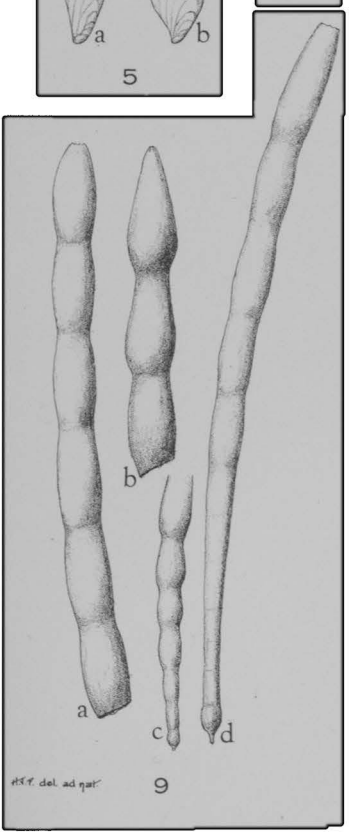

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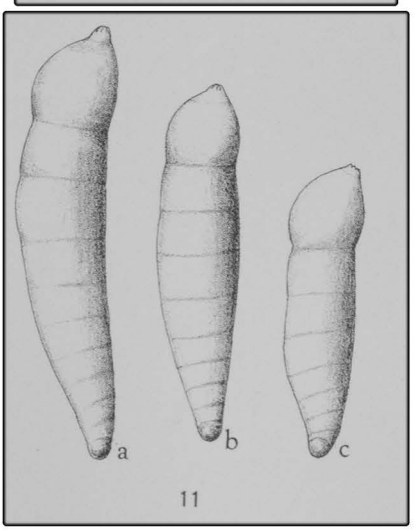

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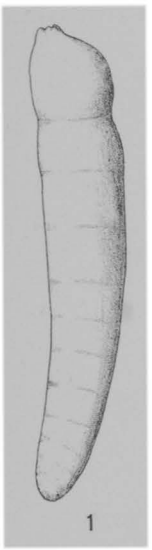
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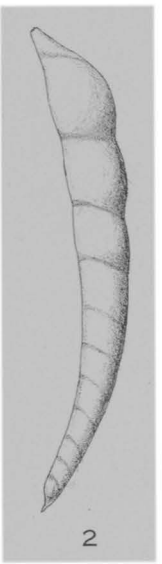
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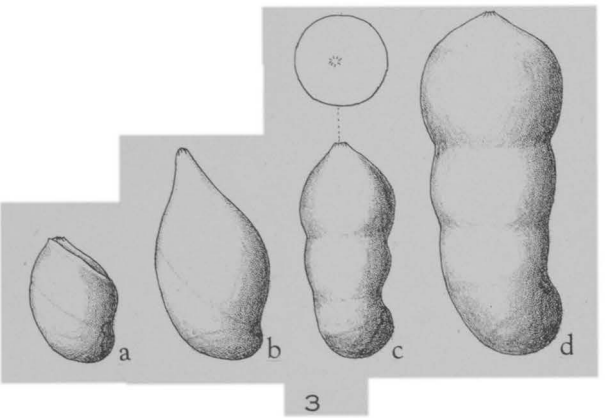
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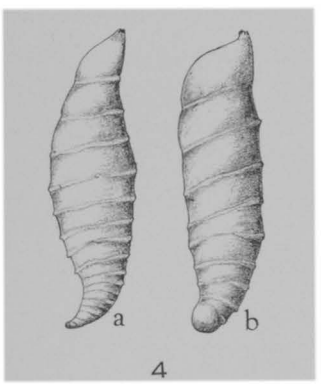
