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Documentation of the Santonian-Campanian and Austinian-Tayloran Stage Boundaries in Mississippi and Alabama Using Calcareous Microfossils

By HARRY J. DOWSETT

U.S. GEOLOGICAL SURVEY BULLETIN 1884

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Documentation of the Santonian-Campanian and Austinian-Tayloran Stage Boundaries in Mississippi and Alabama Using Calcareous Microfossils

By Harry J. Dowsett

Abstract

Identification of foraminifers, calcareous nannofossils, and ostracodes in samples from the Upper Cretaceous Eutaw, Mooreville, and Demopolis Formations of Mississippi and Alabama allows correlations between the standard European and provincial Gulf Coast Stages. The Austinian-Tayloran boundary, represented by a sedimentary hiatus in Texas and Arkansas, is within the Mooreville Formation of the eastern Gulf Coast. The Santonian-Campanian boundary is within the Eutaw Formation of Mississippi and the lower Mooreville Formation of central Alabama. The Arcola Limestone Member of the Mooreville Formation, previously used as a marker bed for the Austinian-Tayloran boundary in the eastern Gulf Coastal Plain, lies well within the Tayloran Stage and appears to be time transgressive.

INTRODUCTION

Purpose and Scope

The Austinian-Tayloran provincial Stage boundary of the U.S. Gulf Coast has been considered correlative with the Santonian-Campanian Stage boundary; however, this has not been universally accepted (Young, 1963; Hazel, 1977). The Upper Cretaceous Eutaw Formation and Mooreville and Demopolis Formations of the Selma Group of Mississippi and Alabama represent an ideal test for documenting both the Santonian-Campanian and the provincial Austinian-Tayloran Stage boundaries in the eastern Mississippi embayment.

In the east Texas embayment, the Austinian-Tayloran Stage boundary usually occurs at a distinctive lithostratigraphic contact. The Austinian and Tayloran provincial Stages were formally defined by Murray (1961). Long before this, however, Gulf Coast geologists were attempting correlations with the type Austin and Taylor units in Texas and were using the terms "Austin" and "Taylor" in a chronostratigraphic sense (Stephenson and Monroe, 1940; Stephenson and others, 1942; Cushman, 1946; Monroe, 1946; Parks, 1958; Shaver, 1958). Based on previously published data, the chronostratigraphic position of the Austinian-Tayloran Stage boundary should fall within the Mooreville Formation of Mississippi and Alabama (Sohl, 1964).

The type sections of the Santonian and Campanian Stages were first described in 1856 and were named in 1857 (Coquand, 1856, 1857). Microfossils from these stratotypes have been studied by many workers (e.g., Van Hinte, 1968; Goharian, 1971; Barr, 1972; Seronie-Vivien, 1972; Sissingh, 1977; Verbeek, 1977). The results of these studies have refined the limits of the stages and made correlations with other areas of the world more precise. Published data suggest that the Santonian-Campanian boundary falls within the Eutaw Formation of Mississippi and Alabama (Young, 1963; Smith, 1975; Russell and others, 1982). This interpretation needs more complete documentation based on detailed sampling. About 50 samples from three outcrop localities and two cores (fig. 1) were examined for the purpose of documenting both the Santonian-Campanian and Austinian-Tayloran Stage boundaries by means of calcareous nannoplankton, foraminifers, and ostracodes.

Acknowledgments

I appreciate the thoughtful reviews of W.V. Sliter, Page Valentine, N.F. Sohl, and J.E. Hazel. I thank N.F. Sohl, J.E. Hazel, and C.C. Smith for helpful discussions regarding the Mesozoic stratigraphy of the Gulf Coastal Plain.

STRATIGRAPHY

Three Upper Cretaceous marine formations have been investigated in the research area. They are, from oldest to

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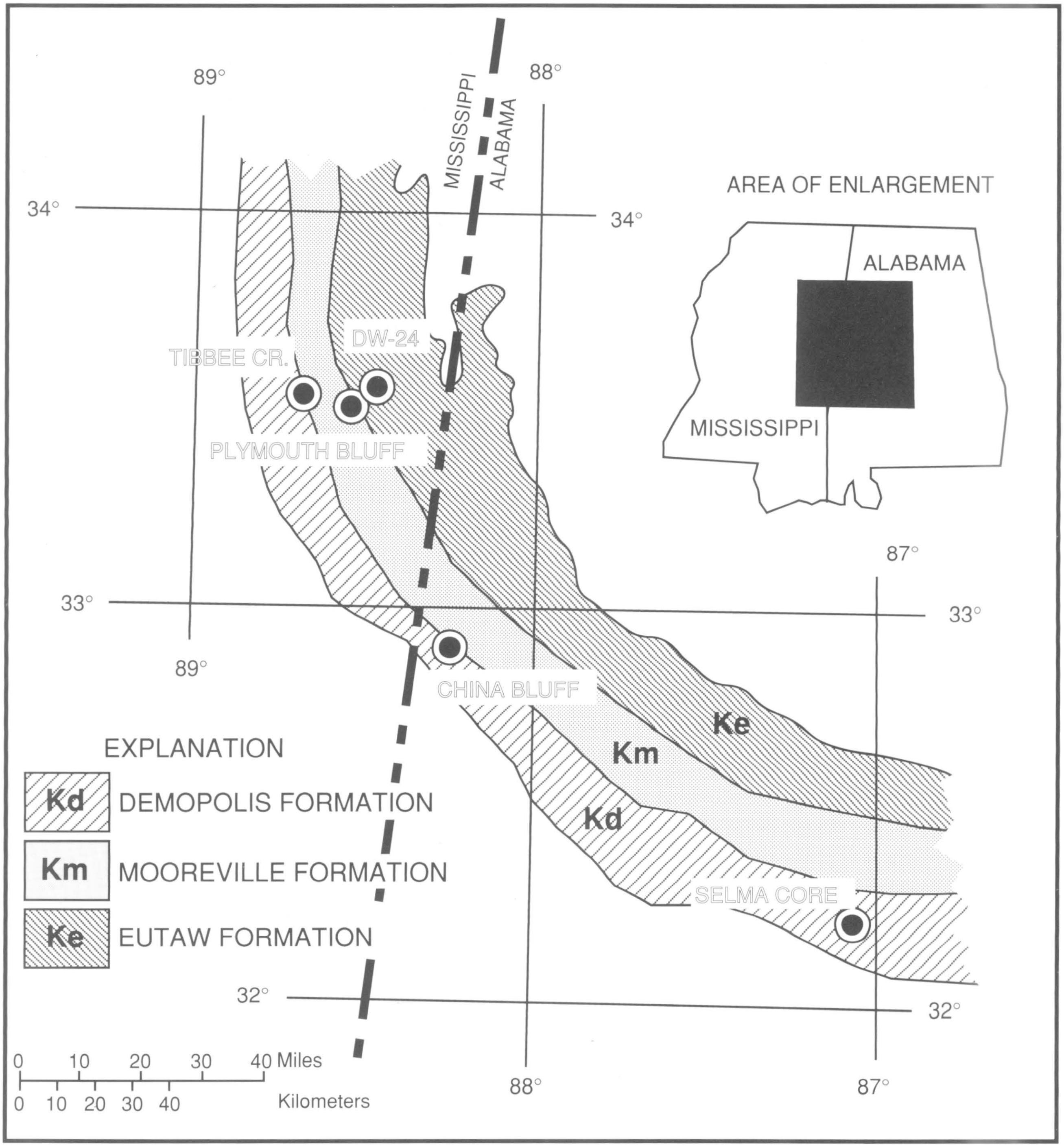

Figure 1. Sample sites and generalized distribution of Upper Cretaceous formations in Alabama and Mississippi.

youngest, the Eutaw Formation, the Mooreville Formation, and the Demopolis Formation. The geographic and stratigraphic distribution of the Eutaw, Mooreville, and Demopolis Formations is shown in figures 1 and 2. The stratigraphic distribution of samples analyzed and an idealized lithology of the localities investigated are shown in figures 5–7.

Eutaw Formation

The Eutaw Formation is separated into lower "typical" beds and the upper Tombigbee Sand Member. The lower unit is composed of glauconitic fine- to medium-grained micaceous sand interbedded with olive-gray to dark-gray clay lenses. Exposed surfaces weather to a deep

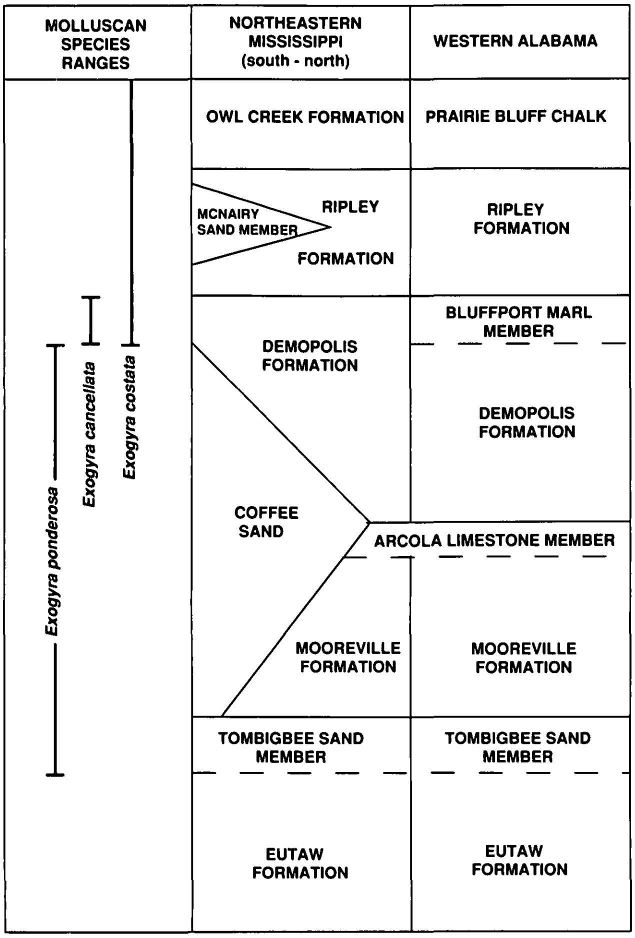

Figure 2. Generalized correlation chart for the eastern Gulf Coastal Plain, including selected molluscan ranges (modified after Sohl and Smith, 1980).

reddish brown. Percolating ground waters deposit iron, forming sandy, oxidized concretions and masses of ferruginous sandstone. The typical Eutaw beds exhibit a high degree of crossbedding. Plant fragments and lignite are common. The sedimentological evidence indicates a high-energy, near-shore, shallow-water environment. Calcareous microfossils are rare to absent in these beds. In the study area, the Tombigbee Sand Member makes up the upper 30 meters of the Eutaw Formation. This member is composed chiefly of massive bedded, glauconitic, calcareous sand. Indurated ledges and concretions are common. The type locality of the Tombigbee Sand Member is at Plymouth Bluff (fig. 1) on the Tombigbee River, Lowndes County, Miss. The upper 15 meters of the Tombigbee is particularly fossiliferous, and the type section at Plymouth Bluff is rich in marine calcareous microfossils. In the study area, the Tombigbee Sand Member appears to have been deposited in open marine sublittoral waters. The lower "typical" Eutaw beds have a maximum thickness of about 76 meters, but only the upper 4 meters were seen in the field area (DW-24, fig. 1). The entire Tombigbee Sand Member was observed during this study.

Mooreville Formation

The Mooreville Formation of the Selma Group is a dark- to blue-gray, slightly micaceous, chalky marl. An increase in sand content near the base of the formation is often referred to informally as the "transitional" Mooreville. Phosphate nodules and fish remains are present at the Mooreville-Tombigbee contact (Braunstein, 1959). Although the Mooreville Formation has been reported to rest disconformably on the Tombigbee Sand Member of the Eutaw Formation (Stephenson and Monroe, 1940; Monroe, 1941; Newton and others, 1959), no physical evidence of a disconformity could be found during this study. If a hiatus is present, it represents less time than can be resolved with the present biostratigraphic framework.

The Arcola Limestone Member is present at the top of the Mooreville Formation. The Arcola is a yellow to gray, highly bored, calcisphere packstone or wackestone (Russell and Keady, 1982). In the field area, the Arcola is exposed at the Gulf, Mobile, and Ohio railroad bridge on Tibbee Creek, Clay County, Miss., and at China Bluff, on the Tombigbee River, Sumter County, Ala.; it also occurs in the Alabama Power Company's South Selma Test Site 1 core, Dallas County, Ala. (fig. 1). In Mississippi, the Arcola Limestone Member consists of two limestone beds, approximately 0.6 meter thick, separated by 0.75 meter of marl. To the east in Dallas County, Ala., the Arcola thickens to approximately 3 meters and consists of a number of limestone beds separated by marl units. Immediately above the Arcola, the basal Demopolis Formation contains phosphate nodules, phosphatic molds, and reworked cobbles of limestone. Stephenson and Monroe (1940) regarded this as a basal conglomerate and interpreted its base to be a diastem or possible unconformity. The entire Mooreville ranges in thickness from 53 meters in Clay County, Miss., to 122 meters in Dallas County, Ala. Calcareous microfossils are abundant throughout the Mooreville Formation. Microfossils are difficult to retrieve from the limestone beds of the Arcola, but they are abundant and well preserved in the marl between the indurated beds.

