UPPER CRETACEOUS AND LOWER TERTIARY GEOLOGY OF THE CHATTAHOOCHEE RIVER VALLEY, WESTERN GEORGIA AND EASTERN ALABAMA

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PREFACE

Upper Cretaceous and lower Tertiary rocks in the Chattahoochee River Valley give geologists an outstanding opportunity to study the composition and evolution of a marginal marine basin. Development and preservation of characteristic, repetitive nearshore marine lithofacies is exceptional in this part of the eastern Gulf Coastal Plain. Deep dissection of the landscape by the Chattahoochee River, from late Tertiary to present, has produced high relief and many good exposures. Unfortunately, some of the best, most extensively studied Cretaceous exposures have been lost since the damming of the Chattahoochee River in the late 1950's (Poort, 1974).

During the past five years, the U.S. Geological Survey, in a project entitled "West Georgia Coastal Plain," has attempted to compile and integrate previous stratigraphic studies with comparative sedimentologic studies and additional biostratigraphic control on more accurate topographic base maps. Some specific missions of the project have been to identify and evaluate: 1) both large and small tectonic features within the region, and more recently, 2) genesis and quality of uranium and thorium resources within Coastal Plain units. The overall goal has been to reconstruct detailed geologic history from Upper Cretaceous to middle Eocene sedimentary rocks along the eastern margin of the Gulf Coastal Plain.

While evaluating and modifying previous lithostratigraphic work, both within the immediate area and during extended reconnaissance trips, we were impressed with the extraordinary areal variability in texture and composition of rocks between central Georgia (predominantly coarse siliciclastic sediment) and central Alabama (predominantly fine siliciclastic sediment and some chalk). The Chattahoochee River Valley is clearly a key area of transition from clastic to chemical and biochemical sedimentation. Also, abrupt vertical and lateral changes in lithofacies are best displayed here. Distribution of these transitions is critical to our understanding of sedimentation as keys to: 1) late Mesozoic to early Cenozoic tectonic activity within the Coastal Plain and adjacent Piedmont Province, and 2) relative effects of world-wide eustatic sea-level changes on river gradients and base levels.

This region is, as Toulmin and LaMoreaux (1963) suggested, a key area for linking the Gulf and Atlantic Coastal Plains, especially from a biostratigraphic viewpoint. In an area of such abrupt facies changes, geologists have long recognized that lithologic criteria alone cannot be used for establishing age relationships (e.g., Stephenson, 1911, p. 66). From the onset, marine macrofossils were used to establish time-stratigraphic relationships throughout the Gulf Coastal Plain, and resulting biostratigraphic zones were correlated over thousands of miles (Stephenson, 1914, 1938). More recently, the opportunity to integrate marine and nonmarine macrofossil and microfossil groups has been more fully realized in the eastern Gulf Coastal Plain. An essential element in our study is integration of sedimentology with biostratigraphy, in order to extend time lines across considerable changes in lithofacies near a basin margin. Also, interpretations of depositional environments have been strengthened by combining paleoecological with sedimentological analyses.

We would like to mention the contribution made by previous field trips to our understanding of the geology of this region. Trips by the Alabama Geological Society in 1966 (Tertiary) and 1968 (Cretaceous) to central and eastern Alabama contain important compilations of previous work and have demonstrated areal variability in lithofacies. More recently, the Georgia Geological Society (Marsalis and Friddell, 1975) conducted an outstanding 2-day Cretaceous and Tertiary field trip in western Georgia; these stops are noted on our guidebook road logs.

Scope of field trip

The present field trip fills a geographic gap between previous trips and, therefore, presents contrasting as well as supplemental stops and information. The general approach will be to proceed up-section across the Cretaceous and Tertiary outcrop belts. On the first day, we shall show depositional patterns and biofacies from the oldest (middle to late Cenomanian) to the youngest (middle Maestrichtian) Cretaceous rocks along the Alabama side of the Chattahoochee River. On the second day, we shall continue up-section into lower Tertiary (Paleocene to middle Eocene) rocks; facies changes and, to a lesser extent, east-west variability in the Midway, Wilcox, and Claiborne sections will be our focus. Time permitting, the trip will end formally on the Cretaceous-Tertiary boundary in Georgia; the road log continues to the Fall Line.

Acknowledgments

Our thanks to the many colleagues who visited and discussed this area with us on previous trips; comments by James Howard, Leo Hickey and James Owens have significantly altered our appreciation of these sediments. Wayne Pryor, Charles Copeland, Ernest Mancini, and Robert Carver reviewed parts of this guidebook; their comments and criticism have improved the final content. Our thanks also to the numerous USGS reviewers and typists for their help in preparing the final manuscript.

Special thanks go to James Estabrook and Arthur Donovan for their physical and moral support during field work, from February 1976 to August 1980, and to Betsy Funk, Effie Shaw, Orrin Oftedahl, David Dowell, Janet Collette, and Kathy Kilduff for sample preparation. Ellen Compton prepared Figures 33-37.

Access to private property on this field trip has been possible through the same courtesy, friendliness, and generosity afforded to us throughout the Chattahoochee River Valley. Our special thanks to: John Franklin (Stop 1) and John Thayer (Stop 2) of Phenix City, Alabama; W.M. Westerman for the Southern Railway System (Stop 5), Birmingham, Alabama; Harbison-Walker Refractories (Stop 8), Eufaula, Alabama; Southern Realty Resources, Inc. (Stop 9), Birmingham, Alabama; and Dr. O.C. Greene (Stop 13), Albany, Georgia.

UPPER CRETACEOUS STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

Juergen Reinhardt

INTRODUCTION

Our present knowledge of the distribution and stratigraphy of Upper Cretaceous rocks along the eastern edge of the Gulf Coastal Plain results largely from early studies by Smith and Johnson (1887) and Stephenson (1926) in Alabama, and Veatch (1909) and Stephenson (1911) in Georgia. The most recent geologic maps of Cretaceous units in the field trip area—geologic map of Georgia (Pickering *et al.*, 1976); geologic map of Barbour County, Alabama (Newton, 1965); geologic map of Russell County, Alabama (Scott, 1962)—rely heavily on mapping done by Fuels Branch of the U.S. Geological Survey in the 1930's and 40's (Monroe, 1941; Eargle, 1950, 1955). The geologic map presented herein (Fig. 1) is a compilation modified from a variety of sources.

Map units from the Tuscaloosa Formation (Cenomanian) to the Providence Sand (Maestrichtian) are thick sequences of clastic sediment that show considerable variation in composition and texture within the 100 km (60 mi)-wide outcrop belt and in the shallow subsurface. The units dip generally to the south at 5.7 to 9.5 m/km (30-50 ft/mi).

Our view of these rocks is necessarily biased by present outcrop patterns, which are controlled largely by the drainage pattern of the Chattahoochee River (Fig. 1) as it has dissected the landscape. A concise discussion of the physiography of the region was presented by Monroe (1941). Weathering of sediments, especially in updip (upland) areas, compounds the already difficult task of mapping units in a region of geographically and stratigraphically abrupt facies changes.

Paleoenvironments of Upper Cretaceous rocks range from largely continental (fluvio-deltaic) for the Tuscaloosa, to predominantly marginal-marine and marine (lagoonal to open shelf) for the Eutaw, Blufftown, Cusseta, Ripley, and Providence. Deposits of the Tuscaloosa Formation are separated from younger Cretaceous units by a temporal gap of 3 to 5 m.y.

Whereas large fluvial systems were predominant during deposition of Tuscaloosa sediments, a relative high stand of sea level and an apparent absence of uplift in the southern Appalachians during the remainder of Late Cretaceous time effectively reduced stream gradients. Conant (1964) suggested that only sluggish streams entered the Cretaceous sea in eastern Alabama and Georgia during Selma (Eutaw through Cusseta) deposition.

Our mapping suggests that distribution of lithofacies in units younger than Tuscaloosa (Eutaw to Providence) were controlled largely by a generally east-west orientation of the Late Cretaceous shoreline near the Chattahoochee River Valley. The outcrop pattern, which diverges from the depositional trend and strikes northwest in western Georgia (Fig. 1), suggests that more continental and restricted marine environments are preserved toward central Georgia, and more open-marine facies are represented in the Chattahoochee Valley. From the Flint River west, the structural and depositional basin opens to the southwest (Herrick and Vorhis, 1963). Distribution and nomenclature for a variety of subsurface structural features in the Chattahoochee Valley and adjacent areas were discussed by Patterson and Herrick (1971).

STRATIGRAPHY

A generalized stratigraphic column and stratigraphic nomenclature for the Chattahoochee Valley section are presented in Figure 2. Evolution of stratigraphic names for units of the Chattahoochee region is discussed by Eargle (1955).

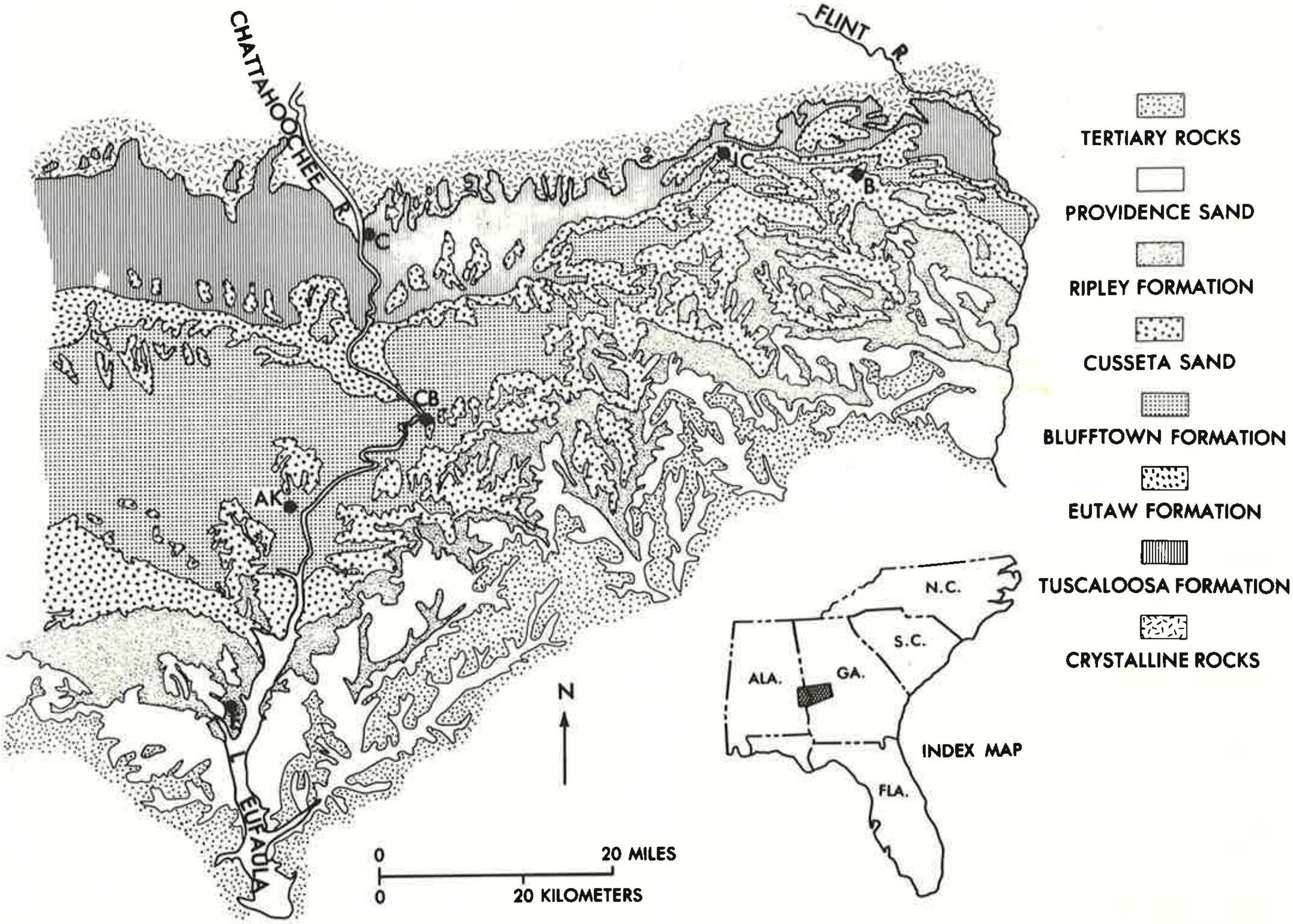

Figure 1. Generalized geologic map of Upper Cretaceous units. Outcrop belt trends northeastward between Flint and Chattahoochee Rivers. C-Columbus, Ga; E-Eufaula, Al; B-Butler, Ga; JC-Junction City, Ga; AK-Alabama Kraft locality; CB-Chimney Bluff locality. (Modified from Eargle, 1950, 1955; Monroe, 1941.)

Tuscaloosa Formation

The Tuscaloosa Formation in the eastern Gulf Coastal Plain can be traced in outcrop from the type section in western Alabama to just west of Macon, Georgia (Christopher, 1980). In the central part of the Gulf Coast (downdip), the section is thicker and the stratigraphy and lithofacies are more complex (Monroe *et al.*, 1946). In the Chattahoochee Valley, the Tuscaloosa is composed of poorly sorted kaolinitic, arkosic sand, probably equivalent to the Gordo Formation (Tuscaloosa Group) of western Alabama, and interbedded red to red-green mottled kaolinitic clay, similar to the Coker Formation (Tuscaloosa Group) of western Alabama. Within the outcrop belt, the Tuscaloosa is as much as 100 m (330 ft.) thick; it thickens to about 300 m (1,000 ft) in the subsurface of southeastern Alabama (Copeland, 1974).

The contact between the Tuscaloosa and underlying crystalline rocks is irregular locally and is difficult to define in weathered sections, where massive saprolite and poorly bedded, basal Tuscaloosa sediments are in contact. Typically, within 2 m of the contact, highly structured saprolite aids in defining the upper limits of weathered crystalline rock versus reworked residuum. Both Drennen (1950) and Madeley (1972) were especially concerned with this contact.

In the Chattahoochee Valley outcrop region, all Tuscaloosa deposits are clearly continental; marine sediments occur only considerably farther downdip and to the west (Applin, 1964; Sohl, 1964a). The most common sedimentary motif is the fining-upward sequence, a characteristic of fluvial point-bar sequences and the primary mode of accumulation within a meandering stream environment. Discussion of characteristic Tuscaloosa lithofacies is given both in the following section and in the road-log description of Stop 1.

Eutaw Formation

The Eutaw Formation unconformably overlies the Tuscaloosa and can be traced in outcrop with considerable certainty from its type locality in western Alabama to east of the Flint River. A few pollen-bearing clays correlative with the Eutaw (traditionally mapped as Tuscaloosa Formation) have been identified in central and eastern Georgia (Christopher, 1980); but the Eutaw does not seem to be a mappable unit east of the Flint River because of thin sections in outcrop and very poor exposures (Eargle, 1955). In the Chattahoochee River Valley, the Eutaw Formation is 30 to 45 m (100-150 ft) thick and is composed of several lithologies, which show some east-west continuity but abrupt north to south transitions in the outcrop belt. These sharp lithologic contrasts can be seen between Stops 2 and 2A.

Along the northern margin of the outcrop belt, the basal part of the Eutaw consists of coarse crossbedded sand containing *Ophiomorpha*, overlain by bioturbated, carbonaceous fine sand, and topped by blocky, montmorillonitic clay. Farther south the unit consists of calcareous, fossiliferous fine sand overlain by laminated to massive clay that is pervasively cut by clastic dikes. Much of the formation in eastern Alabama contains massive local accumulations of *Ostrea cretacea* Morton (Frazier and Taylor, 1980).

Blufftown Formation

The Blufftown Formation overlies the Eutaw in the Chattahoochee River Valley and intertongues with the Mooreville Chalk in central Alabama (Monroe, 1941). The Blufftown outcrop belt thins eastward to about 2.4 km (1.5 mi) at the Flint River (Fig. 1; Eargle, 1955) where the formation becomes difficult to distinguish from the Cusseta Sand. Lithologic heterogenity of the unit is greatest near the Chattahoochee River. In the valley, the Blufftown is 120 to 180 m (400-600 ft) thick in its broad outcrop belt.

The basal part of the Blufftown Formation is composed of crossbedded sand, as much as 45 m (150 ft) thick, locally containing *Ophiomorpha*. Most of the "lower" part of the Blufftown—about 75 m (250 ft) thick— is composed of glauconitic calcareous fine sand to micaceous clay and marl. This transition will be seen at Stop 3. The "upper" part of the Blufftown is composed of carbonaceous clay and silt, crossbedded sand, and highly fossiliferous clay to glauconitic fine sand; this unit is about 45 m (150 ft) thick. The "upper" part is poorly preserved updip, but is well exposed in the vicinity of Alabama Kraft Paper (Fig. 1; also field trip Stop 5) near Cottonton, Alabama. The transition of Blufftown-Cusseta environments is seen at Stop 4.

Cusseta Sand

The Cusseta Sand abruptly overlies the Blufftown Formation in the Chattahoochee River Valley; the basal contact becomes less distinct toward central Alabama, where the Cusseta intertongues with the Demopolis Chalk, and east of the Flint River, where the Cusseta merges with crossbedded sands of the Blufftown. The Cusseta is somewhat variable in thickness but is typically slightly less than 60 m (200 ft) thick. In eastern Alabama, the Cusseta is the lower member of the Ripley Formation; in western Georgia, the Cusseta has formational rank.

Type Cusseta deposits are coarse sands containing large-scale crossbeds and locally abundant *Ophiomorpha*. The unit has increasing amounts of thinly bedded, carbonaceous clay toward the upper contact. These two lithologies dominate updip exposures in the Chattahoochee River Valley. Scale of crossbedding and mean size and amount of sand in the Cusseta decrease downdip. In western Alabama, immediately north of Eufaula (Fig. 1), the Cusseta is composed predominantly of thinly bedded, laterally continuous, micaceous silt and clay and local bivalve accumulations, mostly as pods. Distribution, composition, and significance of lithofacies within the Cusseta Sand were discussed extensively by Hester (1968).

Ripley Formation

Apparently, the Ripley Formation sharply but conformably overlies the Cusseta Sand, especially in downdip sections. The Ripley can be traced across Alabama with considerable certainty because of both diagnostic calcareous fossils, such as *Exogyra costata* Say, and lithologic homogeneity. The distinct marine character of the Ripley also can be traced eastward to the Flint River; between the Flint and the Ocmulgee Rivers, the Ripley seems to change facies to a crossbedded quartz sand (Eargle, 1955). In the Chattahoochee River Valley, the Ripley is about 40 m (135 ft) thick, according to Eargle (1955); Newton (1965) estimated the unit to be about 75 m (250 ft) thick in the area around Eufaula, Alabama.

The Ripley, through most of the eastern Gulf Coast, is a massive, bioturbated, micaceous, glauconitic fine sand. Overall, it is highly fossiliferous; locally, indurated calcareous ledges and (or) concretions are discontinuous along bedding planes. Lithologic character of the unit, and its relationship to the overlying Perote Member of the Providence Sand, will be seen at Stop 6.

Providence Sand

The Providence Sand can be traced from central Alabama, in a broad belt through the Chattahoochee Valley, eastward to the Flint River. East of the Flint, the Providence is present in surface exposures only as inliers in secondary stream valleys (Eargle, 1955). A thin basal unit of laminated carbonaceous clay and silt, the Perote Member, is traceable over much of the study area; but the Perote thickens and changes character toward central Alabama. The Perote reaches a maximum thickness of 45 m (150 ft) in western Alabama (Eargle, 1950).

The unnamed upper sand member thins from about 45 m (150 ft) east of the Chattahoochee River to zero in central Alabama. The sand member shows gradational changes from thickly bedded sand, containing large, unidirectional crossbeds, abundant clay clasts, and locally abundant *Ophiomorpha*, to massive sand with calcareous intervals containing *Exogyra costata* Say, *Turritella trilira* Conrad, ammonites, and echinoids; such changes occur from updip to downdip sections along the Chattahoochee River, as well as from east to west in the outcrop belt.

The Perote and unnamed sand members will be seen at Stop 6B and Stop 14. The unconformable contact with the overlying Clayton Formation will be discussed at the Clayton type locality (Stop 7) and will be seen near the top of the Providence Canyons section (Stop 14).

LITHOFACIES AND DEPOSITIONAL CYCLES

Preceding discussions of stratigraphic units indicate that most Upper Cretaceous units contain two or more major lithofacies. The process of describing constituent lithofacies in detail, within any of the Cretaceous units, was begun only recently: Hester (1968)—Cusseta Sand; Madeley (1972)—Tuscaloosa; and Frazier (1980)—Tuscaloosa and Eutaw Formations. Scale of facies subdivision for all Cretaceous units requires additional refinement.

Although only the Tuscaloosa Formation contains continental lithofacies in the Chattahoochee Valley, all younger Cretaceous units, except for the Ripley, show transitions to predominantly continental lithofacies between the Chattahoochee and Flint Rivers. Discussions of continental lithofacies here apply mostly to the Tuscaloosa, especially as seen in the Chattahoochee Valley.

Continental facies

Crossbedded, arkosic, fine to very coarse sand and massive, color mottled, kaolinitic clay constitute the predominant continental lithofacies. Sand intervals commonly contain intraformation clay clasts and poorly rounded quartz gravel. Clay clasts typically are brick red and commonly have a green rind. The reduced state of iron in the rind suggests a change in oxidation state of iron, from the environment of clay accumulation (subaerial floodplain or flood basin) to its final depositional environment within a fluvial channel. Clay matrix in the sand locally contributes to case hardening. Abundant, partially decomposed potassium feldspars, and distribution and color of the matrix, suggests that it is largely a kaolin epimatrix (Frazier, 1980).

Overall, medium-scale, trough-crossbedded sands of fluvial channels constitute the facies best represented in the Tuscaloosa Formation within the Chattahoochee River Valley. Extensive floodplain deposits or cut-off meander fills (oxbow lake sediments) are not predominant stratigraphically, but dewatering features and subaerial oxidation features (soil profiles) are conspicuous below numerous sand-clay contacts. Locally, the Tuscaloosa contains burrows of sediment-feeding animals of uncertain identity, in massive red silty clay; well-preserved leaves in laminated gray clay; and lignitized wood in floodplain deposits and as lags in the base of channels.

Tuscaloosa sediments occur in well-defined fining-upward sequences, 3 to 6 m (10-20 ft) thick; these are well exposed at Stops 1 and 2. Small amounts of clay in several of the thinner fining-upward sequences and many lensoid sand bodies suggest that lateral accretion and channel aggradation were the dominant processes in a meandering stream system. Further, meander loops apparently were abandoned largely by chute cut-offs (see Walker and Cant, 1979).

Continental deposits of similar, although less kaolinitic and arkosic, high-energy sand are present in the Eutaw, Blufftown, and Cusseta between Junction City and Butler, Georgia (Fig. 1). Interbedded thin to thick silty clay beds provide abundant clay clasts to the channel-floor deposits, typically less oxidized than in the Tuscaloosa. Unfortunately, stops 80 to 100 km (50-60 mi) east of the Chattahoochee River are too far away for this trip.

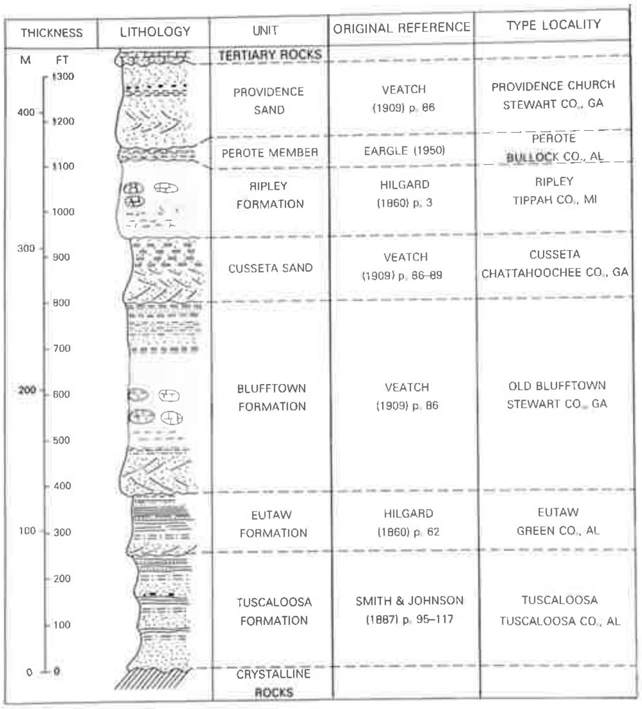

Figure 2. Generalized stratigraphic column of Upper Cretaceous rocks in the Chattahoochee Valley.

Marine facies

Basal parts of the Eutaw, Blufftown, and Cusseta, and the upper unit of the Providence Sand, near the Chattahoochee River, are also composed of crossbedded quartz sand, locally containing abundant clay clasts (Fig. 2). However, key differences in sedimentary structures between these beds and the continental facies are: 1) strong biomodality in crossbed directions within single outcrops, and 2) extremely abundant *Ophiomorpha nodosa*, indicating back-barrier to open-marine sedimentation (Weimer and Hoyt, 1964; Frey *et al.*,1978). Well-defined clay-lined channels occur within this lithofacies, apparently representing tidal channel fillings within a barrier-island complex. These features (barrier-bar facies) are especially well shown in the updip Eutaw section of Stop 2.

The high-energy barrier-bar sand facies commonly is overlain by a poorly bedded, micaceous, clayey sand interval containing extremely abundant wood fragments (large pieces commonly are bored) and bivalves, all of which suggest a slightly to moderately restricted back-barrier (moderately open bay) environment (faunal interpretation by N.F. Sohl, 1977, written comm.). For such a vertical sequence to be deposited, the barrier system had to migrate seaward, or prograde; the sequence could reflect either a local or regional marine regression. Offshore bar emergence could produce a similar vertical sequence; this process seems to be more predominant during sea-level retreat.

Depositional cycles

This brief summary of vertical sequences reiterates the concept of lithologic transitions and repetitions, or cycles, which will be the focus of discussion at several

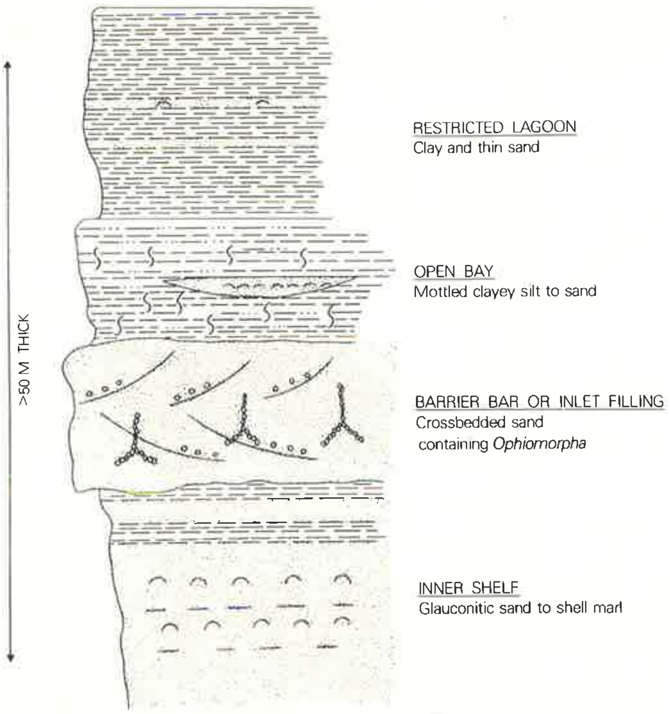

Figure 3. Generalized regressive phase of a cycle that includes the bulk of Upper Cretaceous sedimentary units near eastern margin of Gulf Coastal Plain. Inferred depositional environments and predominant lithologies are shown; lithofacies are discussed in text.

stops in both Cretaceous and Tertiary units. Sedimentary cycles were first described for Cretaceous rocks in this region by Eargle (1950). Cycles are most complete in marginal marine sediments near the Chattahoochee drainage. Asymmetrical cycles, composed of a regressive and a transgressive phase, can be recognized within this geographic region.