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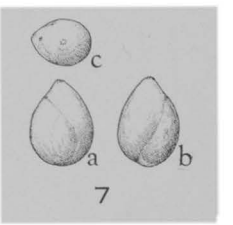
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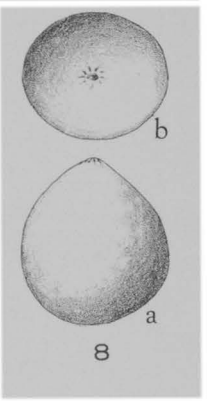
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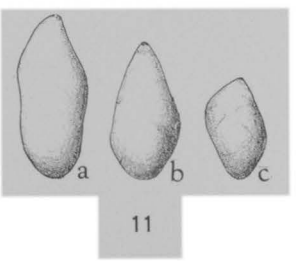
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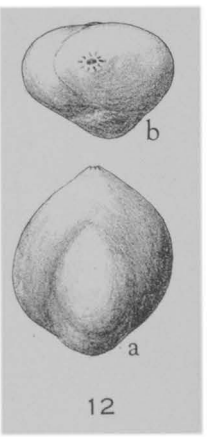
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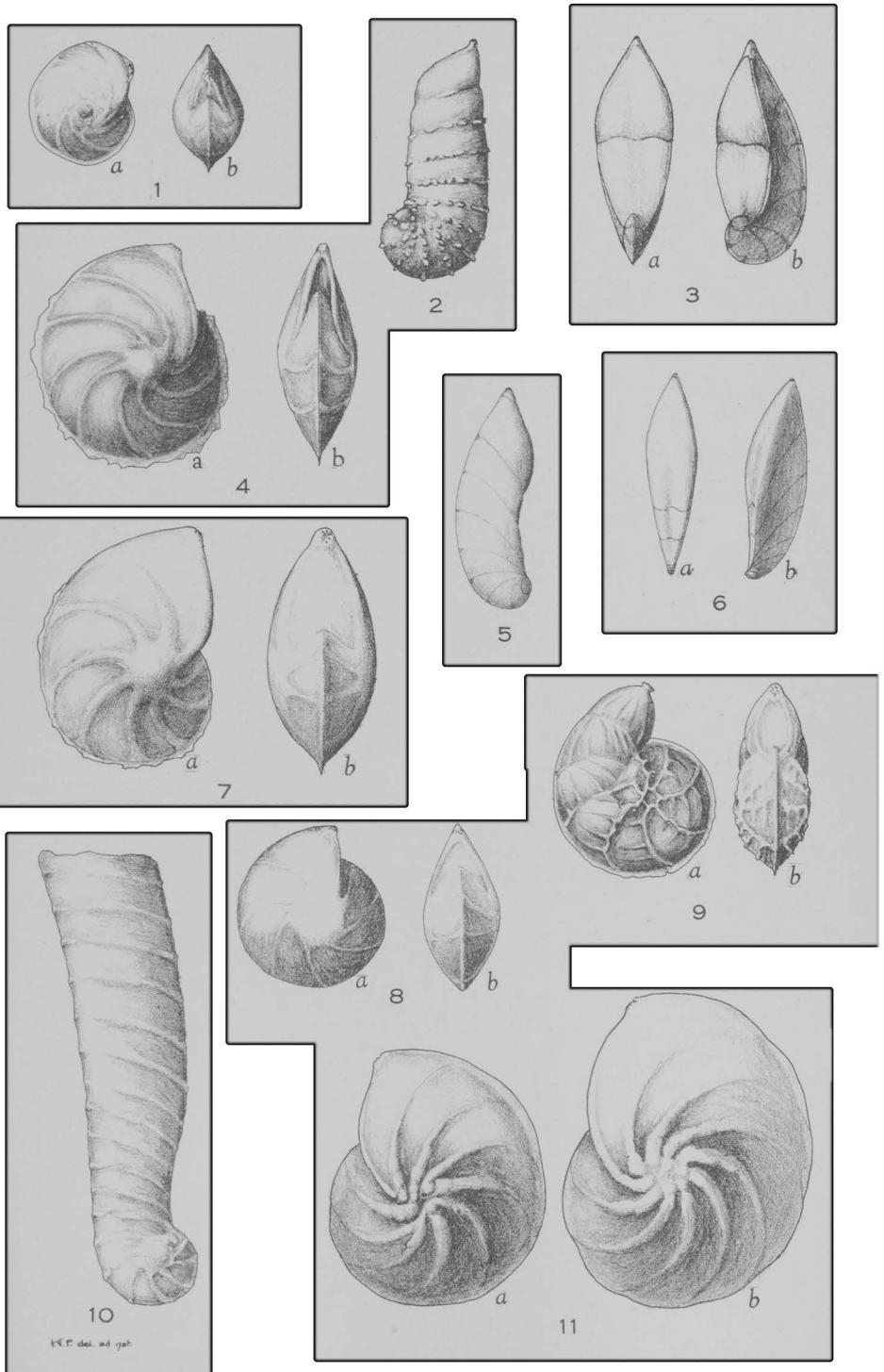