Demopolis Formation

The Demopolis Formation of the Selma Group rests conformably on the Arcola Limestone Member of the Mooreville Formation. The Demopolis Formation consists of medium- to light-bluish-gray chalk, impure chalk, and marl. The Demopolis Formation is divided into a lower, unnamed member and the upper Bluffport Marl Member. Only the lower part of the unnamed member was examined in the present study. The lower 20 meters of the formation are lithologically similar to the Mooreville Formation, and are difficult to distinguish when the Arcola Limestone Member is covered. The lower, unnamed member consists of approximately 60 meters of marl overlain by 60 meters of chalk. The Bluffport Marl Member is approximately 15 meters thick and has a greater clastic fraction than the conformably underlying chalks (Russell and Keady, 1982). The calcium carbonate content of the chalk ranges from 72 to 90 percent; this fraction is made up of calcareous nannofossils and lesser amounts of foraminifers, mollusks, and other calcareous remains. The Demopolis Formation, like the underlying Mooreville Formation, contains an excellently preserved assemblage of foraminifers, nannofossils, and ostracodes.

GULF COAST-EUROPEAN CORRELATIONS

Molluscan faunal zones have been established in the chalks and marls of the Selma Group mainly on the basis of ranges of species of the ostreid *Exogyra* (fig. 2). The present study is restricted to the *Exogyra ponderosa* range zone, which extends from the Tombigbee Sand Member of the Eutaw Formation, underlying the Selma Group, to about 31 meters below the top of the Demopolis Formation, frequently related to strata of latest Santonian through latest Campanian age (Stephenson and Monroe, 1940; Stephenson and others, 1942; Monroe, 1946; Keady, 1962; Copeland, 1968; Sohl and Smith, 1980; Russell and others, 1982).

Stephenson and Monroe (1940) listed the faunas present in the various *Exogyra* zones in Mississippi and attempted several informal correlations to the standard Texas and European Stages. The presence of the planktonic crinoid *Marsupites americanus* Springer and of members of the ammonite genus *Muniericeras* in the Tombigbee Sand Member was cited as evidence of a Santonian age. Forms closely related to *Placenticeras guadalupae* (Roemer) and *Texanites texanus* (Roemer), which are present in the upper Austin Group (Young, 1963), were also found by Stephenson and Monroe (1940). The presence of *Mortoniceras* in the lower part of the Selma Group indicated a late Austin age. The *Diploschiza cretacea* Zone, a short taxon range zone in the Demopolis Formation, was correlated with the Pecan Gap Formation of the Taylor Group in Texas. Stephenson and Monroe (1940, p. 243) summarized their findings by stating that "the basal beds of the Selma Chalk in Mississippi and Alabama are believed to be as old as the uppermost beds of the Austin Chalk of Texas; the part of the Selma that lies between these basal beds and the base of the *Exogyra costata* Zone correspond in age to the Taylor marl of Texas."

Stephenson and others (1942) published a correlation chart of the outcropping Cretaceous formations of the Atlantic and Gulf Coastal Plains and Trans-Pecos Texas and stated that "the Taylor marl and its age equivalents in the Atlantic and Gulf Coastal Plains are co-extensive with all but the lowermost part of the *Exogyra ponderosa* Zone." These authors correlated the Austinian-Tayloran boundary to about the middle of the Mooreville Formation. Monroe (1946) changed the position of the Austinian-Tayloran boundary to coincide with the Mooreville-Demopolis contact. Monroe cited unpublished work by Applin and Braunstein that identified Tayloran foraminifers from the lower Demopolis and Austinian foraminifers from the Arcola as evidence justifying this change. Eargle (1950) claimed that the Mooreville foraminifers and ostracodes were abundant and generally similar to those found in the Austin Group of Texas. He cited the work of Higgs (1945) that documented Austinian and Tayloran species throughout the Mooreville in Montgomery County, Ala. A review of Higgs' thesis by the author showed that whereas species known to be present in the upper Austinian range throughout the Mooreville Formation, the diagnostic Austin species *Vaginulina texana* Cushman is restricted to the lower Mooreville. These data have been reproduced in the present study. In the subsurface, the top of the Mooreville is generally picked at the highest occurrence of *V. texana* (Braunstein, 1959). According to Braunstein, the Arcola Limestone Member marks the Austinian-Tayloran boundary.

Little has been done to determine accurately the relative positions of the Santonian-Campanian and Austinian-Tayloran boundaries in the eastern Mississippi embayment. Seemingly for convenience, the two boundaries are drawn by some authors at the same stratigraphic level (Stephenson and others, 1942; Pessagno, 1967). The use of the Arcola as a boundary marker seems to be entrenched in the literature (Braunstein, 1959; Canis and Zullo, 1986).

Several more recent studies have added valuable data to the Upper Cretaceous stratigraphy of the Gulf Coastal Plain. Masters (1970) studied the stratigraphic distribution of planktonic foraminifers in the Selma Group of Alabama. He indicated that the Santonian-Campanian boundary occurred within the Mooreville Formation but did not relate his findings to the standard Texas section. Brouwers and Hazel (1978), using ostracodes, gave the Arcola Limestone Member a Tayloran age. More recently, Mancini and Smith (1982) provided a preliminary biostratigraphic framework for the Upper Cretaceous deposits of the lower Mississippi embayment in Tennessee and Mississippi. Using nannofossils and planktonic foraminifers, they related units to the standard European stages only, concluding that the Santonian-Campanian boundary was within the Tombigbee Sand Member of the Eutaw Formation. Ross and Maddocks (1983) and Chimene and Maddocks (1984) studied the distribution of ostracodes in the upper Austin and Taylor Groups in Texas. Their results confirm the biostratigraphic zonation produced by Hazel and Brouwers (1982), which is used in this study.

Santonian-Campanian Boundary

In 1856, Coquand described the Upper Cretaceous rocks of the Charente region, France, distinguishing several lithologic "formations" which have since gained worldwide acceptance as stage and age names (Van Hinte, 1965). Coquand designated the section at Aubeterre the stratotype for the Campanian, but did not clearly designate a stratotype for the Santonian. According to Van Hinte (1965), Coquand used a currently fragmented section along the road from Javresac to Saintes as a starting point for his investigation of the Santonian. Just where along the road the stratotype should be placed, and what the true limits of the Santonian are, remain in question.

A standard for the Cretaceous System was presented by Muller and Schenck in 1943. The standard was built up by fitting together continuous, well-exposed sections in Europe; it was divided into series, stages, and zones on the basis of paleontological evidence. The basal Campanian ammonite zone is characterized by the first appearance of *Diplacnoceras bidorsatum*. An examination of the planktonic foraminifera contained in this zone shows that the first appearance of *Globotruncanita elevata* (Brotzen) closely approximates the first appearance of *D. bidorsatum*. Based on this evidence, the use of *G. elevata* as a marker species has found worldwide acceptance (Dalbiez, 1955; Pessagno, 1967; Postuma, 1971; Sigal, 1977; Butt, 1981; Dowsett, 1984). A close look at the biostratigraphic position of the Santonian and Campanian stratotypes reveals a more complicated situation. The macrofossil zonation does not come directly from the stratotypes. No single group of macrofossils is present in all the stratotypes. Second-order correlations are required to correlate the macrofossil biozonations with the stratotypes, resulting in confusion (Van Hinte, 1968; Barr, 1972; Seronie-Vivien, 1972; Verbeek, 1977). The Santonian and Campanian stratotypes contain foraminifers and calcareous nannofossils, however, and the nannofossils allow a first-order correlation of the stratotypes (Verbeek, 1977). As stated earlier, the exact location of the Santonian stratotype is uncertain. Verbeek (1977) examined several samples and identified a poorly preserved nannofossil flora belonging to his *Zygodiscus spiralis* Zone. This zone can be correlated with the *Calculites obscurus* nannofossil zone and the upper, but not uppermost, part of the *Dicarinella asymetrica* planktonic foraminiferal zone used here. The base of the Campanian stratotype is in the *Ceratolithoides aculeus* Zone, according to Verbeek (1977). This zone correlates with the lower, but not lowest, part of the *G. elevata* Zone (fig. 3).

The placement of the Santonian-Campanian boundary at the first appearance of *Globotruncanita elevata* in light of the nannofossil evidence may or may not be accurate. Many calcareous nannofossil workers (Thierstein, 1976; Sissingh, 1977; Verbeek, 1977) place the boundary at the first appearance of *Aspidolithus parcus* (Stradner), which is most probably in the gap between the stratotypes of both stages. In the present study, the first appearance of *A. parcus* is used as the Santonian-Campanian boundary marker.

Austinian-Tayloran Boundary

The term "Gulf series" was first used by Hill (1887) to define the youngest Cretaceous in the Gulf Coastal province. The Gulf series is currently applied to the upper part of the marine Cretaceous rocks in the Gulf Coastal province. The Gulf series is commonly divided into five stages, from youngest to oldest, as follows: Navarroan, Tayloran, Austinian, Eaglefordian, and Woodbinian.

Rocks now belonging to the Austin Group were originally described by Shumard (1860) as the Austin limestone, a fossiliferous, cream-colored, bluish, earthy limestone that had an exposure of approximately 100 feet (30 meters) in the vicinity of Austin, Travis County, Tex. In 1937, Stephenson redescribed the Austin chalk and assigned a thickness of 420 feet (128 meters) in the type area. He noted that the relation of faunal zones in the upper part of the Austin chalk to the top of the chalk indicated a regional unconformity of varying magnitude between the Austin chalk and Taylor marl. He attributed this to unequal erosion at the top of the Austin chalk and differential warping in early Taylor time. The Taylor marl, or *Exogyra ponderosa* marl, now belonging to the Taylor Group was first described by Hill (1892) as a chalky clay 1,200 feet (366 meters) thick, characterized by *E. ponderosa*.

In the east Texas embayment there is generally a distinctive contact, with a hiatus, generally of short duration, between the upper Austinian and lower Tayloran lithostratigraphic units (Hazel and Brouwers, 1982; Young, 1982). The lithostratigraphic sequence for the Austin and Taylor Groups is shown in figure 4. By examining the published literature on macrofossils, foraminifers, calcareous nannofossils, and ostracodes, several first and last appearances come to light that closely approximate the Austinian-Tayloran Stage boundary. There are no planktonic foraminifers with easily identifiable datums at the Austinian-Tayloran boundary. Pessagno's (1967) monograph is difficult to follow on this point because the Santonian-Campanian and Austinian-Tayloran boundaries are drawn at the same level. Several species first appear or disappear at the Austinian-Tayloran boundary, but more recent studies have extended the ranges of these taxa. A recent study of the boundary by Marks and Stam (1983) suggests no significant planktonic faunal changes.

One benthic foraminifer, *Vaginulina texana* Cushman, has a last appearance at the Austinian-Tayloran boundary (Cushman, 1946; Braunstein, 1959). *V. texana* has been used extensively by researchers over the last 40 years to identify the Austinian-Tayloran boundary in both subsurface and outcrop sections.

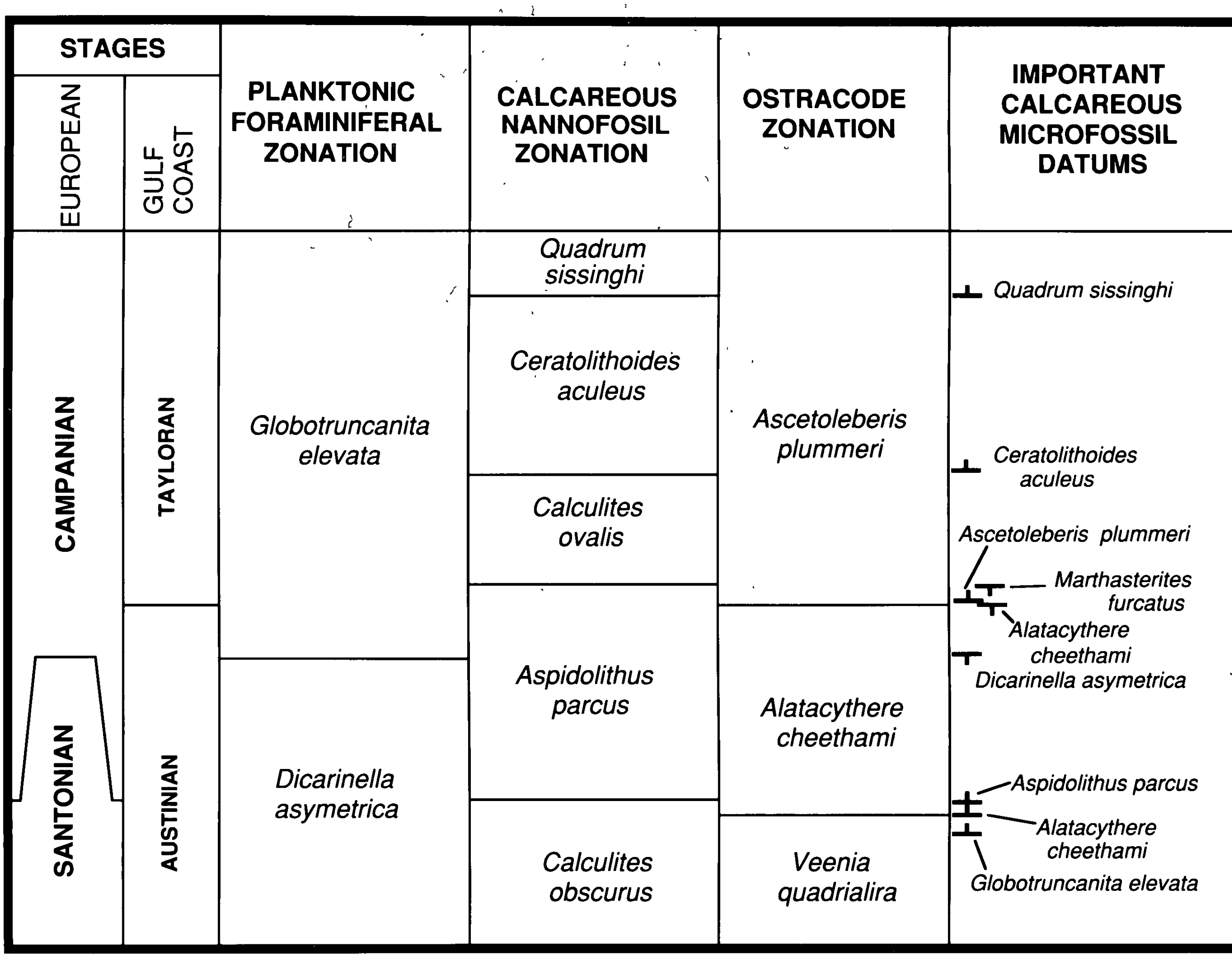

Figure 3. Approximate correlation of biostratigraphic zonations, important fossil events, and European and provincial stages discussed in the text.