Sediments deposited during regressive phases (Fig. 3) constitute the bulk of Upper Cretaceous sedimentary rocks in the Chattachoochee region. The entire Eutaw Formation, for example, following initial transgression of the sea across a Coastal Plain composed of Tuscaloosa sands and clays, represents a single regression. The considerable thickness of these regressive phases (commonly greater than 50 m), or even the thickness of a single lithofacies with the regressive phase (as much as 30 m), means that the record of an entire cycle cannot be seen in a single outcrop; but records of four such cycles are preserved within the total Upper Cretaceous section. Cycles have resulted largely from rapid transgression followed by progradation, due to sedimentation rates greater than basin subsidence, or possibly a gradual sea-level drop. This contrasts sharply with the view that worldwide sea level may have dropped rapidly several times during the Late Cretaceous (Vail *et al.*, 1977).

Regressive phase

Major lithologies that constitute the regressive phase of an ideal cycle represent progressively more continental facies upward in the cycle (Fig. 3). From base to top, the ideal cycle contains lithofacies from inner-shelf, barrier-bar, open-bay, and restricted-lagoon environments.

Inner-shelf lithologies range from clayey shell marl to very fine, glauconitic sand. These lithologies grade to marls and chalks of the Selma Group in central and western Alabama (Monroe, 1941; Copeland, 1968). Bedding typically is massive, and sediments commonly are bioturbated rather than distinctly burrowed. Variable amounts of shell debris or whole shells are scattered through shelf lithologies; locally, shell lags delineate bedding planes, storm layers, and omission surfaces. In outcrop, distinct concretion bands are seen within thick sequences of shelf lithologies (lower part of Blufftown and Ripley Formations). Toward the top of this facies, bedding becomes thinner, and the amount of carbonaceous debris increases considerably; these features apparently correspond to a lower shoreface or possibly tidal-flat environment. Faunal diversity and preservation of shell material decrease correspondingly. These trends are especially well displayed at Stop 6 in the Ripley-Perote transition and, to some extent, at Stop 4 in the Blufftown-Cusseta transition.

The barrier-bar facies is characterized by trough-crossbedded quartz sand containing *Ophiomorpha*. Bedding features are smaller in scale, and are progressively more modified by crustacean and polychete burrows, from updip to downdip areas. Clay drapes and clay clasts are common lithologic components that delineate bedding features. This lithofacies is best preserved, in the Chattahoochee Valley, within the regressive part of a cycle in updip outcrops: in the lower part of the Eutaw, the "type" Cusseta Sand, and in "continental facies" of the Providence Sand.

The open-bay, or back-barrier, facies is characterized by lenses of well-sorted fine quartz sand containing planar bedded shell lags in a highly bioturbated clayey sand. Fossils in this lithology may vary considerably and may be difficult to distinguish from a lower shoreface assemblage (N.F. Sohl, 1978, written comm.) Locally, high concentrations of wood and woody debris are another distinguishing characteristic of back-barrier environments. This lithofacies is especially well displayed in the Eutaw Formation, west of the Chattohoochee River, and in the Blufftown, considerably east of the Chattahoochee.

Another well-represented back-barrier lithofacies is considered to be the result of sedimentation in a restricted-lagoon environment. This lithofacies is dominated by thick clay intervals containing thin sand beds laminated by carbonaceous debris ("coffee grounds"). Sand interbeds may contain burrows of rather abundant infaunal animals, which disrupt the carbonaceous laminae. Shell debris and molds are not typically preserved in this lithofacies. Locally, however, linguloid brachipods and whole leaves are well preserved. Eutaw and Cusseta deposits, especially east of the Chatahoochee, contain rather thick intervals representative of this lithofacies.

A fluvial component also could be added at the top of an idealized cycle, but vertical transitions from marginal-marine to fluvial lithologies are not well preserved in Chattahoochee Valley sections. Lateral transitions from fluvial to marine lithofacies are much better preserved. Basin fill as a function of marine regression is only part of the record as seen in vertical sequences.

Transgressive phase

Numerous well-exposed sections in the Chattahoochee Valley document transgressive events. For example, at Chimney Bluff (Fig. 1), the transition upward from a barrier-bar sand in the lower Blufftown looks superficially like a transition to a back-barrier lithofacies. The channeled top of the sand is filled with abundant carbonaceous debris, coarse quartz grit, and pebbles in a sandy clay matrix. This very poorly sorted unit (ravinement unit, Fig. 4) records a barrier destructional event and is overlain by massive open-marine clays. Farther west and downdip, "barrier-drowning" or destruction does not occur, but vertical transitions from massive clean quartz sand to overlying glauconitic silt and micaceous marl record the effect of transgression on sediment size and composition within the inner-shelf environment. This type of vertical transition is seen in the lower part of the Blufftown at Stop 3.

Cycles recording sedimentation during a transgressing sea are not well preserved in the geologic record (Fischer, 1961; Swift, 1968; Ryer, 1977). However, the record of a transgressing sea has been noted as thin sheet sands (Kraft, 1971) and as sedimentary packages as much as 750 m thick (Hobday and Tankard, 1978). In the Chattahoochee Valley, lithofacies in transgressive (Fig. 4) and regressive phases (Fig. 3) are generally similar, except for the ravinement unit. Two other obvious differences in regressive and transgressive phases of a cycle are: 1) vertical arrangement of lithofacies and 2) thickness of deposits.

Scale of the transgressive phase of a cycle (less than 20 m thick) enables us to see its record at a single locality. For example, along the Southern Railroad Spur into Alabama Kraft Paper (Stop 5), sediments (Blufftown Formation) from the entire transgressive phase of a cycle are preserved. Within this one exposure, three sharp lithologic transitions may be seen. Ripple cross-laminated and channeled micaceous silt (Fig. 5, unit A) at the base contains very abundant carbonaceous debris (back-barrier). This unit is overlain by a thin, crossbedded sand unit (Fig. 5, unit B) containing well-preserved *Ophiomorpha nodosa* (barrier). The sand unit is sharply overlain by a massive, very poorly sorted, pebbly sand clay (Fig. 5, unit C, ravinement). The top of the exposure is made up of a fissile, poorly bedded, clay to silty clay unit (Fig. 5 unit D) containing diverse bivalve and gastropod assemblages (inner shelf).

GEOLOGIC SUMMARY: A DYNAMIC STRATIGRAPHY

By combining the various lithologic elements and components of despositional cycles described above, we can document a history of sea-level change as seen in Upper Cretaceous stratigraphy near the margin of the eastern Gulf Coastal Plain (Fig. 6). The highly schematic record of deposition is tied to geologic time through biostratigraphic zonation of numerous samples from the project area. Regional biostratigraphy and age assignments for Upper Cretaceous units are discussed more fully in the following section.

The pattern of deposition for the Tuscaloosa is largely inferred (dashed line in Fig. 6) from farther west (Monroe *et al.*, 1946). Only the continental part of Tuscaloosa deposition is recorded at the eastern

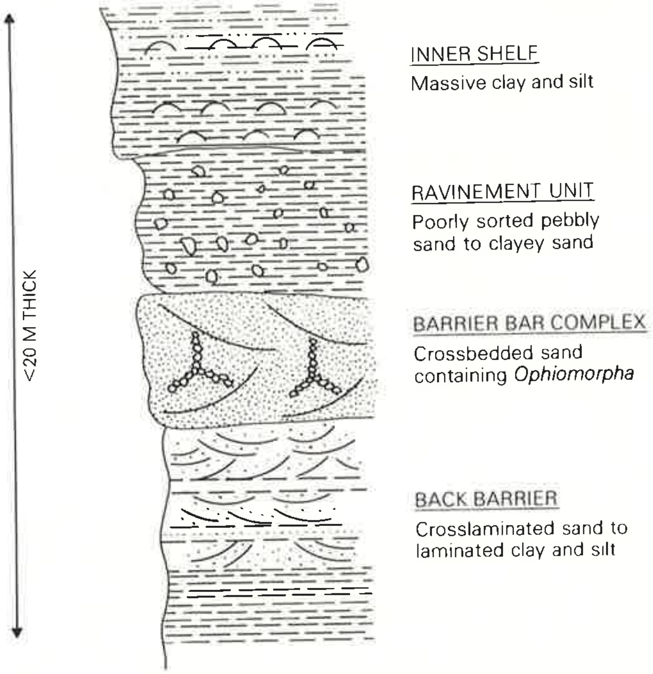

Figure 4. Generalized transgressive phase of a cycle as preserved within barrier-island facies, following destructional events. Based on field examples in Chattahoochee Valley. Units not to scale.

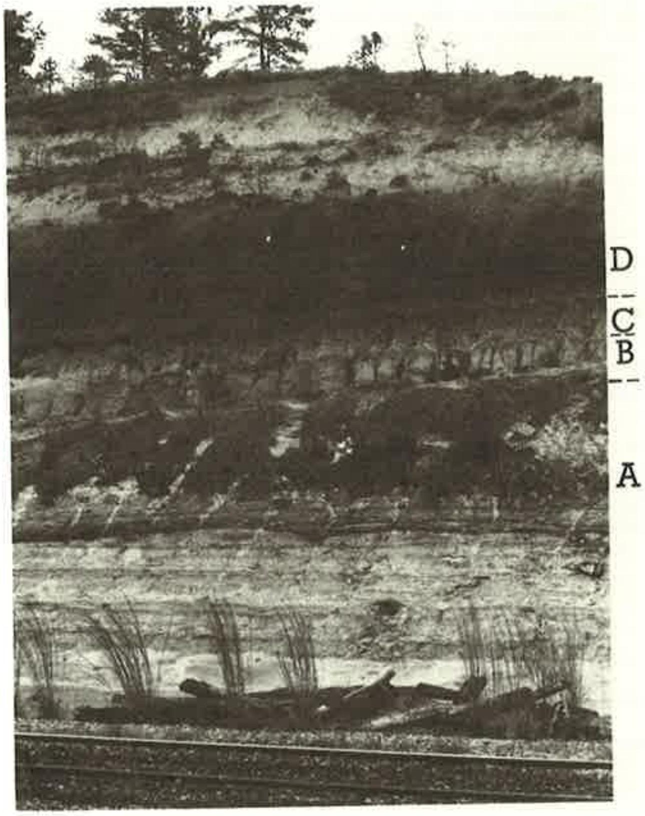

Figure 5. Railroad cut near Alabama Kraft Paper, Omaha Quadrangle, Alabama. Sequence preserves entire transgressive phase of a generalized cycle (Fig. 4). A-back-barrier deposits; B-poorly preserved barrier-bar sands; C-ravinement unit; D-open-marine clays. Lighter interval in upper part of unit D is largely a weathering profile and thin terrace gravel.

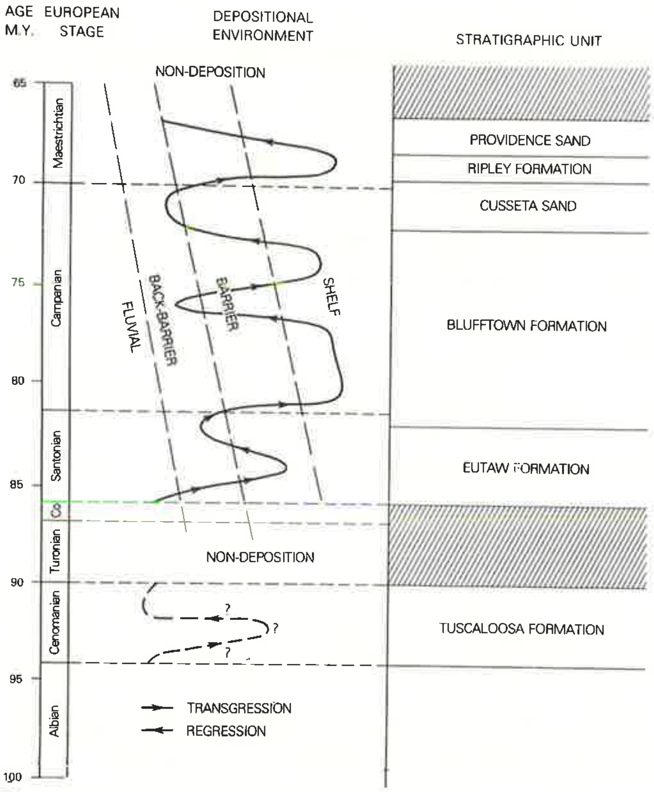

Figure 6. Schematic representation of sea-level fluctuations during Late Creataceous, as inferred from deposits in eastern Gulf Coastal Plain. Depositional environments represented in outcropping sections in Chattahoochee Valley are superimposed on "sea level curve." European state boundaries and absolute ages from Obradovich and Cobban (1975).

margin of the Gulf Coastal Plain. After a substantial interval of nondeposition (3–5 m.y.), the sea transgressed across a broad coastal-plain margin, leaving only a thin, reworked surface. Most of the Eutaw Formation is the record of a marine regression that continued, with only minor fluctuations, until the sea transgressed near the beginning of the Campanian. Basal sands of the Blufftown Formation record the landward migration of a barrier-bar system. In much of the area, these barriers were breached; the ravinement has been preserved. Considerable thickness of marl and glauconitic sand in the lower part of the Blufftown is the record of this second major marine transgression. A thin regressive phase separates the lower from the upper part of the Blufftown. A second well-preserved ravinement unit marks a later Campanian transgressive event (Alabama Kraft section, Fig. 5).

The transition upward from the Blufftown to the Cusseta represents shoaling; regression is recorded by a flood of coarse clastic sediments, caused either by sea-level retreat (changing stream gradients) or by progradation of a deltaic system, as favored by Hester (1968). Transition to shelf sediments of the Ripley (another major marine transgression) is poorly seen in outcrop, but a transgressive phase is indicated through the Cusseta-Ripley contact. The Ripley-Providence transition is within a regressive phase of this fourth cycle and resembles the Blufftown-Cusseta contact in scale and composition. The Providence is unconformably overlain by the Clayton Formation of Paleocene (Danian) age; the gap in sedimentation probably represents about 3 m.y.

CONCLUSIONS

The completeness and variability of the geologic record during Cretaceous time near the eastern margin of the Gulf basin presents an ideal opportunity to document the interplay of continental sedimentation, which resulted largely from onshore tectonics, and eustatic sea-level changes, which resulted from a variety of factors involving the world water budget. At least during the last 20 m.y. of the Late Cretaceous, the composition and distribution of sediments in the eastern Gulf Coastal Plain were controlled largely by eustatic sea-level changes.

NOTES ON CRETACEOUS BIOSTRATIGRAPHY

Norman F. Sohl and Charles C. Smith

INTRODUCTION

Knowledge of the biostratigraphy of Upper Cretaceous rocks in the Chattahoochee River Valley remains the reconnaissance level. Information is scattered through many publications, but the ultimate goal—a biostratigraphic zonation integrating information based on study of both mega- and microfossil groups—is not presently possible. Much more work needs to be done before such a sophisticated level of knowledge is attained. The critical geographic position of this area, which links the Atlantic with the Gulf Coastal Plain, makes study of faunas here of special importance. The following summary provides a status-of-knowledge report, points out areas of conflict or confusion in correlation, and provides a few new data points. It is directed partially to information related to individual field trip stops, but it also should provide a biostratigraphic framework to which the lithostratigraphic interpretations presented here can be related.

STATUS OF STUDY ON MOLLUSCAN BIOSTRATIGRAPHY

The best published summary of macrofossil distribution in Upper Cretaceous units of the Chattahoochee River Valley region is still the faunal lists of Veatch and Stephenson (1911) and Stephenson's summary charts (1914). Unfortunately, these summaries are outdated relative to current taxonomic usage. Because they lack illustrations or descriptions of the fossil material cited, these data have little solid basis for construction of a refined molluscan zonation. Specimens from the Chattahoochee Valley region that are illustrated for comparative purposes and discussed in monographs on faunas of other areas provide some biostratigraphic aid. Stephenson's (1956) monograph on some fossils in the Eutaw Formation is the only study that applies strictly to this field trip area. A modest number of specimens, listed primarily from the basal part of the Cusseta Sand, were illustrated by Stephenson (1923) for comparison with materials from North Carolina. Similarly, Sohl (1960, 1964b) illustrated several gastropods from the Ripley Formation and Providence

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Plate 1. Characteristic bivalves from Upper Cretaceous rocks of Chattahoochee River Valley

1,4. ***Flemingostrea subspatulata*** **(Forbes), late form. Internal view of bored right valve (x1) and external view of bored right valve (x1) from basal beds of unnamed member of Providence Sand, right bank of Chattahoochee River at Alexanders Landing, 14.2 km (8.9 mi) by river, below Eufaula Landing, Barbour County, Ala. USGS 28423; USNM 305114, 305130.**

2,3. ***Flemingostrea pratti*** **(Stephenson). Internal and external views of bored left valve (x1) from lower part of Cusseta Sand Member of Ripley Formation at old Woolridge Landing, right bank of Chattahoochee River, 21,8 km (13.6 mi) by river, above Eufaula Landing, Barbour County, Ala. USGS 26027; USNM 305115.**

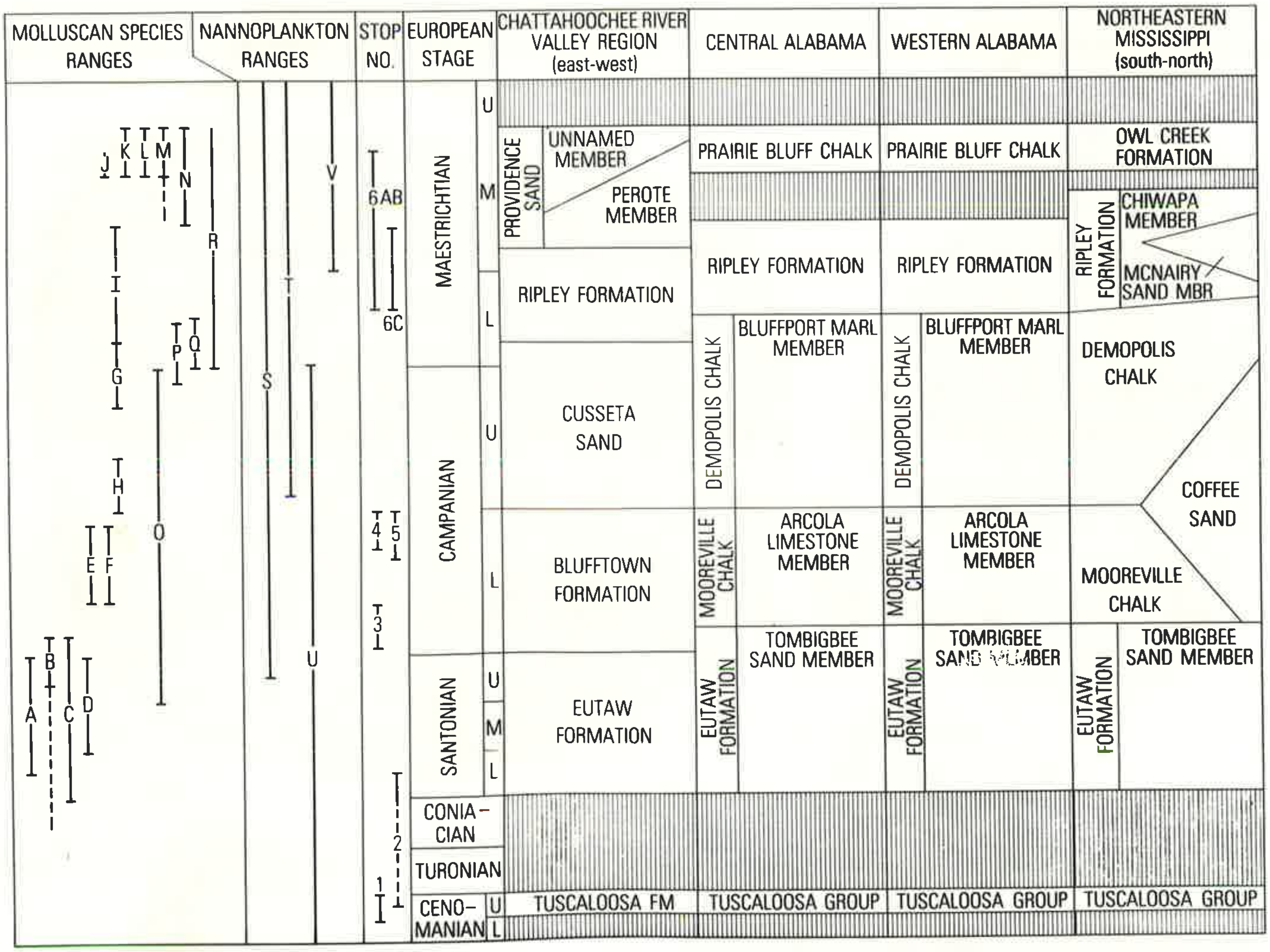

Figure 7. Correlation of Upper Cretaceous deposits of East Gulf Coastal Plain. A - *Ostrea cretacea* Morton, B - *Pycnodonte aucella* (Roemer), C - *Exogyra upatoiensis* Stephenson, D - *Lopha knappi* (Stephenson), E - *Scaphites hippocrepis* Dekay (type 111), F - *Delawarella delawarensis* (Morton), G - *Flemingostrea pratti* (Stephenson), H - *F. subspatulata* (Forbes), early form, I - *F. subspatulata* (Forbes), normal form, J - *F. subspatulata* (Forbes), late form, K - *Haustator bilira* (Stephenson), L - *Scabrotrigonia angulicostata* (Gabb), M - *S. cerulia* (Whitfield), N - *Sphenodiscus* spp., O - *Exogyra ponderosa* Roemer, P - *Anomia tellinoides* Morton, Q - *Exogyra cancellata* Stephenson, R - *E. costata* Say, S - *Broinsonia parca* zone, T - *Tetralithus aculeus,* U - *Eiffellithus eximinus,* V - *Lithraphidites quadratus.*

Plate 2. Characteristic bivalves from Upper Cretaceous rocks of Chattahoochee River Valley

1. *Flemingostrea subspatulata* (Forbes), early form. External view of right valve (x1) from Cusseta Sand Member of Ripley Formation, right bank of Chattahoochee River, 0.56 km (0.35 mi) below mouth of Cowickee Creek, Barbour County, Ala. USGA 26051; USNM 305109.

2. *Lopha ucheensisis* (Stephenson). External view of left valve (x1) from Eutaw Formation, 4.2 to 4.6 km (2.6–2.9 mi) northwest (airline) of Uchee, Russell County, Ala. USGS 18309; USNM 305110.

3,5. *Ostrea cretacea* Morton. External view of right valve (x1) and internal view of left valve (x1) from Eutaw Formation at Stop 2A, roadcuts at intersection U.S. 431 and Alabama 165, Russell County, Ala. USGS 31350; USNM 305128.

4. *Anomia tellenoides* Morton. External view of left valve (x1.5) from the Cusseta Sand Member of Ripley Formation, downstream of bridge of secondary road over Cowickee Creek, Barbour County, Ala. USGS 26974; USNM 305112.

6,7. *Flemingostrea subspatulata* (Forbes), normal form. Internal view of right valve (x1) and external view of left valve (x1) from Ripley Formation, in roadcuts of U.S. 27, 5.9 km (3.7 mi) north of Lumpkin, Stewart County, Ga. USGS 25554; USNM 305113, 305129.


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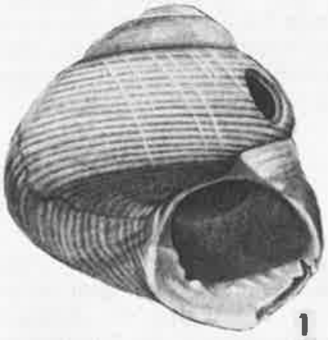
Sand in the Chattahoochee Valley for comparison with those of coeval deposits in the Mississippi Embayment. Other data are presented in scattered references to fossil occurrences in sections described by such workers as Monroe (1941) and Eargle (1955).

Existing formal molluscan zonation of Cretaceous rocks in the field trip area is coarse, and zones encompass thick stratigraphic intervals. They are based mainly upon range zones of species of the ostreid *Exogyra,* as shown on the correlation chart (Fig. 7). The lowest zone is that of *Exogyra ponderosa* Roemer (O, on Fig. 7; Pl. 3, fig. 8), which ranges through upper Santonian and Campanian levels, and the upper zone of *Exogyra costata* Say (R; Pl. 3, fig. 7), which ranges through the Maestrichtian. The lower part of this zone has been subdivided as the *Exogyra cancellata* Stephenson subzone (Q; Pl. 3, fig. 6). Further subdivision of these two broad zones is possible; Sohl (1977) proposed the *Haustator bilira* assemblage zone (J-N; Pl. 3, fig. 3), encompassing the middle to upper parts of the middle Maestrichtian. However, further documentation and refinement must await future investigation.

In general, existing information of molluscan ranges, coupled with that from microfossil groups, provides a reasonable, if not precise, basis for assignment of age ranges to Cretaceous formations of this area, as well as for correlation with other eastern Gulf Coastal Plain areas (Fig. 7.) To some extent, local correlations within the Chattahoochee Valley region are more difficult than correlation of the formations with other, more distant geographic areas. This difficulty is caused largely by abrupt lateral and updip-downdip facies changes in the area. For example, among benthic mollusks, the more marginal-marine quartzose sandy facies updip are dominated by low-diversity infaunal suspension-feeding bivalve assemblages *(Cymbophora-Trachycardium).* Downdip river outcrops, however, contain a succession of ostreids, to diverse infaunal suspension-feeding bivalve assemblages in sand units, to dominantly deposit-feeding bivalve assemblages in more clayey beds. Thus, correlating generalized, longer ranging mollusks in isolated updip outcrops to precise parts of thicker downdip sections containing much more diverse faunas, commonly is difficult.