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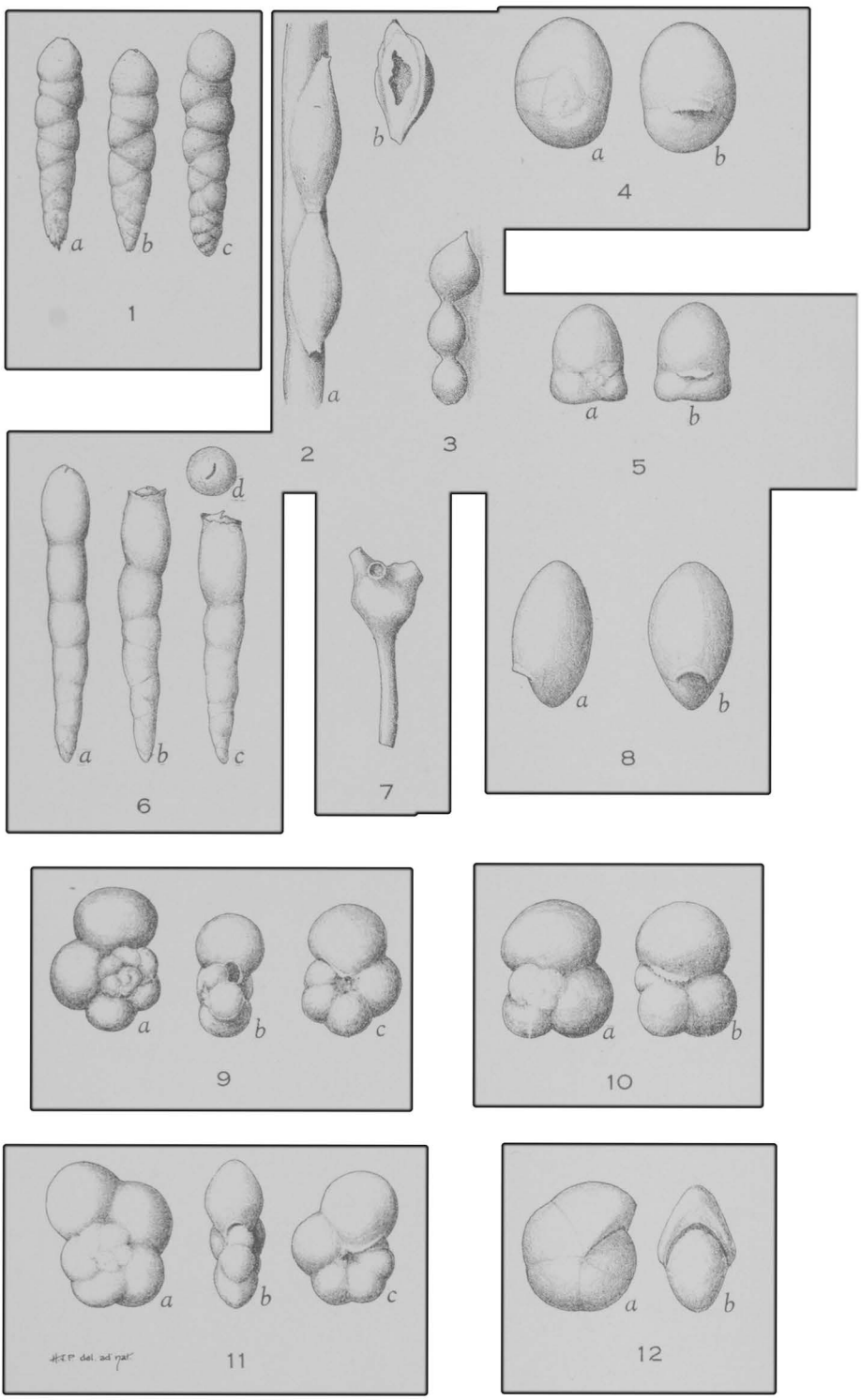
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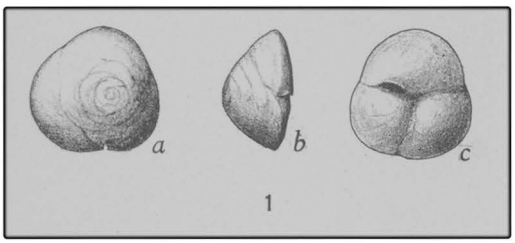
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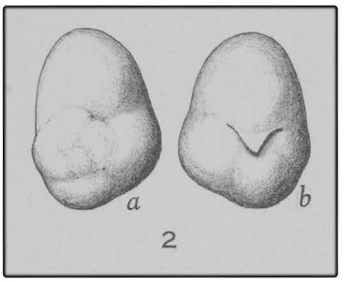
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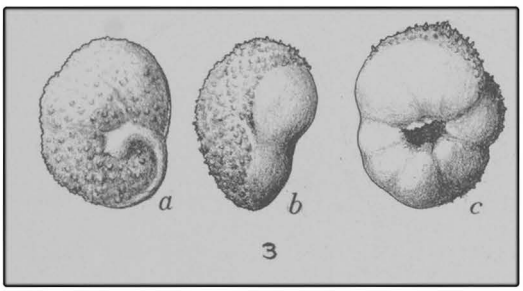
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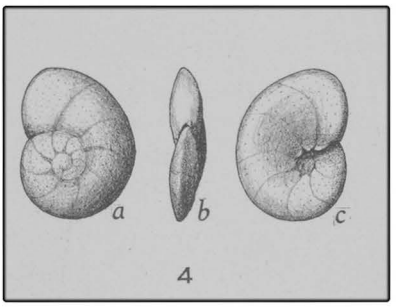