Several calcareous nannofossil datums fall on either side of the boundary, giving a reasonable approximation of its location. *Aspidolithus parcus*, the nannofossil marker for the Santonian-Campanian boundary, makes its first appearance in the upper Austinian (Leshner, 1983). The last appearance of *Marthasterites furcatus* (Deflandre) occurs in the lower Tayloran (Gartner, 1968; Bukry, 1969; Barrier, 1980). Both datums have been well established in the Coastal Plain and bracket the boundary.

A review of the stratigraphic distribution of Cretaceous ostracodes of the Atlantic and Gulf Coastal Plains shows several species with important first and last appearances in the Austinian-Tayloran boundary interval (Hazel and Brouwers, 1982). *Ascetoleberis plummeri* (Israelsky) and other species of this genus make their first appearance at the boundary, making it relatively easy to distinguish. *Alatacythere cheethami* (Hazel and Paulson) and *Brachycythere durhami* Hazel and Paulson have last appearances either just below or at the boundary. *Haplocytheridea insolita* has a first appearance in the lower part of the *A. plummeri* Zone (Hazel and Brouwers, 1982).

By integrating the foraminifers, ostracodes, and calcareous nannofossils, several reliable and easily identifiable datums can be used to document the Austinian-Tayloran boundary (see also fig. 3).

MICROFOSSIL ZONATIONS

Planktonic Foraminiferal Zonation

Zonations of the Upper Cretaceous based on planktonic foraminifers have been proposed by Bolli (1966), Pessagno (1967), Postuma (1971), Sigal (1977), Van Hinte (1976), Wonders (1980), and Caron (1985). The planktonic foraminiferal zonation presented here (fig. 3) follows closely the zonation of Caron (1985).

Dicarinella asymetrica Zone: The base is defined by the first appearance datum of *D. asymetrica* (Sigal, 1952).

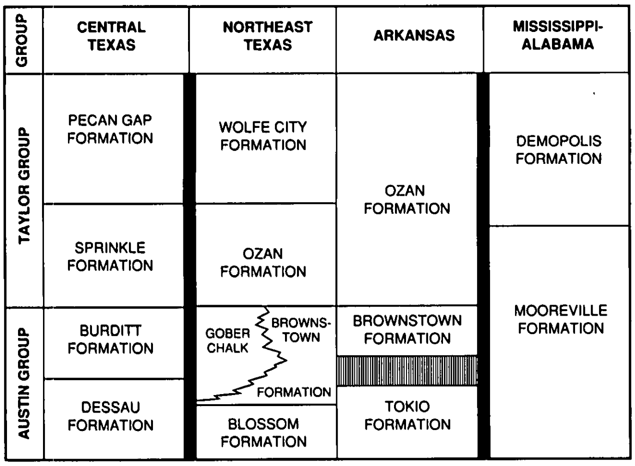

Figure 4. Generalized correlation chart for the east Texas embayment and the eastern Gulf Coastal Plain (modified after Hazel and Brouwers, 1982).

The top is defined by the last appearance of *D. asymetrica* (Sigal, 1952). The *D. asymetrica* Zone was first used by Postuma (1971). His *Globotruncana concavata carinata* Zone, by synonymy, is equivalent to the *D. asymetrica* Zone used here. The *D. asymetrica* Zone includes the *Globotruncanita elevata-Dicarinella asymetrica* concurrent range zone concept of many authors (Masters, 1970, 1977; Van Hinte, 1976; Wonders, 1980; Dowsett, 1984).

Globotruncanita elevata Zone: The base is defined by the last appearance of *Dicarinella asymetrica* (Sigal, 1952). The top is defined by the first appearance of *Globotruncanita calcarata* Cushman, 1927. The *G. elevata* Zone was first used by Dalbiez (1955). Although not formally defined, his *Globotruncana elevata* faunizone can be interpreted to begin with the first appearance of *G. elevata* and end with the first appearance of *G. calcarata*. As it is used here, the *G. elevata* Zone was originally proposed by Postuma (1971). The author follows the example of many workers (e.g., Postuma, 1971; Premoli Silva and Boersma, 1977; Sigal, 1977) in defining the top of the *G. elevata* Zone with the first occurrence of *G. calcarata*. Wonders (1980) defined the top of his *Globotruncana elevata* (= *G. elevata*) Zone as the first occurrence of *Globotruncana ventricosa* White. He stated (p. 53, 54), however, that *G. ventricosa* may be an immigrant to the western Mediterranean and therefore not useful for interregional correlation. Caron (1985) also terminates his *G. elevata* Zone with the first appearance of *G. ventricosa*. *G. ventricosa* has not traditionally been used in the Gulf Coast to mark the top of this zone (Caron, 1985) and is not used as a marker in this study. In a recent study (Dowsett, 1984), *G. ventricosa* was observed in both lower Campanian and uppev Santonian samples from a core in the northeastern Gulf of Mexico. During the present study, individuals of *G. ventricosa* have been observed chronostratigraphically below the level at which Wonders (1980) found the first *G. ventricosa* in North Africa.

Calcareous Nannofossil Zonation

Calcareous nannofossil zonations covering the Santonian-Campanian part of the Upper Cretaceous have been proposed by Cepek and Hay (1969, 1970), Bukry (1969), Bukry and Bramlette (1970), Manivit (1971, 1972), Roth and Thierstein (1972), Bukry (1973), Roth (1973), Thierstein (1976), Sissingh (1977), Perch-Nielsen (1979), and Stradner and Steinmetz (1984). The calcareous nannofossil zonation proposed by Sissingh (1977) is applicable to the Gulf Coast Upper Cretaceous and is used here (fig. 3).

Calculites obscurus Zone (CC17): The base is defined by the first appearance of *C. obscurus* (Deflandre, 1959). The top is defined by the first appearance of *Aspidolithus parcus* (Stradner, 1963). The *C. obscurus* Zone was first used by Sissingh (1977). It is difficult to correlate the base of the *C. obscurus* Zone with other published nannofossil zonations because of the lack of agreement on the first occurrence of *C. obscurus*. Sissingh (1977) indicated that the first occurrence of *C. obscurus* was correlative with the Santonian-Campanian boundary and with the base of the foraminiferal *Globotruncana elevata* Zone of Postuma (1971). Thierstein (1976) placed the initial appearance of *Tetralithus obscurus* (= *C. obscurus*) within the Santonian. Citing a poorly understood variation in the genus *Calculites*, Verbeek (1977) placed the first occurrence of the *C. obscurus* group in the middle Turonian. As used in the present study, the *C. obscurus* Zone correlates at least in part with the *Zygodiscus spiralis* Zone of Verbeek (1977) and represents the uppermost Santonian.

Aspidolithus parcus Zone (CC18): The base is defined by the first occurrence of *A. parcus* (Stradner, 1963). The top is defined by the last occurrence of *Marthasterites furcatus* (Deflandre, 1954). The *A. parcus* (= *Broinsonia parca*) Zone was first used by Sissingh (1977). Bukry and Bramlette (1970) described an *Eiffellithus augustus* Zone as the interval between the first occurrence of *A. parcus* and the extinction level of *E. augustus*. The *A. parcus* Zone as used in the present study correlates with the lower portion of the *E. augustus* Zone of Bukry and Bramlette (1970). The *Broinsonia parca* Zones of Bukry (1973) and Roth (1973) are partial range zones and occur stratigraphically higher than the *A. parcus* Zone used here. The *A. parcus* Zone is equivalent to the lower half of the *B. parca* Zone of Verbeek (1977). Sissingh (1977) and Perch-Nielsen (1979) divide this zone into three parts on the basis of first occurrences of *Bukryaster hayi* and *Ceratolithoides verbeekii*. The *A. parcus* Zone represents the lowermost Campanian.

Calculites ovalis Zone (CC19): The base is defined by the last occurrence of *Marthasterites furcatus*

(Deflandre, 1954). The top is defined by the first occurrence of *Ceratolithoides aculeus* (Stradner, 1961). The *C. ovalis* Zone was first used by Sissingh (1977). Sissingh (1977) and Perch-Nielsen (1979) divide this zone into two parts on the basis of the last occurrence of *Bukryaster hayi*.

Ceratolithoides aculeus Zone (CC20): The base is defined by the first occurrence of *C. aculeus* (Stradner, 1961). The top is defined by the first occurrence of *Quadrum sissinghi* Perch-Nielsen, 1984 (=*Tetralithus nitidus*) Martini (1961). Cepek and Hay (1969) originally defined the *Tetralithus aculeus* Zone. While their base is defined by the first occurrence of *T. aculeus* (=*C. aculeus*), their top is defined by the first occurrence of *Chiastozygus initialis*. Sissingh emended the zone to its present definition in 1977. This zone is equivalent to the *C. aculeus* Zone of Verbeek (1977).

Quadrum sissinghi Zone (CC21): The base is defined by the first occurrence of *Q. sissinghi* Perch-Nielsen, 1984. The top is defined by the first occurrence of *Quadrum trifidum* (Stradner, *in* Stradner and Papp, 1961). The *Q. sissinghi* (=*Tetralithus nitidus*) Zone was first used by Sissingh in 1977. This zone is recognized by Verbeek (1977) and Perch-Nielsen (1979, 1985).

Ostracode Zonation

The ostracode zones used here (fig. 3), all of which are based on first occurrences, are those of Hazel and Brouwers (1982).

Veenia quadrialira Zone: The base is defined by the first appearance of *V. quadrialira* (Swain, 1952). The top is defined by the first appearance of *Alatacythere cheethami* (Hazel and Paulson, 1964).

Alatacythere cheethami Zone: The base is defined by the first appearance of *A. cheethami* (Hazel and Paulson, 1964). The top is defined by the first appearance of *Ascetoleberis plummeri* (Israelsky, 1929).

Ascetoleberis plummeri Zone: The base is defined by the first appearance of *A. plummeri* (Israelsky, 1929). The top is defined by the first appearance of *Limburgina verricula* (Butler and Jones, 1957).

RESULTS

The localities investigated during this study can be divided into several groups (sample localities are shown in fig. 1 and are further described in the appendix). The Plymouth Bluff, Tibbee Creek, and DW-24 sites form a composite section within the Eutaw, Mooreville, and Demopolis Formations in northeastern Mississippi. This section is hereafter referred to as the "Mississippi composite." The Selma core, located farther to the east on the Alabama River, also represents an interval within the Eutaw (Tombigbee Sand Member), Mooreville, and Demopolis Formations. The section at China Bluff on the Tombigbee River is situated geographically between the Selma core and the Mississippi composite (see also fig. 1). China Bluff exposes the upper Mooreville Formation, including the Arcola Limestone Member. The stratigraphic occurrence of selected microfossils from these localities is shown in tables 1–3.

Selma Core

The most complete section investigated during this study is at the Alabama Power Company South Selma Test Site 1, called the Selma core. Both the Santonian-Campanian and Austinian-Tayloran boundaries can be documented using the three fossil groups previously discussed. The positions of samples and zonal assignments are shown in figure 5. The stratigraphic distribution of microfossils within the Selma core is given in table 1.

The Santonian-Campanian boundary is placed at the first appearance of *Aspidolithus parcus*. As discussed earlier, this datum is accepted as the boundary marker by many workers. The first appearance of the nannofossil species *A. parcus* occurs stratigraphically above the first appearance of *Globotruncanita elevata*. Whether *G. elevata* or *A. parcus* is used to mark the boundary is unimportant. The integrated nannofossil and foraminiferal datums within the boundary interval in the Selma core fit well with the established literature.

The first appearance of *Globotruncanita elevata* occurs 143.20 meters below the surface in sample ALA7. The Tombigbee Sand Member of the Eutaw Formation present in the Selma core, along with the lower 35 meters of the Mooreville Formation, is placed in the *Dicarinella asymetrica* Zone. The basal Campanian *G. elevata* Zone ranges between sample ALA7 (143.20 meters) and the top of the studied portion of the core (50 meters). The last appearance of *Sigalia deflaensis* (Sigal) has been shown to occur within the concurrent range of *G. elevata* and *D. asymetrica* by many workers (Barr, 1972; Salaj, 1980; Butt, 1981; Dowsett, 1984). Masters (1970), studying material from Alabama, identified the last appearance of *S. deflaensis* below the first appearance of *G. elevata*. In the Selma core, *S. deflaensis* was recovered from Santonian sediments only (samples ALA3, ALA31).