Plate 3. Characteristic gastropods and bivalves from Upper Cretaceous rocks of Chattahoochee River Valley

1. ***Ataphrus* n. sp. Aperture view of bored specimen (x7.5) from unnamed member of Providence Sand at narrows of Pataula Creek, Clay County, Ga. USGS 25556; USNM 305116.**
2. ***Potamides cowickeensis* Sohl. Aperture view of broken specimen (x6) from Blufftown Formation on North Fork of Cowickee Creek, on line between Russell and Barbour Counties, Ala. USGS 26980; USNM 131606.**
3. ***Haustator bilira* (Stephenson). Back view of specimen (x2) from unnamed member of Providence Sand in cuts of U.S. 82, south of bridge over Pataula Creek, Quitman County, Ga. USGS 25992; USNM 305117.**
4. ***Aciculiscala acuta* Sohl. Back view of specimen (x14) from Ripley Formation at former site of Mercers Mill on Tabannee Creek, 1.2 km (0.75 mi) south-southeast of Georgetown, Quitman County, Ga. USGS 25557; USNM 305118.**
5. ***Scobinodola guttatus* Sohl. Aperture view of specimen (x14) from Ripley Formation; locality as in figure 4. USGS 27878; USNM 305119.**
6. ***Exogyra cancellata* Stephenson. External view of bored left valve (x1) from Ripley Formation, in cuts of U.S. 280, about 0.4 km (0.25 mi) north of Renfroe in Chattahoochee County, Ga. USGS 26972; USNM 305120.**
7. ***Exogyra costata* Say. External view of bored left valve (x1) from Ripley Formation, bluffs of Chewalla Creek, Barbour County, Ala. USGS 27891; USNM 305121.**
8. ***Exogyra ponderosa* Roemer. External view of bored left valve (x1) from Blufftown Formation, in roadcuts near Pittsview, Russell County, Ala. USGS 31616; USNM 305122.**
9. ***Scabrotrigonia eufaulensis* (Gabb). External view of left valve (x1.5) from Ripley Formation; locality as in figure 4. USGS 25557; USNM 305123.**
10. ***Exogyra upatoiensis* Stephenson. External view of left valve (x1.5) from Eutaw Formation at Stop 2A, in roadcuts at intersection between U.S. 431 and Alabama 165, Russell County, Ala. USGS 31350; USNM 305124.**
11. ***Scabrotrigonia cerulia* (Whitfield). External view of broken left valve (x1) from unnamed member of Providence Sand, at former site of Alexanders Mill on White Oak Creek, Henry-Barbour County line, Ala. USGS 28441; USNM 305125.**
12. ***Scabrotrigonia bartrami* (Stephenson). External view of fractured right valve (x1) from basal beds of Cusseta Sand Member of Ripley Formation at Old Woolridge Landing, 21.8 km (13.6 mi) by river, above Eufaula, Barbour County, Ala. USGS 26027; USNM 305126.**
13. ***Scabrotrigonia angulicostata* (Gabb). External view of left valve (x1.5) from unnamed member of Providence Sand; locality as in figure 11. USGS 28441; USNM 305127.**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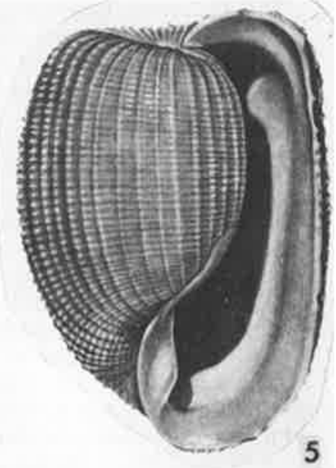
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BIOSTRATIGRAPHY

The following biostratigraphic discussions proceed from oldest to youngest Cretaceous units. Our specific sampling points at each field trip stop are shown on measured sections within the first day's road log.

Tuscaloosa Formation

Marine invertebrates have not been found in the Tuscaloosa Formation in the Chattahoochee River Valley, and they are very rare elsewhere. Stephenson (1953, p. 18) reported a few scattered impressions of mollusks at four localities in western Alabama. Sohl (1964a, p. 61-62) listed a better preserved molluscan assemblage from an outcrop in Bibb County and in shallow subsurface cores in Perry County, Alabama, which he correlated with the middle Cenomanian Woodbine Formation of Texas, as did Applin (1964, p. 65-70) on the basis of foraminifers. Subsequently, Christopher (1980), on the basis of much more abundant palynological data, assigned to the Tuscaloosa a late Cenomanian (early Eaglefordian) Age in this outcrop area.

As with larger invertebrates, outcropping nonmarine Tuscaloosa sediments within the field trip area, including strata of stream point-bar and floodplain origin, preclude the presence of calcareous marine microfossils, including calcareous nannofossils. Toward the west, near the Alabama-Mississippi border in the southeastern part of Choctaw County, Alabama, subsurface samples from the so-called "middle marine shale" of the Tuscaloosa Group have yielded a rich calcareous nannofossil flora and planktic foraminiferal fauna of late Cenomanian age. These data, although geographically some distance from the field trip area, tend to support the inferred Cenomanian age of the outcropping Tuscaloosa in eastern Alabama and western Georgia, derived from spore-pollen biostratigraphy.

Eutaw Formation

Within the area of outcrop in the Chattahoochee Valley region, the Eutaw Formation is considered to be of Santonian age (Fig. 7). Westward, in western Alabama and Mississippi, an upper unit, the Tombigbee Sand Member, has been distinguished. At several places ammonites have been recovered in this member that are considered by Young (1963) to be assignable to the lower part of the Campanian. Such diagnostic ammonites have not been collected in eastern Alabama or in Georgia (Stephenson, 1956). An inoceramid bivalve collected in the lower part of the formation on Ochille Creek (Fort Benning Military Reservation) in Georgia, however, does provide a data consistent with microfossil data from other localities in the Eutaw of this area. Erle Kauffman (U.S. National Museum) identified the specimens as *Sphenoceramus* n. sp., transitional between *"Inoceramus" stantoni* (Sokolow) and *Sphenoceramus pachti* (Archangelski), and suggested an early to middle Santonian age for them.

Plate 4. Characteristic nannofossils from Upper Cretaceous rocks of Chattahoochee River Valley. All transmitted light micrographs are x2600

1-3, 23, 24. *Arkhangelskiella cymbiformis* Vekshina 1959 1-3—transmitted light micrographs; 23—SEM of distal surface, x7500; 24—SEM of proximal surface, x6450. Early Maestrichtian part of Ripley Formation at Stop 6A, Barbour County, Ala.

4-6. *Arkhangelskiella specillata* Vekshina 1959. From bored cobble bed (Early Maestrichtian) marking contact between Ripley Formation and Providence Sand at Stop 6C, Barbour County, Ala.

7, 8. *Broinsonia parca* (Stradner 1963). Early Maestrichtian part of Ripley Formation; locality as in figure 1.

9-11. *Eiffellithus eximius* (Stover 1966). Early Campanian part of Blufftown Formation at Stop 3, Russell County, Ala.

12, 13, 26. *Eiffellithus turriseiffeli* (Deflandre 1954). 12, 13—transmitted light micrographs; 26—SEM of distal surface, x6330. Locality as in figure 4.

14, 15, 30: *Micula staurophora* (Gardet 1955). 14, 15—transmitted light micrographs; 30—SEM, x9160. Locality as in figure 1.

16-18, 31. *Tetralithus aculeus* (Stradner 1961). 16-17—transmitted light micrographs; 31—SEM, x9160; locality as in figure 1. 18—transmitted light micrograph; locality as in figure 4.

19, 20. *Tetralithus obscurus* Deflandre 1959. Locality as in figure 9.

21, 22. *Tetralithus ovalis* Stradner 1963. Locality as in figure 1.

25. *Corollithion exiguum* Stradner 1961. SEM of proximal surface, x1250. Locality as in figure 1.

27. *Kamptnerius punctatus* Stradner 1963. SEM of distal surface, x7500. Locality as in figure 1.

28. *Microrhabdulus belgicus* Hay & Towe 1963. SEM, x4500. Locality as in figure 1.

29. *Lucianorhabdus cayeuxii* Deflandre 1959. SEM, x2915. Locality as in figure 1.


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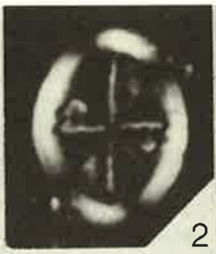
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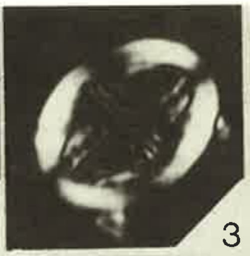
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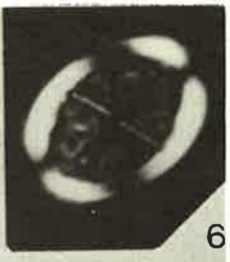
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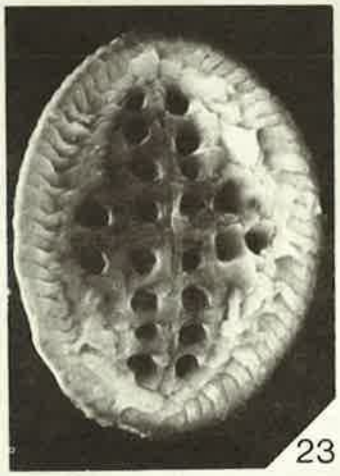
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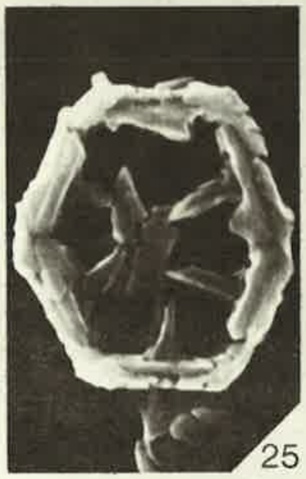
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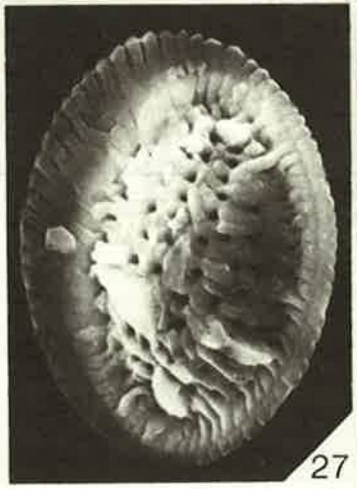
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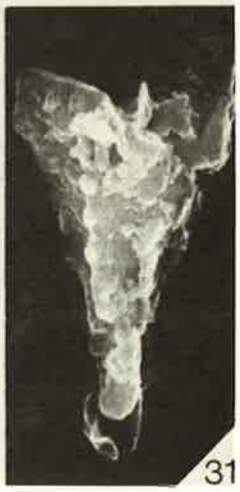
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Several species of oysters occur widely throughout the outcrop area of both the Eutaw and its Tombigbee Sand Member and provide a gross basis for correlation: *Ostrea cretacea* Morton (Pl. 2, figs. 3,5), *Lopha ucheensis* (Stephenson) (Pl. 2, fig. 2), *Pycnodonte aucella* (Roemer) (=*Gryphaea wratheri* Stephenson), and *Exogyra upatoiensis* Stephenson (Pl. 3, fig. 10). *Ostrea cretacea* forms thick biostromal masses in the Tombigbee Sand Member of Russell County, Alabama, to at least the Alabama River area. This species is known at a similar stratigraphic level along the Atlantic Coastal Plain, from South Carolina (Hazel *et al.*, 1977) to New Jersey (Sohl and Mello, 1970). *Lopha ucheensis* is found in coeval beds in South Carolina *(Ostrea knappi;* Stephenson, 1923) and in the Gulf Coastal Plain as far west as the Tombigbee outcrops of Mississippi. *Exogyra upatoiensis* ranges from the Chattahoochee River Valley to Texas, where it is found in upper Austinian units.

The two Eutaw Formation outcrops to be visited during the field trip show strikingly different molluscan assemblages. At Stop 2, unit 6 contains prints of poorly preserved bivalves that represent a low-diversity, dominantly infaunal suspension-feeding assemblage suggestive of a restricted, perhaps lagoonal, setting. This assemblage contrasts sharply with the fauna present in bed 6 at Stop 2A. Here, a more diverse molluscan assemblage occurs that is dominated numerically by *Ostrea cretacea* Morton and *Anomia preolmstedi* Stephenson. Infaunal suspension feeders and, less commonly, deposit feeders also are present. In total, this assemblage suggests a middle shoreface setting. Similar associations of *Ostrea, Exogyra upatoiensis,* and *Anomia* have been noted at the base of the Eutaw in downdip river sections (Stephenson, 1911).

Within the Chattahoochee Valley, the Eutaw Formation represents the oldest outcropping Upper Cretaceous stratigraphic unit to contain marine beds with common calcareous nannofossils. Eutaw sediments at Stop 2 (Fig. 22), are partly of shallow marine origin but subsequently have been leached and oxidized, resulting in removal of preexisting calcareous microfossils. Similarly, basal Eutaw sedimentary rocks exposed at the alternate stop southwest of Phenix City (Stop 2A, Fig. 24) yield only a rare, extensively etched calcareous nannofossil flora. Unfortunately, of the few species recovered, all are somewhat long-ranging forms, and little can be deduced regarding the biostratigraphic zonal assignment of these beds. The presence of *Eiffellithus eximius, Lithastrinus floralis,* and *Micula staurophora,* among others, suggests only that basal Eutaw sediments are no older than middle Turonian nor younger than late middle Santonian.

Toward the west, within the northwestern part of Russell County, Alabama, samples from both the middle and upper parts of the Eutaw have yielded a much more abundant and diverse nannoplankton flora. Upper Eutaw strata exposed along the Marvyn-Hurtsboro Road (Alabama State Hwy. 37) contain, among many other species, *Lithastrinus floralis, Marthasterites furcatus,* and common to abundant *Tetralithus obscurus,* co-occurring forms generally regarded as indicative of a late Santonian age.

Blufftown Formation

Parts of the Blufftown Formation are of early Campanian age but, as discussed below, the age of the lowermost part remains in doubt. Molluscan fossils are abundant throughout the formation. Assemblages range from concretionary sandstone beds and unconsolidated sands packed with *Exogyra ponderosa* to highly diverse, aragonitic shelled, inner shelf assemblages at the type section. Of prime importance from a biostratigraphic standpoint is the joint occurrence of the ammonite *Delawarella delawarensis* (Morton) and *Scaphites hippocrepis* (Dekay) in the middle and upper parts of the formation. Cobban (1969) discussed the age significance of *S. hippocrepis* in detail; Blufftown specimens conform to his type III, which is assigned an early, but not earliest, Campanian age. Owens *et al.*, (1977, p. 30) discussed New Jersey to Texas distributions of this ammonite association.

Molluscan fossils occur throughout the lower 20 m of section at Stop 3. Abundance of *Exogyra ponderosa*, associated with indurated beds, as observed in unit 3, is very common in the lower half of the Blufftown, both in downdip river sections and westward to Bullock County. In general, diversity of infaunal species increase upward from unit 1 to unit 4. Together with other factors, this distribution suggests a deepening trend, from a middle to lower shoreface transitional to a shallow-shelf setting.

Units 1 and 2 at Stop 4 contain an abundant and diverse molluscan assemblage. Silty clays of unit 1 contain a dominantly (79%) infaunal assemblage having high representation (40% of individuals) of deposit feeders. This pattern gives way in the more sandy unit 2 to an assemblage dominated by infaunal suspension feeders. Abundant broken shell material in unit 2, together with the fauna and increased grain size, suggest conditions of increased energy upward in the section.

The lower part of the Blufftown exposed at Stop 3 (see Fig. 26) contains a poorly preserved, rare to common nannofossil flora consisting of about 30 species. As in the Eutaw Formation, samples contain rare individuals of *Lithastrinus grillii, Marthasterites furcatus, Tetralithus obscurus,* and other species generally considered to be of Santonian age. However, megafossils from Stop 3, as well as other lower exposures of the Blufftown, suggest that these sediments may be of early Campanian age. This discrepancy is presently believed to be due to several factors, including our poor understanding of relationships between calcareous nannofossil ranges and the Santonian-Campanian boundary as defined by planktic foraminifers and ammonites. Recently completed, but presently unpublished, planktic foraminiferal and ammonite data (W.A. Bryant, 1979, personal comm.) on the Santonian-Campanian boundary in the western Gulf Coastal Plain, indicate that the boundary is somewhat lower than previously indicated. Thus, the base of the overlying nannofossil *Broinsonia parca* zone, established previously as coinciding with the planktic formaniferal *Globotruncata fornicata-stuartiformis* assemblage zone and presently regarded as marking the Santonian-Campanian boundary, must be reevaluated in light of these new foraminiferal data. At present, the base of the *B. parca* zone clearly seems to be somewhat above the base of the Campanian; thus, underlying strata, including those of the lower part of the Blufftown, may indeed be of early Campanian age. This question can be resolved satisfactorily only through detailed, integrated paleontological investigations. Until such studies can be completed, some question remains regarding the precise chronostratigraphic assignment of lower strata of the Blufftown. For the present, however, they are perhaps best assigned to the early Campanian (Fig. 7).

In contrast, only a few miles to the east, along the east bank of the Chattahoochee River, richly fossiliferous sediments exposed at the type locality of the Blufftown yield a diagnostic calcareous nannofossil flora assignable to the lower and lower middle Campanian *Broinsonia parca* zone. The base of these lower Campanian-type Blufftown sediments are stratigraphically about 50 to 60 ft. above the Eutaw-Blufftown contact; thus, only the lowermost Blufftown sediments (basal 50 ft. or so) cannot be related confidently to either the late Santonian or early Campanian on the basis of calcareous nannofossil floras alone.

Within central and western Alabama, as well as in eastern Mississippi, Upper Cretaceous strata assignable to the *Broinsonia parca* zone include the Mooreville Chalk, the Arcola Limestone Member at its top, and the overlying basal 10 to 15 feet of the Demopolis Chalk. Although this zone admittedly is a rather long biostratigraphic interval, many Blufftown exposures within the Chattahoochee Valley, as well as the Mooreville Chalk toward the west, are richly microfossiliferous. More intensive microfossil study of these units, among others in this area, should eventually result in a finer biostratigraphic subdivision of the *B. parca* zone, resulting in more refined biostratigraphic correlation of those Blufftown rocks with lithostratigraphic units toward both the west and northeast. Unfortunately, Blufftown strata at Stop 5 (refer to Fig. 30) bear no calcareous microfossils.

Cusseta Sand

The Cusseta Sand is of late Campanian to earliest Maestrichtian age. To date, samples examined in the field trip area have failed to yield calcareous microfossils. Megafossils, however, are common in many sections. In updip sands, they are preserved most commonly as imprints or molds. In downdip river and some tributary sections, both aragonitic and calcitic molluscan shells are preserved.

Molluscan assemblages at the base of the Cusseta are correlative with the upper part of the Black Creek Formation of the Carolinas and the upper part of the Coffee Sand of Mississippi (Sohl, 1964c). The uppermost part of the formation contains a diminutive form of *Flemingostrea subspatulata* (Forbes) (Pl. 2, fig. 1), *Anomia telenoides* (Pl. 2, fig. 4), and rarely *Exogyra cancellata* and represents the lowermost part of the *E. costata* zone: the *E. cancellata* subzone. This subzone is recognized throughout the Atlantic and Gulf Coastal Plains (Stephenson, 1938), and on the basis of associated planktic foraminifers, is assigned an early Maestrichtian age.

In the field trip area, silty clays of this upper part of the Cusseta were formerly exposed in banks of the South Fork of Cowickee Creek and in the small tributary at the bridge just north of Stop 6A. In both instances, these beds contained faunal elements of the *E. cancellata* subzone.

Ripley Formation

As restricted by Eargle (1950) and used herein, the Ripley Formation in the Chattahoochee River Valley ranges in age from early Maestrichtian to earliest middle Maestrichtian (Stop 6), on the basis of planktic foraminifers and nannofossils. In terms of molluscan fossils, the sands and sandstones contain assemblages dominated by marine ostreids. Locally, more diverse assemblages are preserved where clay content in sands increases and infaunal, aragonitic shelled mollusks may dominate over epifaunal, calcitic shelled oyster assemblages (Stops 6C and 14).

Exogyra cancellata has been collected in sand at the base of the formation in both Alabama and Georgia, which indicates the lack of a significant time gap between the Cusseta and Ripley. The normal, robust, large form of the ostreid *Flemingostrea subspatulata* (Forbes) is found at all post-*Exogyra cancellata* zone levels, and is found in coeval beds from the Nacatoch Sand of Texas to the Peedee Formation of the Carolinas. Elsewhere, as in Mississippi (Fig. 7), some beds assigned to the Ripley Formation are considerably younger in age. Here, the Chiwapa member at the top of the formation contains mollusks of the *Haustator bilira* assemblage zone (Sohl, 1977); but in the Chattahoochee Valley, mollusks of this zone are found only in the Providence Sand (Fig. 7).

At locality 6A, unit 1 contains a typical Ripley Formation, oyster-dominated assemblage, including mainly *Flemingostrea subspatulata, Exogyra costata, Agerostrea falcata, Ostrea tecticosta,* and *Anomia argentaria.* Higher, more massive sands of unit 4 at Stop 6B contain the massive form of *Flemingostrea subspatulata, Exogyra costata,* and *Pycnodonte vesicularis* (Lamarck) as the most noticeable elements, but *Lima* and several pectinoid bivalves also are present. Several concretionary sand masses have been found near the top of the Ripley here that contain whole crab carapaces and attached appendages *(Avitelmesus graphsoides* Rathbun). This crab occurs at the same high-Ripley level in sections just below the Providence Sand at many localities to the west.

Abundant, well-preserved calcareous nannofossils have been recovered from several exposures of the Ripley Formation in both eastern Alabama and western Georgia. Ripley exposures at Stops 6A and 6B are no exception, and contain a rich, well-preserved flora found also in European strata of both early and middle Maestrichtian age. Two samples from the lower part of the Ripley at Stop 6A, one from the lowermost fossiliferous sandstone ledge and the other from the fourth prominent sandstone ledge above the base (refer to Fig. 34), contain 46 nannofossil species, including *Broinsonia parca, Tetralithus aculeus,* and *Tetralithus trifidus.* Presence of the latter two species and absence of *Eiffellithus eximius, Lithraphidites prequadratus,* and *L. quadratus,* indicate that the lower part of the Ripley exposed at Stop 6A is of early Maestrichtian age. Other samples from lower and middle parts of the Ripley in this general area, such as those along the southern bank of Barbour Creek, about 11 km (7 mi) south-southwest of Stop 6A, have yielded a similar nannofossil flora.

At Stop 6A, a sample taken from the prominent, discontinuous concretion bed, about 4 m below the Ripley-Providence contact (see Fig. 34), yielded only a sparse, poorly preserved (recrystallized) calcareous nannofossil flora. However, among the few species present are very rare to rare individuals of *Lithraphidites quadratus*, the lowermost occurrence of which is regarded by most nannofossil specialists as approximating the early-middle Maestrichtian boundary. Its presence in this sample, and absence of diagnostic early Maestrichtian species, indicates that the upper part of the Ripley at Stop 6A is of middle Maestrichtian age. Samples from the overlying 4 m of the upper part of the Ripley at Stop 6A are noncalcareous and barren of calcareous nannofossils.

Providence Sand

The Providence Sand throughout its outcrop area is of middle Maestrichtian age, although in downdip sections along the Chattahoochee River, it possibly includes some beds of early Maestrichtian age. Biostratigraphic relationships of the lower member, the Perote, are somewhat confused. Along the Chattahoochee River, Eargle (1950) included units exposed at Eufaula Bluffs, as its base (Stop 6C), and a series of micaceous sands and sandstones cropping out along the river 14 km (8.9 river mi) southward to Alexanders Landing, where they are overlain by coarse, echinoid-bearing sands and sandstones of the basal part of the upper unnamed member. In these coarse sands, the first faunal elements of the *Haustator bilira* assemblage zone appear. Thus, in terms of the river section, the upper unnamed member of the Providence is correlative with the Prairie Bluff Chalk of central Alabama, and the Perote Member equates with the upper part of the Ripley Formation of that region. At the type section of the Perote Member in Bullock County, the base of the unit is correlative with that at Stop 6C (Eufaula Bluffs). The top of the member, however, is placed in beds well within the *Haustator bilira* assemblage zone. Thus, the top of the Perote becomes younger in age from the Chattahoochee River to the type area. Still farther to the west, the whole member changes biostratigraphically; the entire formation lies within bounds of the *H. bilira* assemblage zone and interfingers westward into the Prairie Bluff Chalk.

As with the Cusseta Sand, the updip Providence is predominantly a shallow marine lithostratigraphic unit; most samples examined to date, including those from the basal part of the Providence at Stop 6B (see Fig. 34), are noncalcareous and barren of calcareous nannofossils. Based on the age of the underlying upper part of the Ripley Formation, the basal part of the Providence at Stop 6B is believed to be middle Maestrichtian. No upper Maestrichtian strata are known from any outcropping sediments in the Gulf or Atlantic Coastal Plain areas, and their presence in the Chattahoochee Valley region is believed to be unlikely.

A single sample of sediment matrix collected from the bored phosphatic pebble zone of the basal part of the Providence at alternate Stop 6C, near old Eufaula Landing (see Fig. 37), contains an abundant, diverse, well-preserved calcareous nannofossil flora. Some important species include *Broinsonia parca*, *Gartnerago obliquum*, *Parhabdolithus regularis*, and abundant *Tetralithus aculeus*, among many others. Noticeably absent are such species as *Eiffellithus eximius*, *Lithraphidites prequadratus*, and *L. quadratus*. Specimens recovered from this pebble matrix are characteristic of strata of early Maestrichtian age. Thus, the interval sampled near old Eufaula Landing is biostratigraphically equivalent to sediments of the middle and upper parts of the Ripley exposed below the discontinuous concretion bed at Stops 6A and 6B.

FACIES CHANGES OF LOWER PALEOGENE STRATA

Thomas G. Gibson

INTRODUCTION

Lower Paleogene strata in the eastern Gulf Coastal Plain are relatively thin but have complex facies relationships. These facies changes have interested geologists since the pioneering work of Smith *et al.* (1894). Although they mentioned sections in eastern Alabama and western Georgia, their primary emphasis, and that of most later studies, was upon richly fossiliferous beds in western Alabama and the less marine sections westward into Texas. General facies patterns and correlations of Paleogene strata in Alabama were well summarized by Copeland (1968) and Toulmin (1977).

Previous work

Toulmin and LaMoreaux (1963) studied the formations in eastern Alabama and western Georgia along the Chattahoochee River, and considered these sections a connecting link between the Gulf Coastal Plain and the Atlantic Coastal Plain. Geologic maps of two counties (Barbour and Henry) in Alabama adjacent to the Chattahoochee River were published shortly thereafter (Newton, 1965, 1968). Marsalis and Friddell (1975) summarized the Cretaceous and Paleogene geology of westernmost Georgia. A recent study by Swann and Poort (1979) examined stratigraphic relationships among upper Paleocene strata.

Of major economic interest in lower Paleogene strata are locally abundant kaolinitic and bauxitic clays. Regions that have been studied for bauxites include the Eufaula district, Alabama (Warren and Clark, 1965; Clarke, 1972), which will be visited during the field trip, the Springvale district in western Georgia (Clark, 1965), the Andersonville district farther east in Georgia (Zapp, 1965), and the area between the Springvale and Andersonville districts (Zapp and Clark, 1965).