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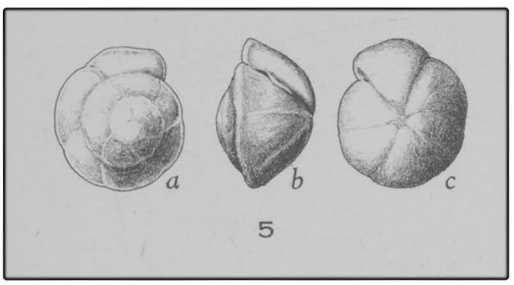
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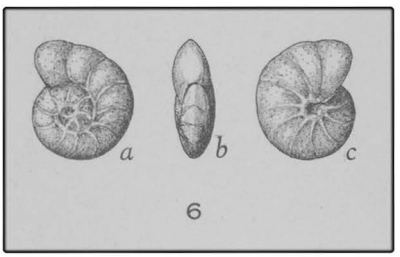
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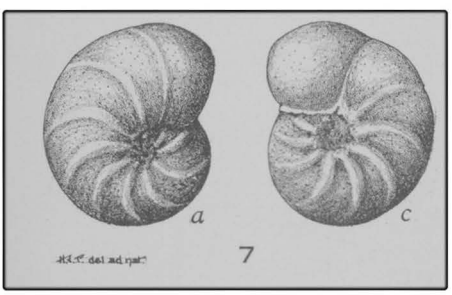
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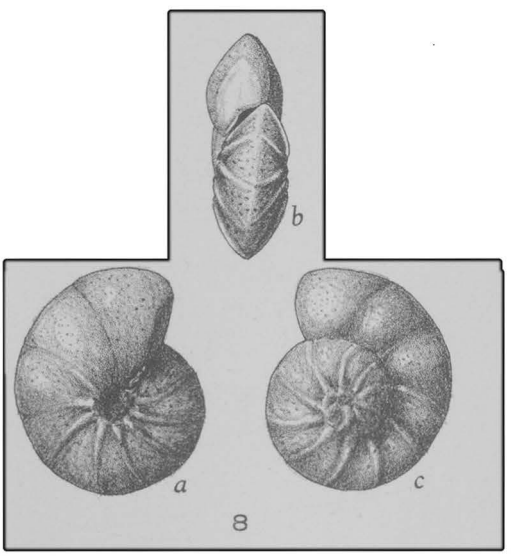
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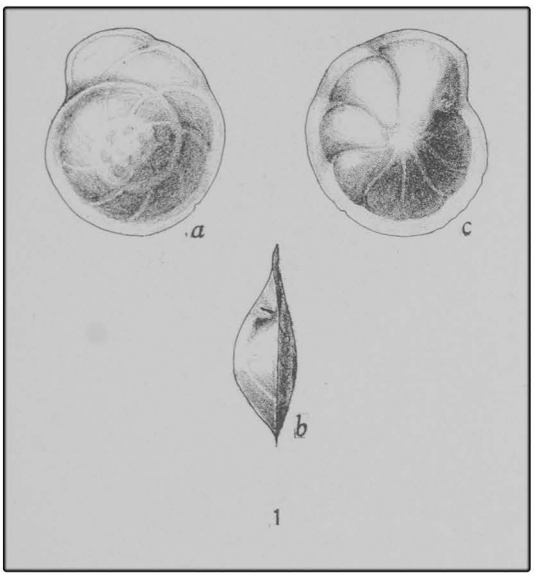
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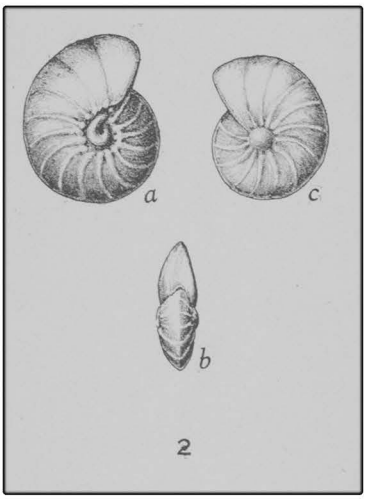