Samples below ALA8 are assigned to the *Calculites obscurus* Zone based on the presence of *C. obscurus* and the absence of *Aspidolithus parcus*. *Marthasterites furcatus* is present from the base of the core to a point 90 meters below the surface (ALA13). This datum marks the boundary between the *A. parcus* Zone below and the *C. ovalis* Zone above. The *C. ovalis* Zone extends upward to sample ALA25, where the first appearance of *Ceratolithoides aculeus* marks the base of the *C. aculeus* Zone. This zone extends to the top of the section of core studied, encom-

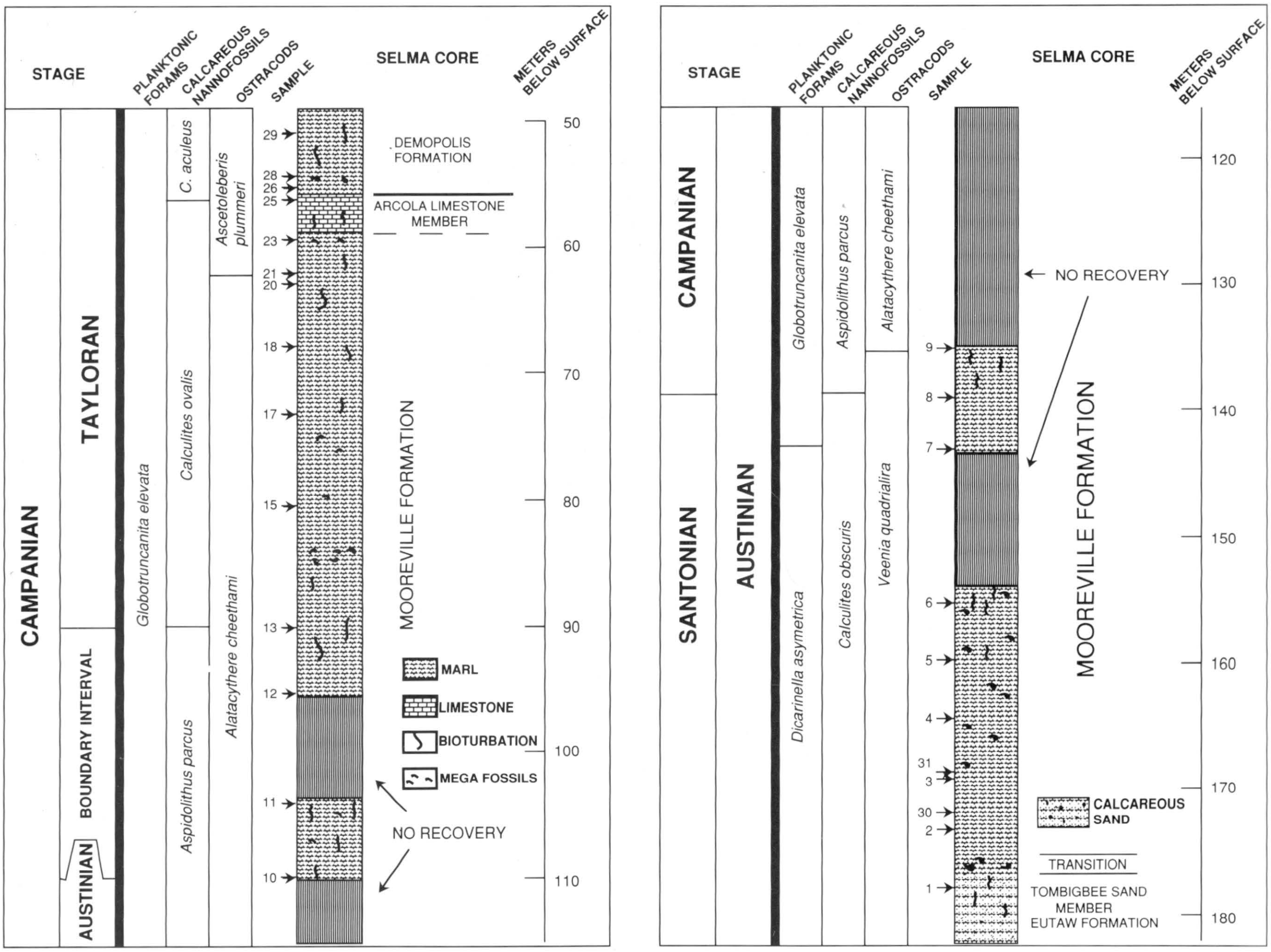

Figure 5. Stratigraphic summary of the Selma core. Arrows indicate position of samples used in this study (sample numbers preceded by ALA in text).

passing the uppermost part of the Mooreville Formation, including the Arcola Limestone Member, and the lower 4.6 meters of the Demopolis Formation.

Small sample size resulted in patchy occurrences and unfilled ranges for many of the ostracode species. Hazel and Brouwers (1982) indicated that the boundary between the *Veenia quadrialira* and *Alatacythere cheethami* Zones approximates the first appearance of *Globotruncanita elevata* and the Santonian-Campanian boundary (fig. 3). However, J.E. Hazel (written commun., 1984), on the basis of new data, states that *G. elevata* first appears before *A. cheethami*. Hazel estimates the difference between the two datums to represent 1.5 million years. In the present study, *V. quadrialira* is represented by one poorly preserved specimen that occurs 170 meters below the surface (sample ALA3). This is well within the Santonian as defined by both foraminifers and nannofossils. *Veenia ozanana* (Israelsky) and *Veenia ponderosana* (Israelsky) are present in many samples below the first appearance of *G. elevata*. Both ostracode species evolved early in the *V. quadrialira* Zone and are evidence that the lower portion of the Selma core can be no older than the *V. quadrialira* Zone. *A. cheethami* has a single occurrence 134.9 meters below the surface (sample ALA9). *A. cheethami* is confined to the *A. cheethami* Zone. The 25-meter uncored section between samples ALA9 and ALA10 may explain there being no higher occurrences of this species. *Brachycythere durhami* normally last appears at or near the top of the *A. cheethami* Zone but was found no higher than sample ALA7. *Brachycythere acuminata* (Hazel and Paulson) and *Physocythere annulospinata* (Hazel and Paulson) have first appearances in the lower part of the zone (Hazel and Brouwers, 1982). Both species first appear in sample ALA9 along with *A. cheethami* in the Selma core. Whereas the base of the *A. cheethami* Zone is a little higher than was expected from the literature, the simultaneous first occurrence of three species that appear early in the zone is here accepted as evidence for a close approximation of the chronostratigraphic position of

Table 1. Microfossil occurrences in the Selma core
[Numbers are ALA sample numbers in text. X, present; --, absent]

	1	2	30	3	31	4	5	6	7	8	9	10	11	12	13	15	17	18	20	21	23	25	26	28	29
Ostracodes																									
Alatacythere cheethami	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ascetoleberis plummeri	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	X	X	X	X	X
Ascetoleberis rugosissima	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	X	X	X	X	X
Brachycythere acuminata	--	--	--	--	--	--	--	--	--	--	X	--	--	--	X	--	--	--	X	--	--	--	--	--	--
Brachycythere durhami	--	--	--	X	--	X	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cytheropteron furcalatum	--	X	--	X	--	--	X	--	--	X	X	X	X	X	X	--	X	X	--	--	--	--	--	--	--
Physocythere annulospinata	--	--	--	--	--	--	--	--	--	--	X	X	X	X	--	--	X	--	X	--	X	--	--	X	--
Veenia ozanana	--	X	--	X	--	X	--	X	--	--	X	X	X	--	X	--	--	--	X	--	--	--	--	--	--
Veenia ponderosana	--	X	--	--	--	X	--	X	--	X	--	X	X	X	X	--	X	X	X	X	X	--	--	--	--
Veenia quadrialira	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Veenia spoori	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	X	--	--	--	--	--	--
Calcareous nannofossils																									
Aspidolithus parcus	--	--	--	--	--	--	--	--	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bukryaster hayi	--	--	--	--	--	--	--	--	--	--	--	--	X	X	X	X	X	X	X	X	X	X	X	--	--
Calculites obscurus	--	--	--	--	--	X	X	--	--	X	X	--	X	--	--	X	--	X	X	X	--	X	X	X	X
Calculites ovalis	X	--	X	X	--	X	X	X	X	X	--	X	--	X	X	X	--	--	X	--	X	X	X	--	X
Ceratolithoides aculeus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	X	X	X
Marthasterites furcatus	X	X	X	--	X	X	X	X	--	X	X	X	X	X	X	--	--	--	--	--	--	--	--	--	--
Foraminifers																									
Archaeoglobigerina cretacea	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dicarinella asymetrica	X	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Globotruncana arca	--	--	--	--	--	--	X	--	--	X	--	X	X	--	--	--	--	--	X	--	--	--	--	--	--
Globotruncana linneiana	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	X	X	--	--	X	X	--
Globotruncana ventricosa	--	X	--	--	--	--	X	--	--	X	X	X	X	X	--	X	--	X	--	X	X	X	X	X	X
Globotruncanita elevata	--	--	--	--	--	--	--	--	X	X	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Marginotruncana marginata	--	X	--	X	--	X	X	X	X	X	X	X	X	--	--	X	X	X	X	X	X	X	X	X	X
Rosita fornicata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sigalia deflaensis	--	--	--	X	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Vaginulina texana	X	--	X	--	--	X	--	--	X	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--	--
Ventilabrella glabrata	--	--	--	X	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--

the base of the zone. The boundary between the *A. cheethami* and *Ascetoleberis plummeri* Zones is used by Hazel and Brouwers (1982) to mark the Austinian-Tayloran boundary. This boundary is marked by the first occurrence of *A. plummeri* and other members of the genus *Ascetoleberis*. In Mississippi and Alabama the boundary has been projected to occur within the Mooreville Formation. The genus *Ascetoleberis* makes its first appearance 61.5 meters below the surface in the Selma core. By definition, this marks the base of the *A. plummeri* Zone. However, inspection of the nannofossil data in the Selma core compared with a U.S. Geological Survey model for the Upper Cretaceous (see Hazel and others, 1984) indicates that the first appearance of *Ascetoleberis* is later in the study area than in Texas and Arkansas. *Cytheropteron furcalatum* Alexander is thought to last occur at the base or in the early part of the *A. plummeri* Zone. In the Selma core, *C. furcalatum* is observed no higher than sample ALA18, 6 meters below the first appearance of *Ascetoleberis*.

The nannofossil species *Marthasterites furcatus* is last observed in lower Tayloran rocks in Texas and Arkansas (Barrier, 1980). In the Selma core, *M. furcatus* last appears in sample ALA13, 28.7 meters below the first appearance of *Ascetoleberis*. As mentioned in a previous section, the last appearance of the benthic foraminifer *Vaginulina texana* has been used extensively to mark the Austinian-Tayloran boundary in the Gulf Coast (Braunstein, 1959). As with the ostracodes, the small sample size may not have allowed detection of the true range of *V. texana* in the Selma core. *V. texana* is last observed in sample ALA10, 110.8 meters below the surface. The evidence presented by the last appearances of *Cytheropteron furcalatum*, *M. furcatus*, and *V. texana* suggests that the Austinian-Tayloran boundary lies below the first appearance of *Ascetoleberis plummeri* in the Selma core. The boundary probably lies between the last appearance of *V. texana* and *M. furcatus* and is tentatively placed between samples ALA10 and ALA13, approximately 100±10 meters below the surface and 36 meters above the Santonian-Campanian boundary. It is difficult to explain the sudden abundant appearance of both *A. plummeri* and *Ascetoleberis rugosissima* (Alexander) in terms of improper sample size. It is possible that the section between the single occurrence of *Alatacythere cheethami* and last appearance of *V. texana* and the first appearance of *A. plummeri* represents the amount of time missing at the Austin-Taylor contact in the western Gulf Coastal Plain. However, the top of *M. furcatus* indicates an early Tayloran age. Therefore, the 28.7 meters between the last appearance of *M. furcatus* and first appearance of *A. plummeri* must be explained

Table 2. Microfossil occurrences at China Bluff

[Numbers are ALA sample numbers in text. X, present; --, absent]

	49	48	47	46	45	44	68	69
Ostracodes								
Alatacythere cheethami	X	X	--	--	--	--	--	--
Ascetoleberis plummeri	--	--	--	--	--	--	--	X
Brachycythere acuminata	X	X	--	--	--	--	--	--
Cytheropteron furcalatum	X	X	--	--	--	X	--	--
Physocythere annulospinata	--	--	--	--	--	--	X	--
Veenia ozanana	X	X	X	X	X	--	X	X
Veenia ponderosana	--	X	--	X	X	--	X	--
Veenia spoori	X	--	X	X	--	X	--	--
Calcareous nannofossils								
Aspidolithus parcus	X	X	X	X	X	X	X	X
Bukryaster hayi	X	X	X	X	X	X	--	--
Calculites obscurus	X	X	X	X	X	X	X	--
Calculites ovalis	X	X	X	X	X	X	X	X
Marthasterites furcatus	X	X	X	X	--	--	--	--
Foraminifers								
Archaeoglobigerina cretacea	X	X	X	X	X	X	X	X
Globotruncana arca	X	X	X	X	X	X	X	--
Globotruncana linneiana	--	--	X	X	X	X	X	--
Globotruncana ventricosa	--	--	--	X	X	X	--	--
Globotruncanita elevata	X	X	X	X	X	X	X	--
Marginotruncana marginata	--	--	X	X	--	X	X	--
Rosita fornicata	--	X	X	X	X	X	X	X
Ventilabrella glabrata	X	X	X	X	X	--	--	--

some other way. Alternatively, the genus *Ascetoleberis* may have migrated eastward to the Alabama area during early Tayloran time, explaining its first appearance so high in the section (J.E. Hazel, personal commun., 1983). Further study of the first appearance of *Ascetoleberis* with respect to the calcareous nannofossil datums and magnetostratigraphy is necessary to resolve this issue.