Chattahoochee Valley

The Chattahoochee River drainage basin is an ideal area in which to examine vertical and lateral facies changes in lower Paleogene rocks. Relatively high altitude of the Coastal Plain in this area—commonly 168 to 198 m (550–650 ft), deep dissection by the Chattahoochee River and its tributaries, and gentle southward dip of strata into the Southwest Georgia Embayment result in a long series of north-south exposures where both updip and downdip facies of individual units may be observed. This wide outcrop area is common in the transition zone from nonmarine or restricted-marine sediments to open-marine facies. For example, lower Paleocene strata of the Clayton Formation are present at altitudes of about 198 m (650 ft) in the northern part of the study area and can be followed southward to altitudes of less than 30 m (100 ft); because the strata have a general dip of 2.9 to 3.8 m/km (15–20 ft/mi), a 32- to 48-km (20–30 mi) -long sequence of exposures exists in an area of transition from mixed marine and restricted-marine environments in the north to completely marine environments in the south.

Another aid in following facies changes in lower Paleogene units is that they are considerably thinner than underlying Cretaceous units, generally being less than 30 m (100 ft) thick in updip areas and as much as 45.7 m (150 ft) in exposures farthest downdip. Thus, several formation contacts commonly can be seen within a single face of one of the more extensive outcrops or mine sections (for example, three formations each at Stops 9, 12, and 13), or can be sampled easily by relatively shallow drilling. Most stratigraphic sections discussed here were selected from abundant outcrops in eastern Alabama and western Georgia; but coreholes were drilled in 10 critical locations, for additional control.

Six lithologic units in Paleocene to middle Eocene rocks of this area were recognized by mapping. Age assignments for the units were obtained by using biostratigraphic data from calcareous nannofossils, dinoflagellates, foraminifers, mollusks, and sporomorphs. Integrating data from the different groups makes possible paleontologic correlations between marine and restricted-marine facies, because restricted-marine strata generally lack calcareous groups but do contain palynomorphs (dinoflagellates and sporomorphs). Although worldwide correlations are not yet available for palynomorphs, the use of calcareous nannofossils and planktic foraminifers from marine facies equivalents of restricted-marine and nonmarine facies permits correlation of the units with world-wide microfossil zonations.

Environments of deposition for the strata are interpreted from paleontologic data (foraminiferal species diversity, planktic-benthic foraminiferal ratios, diversity and relative abundance of dinoflagellates and sporomorphs, and molluscan assemblages), sedimentary structures, and regional patterns of deposition. A more detailed discussion of paleontologic interpretations of paleoenvironments, by T.G. Gibson, L.E. Edwards, and N.O. Frederiksen, is given subsequently.

FORMATIONAL CHARACTERISTICS

Type sections for lower Paleogene units are in western Alabama, except for that of the Clayton Formation, which will be visited on the field trip (Stop 7). Lithologic sections of units presented here extend from a western limit of Clayton and Echo, Alabama, to Preston, Georgia, in the east (Fig. 8), a distance of 113 km (70 mi).

Lower Paleogene depositional units are much thinner than underlying Cretaceous strata and lower Paleogene facies do not change as much laterally, from east to west within Alabama, as Cretaceous facies do. In lower Paleogene strata, facies similar to those of western Alabama extend across Alabama and approximately 32 km (20 mi) into Georgia; farther eastward, units become thinner, and strata of restricted-marine origin become more dominant. The extent of marine deposition eastward into Georgia, is much greater than has previously been recognized, however, as seen at Stop 13.

Lithologies of lower Paleogene formations reflect differences in depositional environments in which they formed, as well as differences in rate of supply of clastic sediments. Carbonate sediments dominate marine facies of the Clayton Formation of early Paleocene age; but above that, they are essentially absent in outcrop sections until inception of the middle Eocene Tallahatta Formation. Except in the Clayton Formation, the significant change along the Gulf Coastal Plain, from clastic sequences in the central and western Gulf area to carbonate deposits in the east, occurs southeast of this area. Glauconitic strata are common throughout marine facies of most formations. Carbonate and glauconitic facies reflect the low amount of detrital material being supplied when these sediments were deposited. Clay, silt, and very fine sand are the dominant clastic deposits in the units; commonly, as seen in the Nanafalia Formation at Stop 8 and the Tuscahoma at Stops 9 and 12, much of the clastic material was ponded in restricted-marine environments that existed north of bar complexes. The major time of significant clastic input is represented by the Tuscahoma Formation, which thickens downdip to 45.7 m (150 ft) of clay and silt (Toulmin and LaMoreaux, 1963).

Clayton Formation

The Clayton Formation in this area was deposited predominantly in shallow-marine environments; few strata formed in restricted-marine environments. In more northerly outcrops, such as those at Stop 7, massive or crossbedded quartzose sands dominate; in some places, these sands contain *Ophiomorpha* and other burrows. These sands represent nearshore subtidal sand sheets and commonly contain local shell lenses, 0.5 to 1 m (1.6–3.2 ft) thick, composed predominantly of oysters and *Turritella.* These lenses generally are indurated because of local leaching and precipitation of carbonate from shell material.

Southeast of the type area, the Clayton Formation thickens abruptly and changes to a predominantly carbonate section (Fig. 8). Toulmin and LaMoreaux (1963) reported a 55 m (180 ft) section mostly of sandy

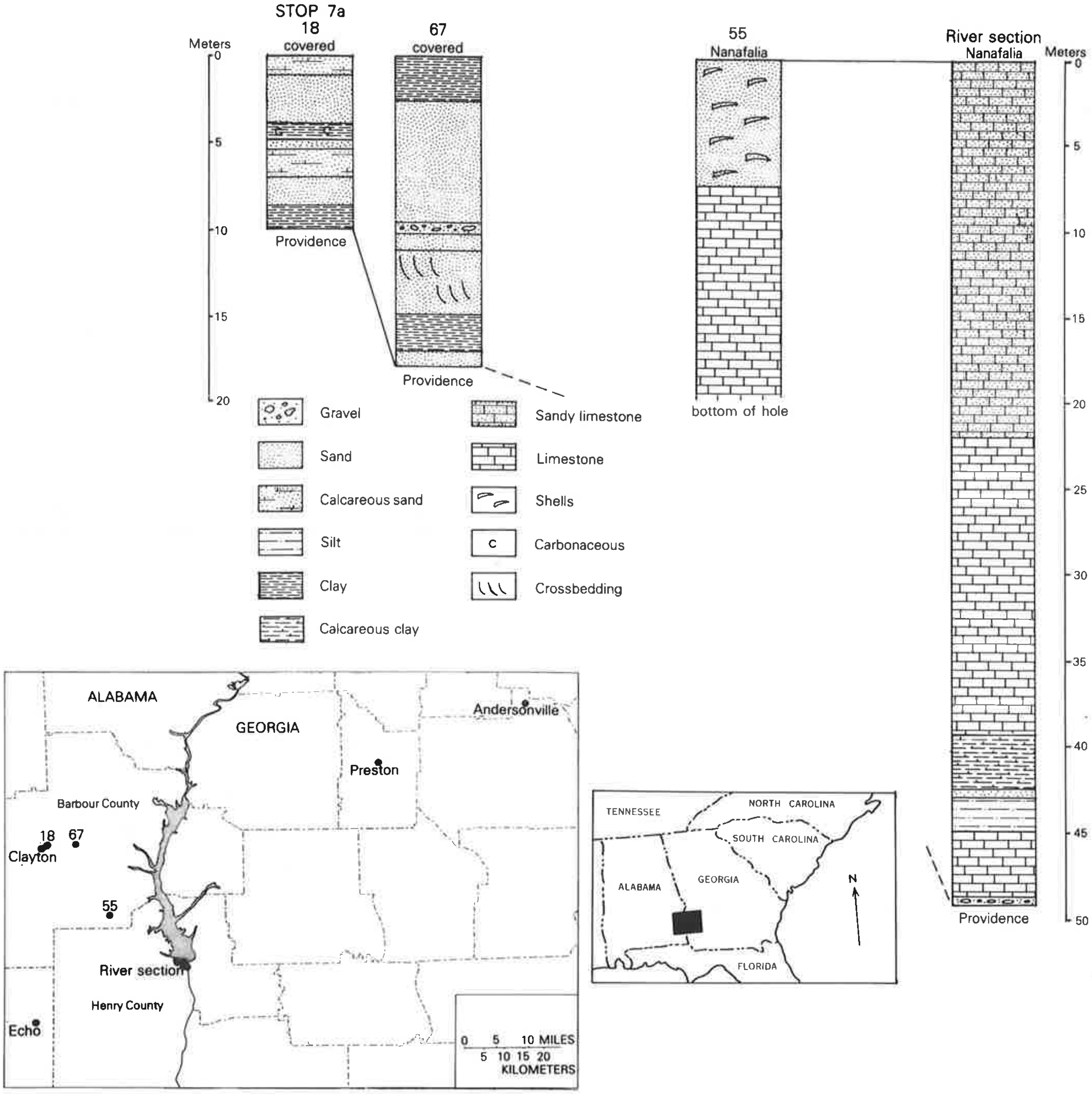

Figure 8. Lithology and thickness of Clayton Formation in eastern Alabama, showing change from sand and clay facies in north to mostly carbonate facies in south.

limestone at the Walter F. George Dam on the Chattahoochee River, near Fort Gaines (Stop 11). The limestone is highly fossiliferous; oysters and bryozoan fragments are dominant constituents. In western Georgia, near Montezuma and Andersonville, a silty clay containing foraminifers characteristic of shallow-marine waters suggests local clastic influx in that area.

The Clayton represents the most widespread marine trangression during Paleocene to middle Eocene time in this part of the Southwest Georgia Embayment. The basal transgressive sand is largely quartzose, contains only minor amounts of glauconite, and probably was derived from thick underlying sediments—as much as 50 m (164 ft) thick—of the Upper Cretaceous Providence Sand. Additional support for interpretation of this source is the large number of reworked sporomorphs of Late Cretaceous age found in the lowermost part of the "leaf bed" of the Clayton (Stop 7) (N.O. Frederiksen, 1979, written comm.). Although dissolution of carbonate is apparent in parts of the Clayton, the northernmost sandy exposures (Stop 7) contain primary sedimentary structures that show no evidence of carbonate dissolution. This basal sand occurs across much of the area of the Clayton is thinner than the overlying marine inundative phase, to which most of the 55 m (180 ft) of limestone at Fort Gaines belongs. The largely carbonate composition of the Clayton in most of the Southwest Georgia Embayment indicates a paucity of clastic influx. The presence near the embayment margin of restricted-marine environments, as seen in the "leaf bed" at Clayton (Stop 7), indicates at least one minor regression during Clayton time. Strata referable to the regressive phase of the Clayton are not found commonly in this area and probably were largely stripped by extensive pre-Nanafalia erosion, which formed karst topography.

Porters Creek Clay

An exposure of waxy appearing, dark-gray to olive-black, silty clay of the Porters Creek Clay occurs near the type area of the Clayton Formation (Stop 7B). The beds crop out on both sides of the road and expose about 1.4 m (4.6 ft) of section; total thickness of the Porters Creek here is 10.5 m (34.4 ft), as determined from a corehole adjacent to the outcrop. Presence of small mollusks, abundant planktic foraminifers, and calcareous nannofossils in the lower 1 m (3.3 ft) of glauconitic silty clay indicates a shallow, open-shelf environment of deposition; sediments higher in the section were deposited in progressively shallower water, and the uppermost sediments probably were deposited in restricted-marine environments, as indicated by microfossils.

Exposures of the Porters Creek at Clayton are the only ones presently known in the entire study area, and represent an outlier of the Porters Creek to the west. However, presence of open-marine Porters Creek strata as far updip as Clayton indicates that this unit originally covered much of this area but subsequently was extensively stripped. The large area stripped away is indicated by the absence of Porters Creek strata even in the most downdip exposures in the study area along the Chattahoochee River, where the Nanafalia Formation rests directly upon karst topography on top of Clayton strata (Stop 11). Porters Creek beds at Clayton probably were included in the top of the Clayton Formation by Cooke (1926).

Composition of the Porters Creek at Clayton, and generally clastic sediments of the Porters Creek throughout the eastern Gulf Coast, indicate that clastic sedimentation was increasing as far eastward as the Chattahoochee River area at this time. Clastic components of the Porters Creek are in contrast with the dominantly carbonate sediments in the underlying Clayton, although both were deposited in shallow-marine environments.

Nanafalia Formation

The northward or updip extent of the marine transgression represented by the Nanafalia (Fig. 9) was considerably less than that of the underlying Clayton and Porters Creek. Transition from restricted-marine to marine beds of the Nanafalia (Stops 10, 11) is found 50 km (31 mi) south (downdip) of Stop 7, where the underlying two units consist of marine beds.

The lower part of the downdip Nanafalia, as exposed at Franklin Landing (Stop 11), is composed of a sequence of carbonaceous clays and micaceous sands. Probably, as Marsalis and Friddell (1975) proposed, these strata are preserved only in sinkholes in the top of cavernous Clayton limestones. They considered the deposits to be equivalent to the Gravel Creek Sand Member of the Nanafalia in western Alabama. These beds, at and near Stop 11, contain a palynomorph assemblage that suggests restricted-marine environments, but of normal or nearly normal marine salinity. Ages suggested by the palynomorphs are older than those found in other parts of the Nanafalia in this area. Palynomorphs from the type area of the Gravel Creek in western Alabama have not been examined yet, but preliminary analysis suggests that assemblages from Stop 11 correlate with the underlying Naheola Formation of western Alabama. Strata at Stop 11 could be updip equivalents of the Naheola transgression, not previously recognized in this area. Pending further study, strata in karst holes at Stop 11 are questionably retained in the Gravel Creek Sand Member.

Nanafalia beds overlying the "Gravel Creek" are sharply divided into a restricted-marine to nonmarine facies, found north of Fort Gaines, and a marine facies, found to the south. In farthest updip areas, broad channels in the top of the Clayton Formation are filled by largely unidirectionally crossbedded, micaceous, medium-grained sand containing many clay clasts. Sedimentary characteristics of the channels, and absence of burrows such as *Ophiomorpha*, suggest a fluvial origin.

To the south, strata deposited in a restricted-marine environment crop out. They consist of kaolinitic clays, locally bauxitic, containing channel units of medium to coarse, micaceous, crossbedded sand and carbonaceous to lignitic clay (Stop 8). Dinoflagellate assemblages have low diversity and suggest deposition in a restricted-marine, lagoon-type environment. Wide extent of these lagoonal environments is indicated by similar beds at (Stop 9), and even farther south, to within 2 km (1.2 mi) of Stop 10, a distance of 24.1 km (15 mi); 2 km (1.2 mi) northwest of Fort Gaines (Stop 10), the Nanafalia contains a relatively thick sand sequence (Fig. 9). This sand represents a bar complex that ponded clay in restricted-marine environments to the north, separating it from glauconitic sand of very shallow-marine environments to the south.

In outcrops near Stop 10, crossbedded sand containing cut-and-fill structures and *Ophiomorpha* suggest estuarine point-bar deposits. At Franklin Landing (Stop 11) and other outcrops in the vicinity of Fort Gaines, these strata change to shelly, glauconitic fine sand, which overlies the "Gravel Creek Sand Member." This massively bedded sand contains *Odontogryphaea thirsae* (Gabb), *Ostrea sinuosa* Rogers & Rogers, and other mollusks, a moderately diverse benthic foraminiferal assemblage, and a low percentage of planktic specimens. These faunal characteristics suggest deposition in very shallow-marine environments. The shelly strata constitute the *Odontogryphaea thirsae* beds of the Nanafalia. Upward in the section along the Chattahoochee River, *O. thirsae* becomes rare to absent; the sediments become highly argillaceous in places and have low foraminiferal diversities, suggesting either several shallowing phases or greater influx of fresher waters. The highest beds of the Nanafalia are sandy deposits containing many lenses of large *Ostrea sinuosa*. A reflection of shallowing upward in the unit also is seen at Johnny Moore Hill, 16 km

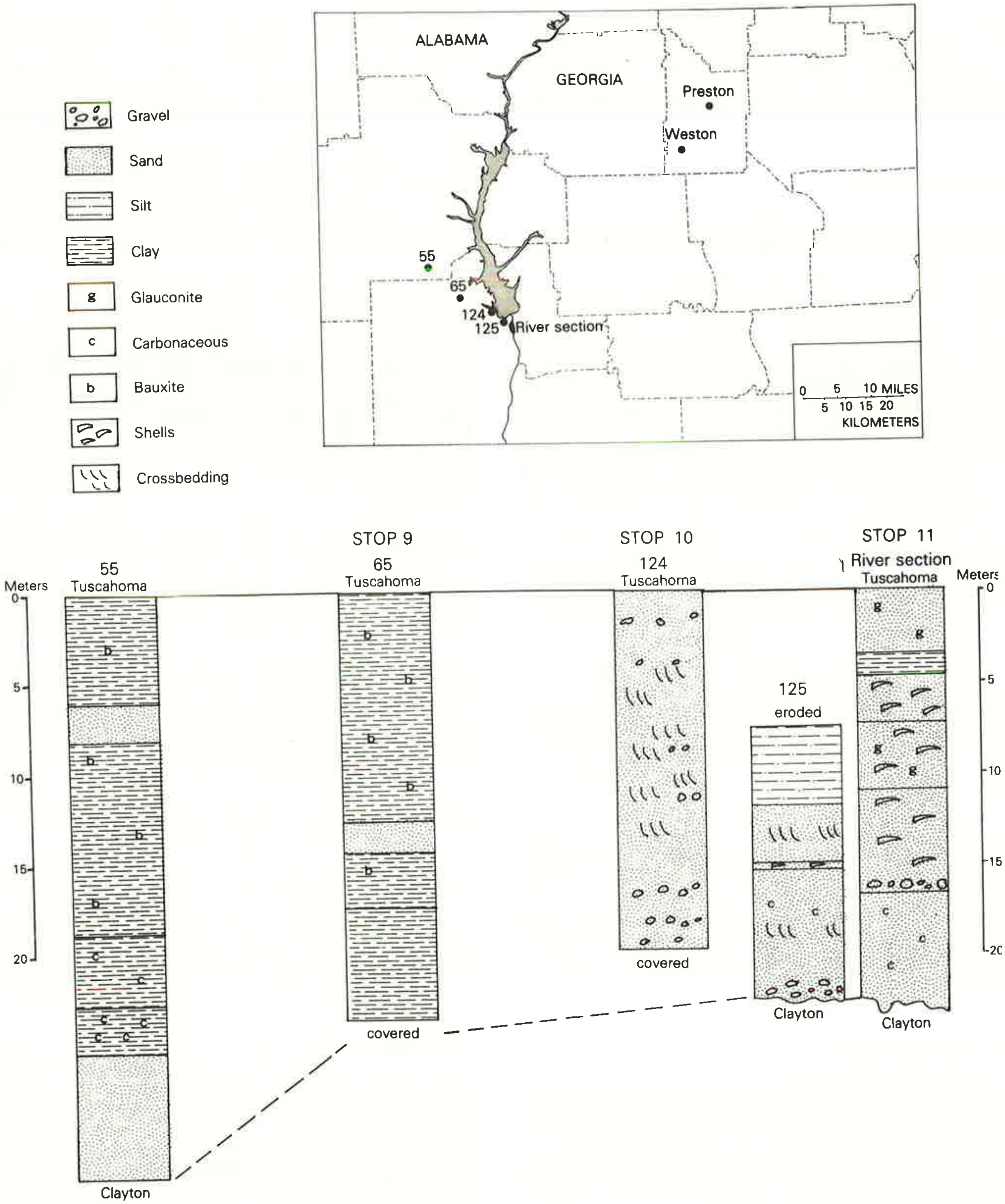

Figure 9. Lithology and thickness of Nanafalia Formation in eastern Alabama, showing change from bauxitic, carbonaceous clay in north to mostly glauconitic shelly sand in south.

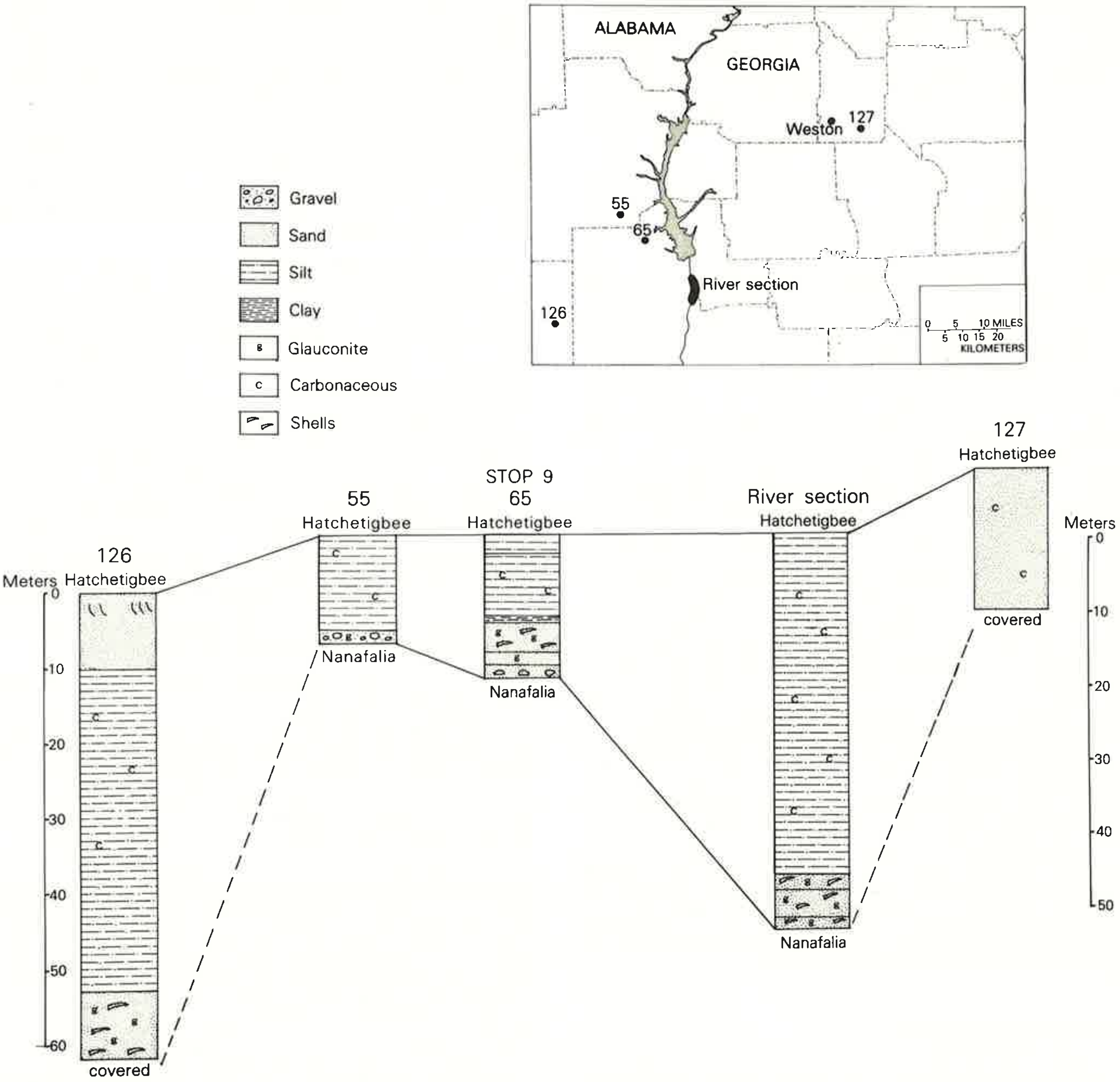

Figure 10. Lithology and thickness of Tuscahoma Formation in eastern Alabama and western Georgia, showing marine facies of glauconitic shelly sand at base, overlain by carbonaceous clay and silt section that thickens abruptly downdip.

(10 mi) northeast of Fort Gaines. Here, as reported by Marsalis and Friddell (1975, p. 18), the lower fossiliferous transgressive phase is overlain by unfossiliferous kaolinitic clays similar to those found in restricted-marine environments around the Eufaula bauxite district.

Considerable eastward extension of the marine Nanafalia is indicated by the presence, near Preston and Weston, Georgia, of crossbedded sand containing abundant *Ophiomorpha* (Fig. 9). Downdip equivalents of these beds are not exposed because of lack of topographic incision.

Tuscahoma Formation

The basal unit of the Tuscahoma is a glauconitic, medium to coarse sand, typically containing quartz and phosphate pebbles, clay clasts as long as 10 cm (4 in), and common mollusks shells, particularly *Chlamys greggi* Harris. These strata represent a transgressive phase that extended 30 km (18 mi) or more northward, or updip, from the contact between marine and restricted-marine facies of the underlying Nanafalia Formation. The contact between dark marine beds of the

Tuscahoma and light-colored kaolinitic and bauxitic clays of the underlying Nanafalia is conspicuous in many bauxite mines of this area. Strata of the Tuscahoma transgressive phase range in thickness from 1 m (3.3 ft) in updip areas to as much as 6 m (19.7 ft) in more downdip exposures (Fig. 10), but they constitute a relatively small part of the formation.

In contrast to other formations having a thick inundative phase following basal transgression, the Tuscahoma has a thick regressive sequence, ranging in thickness from 15 m (49.2 ft) updip to 45 m (147.6 ft) downdip, of laminated silts and clays, commonly carbonaceous. Calcareous fossils have not been found in these beds. Fine-grained laminated beds, abundant carbonaceous debris, and low diversity of dinoflagellate assemblages suggest that these beds formed in a protected area of lowered salinity. To the south, fine sand becomes more abundant; fine lamination, such as that seen at Stop 12, suggests deposition in fluctuating energy environments, possibly tidal flats. The Tuscahoma Formation extends eastward into the Andersonville bauxite district; although lithologically similar here, it is considerably thinner. Section 127, near Weston, Georgia (Fig. 10), has a glauconitic sand at the base, representing the transgressive phase, overlain by restricted-marine strata of the regressive phase. The facies pattern west of the Chattahoochee Valley is similar (section 126); a glauconitic sand (transgressive phase) at the base is overlain by silt and clay of a restricted-marine environment. Strata to the north seem to represent a lagoonal environment and are thinner than those of more southern exposures, which have cross-laminations suggestive of tidal-flat deposits.

Coreholes slightly south of the outcrop belt have not penetrated marine beds in the upper part of the Tuscahoma; thus, the regression must have been of considerable extent, although of relatively short duration. Thickness of silt and clay indicates that significant amounts of clastic material were deposited in this protected area during the late Paleocene. Buildup of these thicknesses in a relatively constant environment suggests an equilibrium between rate of subsidence or sea-level rise and influx of sediments.