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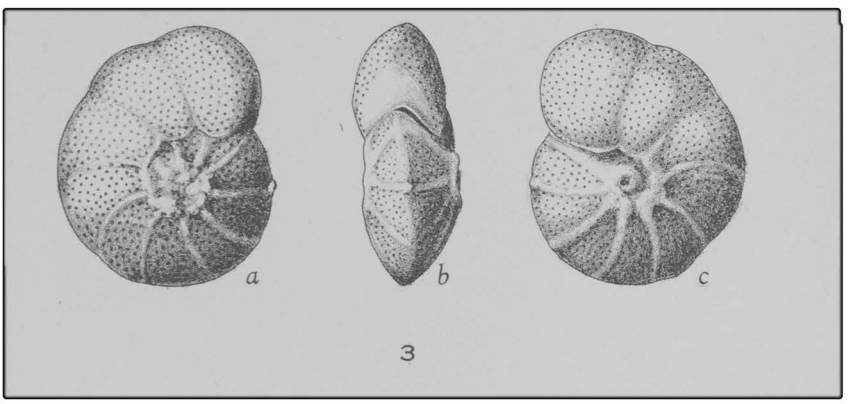
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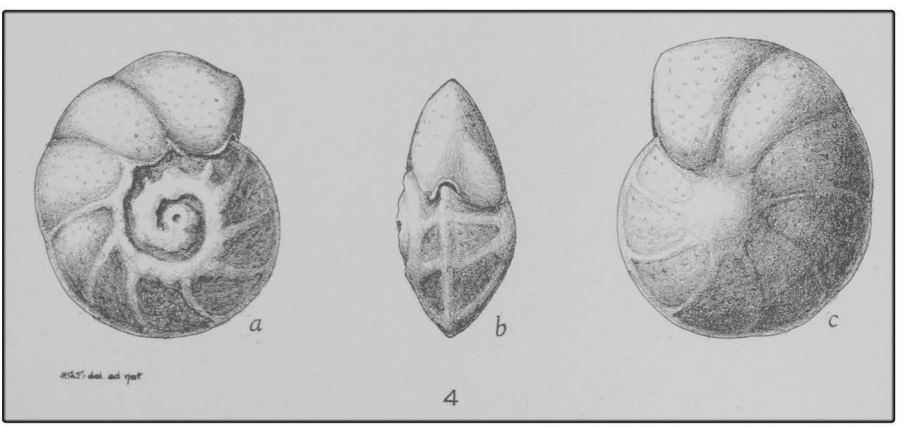
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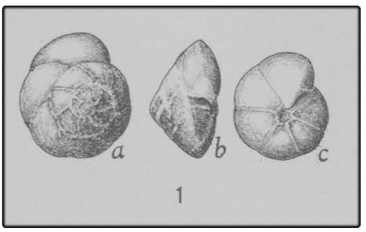
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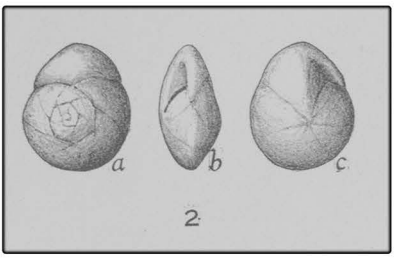
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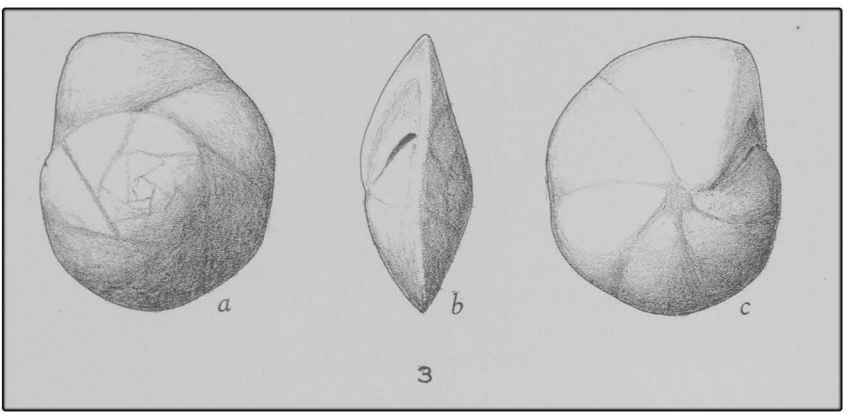