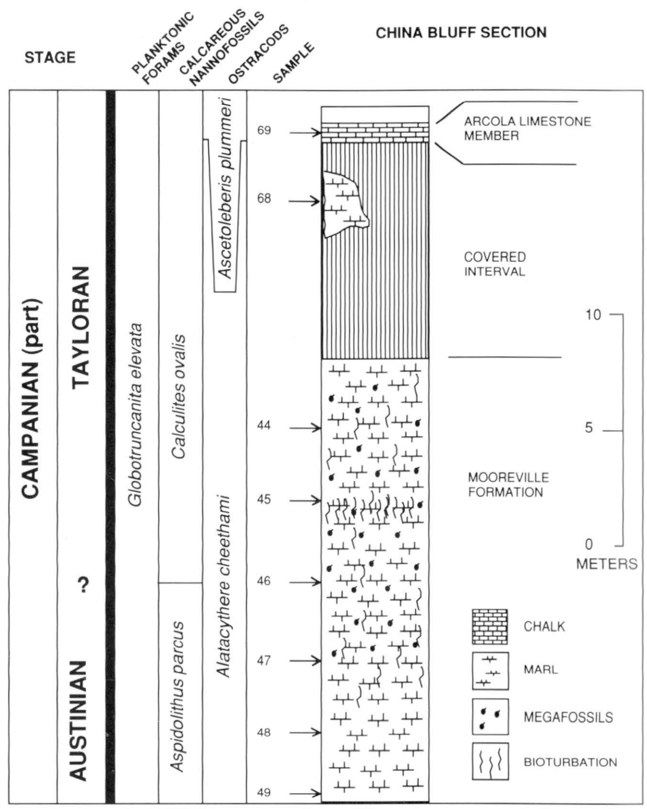

Figure 6. Stratigraphic summary of the China Bluff locality. Arrows indicate position of samples used in this study (sample numbers preceded by ALA in text).

China Bluff

The section investigated at China Bluff straddles the Austinian-Tayloran boundary and is placed entirely in the early Campanian. The stratigraphic distribution of microfossils from China Bluff is given in table 2. The position of samples and zonal assignments in the China Bluff section are shown in figure 6. The presence of *Globotruncanita elevata*, and the absence of both *Dicarinella asymetrica* and *Globotruncanita calcarata* in all samples, place the China Bluff locality entirely in the *G. elevata* Zone, which is Campanian in age. The presence of the nannofossil species *Aspidolithus parcus* in all samples is additional evidence for the section being no older than early Campanian.

The last appearance of *Marthasterites furcatus* 9.1 meters above the base of the exposure indicates an early Tayloran age and defines the boundary between the *Aspidolithus parcus* and *Calculites ovalis* Zones. Samples ALA49–ALA46 are placed in the *A. parcus* Zone. The part of the section above sample ALA46 is assigned to the *C. ovalis* Zone. Sissingh (1977) used the last appearance of *Bukryaster hayi* to subdivide the *C. ovalis* Zone. Although this datum does not show up consistently in the material studied, it can be used to subdivide the *C. ovalis* Zone above and below sample ALA44 at China Bluff.

The presence of *Alatacythere cheethami* and *Cytheropteron furcalatum* in the lowest samples at China Bluff indicates a late Austinian age. *Ascetoleberis plummeri* first appears near the top of the section. As in the Selma core, this occurrence is anomalously high and is best explained by a migration from the west. *Vaginulina texana*, the foraminiferal Austinian-Tayloran boundary marker, is not present at China Bluff.

Mississippi Composite

By combining the occurrence data from Tibbee Creek, Plymouth Bluff, and the DW-24 core (table 3), a composite section for northeastern Mississippi can be formed (fig. 7). Approximately 2.4 meters of section is missing between the top of the DW-24 core and the base of the Plymouth Bluff section (fig. 7). Information from well logs in the area indicates that the Mooreville Formation is approximately 46 meters thick. Approximately 40 meters of section is missing between the base of the Tibbee Creek section and the top of Plymouth Bluff; therefore, several supplementary samples from within this gap (from a section downstream from the Tibbee Creek locality) were analyzed to provide better control.

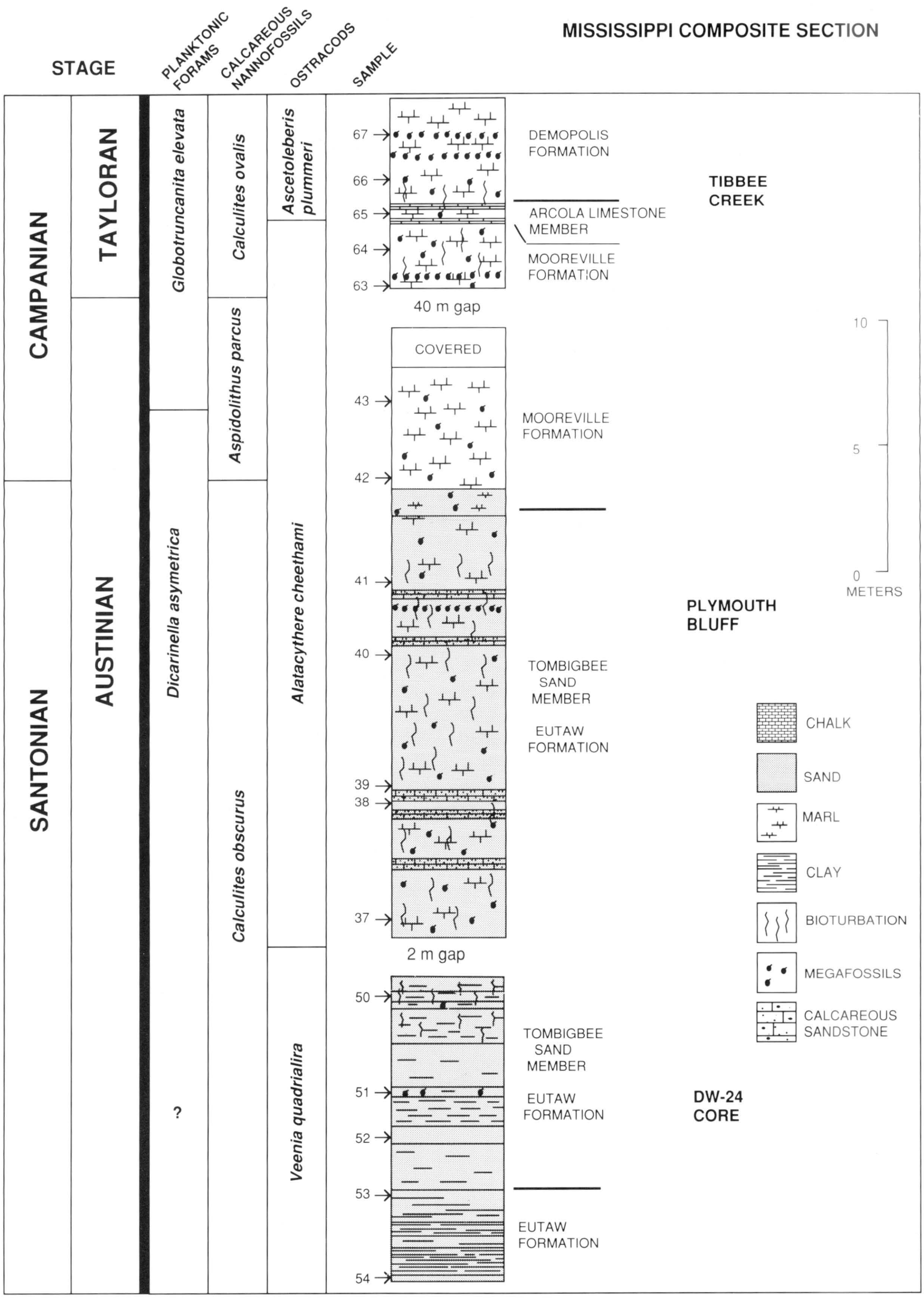

Figure 7. Stratigraphic summary of the Tibbee Creek and Plymouth Bluff localities and DW-24 core. Arrows indicate position of samples used in this study (sample numbers preceded by MIS in text).

Table 3. Microfossil occurrences in the Mississippi composite

[Numbers are MIS sample numbers in text. X, present; --, absent]

	DW-24 Core					Plymouth Bluff							Tibbee Creek				
	54	53	52	51	50	37	38	39	40	41	42	43	63	64	65	66	67
Ostracodes																	
Ascetoleberis plummeri	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	X	X
Ascetoleberis rugosissima	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	X	X
Physocythere annulospinata	--	--	--	--	--	--	X	--	X	--	X	X	X	X	X	X	X
Veenia ozanana	--	--	--	--	X	X	X	X	X	--	X	X	X	X	X	X	X
Veenia ponderosana	--	--	--	--	--	X	--	X	--	--	X	--	--	--	--	X	--
Veenia spoori	--	--	--	--	--	--	--	--	--	--	--	--	X	--	X	X	--
Calcareous nannofossils																	
Aspidolithus parcus	--	--	--	--	--	--	--	--	--	--	X	X	X	X	X	X	X
Bukryaster hayi	--	--	--	--	--	--	--	--	--	--	--	--	X	X	X	--	--
Calculites obscurus	--	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Calculites ovalis	--	--	X	X	--	X	X	X	X	X	X	X	X	X	X	X	X
Marthasterites furcatus	--	--	X	X	--	X	X	X	X	X	X	X	--	--	--	--	--
Foraminifers																	
Archaeoglobigerina cretacea	--	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dicarinella asymetrica	--	--	--	--	--	X	X	X	X	X	X	--	--	--	--	--	--
Globotruncana arca	--	--	--	--	X	--	X	--	X	X	--	X	X	X	X	X	X
Globotruncana linneiana	--	--	--	--	--	--	--	--	X	X	--	--	X	X	X	X	X
Globotruncana ventricosa	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	X
Globotruncanita elevata	--	--	--	--	--	X	X	X	X	X	X	X	X	X	X	X	X
Marginotruncana marginata	--	--	--	--	X	X	--	X	--	X	X	X	X	X	X	X	X
Rosita fornicata	--	--	--	--	X	X	X	X	X	X	X	X	X	X	X	X	X
Vaginulina texana	--	--	X	X	X	X	X	X	--	--	--	X	--	--	--	--	--
Ventilabrella glabrata	--	--	--	--	--	X	X	--	X	X	X	X	X	X	X	X	X

DW-24 Core

The lowest samples in the DW-24 core are in the lower unnamed unit of the Eutaw Formation, below the Tombigbee Sand Member, and contain no calcareous microfossils (samples MIS53 and MIS54). The presence of *Calculites obscurus* and the absence of *Aspidolithus parcus* in the upper 8.5 meters of the core indicate that the lower part of the Tombigbee Sand Member is assignable to the *C. obscurus* Zone, which suggests a Santonian age. Although poorly preserved, ostracodes are present throughout the Tombigbee in the DW-24 core; however, none gives a diagnostic age. The presence of *Veenia ozanana* indicates that the Tombigbee here can be no older than the *Veenia quadrialira* Zone. Foraminifers are rare and are not indicative of either a Santonian or a Campanian age. The absence of *Globotruncanita elevata* suggests a Santonian age but is most probably indicative of shallow water depth. *Dicarinella asymetrica*, present in the Tombigbee at Plymouth Bluff, is not found in the DW-24 core. All of the foraminifers observed are broken, incomplete specimens. The lower part of the Tombigbee represents a shallow marine environment probably unsuitable for globotruncanids.

Plymouth Bluff

The cooccurrence of *Dicarinella asymetrica* and *Globotruncanita elevata* in all but the highest sample at Plymouth Bluff places the lowest 19.8 meters of the Plymouth Bluff section in the uppermost part of the *D. asymetrica* Zone of earliest Campanian-latest Santonian age. The first appearance of *Aspidolithus parcus* in sample MIS42, 19.8 meters above the base of the section, defines the base of the *A. parcus* Zone and the Santonian-Campanian boundary. The lower 19.8 meters of the Plymouth Bluff section are assigned to the *Calculites obscurus* Zone. The presence of *Physocythere annulospinata* throughout the Plymouth Bluff section suggests that the section may be no older than the *Alatacythere cheethami* Zone. No specimens of *A. cheethami* are found at Plymouth Bluff, but in supplementary samples in the area, *A. cheethami* was found to cooccur with *G. elevata* and *D. asymetrica*. *Vaginulina texana* is present throughout the DW-24 core and the entire Plymouth Bluff section.

Tibbee Creek

The upper Mooreville Formation, including the Arcola Limestone Member, and the basal Demopolis Formation exposed at Tibbee Creek are assigned to the *Globotruncanita elevata* Zone. The presence of *Calculites ovalis* (Stradner) and the absence of both *Marthasterites furcatus* and *Ceratolithoides aculeus* indicate the entire Tibbee Creek section to be assignable to the *C. ovalis* Zone. The exposed Mooreville, including the Arcola, is assigned to the lower half of the zone, and the Demopolis is assigned to the upper half. According to Mancini and Smith (1982), *C. aculeus* makes a first appearance 5.3 meters above the Arcola in the Tibbee Creek area. The absence of both *M. furcatus* and *Vaginulina texana* at Tibbee Creek suggests a Tayloran age. *Ascetoleberis plummeri* and *Ascetoleberis rugosissima* first appear within the Arcola Limestone Member. This datum marks the base of the *A. plummeri* Zone of earliest Tayloran age. With respect to the foram and nannofossil datums, the base of the genus *Ascetoleberis* is appearing high in the section. Four supplementary samples were obtained from a 24.5-meter exposure that falls stratigraphically between the Plymouth Bluff and Tibbee Creek localities. *Vaginulina texana* has its last occurrence within this supplementary section, while *M. furcatus* is present throughout. Taking the thickness of the Mooreville Formation in this area to be about 46 meters, the Austinian-Tayloran boundary (based on the last appearance of *V. texana*) projects 21 ± 6 meters above the top of the Plymouth Bluff section.

In the past the Arcola Limestone Member of the Mooreville Formation has been used to designate the Austinian-Tayloran boundary in the Gulf Coast (Braunstein, 1959). The data derived in this study indicate that this boundary is located well below the Arcola. The Arcola Limestone Member appears to be time transgressive. At the Tibbee Creek and China Bluff localities, the Arcola is placed in the upper half of the *Calculites ovalis* Zone. In the Selma core, the Arcola falls within the basal part of the *Ceratolithoides aculeus* Zone. The ostracode genus *Ascetoleberis* consistently first appears at the level of the Arcola. If *Ascetoleberis* has migrated from the west as hypothesized, this is additional evidence for the Arcola being time transgressive.