Hatchetigbee Formation

Lowermost beds of the Hatchetigbee Formation represent a basal marine transgressive phase in the earliest Eocene. The transgression is widespread, extending northward almost to Baker Hill, Alabama (Fig. 11), and eastward well into western Georgia (Stop 13). Marine strata crop out even farther eastward, in Stewart and Webster Counties, Georgia. Like basal Tuscahoma beds, basal Hatchetigbee beds are highly glauconitic and contain abundant molluscan shells. However, the Hatchetigbee does not contain gravel and does contain much finer sand and glauconite grains, in the fine to very fine sand range, than does the Tuscahoma. Overlying these sediments in downdip sections is glauconitic very fine sand to silty clay; these beds of the marine inundative phase constitute most of the section and suggest slightly greater water depths of deposition—approaching 60 m (197 ft)—than the underlying units, as interpreted from foraminiferal assemblages. Preservation of part of the regressive phase is indicated by upward decrease of planktic foraminiferal percentages and benthic foraminiferal diversity, and by the common presence at the top of downdip sections of approximately 1 m (3.3 ft) of nonfossiliferous gray clays, which commonly are laminated, carbonaceous, and contain pyrite but not glauconite. These downdip sections maintain a relatively constant thickness of 9 to 10 m (29.5–32.8 ft). Lithology of a shelly very fine sand in much of the sections at Stops 12 and 13, particularly in the lower and middle part, is similar to that of the Bashi Marl Member at the base of the Hatchetigbee Formation in western Alabama.

Significant facies changes exist in the formation northward (updip) in the Southwest Georgia Embayment. At section 101 (Fig. 11), the entire thickness consists of nonfossiliferous fine to very fine sand, silt, and clay. Most of the section has the appearance of "sawdust sand"; Pryor and Vanwie (1971) explained that this texture superficially resembles that of medium to coarse sand but that, in reality, it consists of floccules of clay that have entrapped silt and very fine sand particles as they rolled along the sea bottom. Pryor and Vanwie suggested an agitated shallow-marine to brackish-water environment of deposition. This type of sand dominates sections 101 and 127 (Fig. 11) of the Hatchetigbee. The sands lack megafossils and burrow structures, are commonly crossbedded, and occur updip from shallow-marine lithologies and near sections interpreted, as per Pryor and Vanwie, as very shallow marine sand and restricted-marine deposits.

Section 101 is considerably thicker—16.3 m (53.4 ft)—than more downdip sections. In the complete section farthest updip, 97 (Fig. 11), the Hatchetigbee is even thicker, as much as 30 m (98.4 ft). The formation here consists of upper and lower sand units separated by a thick clay unit that commonly is laminated and lacks calcareous fossils. The basal sand is highly crossbedded and contains burrows, suggesting a shallow-marine to high-energy, restricted-marine environment; this unit will be seen at Stop 9. The middle clay unit contains a limited dinoflagellate assemblage but no calcareous fossils and is considered to represent a restricted-marine deposit. The uppermost sand unit is a well-sorted fine to very fine sand containing molluscan molds; it suggests very shallow-marine to possibly slightly restricted-marine environments.

Calcareous nannofossil assemblages are found throughout the downdip sections of the Hatchetigbee. All sections yield ages of Zone NP10 (L.M. Bybell, 1979, personal comm.), indicating a short time span for Hatchetigbee deposition. As the upper boundary is well marked by the basal shelly gravel of the overlying Tallahatta Formation throughout the area, and the lower boundary is marked by the carbonaceous silts and clay of the Tuscahoma, the ages of both the thinner downdip facies (usually called the Bashi Marl Member) and the thicker updip facies (called simply Hatchetigbee or the unnamed upper member) are the same. Therefore, in this area, the Bashi Marl is not a subdivision or member of the Hatchetigbee, but is equal in age to the entire updip facies called the Hatchetigbee. The thinning of the unit downdip probably has kept this fact obscured. Initial work in western Alabama by L.M. Bybell, (1980, oral comm.) indicates that the upper part of the Hatchetigbee there also belongs to Zone NP10, and could be just an updip thicker facies equivalent of the Bashi.

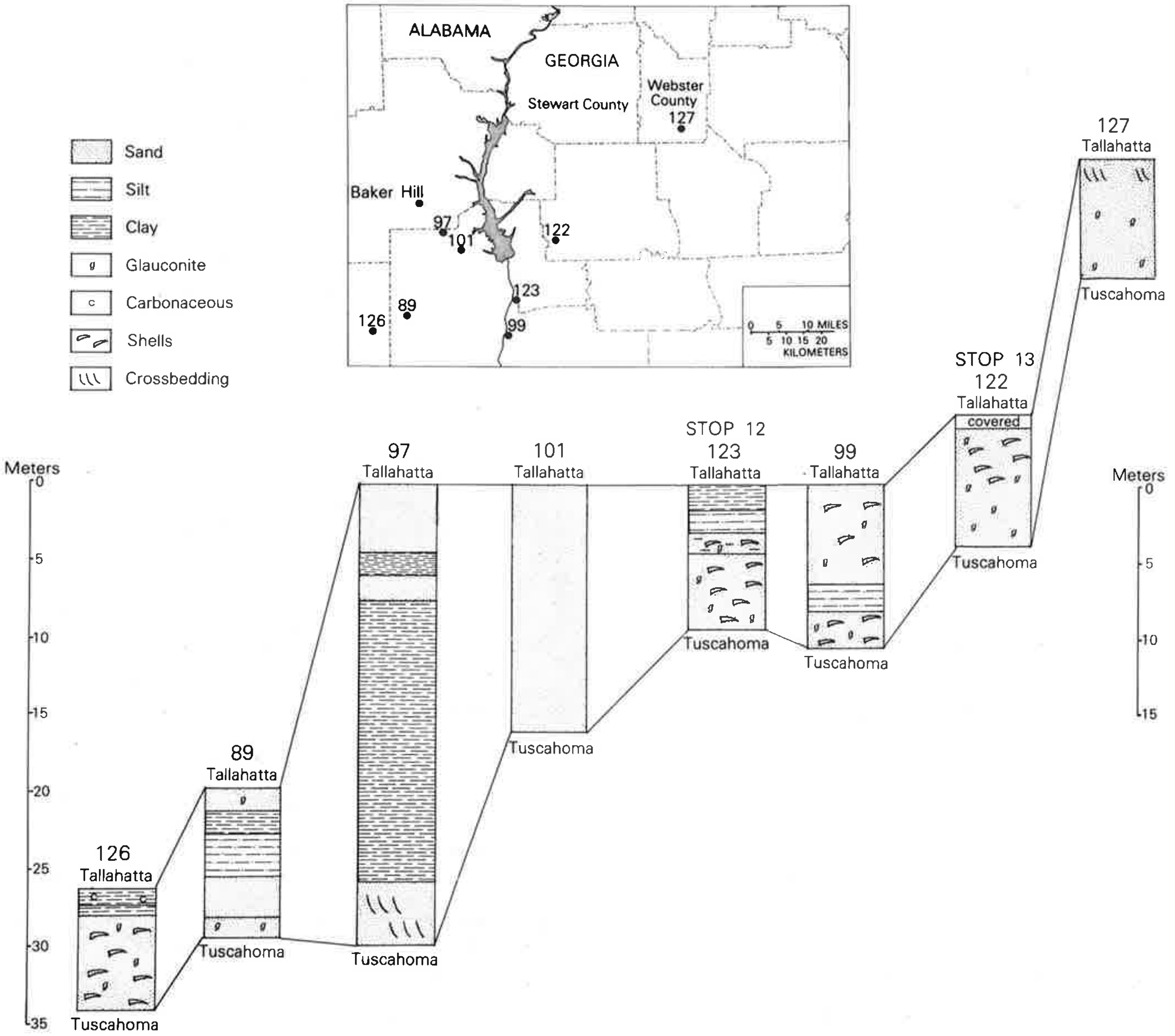

Figure 11. Lithology and thickness of Hatchetigbee Formation in eastern Alabama and western Georgia, showing general thinning to south and southwest, and change from sand and clay to glauconitic shelly sands.

Tallahatta Formation

The Tallahatta Formation, of middle Eocene age, has a less extensive marine phase than the underlying Hatchetigbee. This relationship is indicated by Tallahatta beds of restricted-marine to nonmarine origin resting upon marine Hatchetigbee strata, in eastern Alabama and western Georgia.

In most northern outcrops, the basal part of the Tallahatta rests in channels on the upper surface of the Hatchetigbee; these channel deposits represent a restricted-marine to nonmarine facies and consist of medium to coarse sand that commonly is gravelly and crossbedded and contains conspicuous clay clasts at or near the base. Channels in which these deposits rest seem similar to, but have less relief than, the "buried hills" surface underlying the Nanafalia. Nevertheless, as Fisher (1964) noted, wherever restricted-marine to nonmarine deposits are present at the base of a unit, a sculptured surface is present. Overlying the basal coarse sand is fine to medium sand; a cristobolitic clay unit, 1.0 to 1.5 m (3.3–4.9 ft) thick, and several thinner clays are present 6 m (19.7 ft) or more above the base of the formation.

Downdip, the basal transgressive marine phase is sandy but has much less glauconite than do deposits of the Wilcox transgressions. The inundative marine phase is dominantly fine to medium sand, which commonly is fossiliferous, and sandy limestone (Toulmin and LaMoreaux, 1963). As in other marine transgressive phases, relief at the base is very low and only small burrows are present.

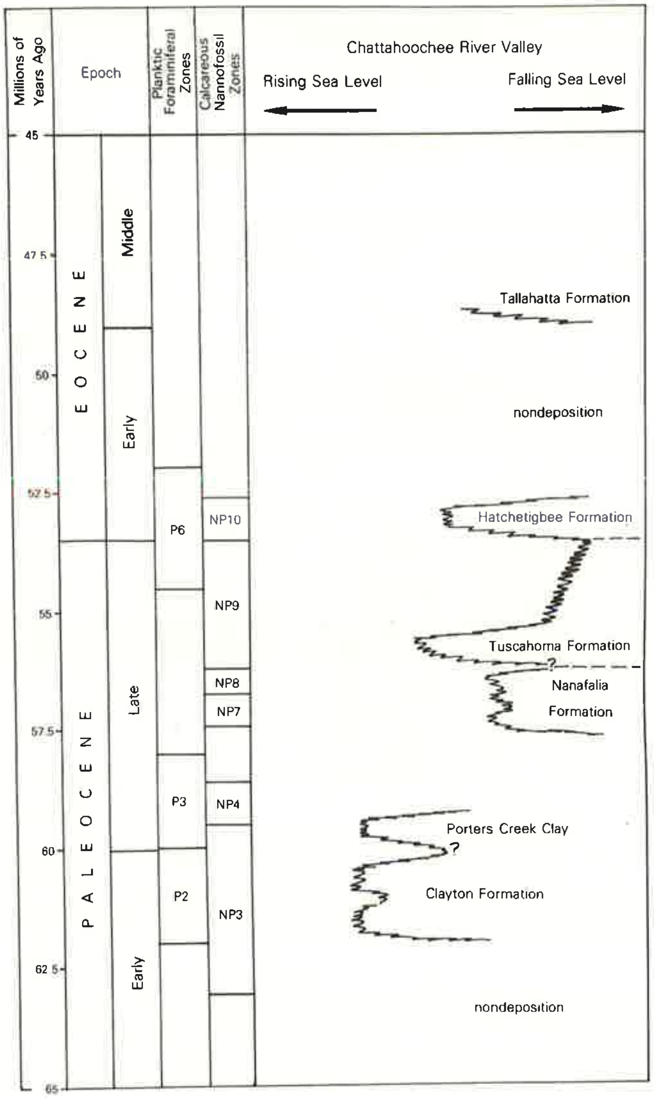

Figure 12. Time and extent of depositional cycles in Paleocene to middle Eocene strata in eastern Alabama and western Georgia. Time scale from Hardenbol and Berggren (1978).

DEPOSITIONAL CYCLES

Each of the formations traditionally recognized in this area constitutes a depositional cycle; both marine and restricted-marine to nonmarine strata have been placed within a single unit. Even though contained strata are somewhat heterogeneous, the formations are mappable units.

Fisher (1964) described depositional cycles in lower Paleogene strata of the central and western Gulf area; most of this well-documented work concerned the Claiborne (middle Eocene), but examples also were given from the Wilcox (upper Paleocene and lower Eocene). Cycles in Wilcox strata in this area (Nanafalia to Hatchetigbee) are similar in facies characteristics to those described by Fisher.

Most of the six transgressive-regressive units in the Chattahoochee Valley represent a relatively short time of deposition—1 million to a maximum of 3 million years (Fig. 12). Two cycles are separated by long periods of nondeposition: the lower Paleocene Clayton Formation from that of the underlying Providence Sand of the Cretaceous, and the lowermost Eocene Hatchetigbee Formation from the overlying Tallahatta Formation of the middle Eocene. The extent of the regressions between the Clayton and Porters Creek, between the Nanafalia and Tuscahoma, and between the Tuscahoma and Hatchetigbee is unclear, pending more downdip control.

The cycles represent repeated shoreline transgressions and regressions, probably taking place within a depositional basin similar to the present Gulf Coast. Each complete cycle (Fig. 13) has a basal marine transgressive sand phase, typically glauconitic and relatively thin; the basal unit is overlain by thicker marine, inner neritic glauconitic shelly sand and silt and lesser amounts of silty clay, representing a stillstand or inundative phase. The marine phase becomes shallower upward and passes into a restricted-marine phase, presumably reflecting a lagoon or bay environment. The greatest preserved thickness of strata represents the marine inundative phase (Clayton, Nanafalia, and Hatchetigbee Formations) or the restricted-marine regressive phase (Tuscahoma Formation). Lithology of the inundative phase depended upon influx of clastic deposits into the basin at that time and ranges from fine sand to silty clay to carbonate. In updip sections, however, an entire formation may be fluvial or may change upward from restricted-marine to fluvial.

Owens and Sohl (1969) noted the differences in thickness of the depositional record of various environmental phases of Cretaceous cycles in New Jersey and called these "asymmetrical cycles." Lower Paleogene formations in the Chattahoochee area also are asymmetrical in that deposits of the basal transgressions are very thin compared with the thick inundative or regressive deposits that follow.

Boundary characteristics of the cycles are variable, depending largely upon the depositional environment of the initial phase. Units having a restricted-marine or fluvial phase at the base commonly contain major channeling. Erosional surfaces generally have low relief where the basal phase is marine.

In a typical cycle having a marine transgressive phase at the base (Fig. 13), the thin basal sand represents a reworked zone, is glauconitic, and commonly contains quartz and phosphate pebbles, entire shells and fragments, shark teeth, and abundant clay clasts of local origin. Burrows commonly extend downward from the basal glauconite into the underlying units, at times as deep as 1.2 to 1.5 m (4-5 ft).

The marine inundative deposit is much thicker than the basal unit and consists of glauconitic sand and silt. Molluscan shells and foraminifers are common and diverse. Only the Hatchetigbee Formation has open-marine silty clay in this phase, suggesting deposition some distance from the shoreline.

Uppermost, or regressive, deposits are argillaceous and silty, commonly contain abundant carbonaceous debris, and consist mostly of more or less laminated silts and clays of lagoonal and tidal-flat environments.

Depositional cycles in the lower Paleogene of the Chattahoochee Valley resulted from changes in the relationship of sea level to the land surface as a result of eustatic change of sea level, regional subsidence, or uplift of the basin; thicknesses of units and types of sediments do not suggest control by source and rates of sediment input, except possibly for the Tuscahoma

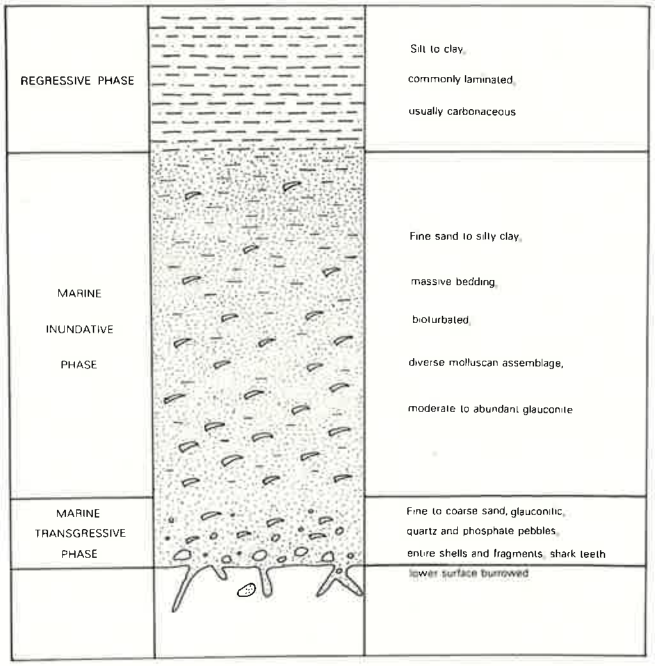

Figure 13. Generalized section of depositional cycle in Paleocene to lower Eocene strata in Chattahoochee Valley.

Formation. The preserved regressive sequence generally is too thin to represent seashore withdrawal. The Tuscahoma, however, has a thick regressive sequence that suggests shoreline withdrawal because of a large clastic input and consequent basinward building out of lagoonal and tidal-flat deposits.

SUMMARY

Facies changes involving nonmarine and restricted-marine to marine transitions were examined in Paleocene to middle Eocene strata in western Georgia and eastern Alabama. Where preserved, nonmarine and restricted-marine deposits consist of kaolinitic clay, crossbedded fine- to medium-grained sand, and poorly sorted coarse clastic material. Open-marine deposits consist of calcareous and glauconitic sand, silt, and silty clay containing abundant macroinvertebrate fossils.

The Clayton (lower Paleocene) and Hatchetigbee (lowermost Eocene) Formations consist of marine facies in much of the area and contain restricted-marine units at their northern limits. The Nanafalia (upper Paleocene) and Tallahatta (middle Eocene) Formations have marine beds downdip but extensive areas of restricted-marine to nonmarine strata updip. The Tuscahoma Formation (upper Paleocene) is composed largely of restricted-marine facies, except for one extensive marine bed at the base.

Each of these formations represents a depositional cycle composed, downdip, of a marine transgressive phase at the base, overlain by beds of a marine inundative phase, and a restricted-marine regressive phase at the top. Updip, the entire formational cycle may consist of restricted-marine and nonmarine beds.

MOLLUSCAN AND FORAMINIFERAL BIOSTRATIGRAPHY OF LOWER PALEOGENE STRATA

Thomas G. Gibson

INTRODUCTION

Samples collected recently from outcrops and cores of fossiliferous Paleocene to middle Eocene strata of eastern Alabama and western Georgia document the ages of marine sediments in this area. This preliminary study of diagnostic mollusks and foraminifers is presented as an aid to collecting during the field trip and as a biostratigraphic summary for surface and shallow subsurface work in progress. The mollusks allow regional correlations of all formations. Benthic foraminifers are helpful in correlating surface and, especially, subsurface sections; correlation with intercontinental zonations by means of planktic foraminifers is possible for the Clayton, Porters Creek, and Hatchetigbee Formations.

Previous Work

The study of mollusks in lower Tertiary deposits of the eastern Gulf Coastal Plain was begun by T.A. Conrad and others in the early to middle 18th century. Subsequently, G.D. Harris published extensive papers dealing with the strata to be seen on this field trip, notably the Midway fauna in 1896 and the Wilcox fauna (then called Lignitic) in 1897 and 1899. The most useful recent review of important molluscan species of various Gulf Coast stages, by Toulmin (1977), serves as a status-of-the-art summary.

Paleogene foraminifers of the Gulf Coast have not been summarized as comprehensively as have Paleogene mollusks. The Midwayan fauna was studied by Cushman (1951) through most of the Gulf Coast, but faunas of the Wilcox Group are more poorly known. Studies by Toulmin (1941) on the Salt Mountain Limestone, by Smith (1967) on the Nanafalia Formation, and by Oliver (1979) on the Tuscahoma Formation were concerned primarily with western Alabama. Foraminiferal faunas from the Hatchetigbee Formation, particularly its Bashi Marl Member, were studied by Cushman and Ponton (1932) in eastern Alabama and by Cushman and Garrett (1939) and Cushman (1944) in western Alabama.

Most of the above studies dealt with benthic foraminifers. During the past 20 years, use of planktic foraminifers for intercontinental correlation has become common; the provincialism of molluscan and benthic foraminiferal species largely precludes their being used. Loeblich and Tappan (1957) first comprehensively studied planktic foraminifers from strata of the Midway and the lower part of the Wilcox on the Gulf Coast. On the basis of planktic species, Berggren (1965) relocated some Gulf Coast stages with respect to European stage and epoch boundaries.

Chattahoochee Valley

Paleogene mollusks are especially important, because they have served as the standard biostratigraphic guides for local and regional correlation. Molluscan species discussed and illustrated herein are those most common and diagnostic of the strata; some have not been recorded previously in the field trip area, although these generally are known from classic sections in western Alabama.

Although most strata in the Chattahoochee River Valley were deposited in very shallow water, several formations contain sufficient planktic foraminifers to allow correlation with global zonations, as summarized by Stainforth *et al.* (1975). Because planktic species are not always available, benthic foraminiferal species diagnostic of each formation also are noted. Some characteristic benthic species of each formation in this area have longer ranges in other parts of the Gulf Coast.

BIOSTRATIGRAPHIC MARKER SPECIES

Clayton Formation

The index mollusk most commonly found in the Clayton Formation of the Chattahoochee Valley area is *Ostrea crenulimarginata* Gabb (Pl. 5, figs. 1-4). This species is abundant at the type locality at Clayton, Alabama (Stop 7A), and is found throughout the outcrop area of the Clayton. In many places it is the only mollusk found in Clayton strata, because its calcitic shell is more resistant to leaching than are aragonitic shells of other species. Another common species at the type locality of the Clayton is *Turritella aldrichi* Bowles (Pl. 5, figs. 5-6). Aragonitic species preserved here and in most updip outcrops typically are silicified.

Iron ore has been mined in western Georgia since the 19th century; it is found at or near the base of the Clayton. This basal residuum in some places contains molluscan molds or silicified mollusks. Arthur Donovan and Juergen Reinhardt collected specimens at a locality in Marion County, Georgia, and found a relatively large assemblage of generally fragmented shells. Stratigraphically important species included *Mesalia alabamiensis bowlesi* Stenzel & Turner (Pl. 5, fig. 7), *Astarte subpontis* Harris (Pl. 5, figs. 8-9), *Venericardia smithii* Aldrich (Pl. 5, fig. 11), and *V. wilcoxensis* Dall (Pl. 5, figs. 12-13). *Astarte subpontis* is characteristic of the upper part of the Clayton Formation at Fort Gaines, Georgia, and *Venericardia wilcoxensis* is found in the upper part of the Porters Creek Clay, the Matthews Landing Marl Member, and the upper part of the Clayton (Toulmin, 1977). The fauna in Marion County, Georgia, suggests that updip residuum beds here represent the upper part of the of the Clayton. If so, the Clayton transgressive phase either occurred in more than one pulse or was continuous through most of the Clayton deposition, reaching its greatest extent, in western Georgia, near the end of the transgression.

Foraminifers have been obtained only from silty clays interbedded with limestones in the eastern part of the study area, near Andersonville, Georgia. These beds contain planktic foraminifers characteristic of the lower Paleocene (Danian), including *Globorotalia pseudobulloides* (Plummer) and *Globoconusa daubjergensis* (Bronnimann). Absence of other diagnostic species suggests an upper Zone P1 or P2 age assignment. Although the range of *G. daubjergensis* is restricted to Zone P1 by Stainforth *et al.*, (1975), other authors (El-Naggar, 1966; Hansen, 1970) indicate that it ranges through the *Morozovelia uncinata* zone (Zone P2), possibly even extending somewhat in to the lower part of Zone P3 (Hansen, 1968). General absence of specimens of *M. uncinata* in Gulf Coast Paleocene strata (Berggren, 1965) makes the upper part of Zone P1 difficult to separate from Zone P2. Specimens of

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Plate 5. Characteristic gastropods and bivalves from Clayton and Nanafalia Formations (Paleocene) of Chattahoochee River Valley

1-4. *Ostrea crenulimarginata* Gabb. Clayton Formation. Macon County, Ga. 1, 2—exterior and interior views of bored left valve (x1). 3, 4—exterior and interior views of bored right valve (x1).

5, 6. *Turritella aldrichi* Bowles. Clayton Formation. 5—front view of broken specimen (x2), Barbour County, Ala. 6—side view of broken specimen (x1), Marion County, Ga.

7. *Mesalia alabamiensis bowlesi* Stenzel & Turner. Clayton Formation, Marion County, Ga. Side view of broken specimen (x1.5).

8, 9. *Astarte subpontis* Harris. Clayton Formation, Marion County, Ga. Exterior and interior views of bored left valve (x2).

10, 14, 15. *Odontogryphaea thirsae* (Gabb). Nanafalia Formation, Henry County, Ala. Dorsal, exterior, and interior views of bored left valve (x1).

11. *Venericardia smithii* Aldrich. Clayton Formation, Marion County, Ga. Antero-ventral fragment of left valve (x1).

12, 13. *Venericarida wilcoxensis* Dall. Clayton Formation, Marion County, Ga. Exterior view of right valve and dorsal view of articulated valves (x2).

16. *Ostrea sinuosa* Rogers & Rogers. Nanafalia Formation, Henry County, Ala. Exterior view of left valve (x0.5).


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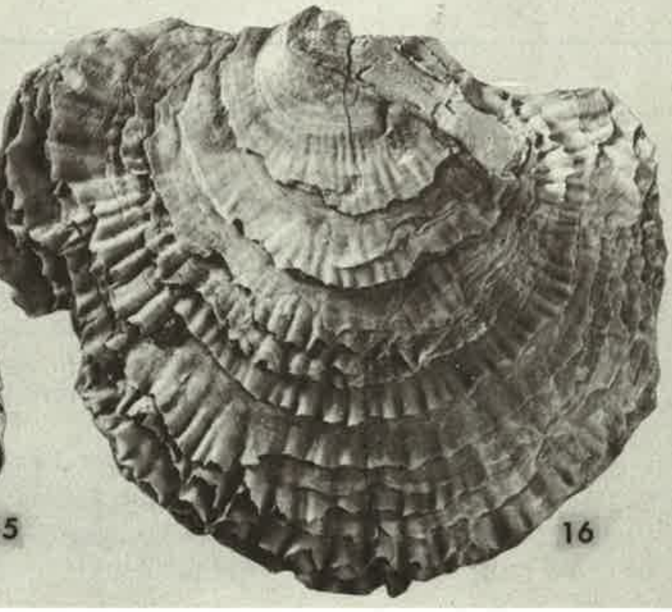
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Globoconusa daubjergensis commonly have supplementary apertures and seem to represent a late developmental stage in the species range (Hansen, 1970). A benthic species, *Cibicides neelyi* Jennings, is restricted to Clayton beds near Andersonville, Georgia, although it is known to have a longer range in other areas.