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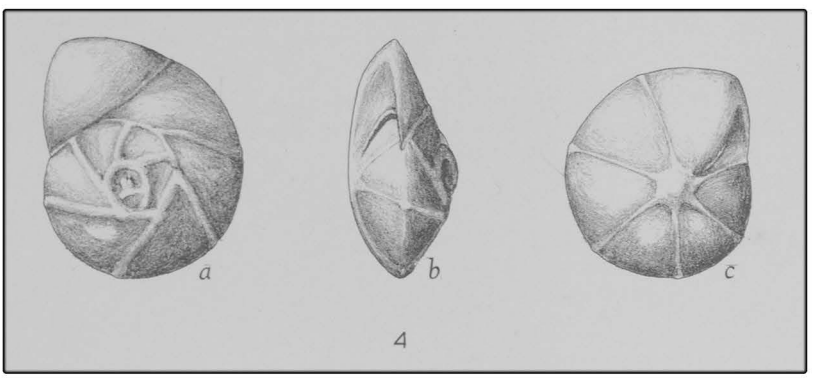
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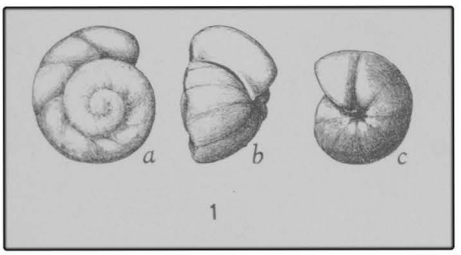
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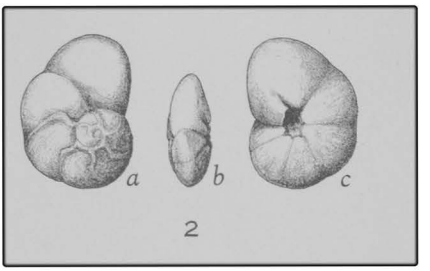
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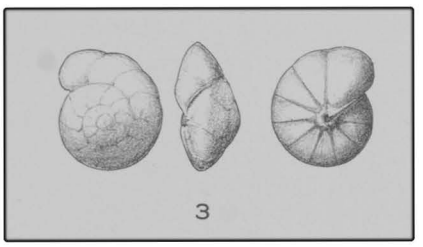
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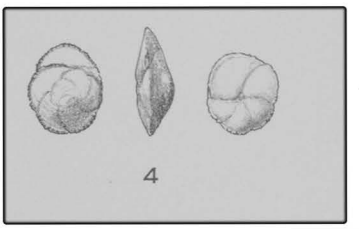