CONCLUSIONS

It is possible to document the stratigraphic separation between the Santonian-Campanian and Austinian-Tayloran Stage boundaries in the eastern Gulf Coastal Plain using a biostratigraphic framework composed of foraminifers, nannofossils, and ostracodes. In eastern Mississippi, the Santonian-Campanian boundary occurs within the Tombigbee Sand Member of the Eutaw Formation. The Austinian-Tayloran boundary occurs within the Mooreville Formation approximately 21 meters above the Santonian-Campanian boundary. In Alabama, the Santonian-Campanian boundary occurs within the Mooreville Formation, approximately 35 meters above the Eutaw-Mooreville contact. The Austinian-Tayloran boundary occurs within the Mooreville Formation, approximately 36.5 meters above the Santonian-Campanian boundary. The Arcola Limestone Member of the Mooreville Formation, previously used to designate the Austinian-Tayloran boundary, lies well within the Tayloran Stage.

TAXONOMIC NOTES

In this section I list ostracode, foraminifer, and nannofossil taxa recorded in tables 1–3. Brief references to publications that document my concept of each taxon are included. Illustrations of selected taxa are provided in plates 1–6.

Ostracoda

Alatacythere cheethami (Hazel and Paulson) Hazel and Brouwers

Plate 5, figure 4

Alatacythere cheethami (Hazel and Paulson) Hazel and Brouwers, 1982, p. 195, pl. 6, fig. 9.

Brachycythere acuminata Hazel and Paulson

Plate 5, figure 1

Brachycythere (*Brachycythere*) *acuminata* Hazel and Paulson, 1964, p. 1060, pl. 157, fig. 12; pl. 149, figs. 9, 11.

Brachycythere durhami Hazel and Paulson

Brachycythere (*Brachycythere*) *durhami* Hazel and Paulson, 1964, p. 1061, pl. 157, fig. 1; pl. 159, fig. 10.

Cytheropteron furcalatum Alexander

Plate 5, figure 5

Cytheropteron furcalatum Alexander, 1933, p. 194, pl. 27, figs. 7a, 7b.

Ascetoleberis plummeri (Israelsky) Brouwers and Hazel

Plate 6, figure 1

Cythereis plummeri Israelsky, 1929, p. 18, pl. 4A, figs. 2, 3.
Ascetoleberis plummeri (Israelsky). Brouwers and Hazel, 1978, p. 35.

Ascetoleberis rugosissima (Alexander) Brouwers and Hazel

Plate 5, figure 2

Cythereis rugosissima Alexander, 1929, p. 101, pl. 9, figs. 13, 14.
Ascetoleberis rugosissima (Alexander). Brouwers and Hazel, 1978, p. 35.

Veenia ozanana (Israelsky) Butler and Jones

Plate 5, figure 3

Cythereis ozanana Israelsky, 1929, p. 13, pl 3a, figs. 1, 3.
Veenia ozanana (Israelsky). Butler and Jones, 1957, p. 44, pl. 3, fig. 4a-3.

Veenia ponderosana (Israelsky) Hazel and Brouwers

Plate 5, figure 6

Cythereis ponderosana Israelsky, 1929, p. 13, pl. 3a, figs. 5–8.
Veenia ponderosana (Israelsky). Hazel and Brouwers, 1982, p. 184, pl. 3, figs. 14–17.

Veenia quadrialira (Swain) Hazel and Brouwers

Plate 6, figure 4

Cythereis quadrialira Swain, 1952, p. 84, pl. 9, figs. 27–30.
Veenia quadrialira (Swain). Hazel and Brouwers, p. 183, pl. 3, figs. 5, 9.

Veenia spoori (Israelsky) Hazel and Brouwers

Plate 6, figure 2

Cythereis spoori Israelsky, 1929, p. 27, pl. 4a, figs. 4, 5.
Veenia spoori (Israelsky). Hazel and Brouwers, 1982, p. 176, pl. 1, fig. 13.

Physocythere annulospinata (Hazel and Paulson) Hazel and Brouwers

Plate 6, figure 3

Orthonotacythere annulospinata Hazel and Paulson, 1964, p. 1049, pl. 157, figs. 2, 4; pl. 159, fig. 4.
Physocythere annulospinata (Hazel and Paulson). Hazel and Brouwers, 1982, p. 192, pl. 5, fig. 16.

Calcareous Nannofossils

Aspidolithus parcus (Stradner) Noel

Plate 7, figures 5, 9, 10

Arkhangelskiella parca Stradner, 1963, p. 10, pl. 1, fig. 3.
Aspidolithus parcus (Stradner) Noel, 1969.

Bukryaster hayi (Bukry) Prins and Sissingh

Plate 7, figures 3, 4, 7, 8

Discoaster hayi Bukry, 1969, p. 65, pl. 38, figs. 10–12.
Bukryaster hayi (Bukry). Prins and Sissingh, *in* Sissingh, 1977, p. 60.

Calculites obscurus (Deflandre) Prins and Sissingh

Plate 7, figures 11, 12

Tetralithus obscurus Deflandre, 1959, p. 138, pl. 3, figs. 36–39.
Calculites obscurus (Deflandre). Prins and Sissingh, *in* Sissingh, 1977, p. 60.

Calculites ovalis (Stradner) Prins and Sissingh

Plate 7, figures 15, 16

Tetralithus ovalis Stradner, 1963, p. 12, pl. 6, fig. 7.
Calculites ovalis (Stradner). Prins and Sissingh, *in* Sissingh, 1977, p. 60.

Ceratolithoides aculeus (Stradner) Prins and Sissingh

Plate 7, figures 1, 2, 6

Zygrhablithus aculeus Stradner, 1961, p. 81, figs. 53–57.
Ceratolithoides aculeus (Stradner). Prins and Sissingh, *in* Sissingh, 1977, p. 60, pl. 1, fig. 8.

Marthasterites furcatus (Deflandre) Deflandre

Plate 7, figures 13, 14

Discoaster furcatus Deflandre, 1954, p. 168, pl. 13, fig. 14.
Marthasterites furcatus (Deflandre). Deflandre, 1959, p. 139, pl. 2, figs. 3–12; pl. 3, figs. 1–5.

Foraminifera

Archaeoglobigerina cretacea (d'Orbigny) Pessagno

Plate 1, figures 7–9

Globigerina cretacea d'Orbigny, 1840, p. 34, pl. 3, figs. 12–14.
Archaeoglobigerina cretacea (d'Orbigny). Pessagno, 1967, p. 317, 318, pl. 70, figs. 3–7.

Dicarinella asymetrica (Sigal)

Plate 4, figures 1, 2, 4

Globotruncana asymetrica Sigal, 1952, p. 35, fig. 35.
Dicarinella asymetrica (Sigal). Robaszynski and Caron, 1979, p. 61–66, pl. 51, figs. 1, 2; pl. 52, figs. 1, 2.

Globotruncana arca (Cushman) Cushman

Plate 1, figures 4–6

Pulvinulina arca Cushman, 1926, p. 23, pl. 3, figs. 1a–1c.
Globotruncana arca (Cushman). Cushman, 1927b, p. 169, pl. 28, figs. 15a–15c.

Globotruncana linneiana (d'Orbigny) Cushman

Plate 2, figures 2, 4, 7

Rosalina linneiana d'Orbigny, 1839, p. 106, pl. 5, figs. 10–12.
Globotruncana linneiana (d'Orbigny). Cushman, 1931, p. 90.

Globotruncana ventricosa White

Plate 3, figures 1–3, 5

Globotruncana canaliculata var. *ventricosa* White, 1928, p. 284, pl. 38, figs. 5a–5c.

Globotruncanita elevata (Brotzen)

Plate 1, figures 1–3

Rotalia elevata Brotzen, 1934, p. 66, pl. 3, fig. C.
Globotruncanita elevata (Brotzen). Robaszynski, Caron, Gonzalez, and Wonders, 1984, p. 228–230, pl. 27, figs. 1–3; pl. 28, figs. 1–3.

Marginotruncana marginata (Reuss)

Plate 3, figures 4, 6

Rosalina marginata Reuss, 1845, p. 36, pl. 8, figs. 54a, 54b, 74a, 74b.

Rosita fornicata (Plummer)

Plate 2, figures 1, 3, 5

Globotruncana fornicata Plummer, 1931, p. 198, pl. 13, figs. 4–6.
Rosita fornicata (Plummer). Robaszynski, Caron, Gonzalez, and Wonders, 1984, p. 250, pl. 38, figs. 1–5.

Sigalia deflaensis (Sigal) Reiss

Plate 2, figure 6

Guembelina (*Ventilabrella*) *deflaensis* Sigal, 1952, p. 36, fig. 41.
Sigalia deflaensis (Sigal). Reiss, 1957, p. 243.

Ventilabrella glabrata Cushman

Plate 3, figure 7

Ventilabrella eggeri var. *glabrata* Cushman, 1938, p. 26, pl. 4, figs. 15–17b.

Vaginulina texana Cushman

Plate 4, figures 3, 5

Vaginulina texana Cushman, 1930, p. 30, pl. 4, figs. 2, 3.

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APPENDIX: LOCALITIES

Selma core: Officially designated the Alabama Power Company South Selma Test Site 1, Corehole 3; taken 0.5 mile west of the Mount Leveton Church, on the east side of the Alabama River, 14 miles south-southwest of Selma, Dallas County, Ala. Twenty-five samples were selected from this core, which contains the Tombigbee Sand Member of the Eutaw Formation, the Mooreville Formation, including the Arcola Limestone Member, and the Demopolis Formation.

China Bluff: An exposure in a small gully on the west side of the Tombigbee River, approximately 2 miles south of Warsaw, Sumter County, Ala., near the site of a U.S. Army Corps of Engineers China Bluff observation area and nature trail. Eight samples were selected from this exposure of the upper part of the Mooreville Formation, including the Arcola Limestone Member.

DW-24: U.S. Army Corps of Engineers dewatering well no. 24, taken at the site of the Columbus lock and dam, at the intersection of Tibbee Creek and the Tombigbee River, Lowndes County, Miss. Five samples were selected from this 40-foot, 4-inch-diameter core, which begins 20 feet below the surface in the Tombigbee Sand Member of the Eutaw Formation and penetrates the lower, unnamed member of the Eutaw Formation.

Plymouth Bluff: A long continuous exposure along the west bank of the Tombigbee River, approximately 1.2 miles downstream from the intersection of Tibbee Creek and the Tombigbee River, 4 miles west-northwest of Columbus, Lowndes County, Miss. Seven samples were selected from this locality, which exposes the uppermost Tombigbee Sand Member of the Eutaw Formation and the lowest Mooreville Formation.

Tibbee Creek: An exposure on the south bank of Tibbee Creek, immediately west of the point where the Gulf, Mobile, and Ohio Railroad bridge crosses Tibbee Creek, Clay County, Miss. Five samples were selected from this locality, which exposes the upper Mooreville Formation, including the Arcola Limestone Member, and the lowest Demopolis Formation.

PLATES 1–7

[Contact photographs of the plates in this report are available, at cost, from the U.S. Geological Survey Photographic Library, Federal Center, Denver, CO 80225]

PLATE 1

Figures 1–3. *Globotruncanita elevata* (Brotzen)

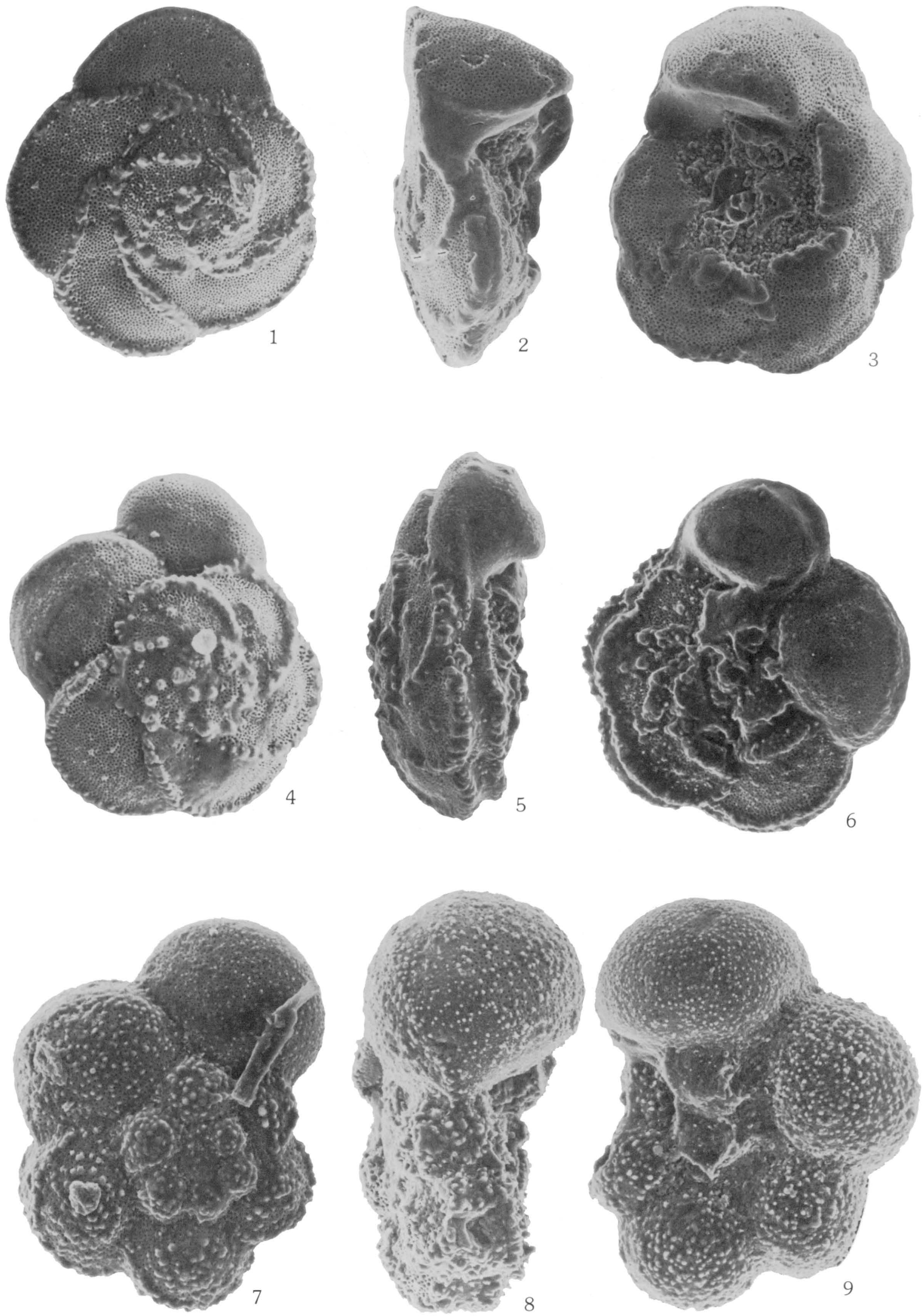
1. Spiral view, × 120, ALA7.
2. Apertural view, × 120, ALA7.
3. Umbilical view, × 120, ALA7.