Porters Creek Clay

The only exposure of the Porters Creek Clay in the Chattahoochee area is at Clayton, Alabama (Stop 7B). Although some small, soft, shell fragments are present in the outcrop, none are large enough to identify, and foraminifers are absent. Foraminifers are present, however, in the lower part of a corehole drilled adjacent to the outcrop. The planktic assemblage contains *Globorotalia pseudobulloides*, *Globoconusa daubjergensis*, and *Globigerina triloculinoides* Plummer. Specimens of *Globoconusa daubjergensis* are advanced forms of the species; they are large, most having supplementary apertures on the spiral side, and have a bulla-like last chamber (Hansen, 1970). This assemblage indicates placement in Zone P2, which is equivalent to most of the upper part of calcareous nannofossil Zone NP3. However, calcareous nannofossils in the sample were determined by L.M. Bybell (next section) to belong to Zone NP4. The upper range of *G. daubjergensis* may have to be extended slightly, or the calcareous nannofossils used may have a lower range in terms of foraminiferal zones. Pending further study, these beds are considered to be of lower Zone P3 or upper Zone P2 age. Diagnostic benthic species include *Siphogenerinoides eleganta* (Plummer) and *Anomalina acuta* Plummer.

Nanafalia Formation

Fossiliferous strata along the Chattahoochee River contain abundant shells of *Odontogryphaea thirsae* (Gabb) (Pl. 5, figs. 10, 14, 15), marker species for the *O. thirsae* beds in the Nanafalia Formation of western Alabama. This species seems to be restricted to the Nanafalia Formation (Toulmin, 1977). *Odontogryphaea thirsae* and *Ostrea sinuosa* (Rogers & Rogers) (Pl. 5, fig. 16) dominate the assemblage seen in the Nanafalia at Stop 11, near Fort Gaines, Georgia.

Planktic foraminifers are rare in the Nanafalia, and diagnostic species were not found. Characteristic benthic species include *Nonion graniferum* (Terquem), which is abundant in most beds of the Nanafalia.

Tuscahoma Formation

The most common megafossil in basal glauconitic sands of the Tuscahoma Formation is *Chlamys greggi* Harris (Pl. 6, fig. 1). Although small, it is conspicuous in strata of the marine transgressive phase, even far updip. In localities where sand is indurated with carbonate cement, presumably from dissolution of aragonitic shells, specimens of *C. greggi* are abundant (as at Stop 9). Another distinctive mollusk in this formation is *Turritella praecincta* Conrad (Pl. 6, fig. 2). *Ostrea sinuosa* continues into this formation from the underlying Nanafalia.

Age-diagnostic planktic foraminifers have not been recovered from the Tuscahoma in the Chattahoochee area, although they occur in marl units of the formation in western Alabama (Oliver, 1979). The benthic species *Cibicides praecursorius* (Schwager) is known only from basal beds of the Tuscahoma in this area, although *C. praecursorius* is known from other formations in western Alabama.

Hatchetigbee Formation

Even though a relatively small time interval separates the transgressive cycle, represented by the Hatchetigbee Formation, from the cycle represented by the underlying Tuscahoma Formation, several distinctive mollusks and foraminifers make their first appearance in the relatively thin marine section that constitutes the Hatchetigbee. *Venericardia hatcheplata* Gardner & Bowles (Pl. 6 figs. 3-4, 8-9) and *V. horatiana* Gardner (Pl. 6, figs. 10-11) are restricted to these beds and are abundant at Stop 13. Another common index fossil restricted

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Plate 6. Characteristic gastropods and bivalves from Tuscahoma (upper Paleocene) and Hatchetigbee (lower Eocene) Formations of Chattahoochee River Valley

1. ***Chlamys greggi*** **Harris. Tuscahoma Formation, Wilcox County, Ala. Exterior view of right valve (x2).**

2. ***Turritella praecincta*** **Conrad. Tuscahoma Formation, Wilcox County, Ala. Front view (x1).**

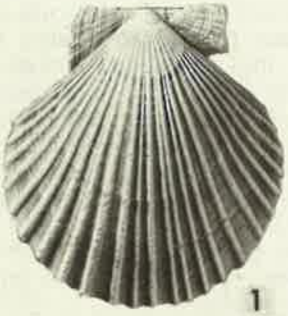
3,4,8,9. ***Venericardia hatcheplata*** **Gardner & Bowles. Hatchetigbee Formation, Randolph County, Ga. 3,4—exterior and interior views of left valve (x1). 8—exterior view of right valve (x1). 9—interior view of broken left valve (x1).**

5. ***Cornulina*** **sp. Hatchetigbee Formation, Stewart County, Ga. Back view of broken specimen (x1).**

6. **"*Siphonalia*" sp. Hatchetigbee Formation, Stewart County, Ga. Front view (x2).**

7. ***Turritella gilberti*** **Bowles. Hatchetigbee Formation, Wilcox County, Ala. Front view (x2).**

10, 11. ***Venericardia horatiana*** **Gardner. Hatchetigbee Formation, Randolph County, Ga. Exterior and interior views of bored right valve (x1).**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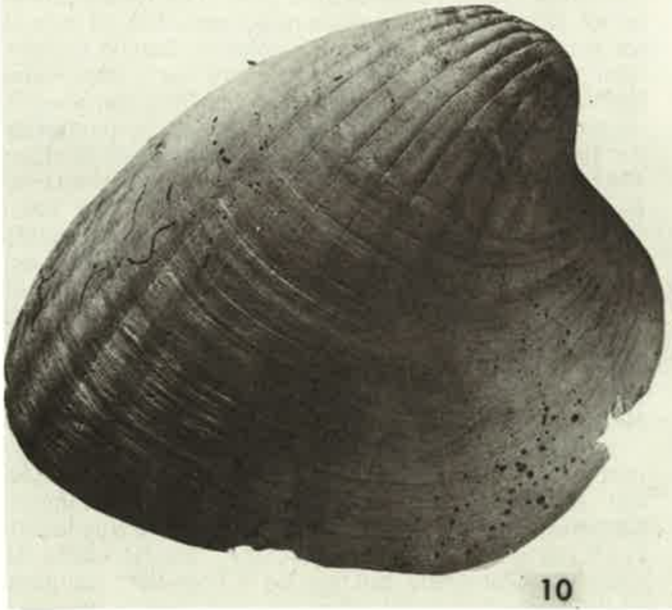
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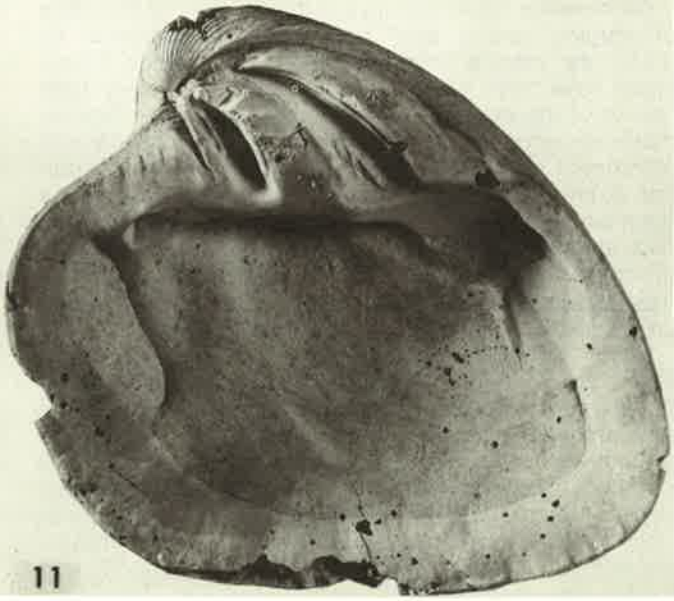
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to this formation is *Turritella gilberti* Bowles (Pl. 6, fig. 7). Two other species, *Cornulina* sp. (Pl. 6, fig. 5) and *"Siphonalia"* sp. (Pl. 6, fig. 6), presently are known to occur only in the Hatchetigbee Formation in western Georgia.

Many samples from the Hatchetigbee Formation contain important planktic foraminiferal species. Those at Stops 12 and 13 include *Morozovella acuta* Toulmin, *M. subbotinae* Morozova, *M. aequa* Cushman & Renz, *Acarinina wilcoxensis* Cushman & Ponton, *A. soldadoensis soldadoensis* Bronnimann, and *Pseudohastigerina wilcoxensis* (Cushman & Ponton). Overlapping ranges of these species indicate an earliest Eocene age for the Hatchetigbee, which belongs to the *Morozovella edgari* zone (middle of P6). This placement agrees with Zone NP10 placement obtained from calcareous nannofossils (L.M. Bybell, next section). Several benthic species are known only from the Hatchetigbee: *Lamarckina wilcoxensis* Cushman, occurring commonly only in basal beds of downdip sections, *Uvigerina wilcoxensis* Cushman & Garrett, and *Virgulina wilcoxensis* Cushman & Ponton.

Tallahatta Formation

Only one locality yielding calcareous fossils was found in the Tallahatta Formation during this study; no identifiable mollusks were present. The foraminifer *Nonion tallahattensis* Bandy is common and distinguishes the formation here, as well as farther west in Alabama (Bandy, 1949).

PALEOGENE CALCAREOUS NANNOFOSSILS

Laurel M. Bybell

INTRODUCTION

Calcareous nannofossils are minute calcite platelets of varying shape and construction, produced by unicellular marine planktic golden-brown algae. These algae have been a major constituent or primary food chains of the marine realm since the Jurassic; their remains are abundant in most marine sediments where no significant removal of calcareous material has occurred. Numbers of individual specimens are greatest in open-ocean sediments deposited above the calcium carbonate compensation depth. The number of individuals decreases shoreward, but numbers of species increase correspondingly. Both diversity and abundance decrease in marginal-marine sediments.

Lower Paleogene sediments in the Chattahoochee River Valley of the eastern Gulf Coastal Plain were deposited in a variety of nonmarine to shallow-marine environments. As expected, calcareous nannofossil abundance and diversity are low in marginal-marine deposits. In spite of these limitations, many sediments can be dated accurately (Fig. 14). Ninety samples collected in the study area—from the Clayton Formation, Porters Creek Clay, Nanafalia Formation, Tuscahoma Formation, Hatchetigbee Formation, and Tallahatta Formation—were examined for calcareous nannofossils. Approximately one-half of these samples could be placed within a specific calcareous nannofossil zone. For comparison, 38 additional samples were examined from localities farther west in Alabama and Mississippi, type areas for most of these formations.

Examination of large numbers of samples that commonly yield sparse assemblages may seem tedious, but in the study area, calcareous nannofossils were the only fossil group studied that provided consistent biostratigraphic results. The calcareous nannofossil zonation served as a framework for calibrating sporomorph and dinoflagellate data with an international standard (see N.O. Frederiksen and L.E. Edwards; subsequent sections). Once calibrated, characteristic sporomorph and dinoflagellate assemblages could be traced from marine through marginal-marine to nonmarine environments, thereby establishing one interrelated biostratigraphic framework.

Practically no previous data have been published on Paleocene and early Eocene calcareous nannofossil distributions in the Gulf Coastal Plain. Information available is restricted to a few, widely scattered samples examined before the establishment of zonation schemes currently used. In this study, Martini's (1971) zonation, as modified (see individual formation descriptions), and Bukry's (1973, 1975, 1978) zonations were used. These various zonations are based upon a sequence of stacked, first and last, evolutionary occurrences. This method provides a much finer zonation than one based only on assemblage zones, but multiple samples from each locality are important for optimum results.

BIOSTRATIGRAPHY

Clayton Formation

Samples from the type locality of the Clayton Formation (Stop 7A) and several other locations were examined for calcareous nannofossils. All were barren except for three outcrop samples collected in Sumter County near Andersonville, Georgia. All are early Paleocene (Danian) in age and are placed in Martini's calcareous nannofossil Zone NP3, the base of which is marked by the first occurrence of *Chiasmolithus danicus* (Brotzen 1959) Hay & Mohler, 1964. This species is very similar to *Chiasmolithus consuetus* (Bramlette & Sullivan 1961) Hay, Mohler, & Wade 1966, and some uncertainty exists as to whether they actually are two separate species. Gartner (1970) found only *C. consuetus* in Gulf Coast Danian sediments; until type material from Europe can be examined, the name *C. consuetus* will be used for this species in the study area, and its first occurrence is assumed to be approximately equal to the base of Zone NP3.

In Alabama, west of the study area, the Clayton Formation has two distinguishable members, the Pine Barren (lower) and the McBryde Limestone (upper). Calcareous nannofossils indicate that at its type locality in Wilcox County, Alabama, the Pine Barren is no older than Zone NP2, but may be in Zone NP3. Samples of the McBryde Limestone at the type locality, and also

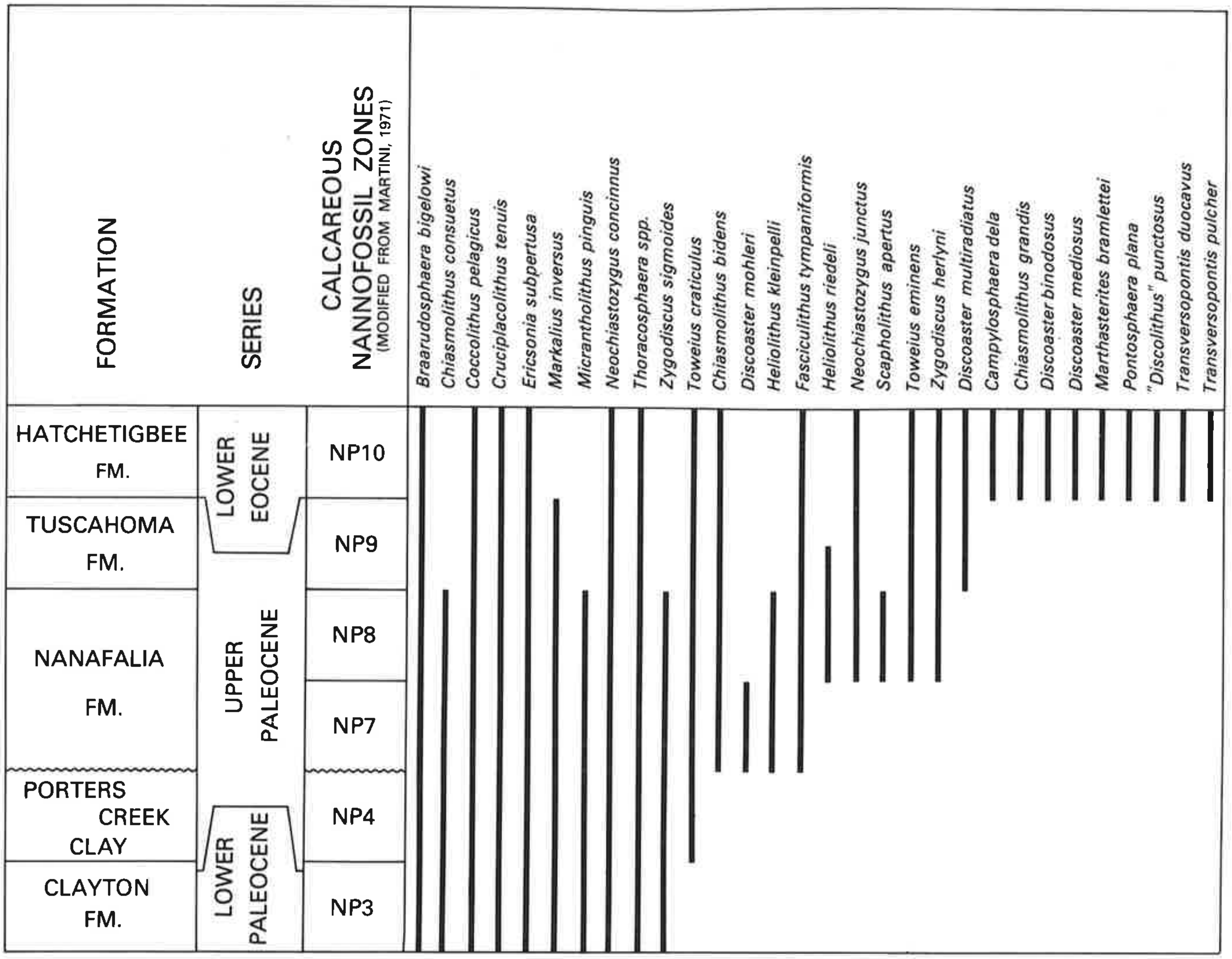

Figure 14. Stratigraphic ranges of selected calcareous Paleogene nannofossils of Alabama and Georgia. Many are illustrated in Plates 7 and 8.

from the type locality of the Midway Group at Midway Landing in Wilcox County, are in Zone NP3. The Clayton Formation in the study area therefore is time-correlative with the McBryde Limestone and may or may not be correlative with the Pine Barren. Zone NP3 is the longest lasting Paleocene zone—about 3.5 m.y. (Hardenbol and Berggren, 1978).

Porters Creek Clay

In the study area, the Porters Creek Clay had not been recognized before this study. However, in Barbour County, Alabama, near the type locality of the Clayton Formation, 1.4 m (4.7 ft) of sediments of typical Porters Creek lithology are exposed (Stop 7B). Samples collected here were barren of calcareous nannofossils, but an adjacent corehole contained similar sediments that were considered approximately equal to Zone NP4, the base of which is marked by the first occurrence of *Ellipsolithus macellus* (Bramlette & Sullivan 1961) Sullivan 1964. This species is present only locally in the study area, but the species *Toweius craticulus* Hay & Mohler 1967 (Pl. 7, fig. 9) also has its first occurrence at the base of Zone NP4 (Gartner, 1971; Okada and Thierstein, 1979; and my unpublished data). *T. craticulus* is common in upper Paleocene sediments of the Gulf and Atlantic Coastal Plains and seems to be a reliable marker for the base of Zone NP4.

To date, no samples from the lower part of the Porters Creek Clay farther west in Alabama contain significant calcareous nannofossils. However, the upper member of the Porters Creek Clay, the Matthews Landing Marl, contains datable nannofossils. Two localities of the Matthews Landing in Wilcox County, Alabama, were examined, one at the type locality of the Naheola Formation and the other near the town of Kimbrough. All samples are in Zone NP4. The Porters Creek material in the study area and the Matthews Landing are, therefore, in the same zone, but their time relationship with the lower part of the Porters Creek currently is unknown.

Nanafalia Formation

The unconformity between the Porters Creek Clay and the Nanafalia Formation represents Zones NP5 and NP6, indicating that no record exists of at least 1 million years (Hardenbol and Berggren, 1978). The precise temporal position of the Naheola Formation, which occurs only west of the Chattahoochee River Valley within the interval represented by this unconformity, is presently unknown.

The Nanafalia Formation, as exposed in Clay County, Georgia, is in Zones NP7 and NP8. A few samples from the upper part of the Nanafalia are in Zone NP9; therefore, in the study area, the Nanafalia Formation probably ranges from Zone NP7 through NP9. The base of NP7 is marked by the first occurrence of *Discoaster mohleri* Bukry & Percival 1971, the oldest discoaster described; the base of NP8 is marked by the first occurrence of *Heliolithus riedeli* Bramlette & Sullivan 1961 (Pl. 8, figs. 2,4); and the base of NP9 is marked by the first occurrence of *Discoaster multiradiatus* Bramlette & Riedel 1954 (Pl. 8, fig. 9).

A few Nanafalia samples also were examined from Choctaw County, western Alabama, near Pennington. Here, the Nanafalia contains calcareous nannofossils of Zone NP7. Examinations of additional samples should clarify the exact time relationship of the Nanafalia in various locations across the Gulf Coastal Plain.

Tuscahoma Formation

Only three samples from the Tuscahoma Formation contained calcareous nannofossils, one from Clay County, western Georgia, and the other two from Dale County, eastern Alabama. All are typical of Zone NP9, uppermost Paleocene zone. This, the second longest lasting Paleocene zone, represents about 2.5 m.y., according to Hardenbol and Berggren (1978).

Hatchetigbee Formation

Thirty-one samples from the Hatchetigbee were examined in the study area, and 20 could be dated using calcareous nannofossils. Samples are from Henry County, Alabama, and Randolph and Early Counties, Georgia. All represent Zone NP10, the lowest zone of the Eocene, the base of which is marked by the first occurrence of *Marthasterites bramlettei* Bronnimann & Stradner 1960. Several species that first appear in this

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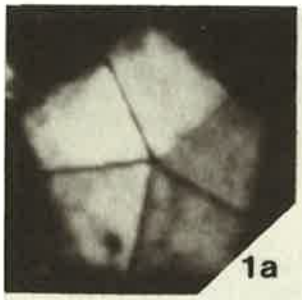
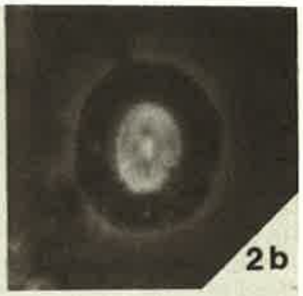
Plate 7. Characteristic calcareous nannofossils from Paleocene and lower Eocene rocks of western Georgia and eastern Alabama
(All specimens x3200; a—cross polarized; b—phase contrast)

1. ***Braarudosphaera bigelowi* (Gran & Braarud 1935) Deflandre 1947. Clayton Formation, Sumter County, Ga.**
2. ***Coccolithus pelagicus* (Wallich 1877) Schiller, 1930. Nanafalia Formation, Henry County, Ala.**
3. ***Cruciplacolithus tenuis* (Stradner 1961) Hay & Molher 1967. Clayton Formation, Sumter County, Ga.**
4. ***Ericsonia supertusa* Hay & Mohler 1967. Hatchetigbee Formation, Early County, Ga.**
5. ***Markalius inversus* (Deflandre 1954) Bramlette & Martini 1964. Clayton Formation, Sumter County, Ga.**
6. ***Micrantholithus pinguis* Bramlette & Sullivan 1961. Nanafalia Formation, Clay County, Ga.**
7. ***Neochiastozygus concinnus* (Martini 1961) Perch-Neilsen 1971. Nanafalia Formation, Clay County, Ga.**
8. ***Zygodiscus sigmoides* Bramlette & Sullivan 1961. Clayton Formation, Sumter County, Ga.**
9. ***Towelus craticulus* Hay & Mohler 1967. Nanafalia Formation, Henry County, Alabama.**
10. ***Chiasmolithus bidens* (Bramlette & Sullivan 1961) Hay & Mohler 1967. Nanafalia Formation, Clay County, Ga.**


1a


1b


2a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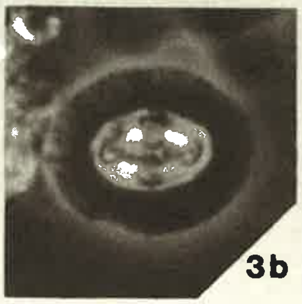
3a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4a


4b


5a


5b


6a


6b


7a

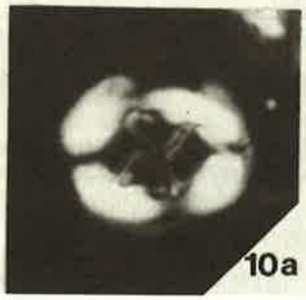

7b


8a


8b


9a


9b


10a


10b

zone (Fig. 14) include: *Campylosphaera dela* (Bramlette & Sullivan 1961) Hay & Mohler 1967, *Chiasmolithus grandis* (Bramlette & Riedel 1954) Hay, Mohler & Wade 1966 (Pl. 8, fig. 7), *Discoaster binodosus* Martini 1958, *Pontosphaera plana* (Bramlette & Sullivan 1961) Haq 1971, *"Discolithus" punctosus* Bramlette & Sullivan 1961 (Pl. 8, fig. 6), and *Transversopontis pulcher* (Deflandre 1954), Perch-Nielsen 1967 (Pl. 8, fig. 8). These data allow the Paleocene-Eocene boundary in the study area to be recognized easily.

Comparative material was examined from the Bashi Marl Member (lower member of the Hatchetigbee Formation) at its type locality in Clarke County, Alabama. These sediments are in Zone NP10. Most of the upper part of the Hatchetigbee farther west is nonfossiliferous, but the uppermost part, as exposed at Tunnel Springs in Monroe County, Alabama, contains calcareous nannofossils characteristic of Zone NP10. Thus, the entire Hatchetigbee is represented by one calcareous nannofossil zone, representing about 500,000 years (Hardenbol and Berggren, 1978).

Tallahatta Formation

All Tallahatta Formation samples examined in the study area are barren of calcareous nannofossils. At Little Stave Creek in Clarke County, Alabama, the upper part of the Tallahatta is in Zone NP16. Until the lower part of the Tallahatta can be dated, the extent of the unconformity separating the Hatchetigbee and Tallahatta Formations cannot be documented.