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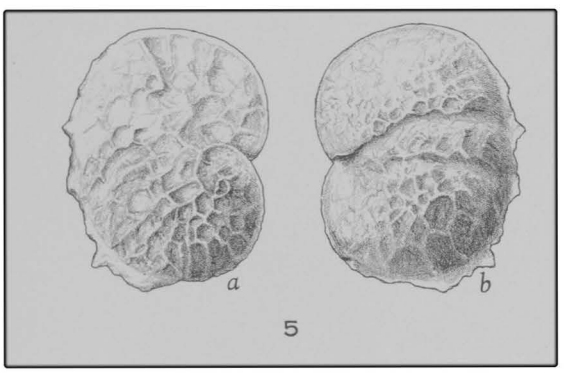
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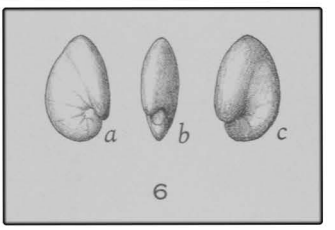
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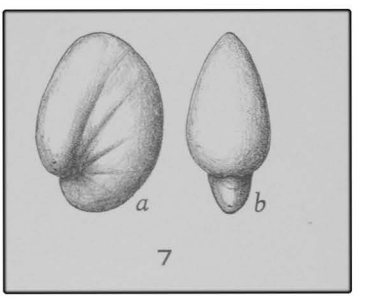
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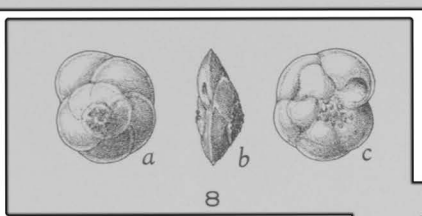
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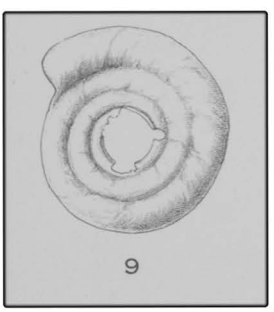