4–6. *Globotruncana arca* (Cushman) Cushman

4. Spiral view, × 120, ALA10.
5. Apertural view, × 120, ALA10.
6. Umbilical view, × 120, ALA10.

7–9. *Archaeoglobigerina cretacea* (d'Orbigny) Pessagno

7. Spiral view, × 180, ALA20.
8. Apertural view, × 180, ALA20.
9. Umbilical view, × 180, ALA20.



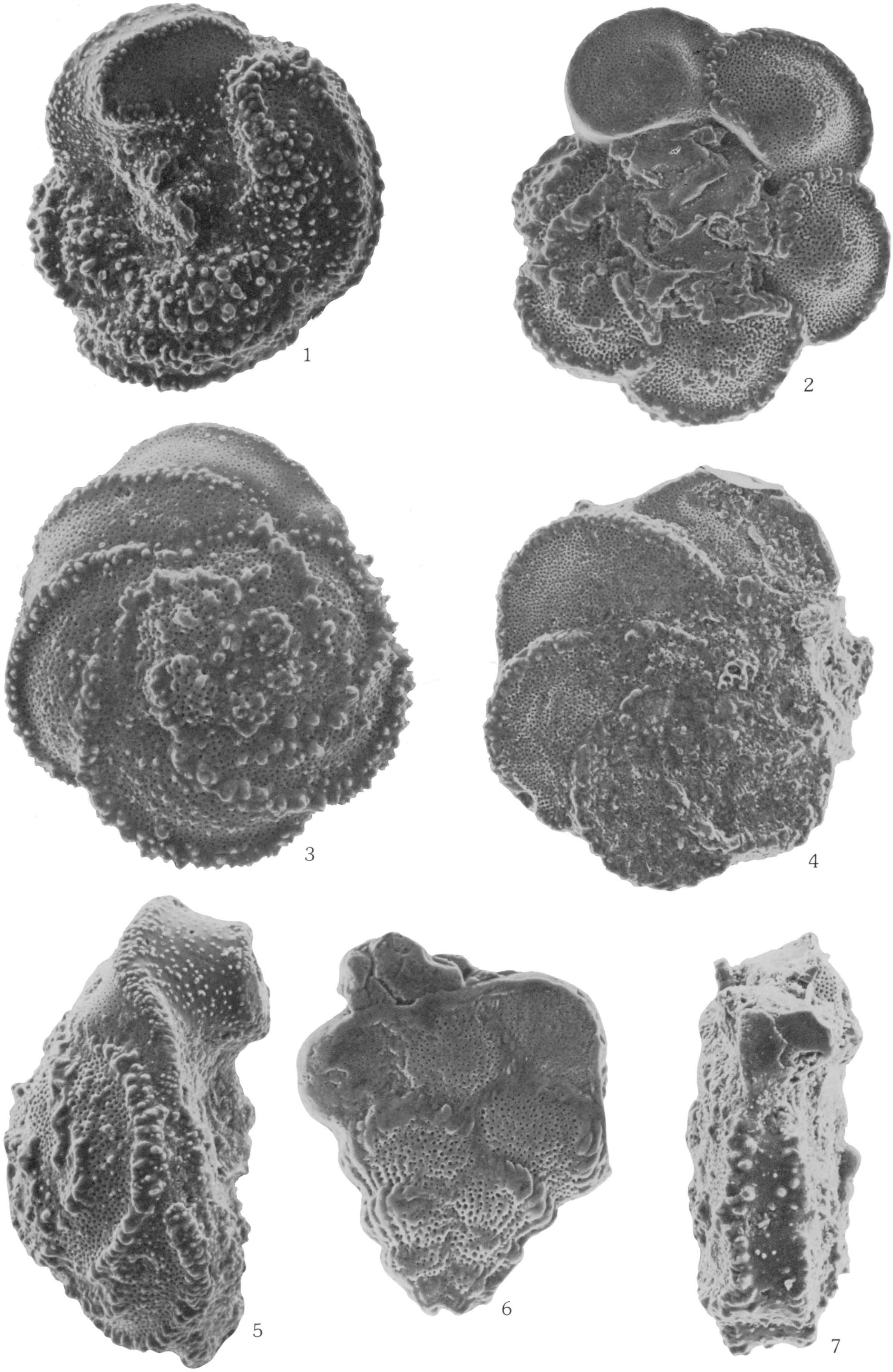
ARCHAEOGLOBIGERINA, GLOBOTRUNCANA, AND *GLOBOTRUNCANITA*

PLATE 2

Figures 1, 3, 5. *Rosita fornicata* (Plummer)
1. Umbilical view, × 180, ALA10.
3. Spiral view, × 180, ALA10.
5. Apertural view, × 180, ALA10.

2, 4, 7. *Globotruncana linneiana* (d'Orbigny) Cushman
2. Umbilical view, × 150, ALA21.
4. Spiral view, × 150, ALA21.
7. Apertural view, × 150, ALA21.

6. *Sigalia deflaensis* (Sigal) Reiss, × 180, ALA3.



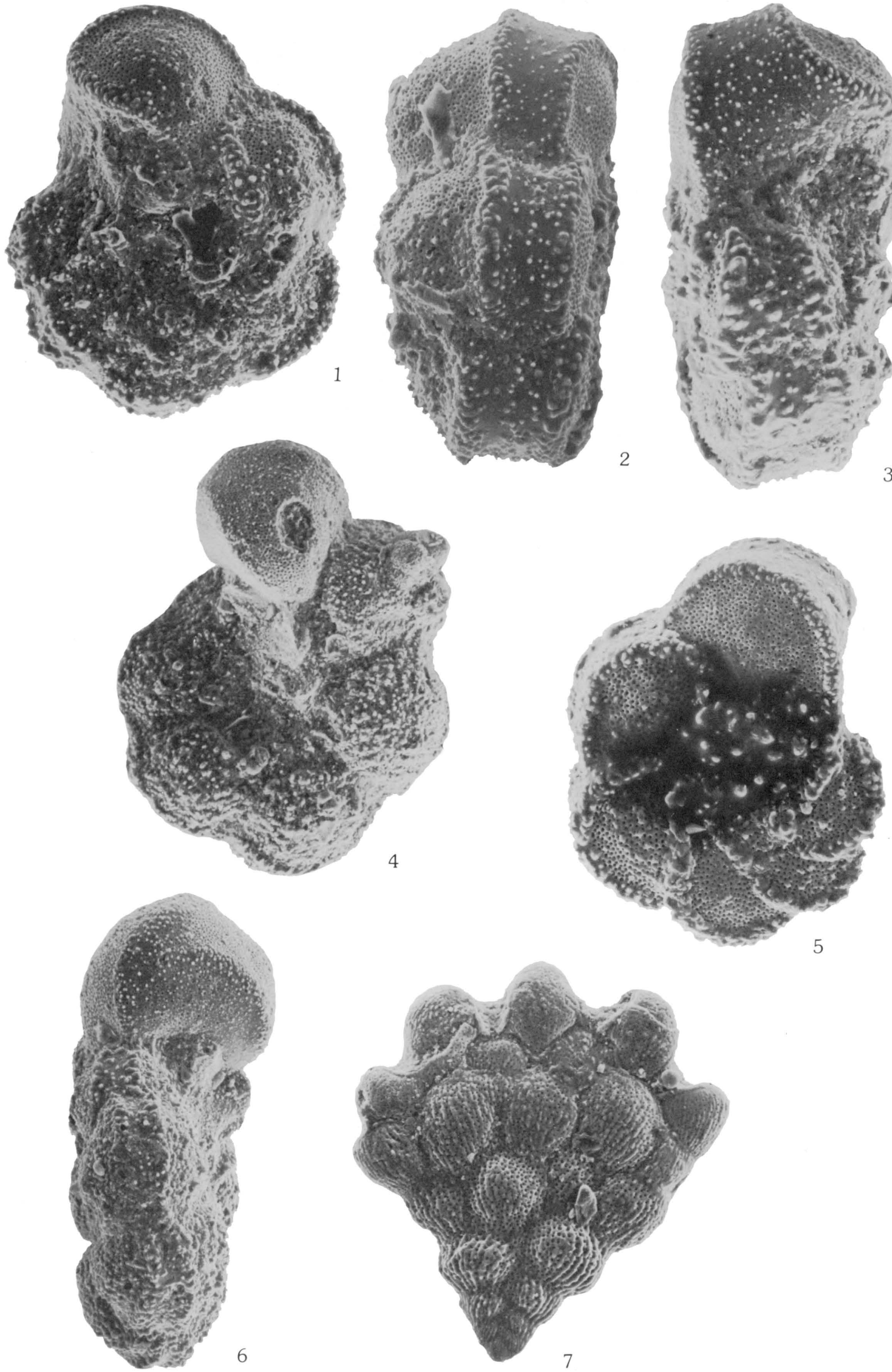
GLOBOTRUNCANA, ROSITA, AND *SIGALIA*

PLATE 3

Figures 1–3, 5. *Globotruncana ventricosa* White
1. Umbilical view, × 160, ALA2.
2. Abapertural view, × 180, ALA2.
3. Apertural view, × 180, ALA2.
5. Spiral view, × 160, ALA2.

4, 6. *Marginotruncana marginata* (Reuss)
4. Umbilical view, × 78, ALA4.
6. Apertural view, × 120, ALA4.

7. *Ventilabrella glabrata* Cushman, × 160, ALA10.

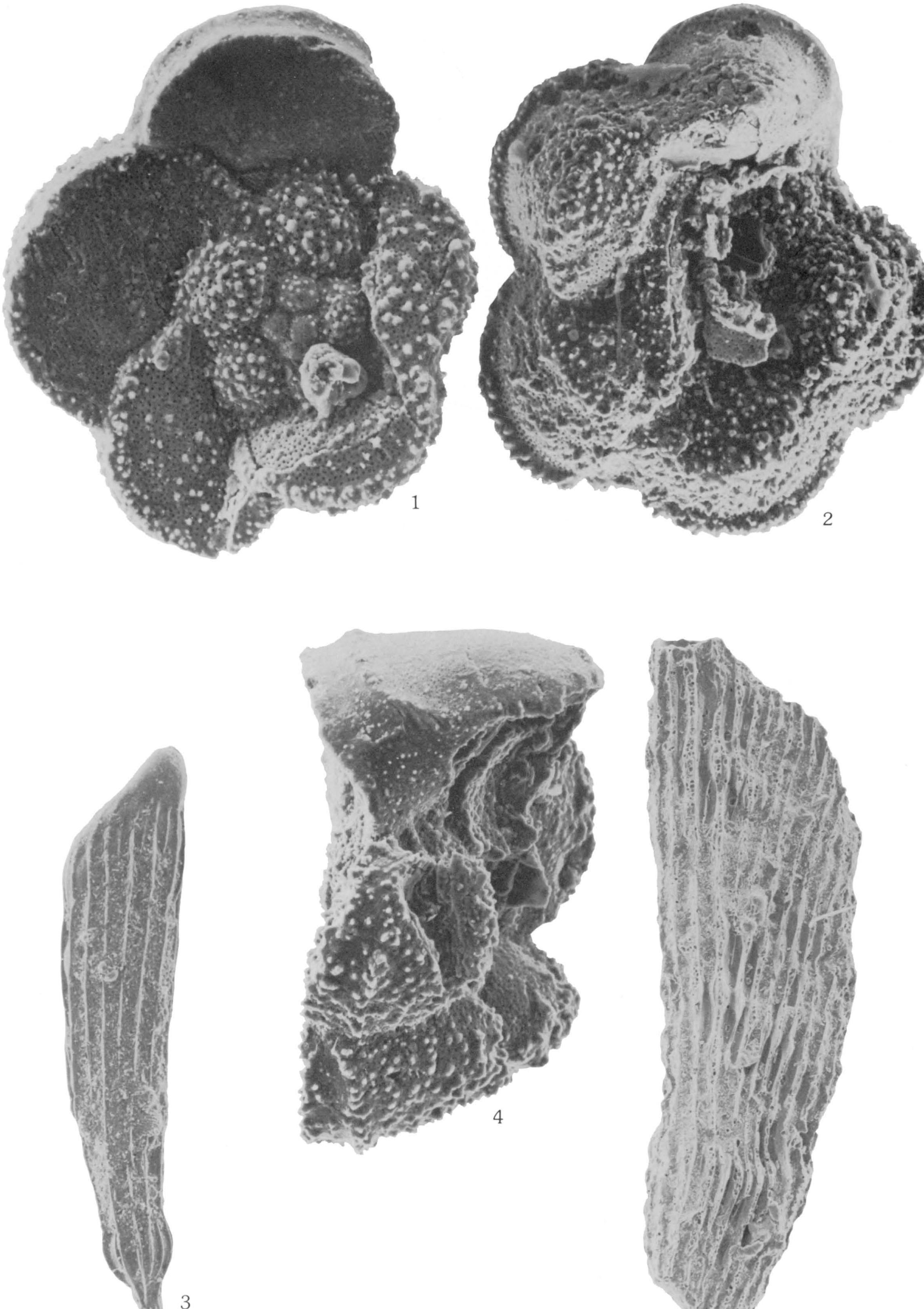


GLOBOTRUNCANA, MARGINOTRUNCANA, AND *VENTILABRELLA*

PLATE 4

Figures 1, 2, 4. *Dicarinella asymetrica* (Sigal)
1. Spiral view, × 120, ALA8.
2. Umbilical view, × 120, ALA8.
4. Apertural view, × 120, ALA8.