Plate 8. Characteristic calcereous nannofossils from Paleocene and lower Eocene rocks of western Georgia and eastern Alabama
(All specimens x3200; a—cross polarized (except 9a); b—phase contrast)

1. ***Heliolithus kleinpelli*** **Sullivan 1964. Nanafalia Formation, Clay County, Ga.**

2, 4. ***Heliolithus riedeli*** **Bramlette & Sullivan 1961. Nanafalia Formation, Clay County, Ga.**

3. ***Toweius eminens*** **(Bramlette & Sullivan 1961) Gartner 1971. Nanafalia Formation, Clay County, Ga.**

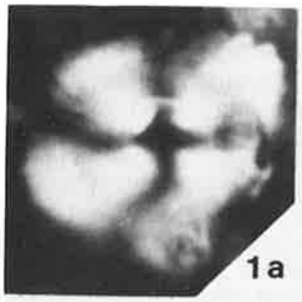
5. ***Zygodiscus herlyni*** **Sullivan 1964. Nanafalia Formation, Henry County, Ala.**

6. ***"Discolithus" punctosus*** **Bramlette & Sullivan 1961. Hatchetigbee Formation, Early County, Ga.**

7. ***Chiasmolithus grandis*** **(Bramlette & Riedel 1954) Hay, Mohler & Wade 1966. Hatchetigbee Formation, Early County, Ga.**

8. ***Transversopontis pulcher*** **(Deflandre 1954) Perch-Nielsen 1967. Hatchetigbee Formation, Early County, Ga.**

9. ***Discoaster multiradiatus*** **Bramlette & Riedel 1954. a—interference contrast. Hatchetigbee Formation, Early County, Ga.**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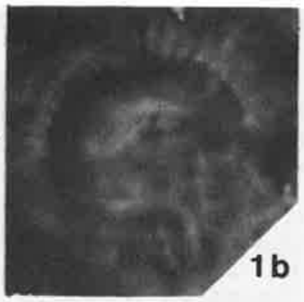
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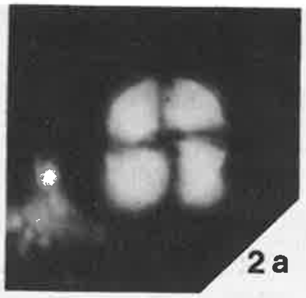
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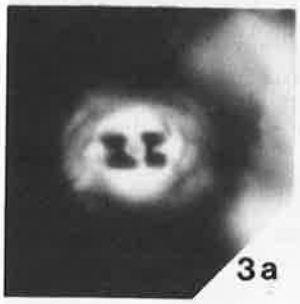
2b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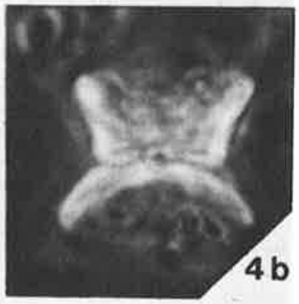
4a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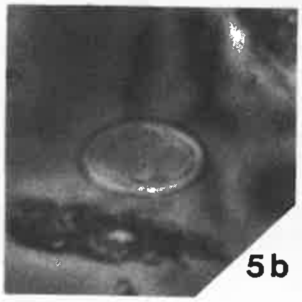
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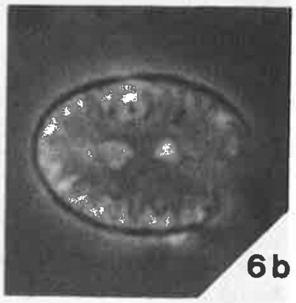
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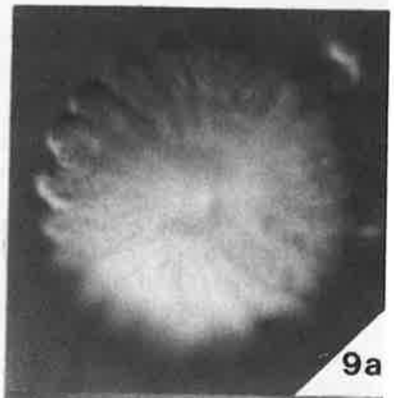
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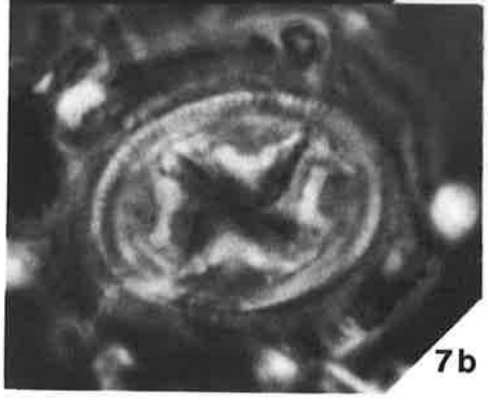
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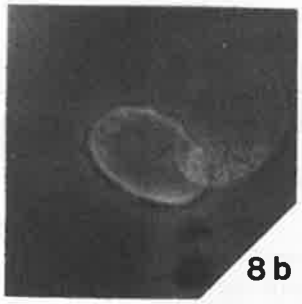
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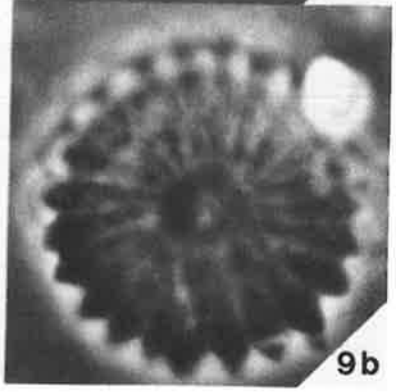
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LOWER TERTIARY SPOROMORPH BIOSTRATIGRAPHY: PRELIMINARY REPORT

Norman O. Frederiksen

INTRODUCTION

Detailed studies of lower Tertiary stratigraphy of eastern Alabama and western Georgia have been initiated in recent years; objectives of these studies mainly have been to determine Coastal Plain structures and to map the distribution of kaolin deposits (Gibson, 1980, this guidebook; Cofer and Frederiksen, 1980). Correlation of some rock units is difficult in certain parts of the study area because of abrupt facies changes along strike and downdip, and because some strata lack marine fossils. Some units are easy to distinguish on the basis of their sporomorph (spore and pollen) content, but others have assemblages that are less distinct. Eventually I hope to determine the geologic ranges of sporomorph taxa accurately enough to permit detailed correlation of individual rock and biostratigraphic units within the interval from the lower Paleocene to the lower middle Eocene of the study area.

BIOSTRATIGRAPHY

Many papers have been published on early Tertiary sporomorphs of the Gulf Coast and Mississippi Embayment; some include range charts for one or more areas of this region. However, published stratigraphic ranges of some early Tertiary sporomorph taxa are difficult to apply in the eastern Gulf Coast, for several reasons. First, many of the sporomorph ranges are based on samples from the Mississippi Embayment and Texas (e.g., Elsik, 1968 a,b,c, 1974; Fairchild and Elsik, 1969; Tschudy, 1973a,b, 1975); ranges of some taxa in these areas may be somewhat different from the local ranges in the eastern Gulf Coast. Second, sporomorph data available are not precise enough to enable palynologists to differentiate formations that are rather similar in age. For example, both the Nanafalia and Tuscahoma Formations of the eastern Gulf Coast are late Paleocene in age, and they are difficult to differentiate by using only published range data. Third, some parts of the lower Tertiary section have been studied more intensely than others, palynologically; relatively little has been published on early Paleocene sporomorphs of the Gulf Coast. This study of early Tertiary sporomorphs from eastern Alabama and western Georgia not only will aid local correlations in the study area, but it also will improve the accuracy of long-range sporomorph correlations between the western Gulf Coast and the Atlantic Coastal Plain.

Twenty-three samples were examined to determine local stratigraphic ranges of sporomorph taxa (Fig. 15). Samples are from the Clayton Formation, Porters Creek Clay, Nanafalia Formation, and Tuscahoma Formation (Paleocene), Hatchetigbee Formation (lower Eocene), and Tallahatta Formation (lower part of the middle Eocene) and were collected in Barbour and Henry Counties, Alabama, and Clay and Early Counties, Georgia (Fig. 38). Some ranges certainly will be extended as more samples are examined. Furthermore, the range chart includes only taxa known from published papers; many previously undescribed species have been observed thus far in the study; when ranges of these species are better known, they should help in distinguishing assemblages of different formations.

Previous studies of the Clayton Formation and Porters Creek Clay (Paleocene; Midwayan) suggested that few differences exist between sporomorph assemblages of these formations, at least in the Mississippi Embayment (Tschudy, 1973b, 1975). Similarly, in the eastern Gulf Coast, all taxa observed in the Clayton probably occur also in the Porters Creek (Fig. 15). Unfortunately, fossiliferous samples from the Clayton are difficult to obtain on the eastern Gulf Coast, except at the type locality of the Clayton in central Barbour County, Alabama (Stop 7). The three Clayton samples (Fig. 15) are from the "leaf bed" of the type Clayton, but even these samples seem to contain only limited numbers of sporomorph taxa. In most areas of eastern Alabama and western Georgia, the Clayton is represented by limestone and/or sand that have low contents of organic matter. In this area, the Clayton and Porters Creek seem to be in part lateral lithofacies of one another (Toulmin and LaMoreaux, 1963; Huddlestun *et al.*, 1974). I hope that some new and previously described species of sporomorphs will be found useful for drawing time lines through this complex of Paleocene rocks.

An unconformity exists between the Porters Creek Clay (upper Midwayan) and the shelly, glauconitic beds of the Nanafalia Formation (lower Sabinian) in most areas of eastern Alabama and western Georgia (Huddlestun *et al.*, 1974; Gibson, 1980; L.M. Bybell, previous section). As expected, the Porters Creek sporomorph assemblage is quite different from that of the Nanafalia (Fig. 15). Locally in eastern Alabama and western Georgia, the "Gravel Creek Sand Member" of the Nanafalia Formation fills solution pits in the top of Clayton limestones (Toulmin and LaMoreaux, 1963; Marsalis and Friddell, 1975). After Figure 15 was drafted, sporomorphs were examined from two samples of the "Gravel Creek" in eastern Alabama, one from Stop 11 and the other from a corehole about 2 km (1.2 mi) to the west-northwest. The "Gravel Creek" contains *Choanopollenites conspicuus* (Groot & Groot 1962) Tschudy 1973, *Margocolporites cribellatus* Srivastava, and *Aesculiidites circumstriatus* (Fairchild *in* Stover *et al.*, 1966) Elsik 1968, species that seem to have overlapping ranges only in the uppermost Midwayan Provincial Stage of western Alabama (Naheola Formation; Srivastava, 1972; Tschudy, 1973b) and of South Carolina (lower part of Black Mingo Formation; Frederiksen, in press). The range data suggest that the Midwayan-Sabinian Provincial Stage boundary in eastern Alabama may coincide with the contact between strata filling the solution pits ("Gravel Creek" strata) and overlying *Odontogryphaea thirsae* beds of the Nanafalia.

Assemblages from the Nanafalia Formation (exclusive of the "Gravel Creek Sand Member") and Tuscahoma Formation (late Paleocene) are quite similar to one another. Differences depend on taxa that have low relative frequencies; therefore, significant differences between assemblages of the two formations are not yet certain. However, *Choanopollenites patricius* Tschudy 1973 has been found previously only in the Nanafalia Formation (Tschudy, 1973b); some taxa observed in the present study (such as primitive *Platycarya*) may prove to be restricted to the Tuscahoma Formation.

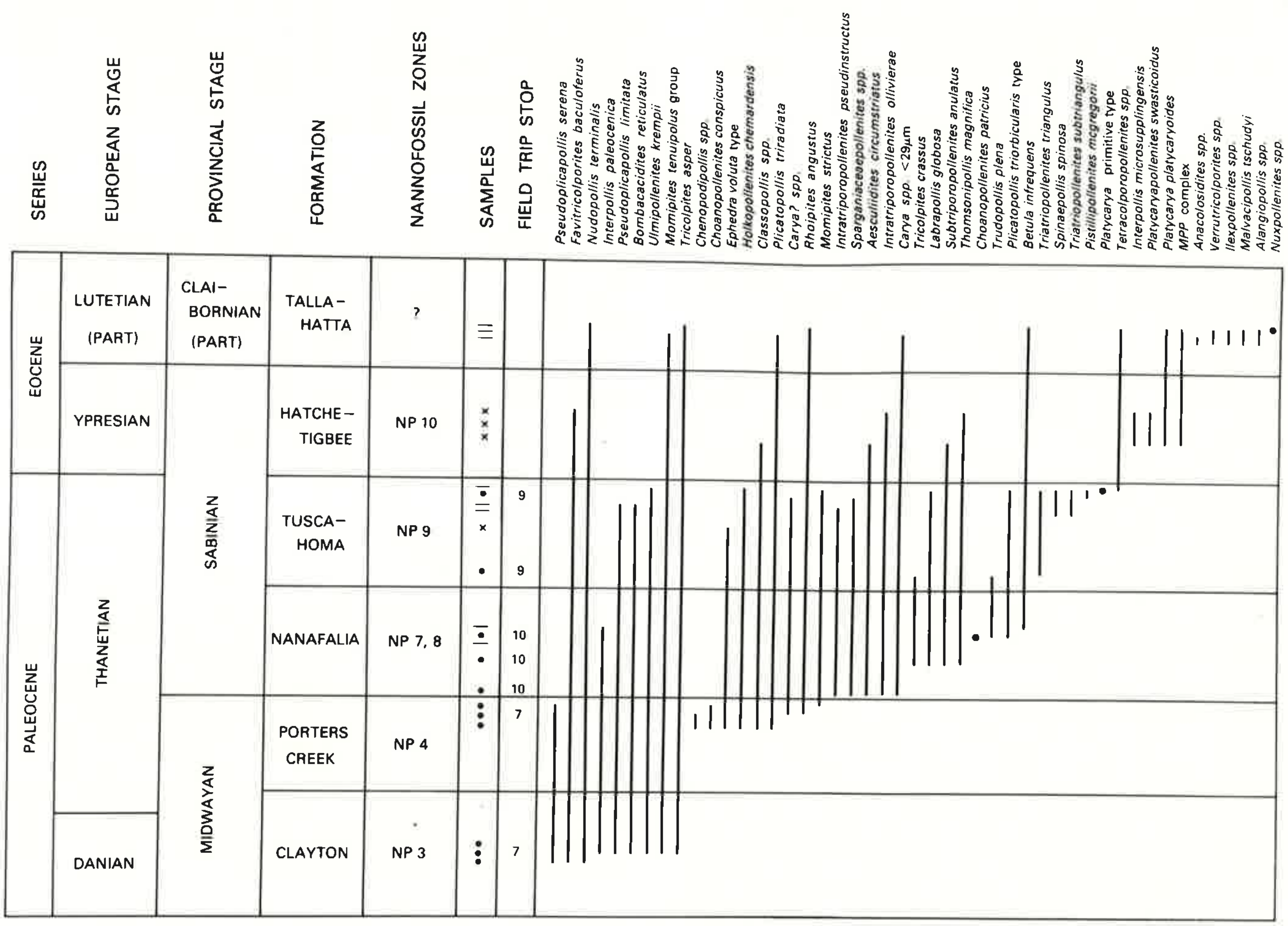

Figure 15. Chart showing observed ranges of 47 sporomorph taxa in lower Paleocene to lower middle Eocene rocks of eastern Alabama and western Georgia. Thickness of units not to scale. Filled circles and dashes mark samples where stratigraphic positions within units are known; filled circles — samples, this field trip. X's mark samples from unknown positions within known units; samples were arbitrarily considered to be from about middle of unit. Nannofossil zones are from L.M. Bybell (Fig. 14). ***MPP*** **complex =** ***Momipites-Plicatopollis-Playtcaryapollenites*** **complex.**

An unconformity probably exists between the Tuscahoma Formation (upper Paleocene) and the Hatchetigbee Formation (lower Eocene) (Huddlestun *et al.*, 1974; Bennison, 1975); but this unconformity seems to represent less time than the unconformity between the Hatchetigbee and Tallahatta (Toulmin, 1977; Gibson, 1980). Nevertheless, the sporomorph assemblage of the Hatchetigbee is easily distinguished from that of the Tuscahoma, because *Platycarya* and *Platycaryapollenites* are everywhere rather abundant in the Hatchetigbee but absent from the Tuscahoma, except for rare, primitive specimens of *Platycarya*. Furthermore, *Momipites strictus* Frederiksen & Christopher 1978 is found in many Paleocene samples but is absent from Eocene ones. Relatively few previously described taxa have been found in Hatchetigbee and Tallahatta samples. However, *Thomsonipollis magnifica* (Pflug *in* Thompson & Pflug 1953) Krutzsch 1960 probably does not range above the Hatchetigbee Formation in the Gulf Coast, whereas *Malvacipollis tschudyi* (Frederiksen 1973, Fredericksen 1980), *Alangiopollis*, and *Anacolosidites* seem to be good markers for the Tallahata (lower middle Eocene) and higher Eocene strata.

SUMMARY

Geologic ranges of sporomorph taxa from lower Paleocene to lower middle Eocene rocks of eastern Alabama and western Georgia indicate that the following units, or groups of units, have distinct assemblages and can be identified readily by these assemblages: Clayton Formation and Porters Creek Clay (Paleocene; Midwayan), Nanafalia Formation and Tuscahoma Formation (Paleocene; lower Sabinian), Hatchetigbee Formation (lower Eocene; upper Sabinian), and Tallahatta Formation (lower part of the middle Eocene; lower Claibornian). The Clayton is overlain conformably by the Porters Creek, and the Nanafalia is overlain conformably by the Tuscahoma; a sporomorph zonation within each of these sets of formations has not yet been established. Sporomorph species ranges suggest that the "Gravel Creek Sand Member" of the Nanafalia Formation in eastern Alabama may be the same age as the uppermost part of the Midwayan Stage in western Alabama and South Carolina.

DINOFLAGELLATE BIOSTRATIGRAPHY: A FIRST LOOK

Lucy E. Edwards

INTRODUCTION

Dinoflagellates are unicellular algae of the Division Pyrrhophyta. As a group, they are second only to diatoms as primary food producers in the world oceans. Most are marine autotrophs; but dinoflagellates also may inhabit fresh or brackish water and may be heterotrophs, parasites, or symbionts. Most people, although not familiar with dinoflagellates, are familiar with their effects. Bioluminescent dinoflagellates cause a sparkling of the sea at night as waves break, and certain dinoflagellates may produce blooms called "red tides," which poison marine life or cause toxins to accumulate in shellfish and poison those who eat them.

The life cycle of many dinoflagellates includes both a vegetative and an encysted stage. The encysted stage of many dinoflagellates, the dinocyst, is composed of a resistant organic wall and is readily fossilizable. Many of the spiny, organic-walled microplankton formerly called "hystrichospheres" are now known to be dinocysts. The term "acritarch" is applied to organic-walled cysts that lack features diagnostic of dinoflagellates. Marine, marginal marine, and non-marine dinoflagellates may form cysts, but fossil dinocysts are most common in marine sediments. Non-marine dinocysts are rare in, but not entirely absent from, the fossil record. Fossil dinocysts offer considerable biostratigraphic potential in nearshore and brackish environments of the Paleogene of the Chattahoochee River Valley.

Scope and previous work

Many authors have studied Paleocene and early Eocene dinocysts from Europe, North America, Asia, Australia, New Zealand, and offshore Canada. However, relatively little has been published on the Gulf Coast region; Drugg and Loeblich (1967) and Drugg (1970) reported Paleogene dinoflagellates from Alabama and Mississippi, and McLean (1968) discussed reworked Cretaceous dinocysts in Paleogene sediments from Alabama. This report is first in an ongoing study of dinoflagellate biostratigraphy of the Chattahoochee River Valley of the eastern Gulf Coast.

Dinoflagellate biostratigraphy is in its infancy; nearly all dinocyst range data have been gathered within the last 20 years. Much of the Chattahoochee area material comes from nearshore or brackish environments, thus species diversity is generally low. In addition, several species were unreported previously. In some samples examined, preservation is poor, and in a few samples, dinocysts are extremely rare. In none of the assemblages are dinocysts highly diverse. Maximum diversity is less than 20 species.

Although dinoflagellate assemblages in the study material are far from ideal, this investigation provides a good opportunity to examine dinoflagellates from nearshore and brackish sediments that also contain calcareous nannofossils (L.M. Bybell, previous section), foraminifers (T.G. Gibson, previous section), and/or terrigenously derived pollen and spores (N.O. Frederiksen, previous section). Our joint studies enable us to integrate all these biostratigraphies.

Material

The present study is based on 35 fossiliferous samples from Barbour, Dale, and Henry Counties, Alabama, and Clay, Sumter, Randolph, and Webster Counties, Georgia. Most samples were taken from outcrops or shallow cores at or very near field trip stops. Supplementary outcrop and shallow core material provide data for updip or downdip facies not included in the field trip. In addition, core material from Dougherty County, Georgia, and outcrop material from Wilcox County, Alabama, were examined for comparative purposes.

BIOSTRATIGRAPHY

Ranges of selected dinoflagellate species in the Chattahoochee River Valley (Fig. 16) were plotted against the calcareous nannofossil zonation (Fig. 14). For marginal marine sediments (and marine sediments lacking datable calcareous nannofossils), stratigraphic relationships and similarity of dinoflagellate floras were used to place samples in their relative positions. Several species found are known to have longer ranges outside the study area, and some seemingly abrupt floral changes depicted (Fig. 16) actually may be the effect of facies control or diagenesis.

Clayton Formation

Samples from the Clayton Formation (lower Paleocene) in eastern Alabama contain much poorer dinoflagellate assemblages than do samples from the Clayton farther west. Four samples from the "leaf bed" of the Clayton at Stop 7A (Barbour County, Alabama), show low diversity and generally are poorly preserved. The flora, although not as rich, seems to resemble that of the Pine Barren Member of the Clayton at its type area in Wilcox County, Alabama. A single sample from a clastic facies of the Clayton in Sumter County, Georgia, shows somewhat greater diversity and may be slightly younger.

Species found in the "leaf bed" include *Cordosphaeridium fibrospinosum* Davey & Williams 1966, *Senegalinium obscurum* (Drugg 1967) Stover & Evitt 1978, *Fibrocysta* sp. A (Pl. 9, fig. 2), *Spinidinium densispinatum* Stanley 1965, and *Adnatosphaeridium* spp. In the Georgia sample, *Deflandrea* sp. cf. *D. diebelii* sensu Drugg 1967 (Pl. 9, fig. 4), *Palaeocystodinium golzowense* Alberti 1961, and *Deflandrea pulchra* Benson 1976 are common.

Porters Creek Clay

Five samples from the Porters Creek Clay (upper Paleocene), from exposures and a shallow core at Stop 7B (Barbour County, Alabama) were examined for dinoflagellates. Dinocysts are extremely abundant,

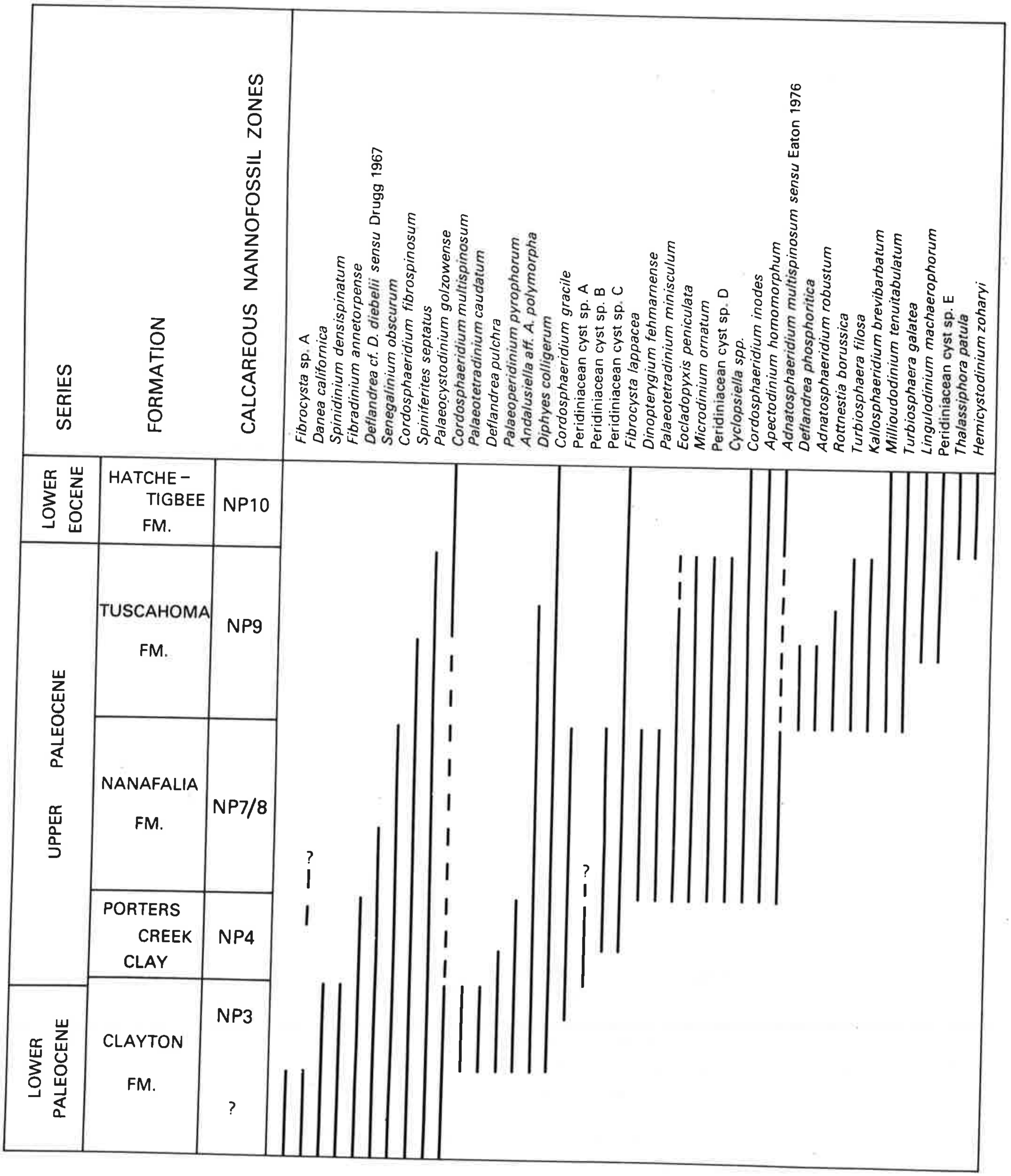

Figure 16. Stratigraphic ranges of selected dinocysts in eastern Alabama and western Georgia. Several species, notably of the genera *Adnatosphaeridium* and *Spiniferites*, were omitted because they proved difficult to identify. Several others were referred to the closest possible species described and may represent new forms. Some are illustrated in Plate 9.

relative to pollen and spores, but diversity is low. All samples are dominated by only one or two species, Peridiniacean cyst sp. B and C (Pl. 9 figs. 10, 11); this domination suggests deposition in an environment having other than normal marine conditions. In addition to Peridiniacean cysts, *Deflandrea* sp. cf. *D. diebelii* sensu Drugg 1967 is present in all samples. *Palaeoperidinium pyrophorum* (Ehrenberg 1838) Sarjeant 1967 is present in the lowest core sample at 7.8 m (25.5 ft).

Nanafalia Formation

Eight samples from the Nanafalia Formation (upper Paleocene) in the Chattahoochee River area were examined for dinoflagellates: two from the "Gravel Creek Sand Member," three from *Odontogryphaea thirsae* beds directly across the river from Stop 11, and three from the carbonaceous layer at Griffin mine, Stop 8 (Henry County, Alabama).

Samples from the "Gravel Creek" at Franklin Landing (Stop 11) and corehole 125, 2 km (1.2 mi) away were examined too late to be incorporated in the chart (Fig. 16). Dinoflagellates in these samples included *Senegalinium obscurum*, *Cordosphaeridium fibrospinosum*, *C. multispinosum* Davey & Williams 1966, *Fibradinium annetorpense* Morganroth 1968, and several unnamed species. The environment of deposition presumably was brackish.

Nanafalia samples from Griffin mine and the *O. thirsae* beds contain similar dinoflagellate floras. Dinocysts are not abundant and diversity is generally low. *Apectodinium homomorphum* (Deflandre & Cookson 1955) Lentin & Williams 1977 (Pl. 9, fig. 9) and *Eocladopyxis peniculata* Morgenroth 1966 first appear.

Tuscahoma Formation

A complete section of the Tuscahoma Formation (upper Paleocene) is exposed at Mathison mine, Stop 9 (Henry County, Alabama). Six fossiliferous samples from this locality and seven additional outcrop and core samples in Dale County, Alabama, and Randolph, Clay, and Webster Counties, Georgia, were examined for dinoflagellates. In the lower part of the Tuscahoma, the flora is diverse, generally well preserved, and dinoflagellates are abundant. Diversity drops sharply upsection; the environment seems to have become brackish. Several dinoflagellate species, *Deflandrea phosphoritica* Eisenack 1938, *Adnatosphaeridium robustum* (Morgenroth 1966) De Coninck 1975, *Kallosphaeridium brevibarbatum* De Coninck 1969, *Millioudodinium tenuitabulatum* (Gerlach 1961) Stover & Evitt 1978, and *Turbiosphaera galatea* Eaton 1976 (Pl. 9, fig. 8), first appear in the lower Tuscahoma. The dinocyst flora closely resembles that from the uppermost 8.4 m (27.6 ft) of the Aquia Formation in a core near Oak Grove, Virginia, as reported by Gibson *et al.* (in press). Reworked Cretaceous dinocysts are conspicuous in several Tuscahoma samples.