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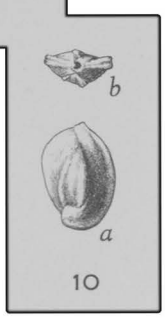
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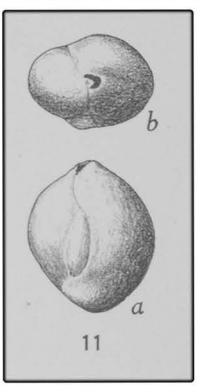
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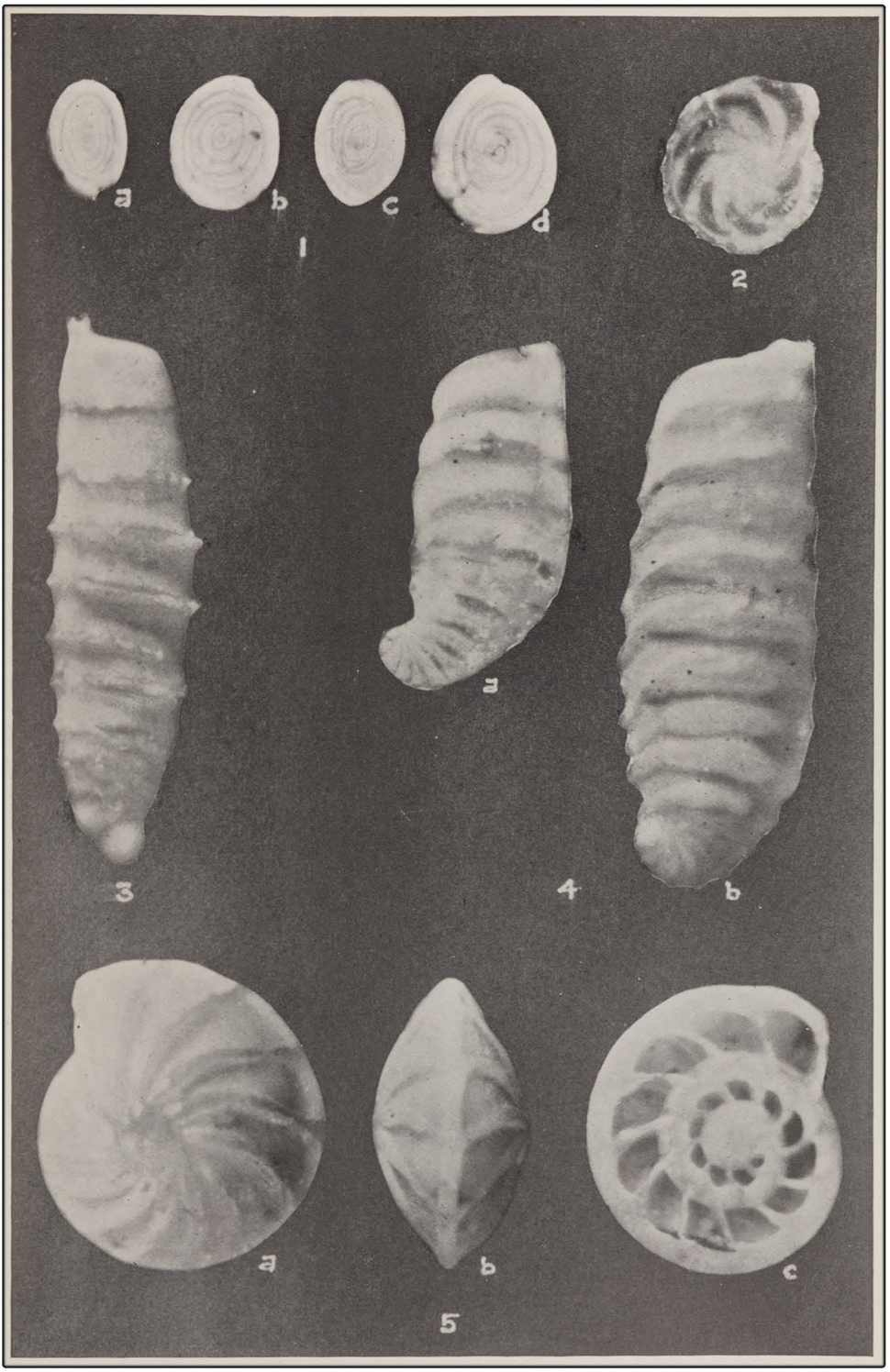
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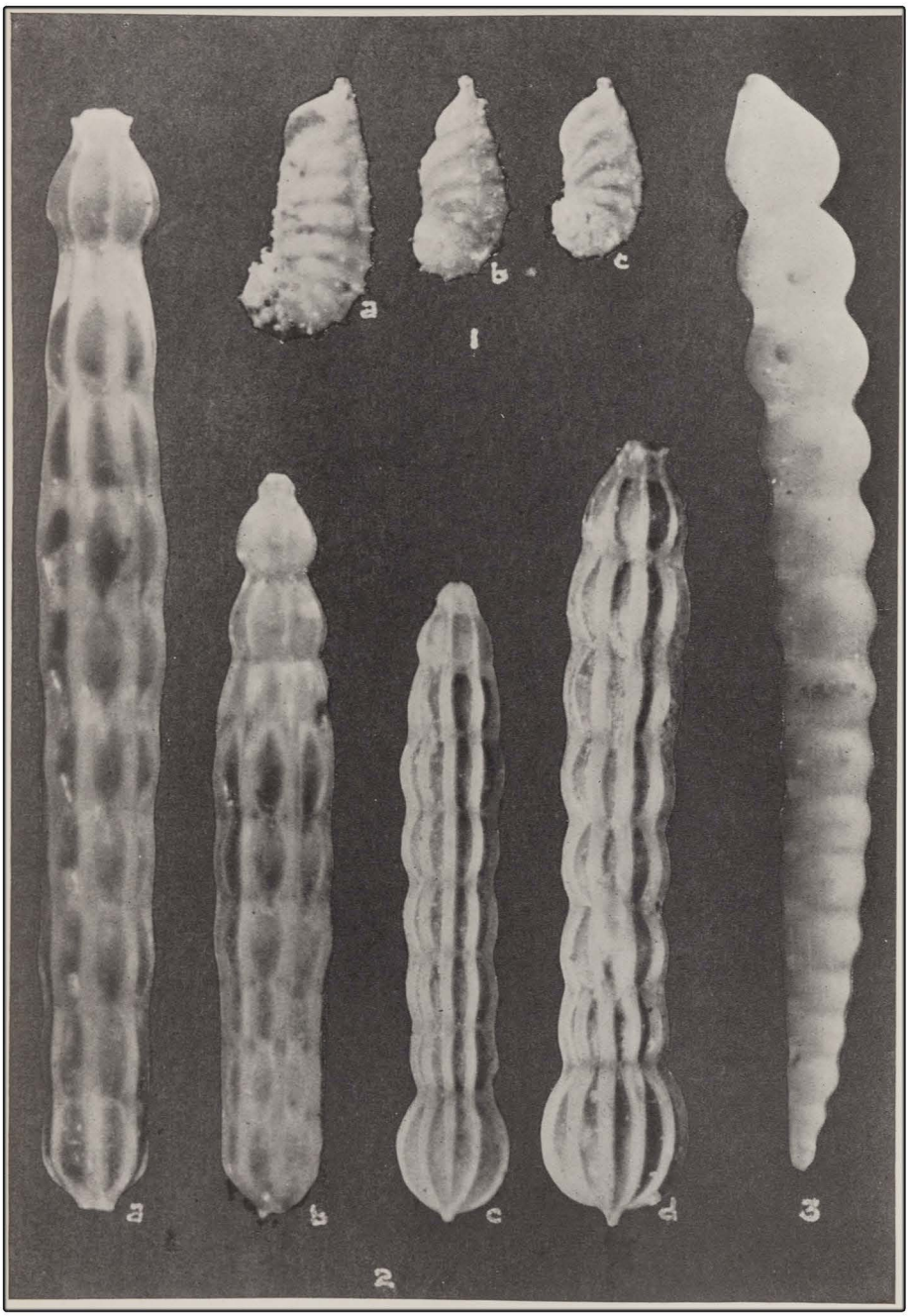
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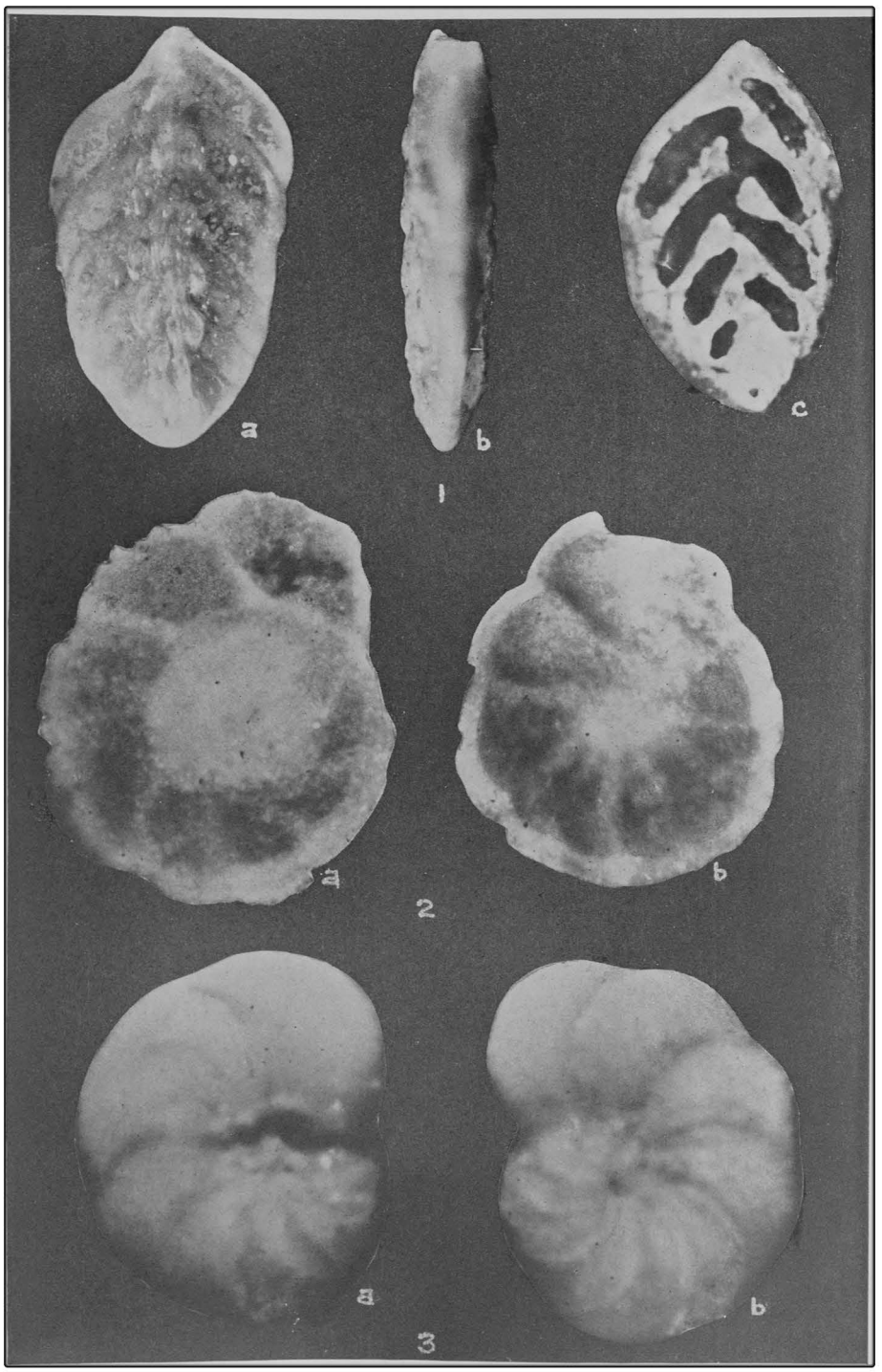
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