3, 5. *Vaginulina texana* Cushman
3. Side view, × 70, ALA10.
5. Side view, × 44, ALA4.

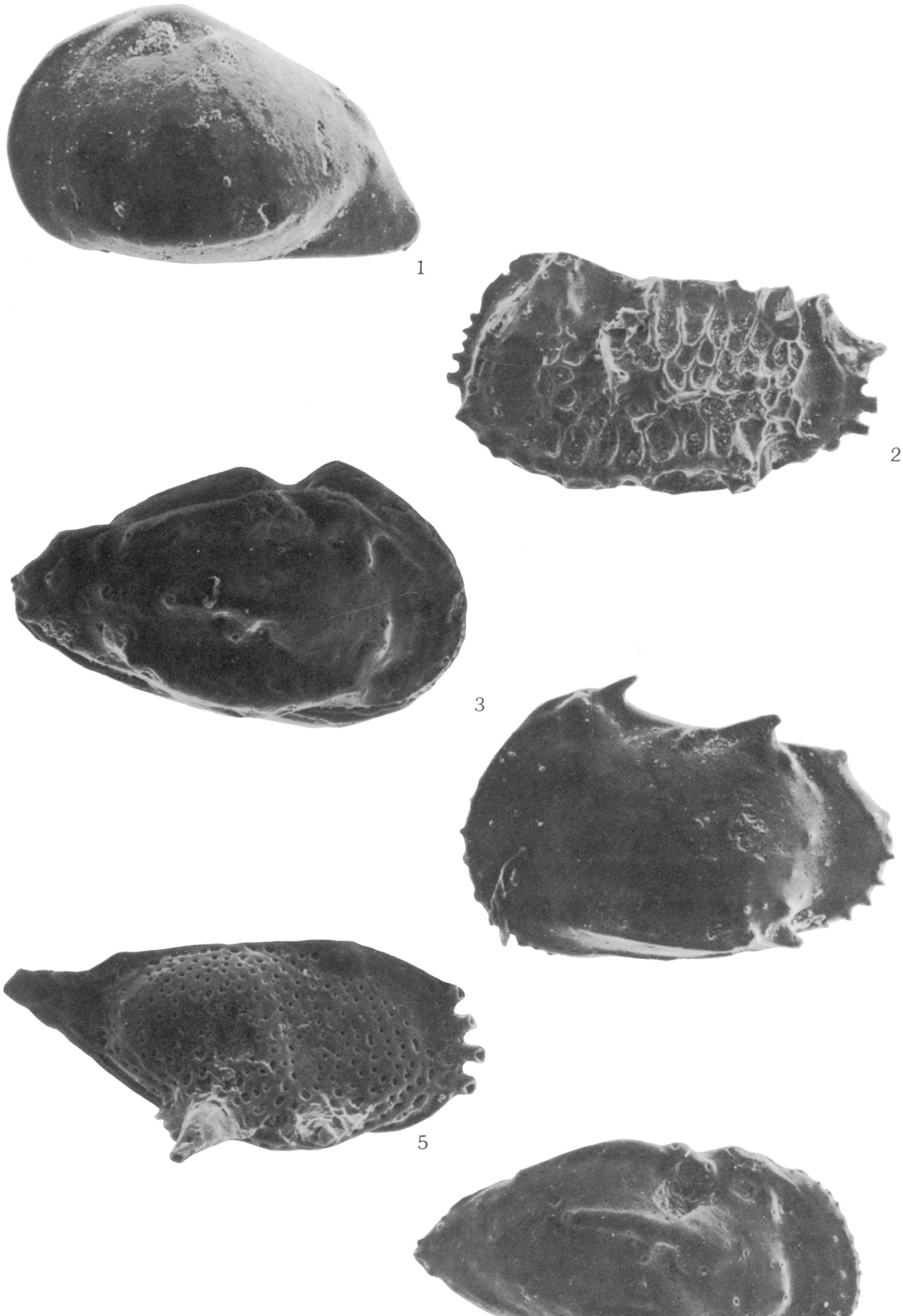


DICARINELLA AND *VAGINULINA*

PLATE 5

Figure 1. *Brachycythere acuminata* (Hazel and Paulson), × 110, ALA48.

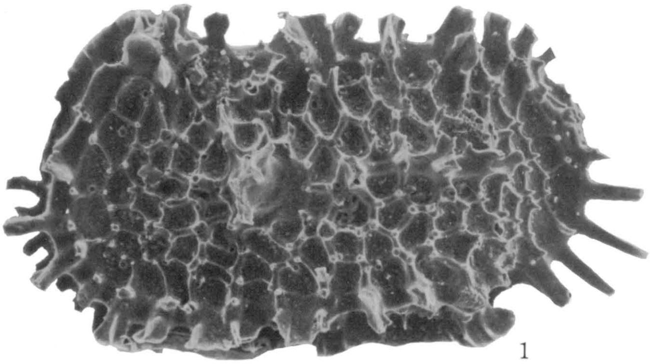
2. *Ascetoleberis rugosissima* (Alexander) Brouwers and Hazel, × 94, MIS65.
3. *Veenia ozanana* (Israelsky) Butler and Jones, × 120, ALA4.
4. *Alatacythere cheethami* (Hazel and Paulson) Hazel and Brouwers, × 110, ALA9.
5. *Cytheropteron furcalatum* Alexander, × 120, ALA10.
6. *Veenia ponderosana* (Israelsky) Hazel and Brouwers, × 86, ALA4.



ALATACYTHERE, ASCETOLEBERIS, BRACHYCYTHERE, CYTHEROPTERON, AND *VEENIA*

PLATE 6

Figure 1. *Ascetoleberis plummeri* (Israelsky) Brouwers and Hazel, × 86, MIS65.
2. *Veenia spoori* (Israelsky) Hazel and Brouwers, × 130, ALA20.
3. *Physocythere annulospinata* (Hazel and Paulson) Hazel and Brouwers, × 180, ALA12.
4. *Veenia quadrialira* (Swain) Hazel and Brouwers, × 150, ALA3.



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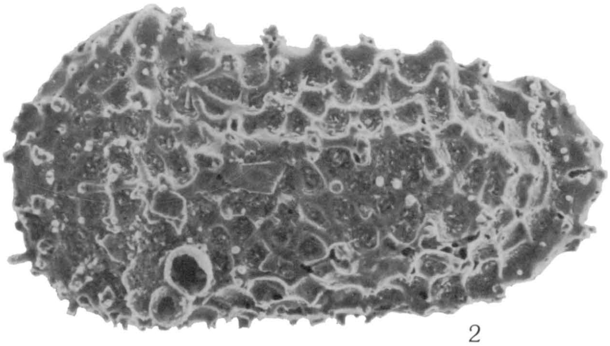

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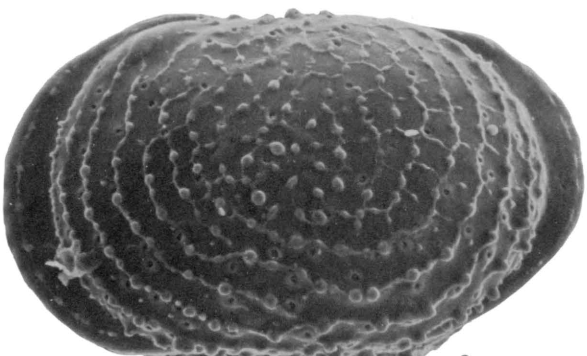

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4

ASCETOLEBERIS, PHYSOCYTHERE, AND *VEENIA*

PLATE 7

[All photographs × 1,600]

Figures 1, 2, 6. *Ceratolithoides aculeus* (Stradner) Prins and Sissingh
1. Phase contrast, ALA26.
2. Cross polarized, ALA26.
6. Cross polarized, ALA26.

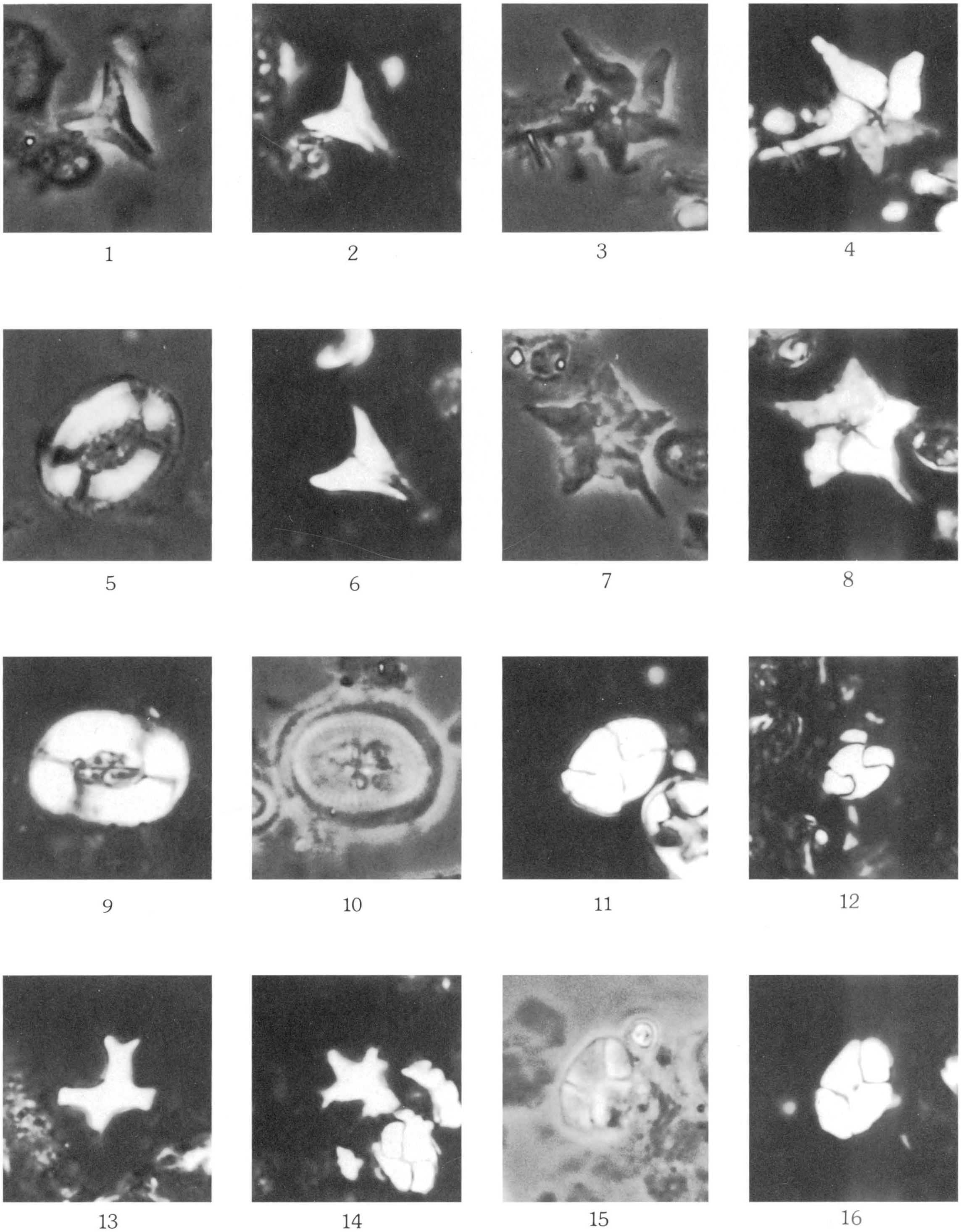
3, 4, 7, 8. *Bukryaster hayi* (Bukry) Prins and Sissingh
3. Phase contrast, ALA11.
4. Cross polarized, ALA11.
7. Phase contrast, ALA11.
8. Cross polarized, ALA11.

5, 9, 10. *Aspidolithus parcus* (Stradner) Noel
5. Cross polarized, ALA8.
9. Cross polarized, ALA8.
10. Phase contrast, ALA8.

11, 12. *Calculites obscurus* (Deflandre) Prins and Sissingh
11. Cross polarized, ALA15.
12. Cross polarized, ALA15.

13, 14. *Marthasterites furcatus* (Deflandre) Deflandre
13. Cross polarized, ALA13.
14. Cross polarized, ALA13.

15, 16. *Calculites ovalis* (Stradner) Prins and Sissingh
15. Phase contrast, ALA10.
16. Cross polarized, ALA10.



ASPIDOLITHUS, BUKRYASTER, CALCULITES, CERATOLITHOIDES, AND *MARTHASTERITES*

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