Hatchetigbee Formation

Only four fossiliferous samples from the Hatchetigbee Formation (lower Eocene) were examined for dinoflagellates. The Hatchetigbee at Greens Branch, Stop 13 (Randolph County, Georgia) is typical: *Hemicystodinium zoharyi* (Rossignol 1968) Wall 1967 and *Thalassiphora patula* (Williams & Downie 1966) Stover & Evitt 1978 =*Muratodinium fimbriatum* of Drugg 1970 (Pl. 9, fig. 6) have their lowest occurrences here.

Plate 9. Selected dinocysts from Paleocene and lower Eocene rocks of western Georgia and eastern Alabama

1. ***Andalusiella* sp. aff. *A. polymorpha* (Malloy 1972) Lentin and Williams 1977. Lateral view (x380) from corehole 19 at Stop 7B, Porters Creek Clay, Barbour County, Ala.**
2. ***Fibrocysta* sp. A, lateral view (x500) from leaf bed in Clayton Formation, at Stop 7A, Barbour County, Ala.**
3. **Peridiniacean cyst sp. D, ventral view of dorsal surface (x500) from carbonaceous "channel" in Nanafalia Formation at Stop 8, Griffin mine, Henry County, Ala.**
4. ***Deflandrea* sp. cf. *D. diebelii* sensu Drugg 1967. Ventral view (x380) from corehole C19 at Stop 7B, Porters Creek Clay, Barbour County, Ala.**
5. **Peridiniacean cyst sp. A, ventral view (x500) from corehole 19 at Stop 7B, Porters Creek Clay, Barbour County, Ala.**
6. ***Thalassiphora patula* (Williams & Downie 1966) Stover & Evitt 1978. Dorsal view (x500), Hatchetigbee Formation, from corehole in Dougherty County, Ga.**
7. **Peridiniacean cyst sp. E. a—dorsal view of dorsal surface; b—dorsal view of ventral surface (x760), from Stop 9, Mathison mine, Tuscahoma Formation, Henry County, Ala.**
8. ***Turbiosphaera galatea* Eaton 1976. Dorsal view at mid-focus (x500), from corehole 126 in Tuscahoma Formation, Dale County, Ala.**
9. ***Apectodinium homomorphum* (Deflandre & Cookson 1955) Lentin & Williams 1977. Dorsal view (x800), from Stop 9, Mathison mine, Tuscahoma Formation, Henry County, Ala.**
10. **Peridiniacean cyst sp. B. Dorsal view (x1000) from exposure at Stop 7B, Porters Creek Clay, Barbour County, Ala.**
11. **Peridiniacean cyst sp. C. Dorsal view (x1300). Locality as in figure 10.**


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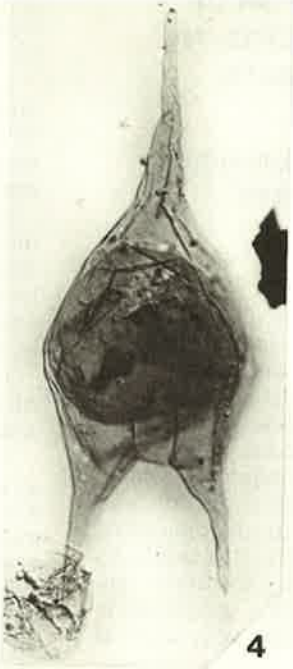
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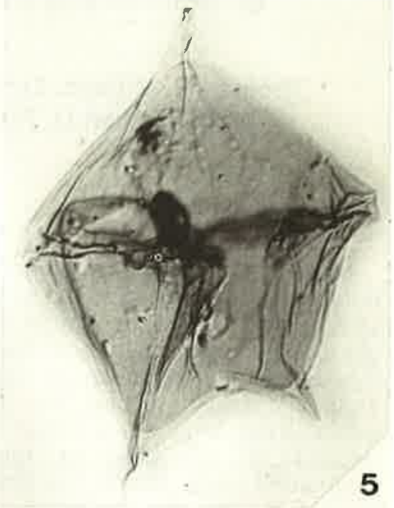
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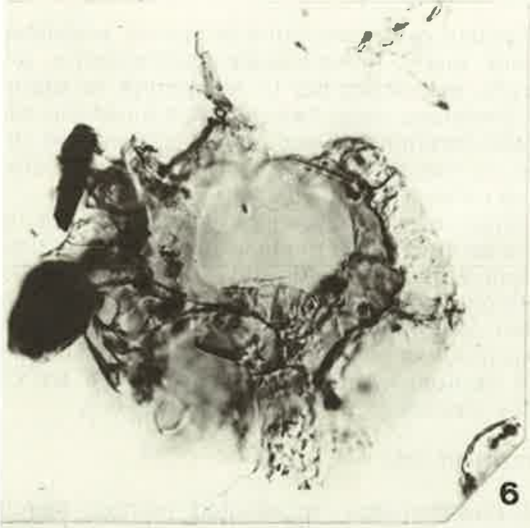
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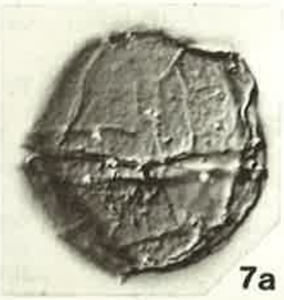
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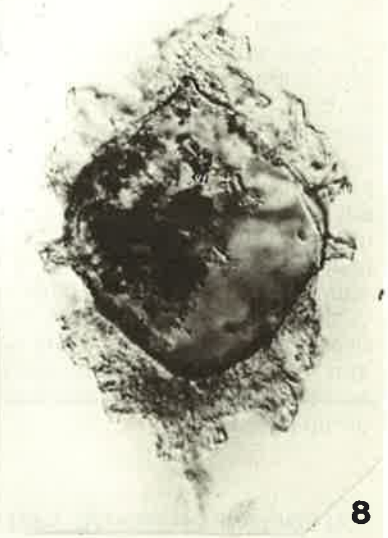
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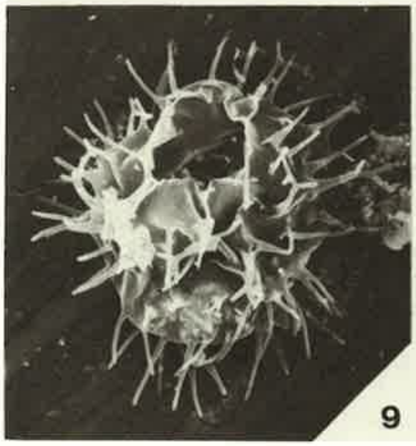
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BIOLOGICAL INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS IN LOWER PALEOGENE STRATA

Thomas G. Gibson, Lucy E. Edwards, and Norman O. Frederiksen

INTRODUCTION

Many rock types are found in various facies of Paleocene and lower Eocene strata in western Georgia and eastern Alabama. These lithofacies range from glauconitic sand, silt, and clay, containing diverse molluscan assemblages, to crossbedded micaceous sand and kaolinitic clay that lack megafossils. The strata have long been known to represent diverse depositional environments, ranging from presumed nonmarine to sublittoral (Toulmin, 1977). Of special interest is the determination of depositional environments for clays and sands that lack megafossils but contain commercially exploited deposits of kaolinite and bauxite.

Detailed studies of lateral and updip-downdip changes within individual stratigraphic units in the Chattahoochee River Valley are now being conducted by U.S. Geological Survey personnel. Lithologic relationships and sedimentary structures provide much information; however, biologic indicators offer the possibility of considerable refinement in determining environments of deposition. An integrated approach utilizing both calcareous and organic-walled organisms is desirable because sediments deposited in restricted-marine and nonmarine environments generally lack calcareous fossils. For this study, we have examined five microfossil groups—one calcareous (foraminifers) and four organic-walled (dinoflagellate, acritarchs, sporomorphs, fungal remains)—and one megafossil group (mollusks).

PALEOENVIRONMENTAL CRITERIA

Paleoenvironmental interpretations in this paper are based upon the following biologic criteria:

1. *Ratios of planktic to benthic foraminifers.* As shown by Grimsdale and van Morkhoven (1955), the percentage of planktic foraminiferal specimens in the total foraminiferal assemblage (planktic plus benthic) generally increases in bottom sediments from the shoreline into open-marine waters of greater depths. Planktic specimens tend to be rare in modern restricted-marine environments.
2. *Relative abundance among the main palynomorph groups.* These groups include sporomorphs (terrestrial spores and pollen), fungal remains (mainly terrestrial), and microplankton (mainly brackish-water to marine dinoflagellates and acritarchs). Generally, an increase in proportion of microplankton upward in a sedimentary sequence has been interpreted to represent a marine transgression. Relative abundance of the three groups here were based upon counts of at least 100 palynomorph specimens, excluding very small, simple acanthomorphid acritarchs. Dinoflagellate fragments (individual paraplates or groups of paraplates) were tallied in such a way that numbers of whole cysts could be approximately reconstructed.
3. *Species diversity of benthic foraminifers.* The basic premise is that the number of species in a given sample of standard size increases progressively from the shoreline outward into deeper water environments of the shelf (Gibson and Buzas, 1973).
4. *Species diversity of dinoflagellates.* Studies of modern phytoplankton show that diversity of dinoflagellate thecae (nonpreservable) and cysts (preservable) may tend to increase seaward (Hulbert, 1963; Wall *et al.*, 1977). With caution, these trends can be extrapolated into the fossil record.
5. *Species diversity of mollusks.* Mollusk species diversity also increases as water depths increase, as shown by Hessler and Sanders (1967).
6. *Species dominance within dinoflagellate assemblages.* Dinoflagellate dominance is measured by the percentage of the assemblage made up of the two most abundant species; that is, DOMINANCE = $100 \times (N_1 + N_2)/N_t$, where N_t is the total number of specimens counted and N_1 and N_2 are the number of specimens of the most abundant and second most abundant species, respectively. Dinoflagellate dominance tends to decrease offshore in marine environments and is highly variable in estuarine environments.

PALEOENVIRONMENTAL CHARACTERISTICS

Dinoflagellate cysts are found in marine, restricted-marine, and, rarely, in nonmarine environments, and sporomorphs are deposited in nonmarine to marine deposits. Therefore, these two groups are used in conjunction with foraminifers and mollusks in marine sections and as the sole biologic criteria in restricted-marine and nonmarine environments.

Index values of various biologic parameters for formations to be studied on the field trip (Figs. 17,18) are mostly from Stops 7,9,11,12, and 13, but information from additional localities also is included. Because organic-walled groups are present in sections lacking calcareous groups and interpreted as restricted-marine, the same sections within a single formation are not necessarily presented on both reconstructions.

Marine environments

Marine environments represented (normal salinity waters seaward of the beach) are characterized by benthic foraminiferal diversities typically greater than 10 species and by low to moderate percentages of planktic specimens (although they may be absent in very shallow-water facies). Dinoflagellate diversities typically are 10 species or greater, and dinoflagellate species dominances are between 40 and 80 percent. Microplankton commonly are more than 50 percent of total palynomorphs, although some inner-sublittoral strata seem to contain floods of sporomorphs transported into the sea. Relatively low diversity of dinoflagellates, foraminifers, and mollusks suggests that marine environments represented by many of the formations studied were characterized by very shallow water, surely less than 30 m (98 ft) and probably less than 15 m (49 ft) depth, where some sediments were deposited.

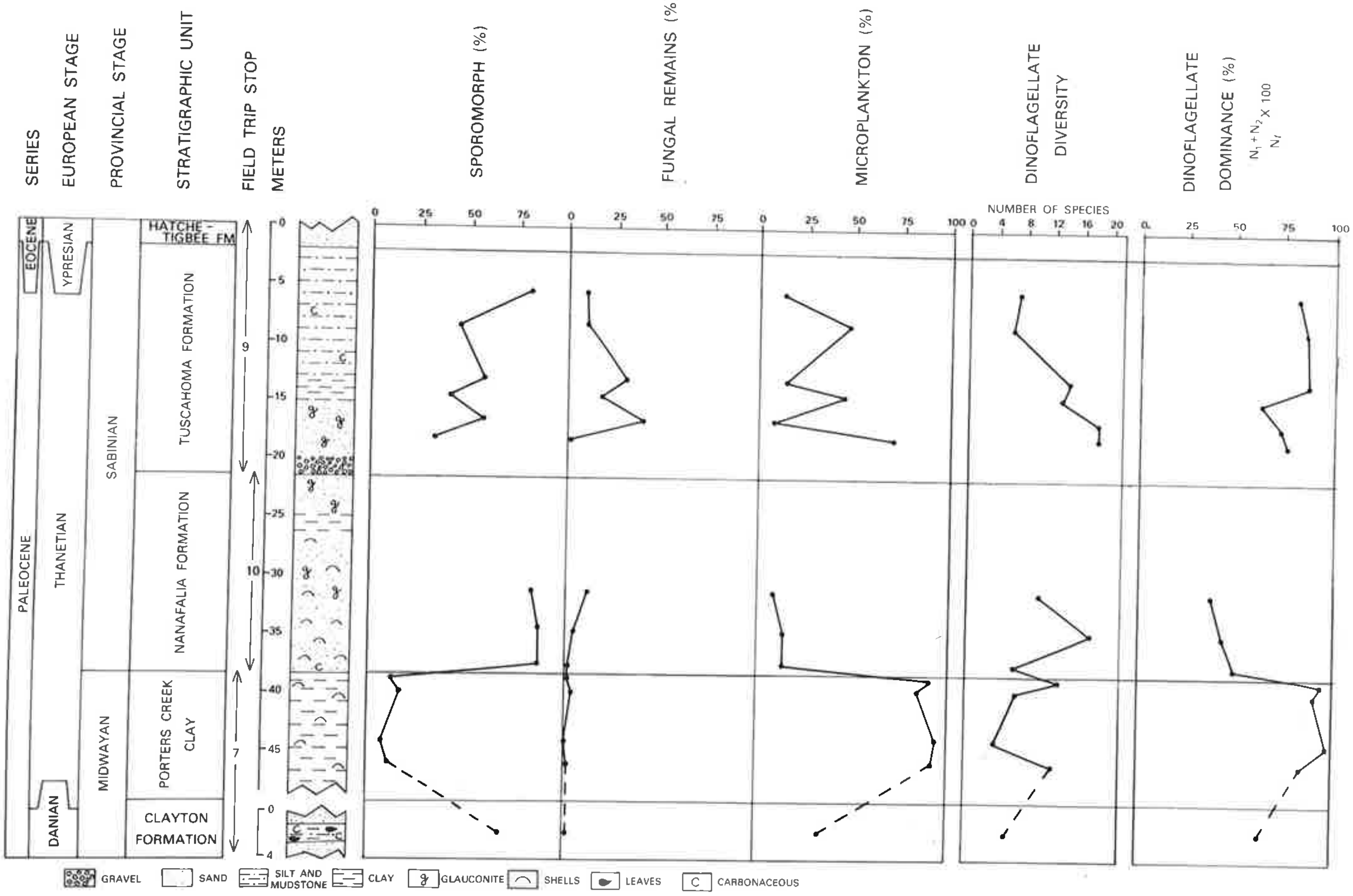


Figure 17. Composite section for Clayton through Hatchetigbee Formations in eastern Alabama and western Georgia, showing relative abundances of three palynomorph groups: sporomorphs (spores and pollen), fungal remains (fungal spores and hyphae), and microplankton (dinoflagellates and acritarchs). Section also shows dinoflagellate species diversity and dominances. Samples from Stops 7, 9, 10.

Restricted-marine environments

Strata postulated to represent deposition in restricted-marine environments (including tidal flat, lagoon, bay, and other areas behind bars or beaches, or near deltas, and having other than normal open-ocean salinity) are characterized by low diversities (typically less than 10 species) and high species dominances (generally more than 80%) of dinoflagellates, microplankton percentages of less than 50 percent, and a general lack of foraminiferal and molluscan assemblages.

Nonmarine environments

Nonmarine strata contain organic-walled microfossils but not calcareous fossils. Sporomorphs dominate the assemblages; in some samples, sporomorphs and fungal remains form the entire assemblage. These sediments tentatively are considered to have accumulated in nonmarine environments.

FORMATION PALEOENVIRONMENTS

Clayton Formation

Sandy, commonly shelly beds of the Clayton Formation at Clayton, Alabama (Stop 7A), are considered inner neritic in origin, on the basis of 16 species of mollusks reported by Harris (1896); several species of *Turritella* dominate the assemblage, and this genus is more common in relatively shallow marine environments than elsewhere in modern seas. The Clayton Formation, as exposed near Andersonville, Georgia, also is considered to have formed in the inner neritic zone, because foraminiferal diversities are moderate (14-18 species) and planktic percentages are about 4.

Four samples studied from the laminated silt and clay "leaf bed" at Clayton (Stop 7A) have a low diversity of dinoflagellates (3-8 species) and a low to moderate percentage of microplankton (18-46%). Fungal remains are sparse (1% or less) in spite of the richness of sediments in organic matter. The leaf assemblage has high abundance but low diversity, dominated by only two species (L.J. Hickey, 1979, oral comm.).

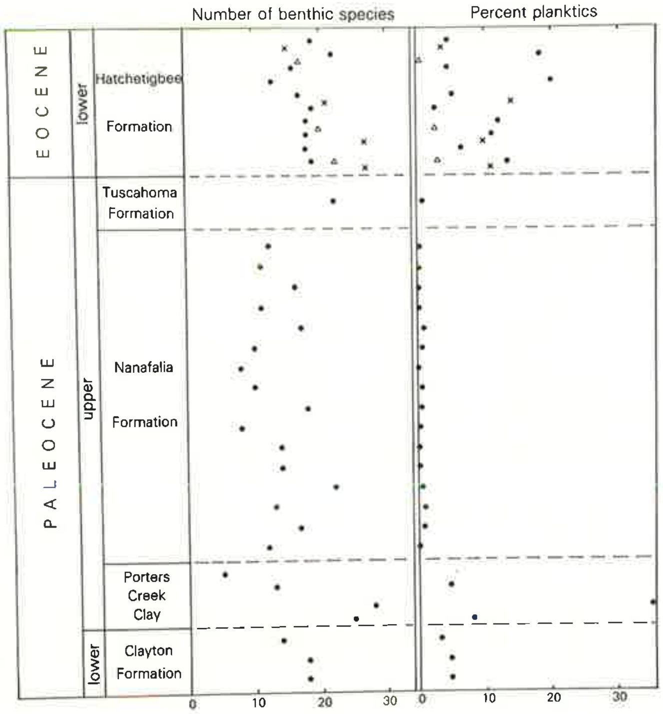


Figure 18. Composite sections for Clayton through Hatchetigbee Formations in eastern Alabama and western Georgia, showing diversity of benthic foraminifers and percent of planktic foraminifers. Clayton data from Andersonville, Ga. (Fig. 8); Porters Creek from Stop 7B; Nanafalia from Stop 11 and adjacent river sections; Tuscahoma from corehole 126 (Fig. 10); locations of Hatchetigbee sections 126, 123, and 99 shown in Figure 11.

Sporomorph assemblages from these beds also have low species diversity. The "leaf bed" seems to have formed in a lagoon, bay, or tidal-flat environment adjacent to coastal swamps or marshes.

Porters Creek Clay

The lowermost 1.5 m (5 ft) of the Porters Creek Clay in corehole 102 at Clayton, Alabama (Stop 7B), is thought to represent an inner neritic environment because of high species diversity of benthic foraminifers (25-28), relatively high percentage of planktic foraminifers (8-36%; Fig. 18), moderately low diversity of dinoflagellates (12), although relatively high for the Chattahoochee area, and high percentage of microplankton (about 90%; Fig. 17). Dinoflagellate species dominance (86%) is higher, however, than usually is found in sediments of the shallow open sea.

Beds of this formation in the upper 6.4m (21 ft) of the corehole show a marked decrease in foraminiferal diversity, to 5 species at 4.9 m (16 ft) below the top; foraminifers are absent above this level throughout the remainder of the corehole and outcrop. Although microplankton percentages remain high over the entire section (more than 90%), dinoflagellate diversity is low but variable (4-13 species), and dinoflagellate species dominances are greater than 90 percent. A few tiny fragments of shell are present in outcrops. The data suggest that this part of the Porters Creek represents a restricted-marine environment, possibly a bay.

Nanafalia Formation

Two samples from the "Gravel Creek Sand Member" at the base of the Nanafalia Formation, Franklin Landing (Stop 11) and corehole 125, about 2 km (1.2 mi) west-northwest of Franklin Landing, yielded palynomorph assemblages dominated by sporomorphs (96 and 70%, respectively). Dinoflagellate diversities are 7 and 10 species, respectively. A brackish-water origin is suggested for the "Gravel Creek" beds in this area, filling sinkholes at the top of the Clayton.

Most of the fossiliferous glauconitic sand of the Nanafalia Formation (*Odontogryphaea thirsae* beds) in the Chattahoochee River bluffs at Franklin Landing (Stop 11) and southward is considered to have been deposited in the inner neritic zone, as indicated by the presence of 13 to 22 species of benthic foraminifers and as many as 17 species of dinoflagellates having low species dominances (Fig. 17). These shallow-water open-marine sediments persist through much of the section; but several intervals with a highly clayey matrix have 10 or fewer foraminiferal species and 0 to 0.4 percent planktic specimens, suggesting restricted-marine environments interspersed with more open-marine ones. Sporomorph:microplankton ratios are high in three samples from the lower part of the section. Whether the high proportion of sporomorphs in these beds, which are interpreted as marine, indicates abundant delivery of sporomorphs to the site of deposition or sparse microplankton populations, is unknown.

Updip, in the Eufaula bauxite district (Stops 8, 9), Nanafalia sediments are mainly micaceous sand and kaolinitic clay, neither of which generally contains calcareous or organic-walled fossils, probably as a result of weathering. Carbonaceous beds at the Griffin mine (Stop 8), however, contain organic-walled microfossils. Here, dinoflagellate diversity is low (7-9 species) and microplankton constitute only 1 to 15 percent of total palynomorphs, whereas fungal remains are 45 to 87 percent (Fig. 17). These data suggest a restricted-marine setting rich in organic matter. The beds are important in determining environments of deposition of high-alumina clays.

The lower bauxitic beds of the Nanafalia Formation in the Mathison mine (Stop 9; these beds unfortunately now are covered by water) include some medium-gray clays suggestive of buried soil profiles. A sample from one of the clays contains only a few sporomorphs, all of them riddled with small perforations thought to result from fungal degradation (Elsik, 1966). The sample also contains many palynomorphs that are small (10-15μ long), smooth, oval to circular, and pale to colorless; such palynomorphs only rarely were observed in other samples, and may be fungal spores or possibly sphaeromorphid acritarchs. Obvious fungal spores and hyphae are rare in this sample. These characteristics suggest deposition in a nonmarine or possibly restricted-marine environment.

Tuscahoma Formation

The basal glauconitic sand of the Tuscahoma Formation represents an inner neritic environment of deposition. Although the molluscan assemblage in these beds is limited generally to the calcitic species *Chlamys greggi* Harris and *Ostrea sinuosa* Rogers & Rogers, this dominance seems to be a result of preservation; a few molds of other species of aragonitic mollusks, such as *Venericardia,* have been found (e.g., Stop 8), which suggests diagenetic removal. The one foraminiferal assemblage obtained from these beds (absence of foraminifers at most localities is owing to either leaching of specimens or induration of beds) is from the western end of the study area, near Echo, Alabama (site 126), and contains a moderate diversity of 22 benthic species and 0.7 percent planktic specimens (Fig. 18); these characteristics are generally found among modern assemblages in waters to 30 m (98 ft) deep. Supporting evidence for inner neritic conditions is the moderately low diversity of dinoflagellates at Stop 9 (18 species) and a high percentage of microplankton (68%) among the palynomorphs (Fig. 17).

Laminated beds in the Tuscahoma, above basal glauconitic strata, show a significant drop in dinoflagellate diversities accompanied by high dinoflagellate species dominances (Fig. 17). Although sporomorph:microplankton ratios fluctuate, microplankton generally are less abundant than sporomorphs. The laminated beds at Stop 9 suggest a lagoonal environment, and tidal-flat deposition is indicated by sedimentary features found at Stop 12. Uppermost beds of the Tuscahoma at Stop 9 show high dinoflagellate dominance and may suggest a low-salinity environment.

Hatchetigbee Formation

Downdip shelly fine sands and clays of the Hatchetigbee Formation are the deepest water marine sediments of the Paleocene to lower middle Eocene outcrop belt in the study area. Somewhat shallower water equivalents of these deposits will be seen at Stops 12 and 13. Downdip sections have benthic foraminiferal diversities of 18 to 27 species and planktic foraminiferal percentages of 5 to 20 (Fig. 18). These figures suggest deposition in the middle neritic zone, perhaps at depths as great as 60 m (197 ft). Beds cored at the base of the Hatchetigbee section at Stop 12 have foraminiferal diversities of 21 to 27 species and planktic foraminiferal percentages of 10 to 14, indicating relatively deep water for this updip area. Equivalent beds even farther updip, for example at Stop 13, have lower diversity values and planktic percentages. A change upward in the Hatchetigbee sections, reflecting shallowing and regression in the depositional cycle (Fig. 18), is accompanied by decreases in diversities and planktic foraminiferal percentages. The amount of decrease, and actual benthic foraminiferal diversities and planktic foraminiferal percentages, are different for each section, because the sections are in different geographic parts of the basin.

Tallahatta Formation

Because sporomorphs are the only fossils found in interbedded clay and sand at the base of the Tallahatta Formation at Greens Branch (Stop 13), a freshwater origin is suggested for these beds.

SUMMARY

Depositional environments represented by different lithofacies found in Paleocene through lower Eocene strata in eastern Alabama and western Georgia were determined on the basis of species diversity of benthic foraminifers, dinoflagellates, and mollusks, ratios of planktic to benthic foraminifers, relative abundance among palynomorph groups (sporomorphs, microplankton, and fungal remains), and species dominance within dinoflagellate assemblages. Nonmarine, restricted-marine, and various neritic sites of deposition were recognized.

The Clayton Formation represents mainly inner-neritic deposition but includes a thin, restricted-marine interval updip. Initial deposition of Porters Creek Clay sediments was in neritic environments, but deposits of the upper part of the formation accumulated in brackish water. Most of the Nanafalia Formation, downdip, represents deposition in the inner-neritic zone, although the bauxitic facies updip is of restricted-marine origin. Sediments of the lower part of the Tuscahoma Formation accreted in marine waters, but the water became brackish as sediments in the upper part of the formation were deposited. The Hatchetigbee Formation is of inner to middle neritic origin and contains possible restricted-marine deposits at the top.

FIELD TRIP 20 ROAD LOG
UPPER CRETACEOUS-LOWER TERTIARY, CHATTAHOOCHEE RIVER VALLEY

Juergen Reinhardt and Thomas G. Gibson

ROAD LOG AND STOP DESCRIPTIONS—FIRST DAY

The route and location of stops for this field trip, as well as stops on the Georgia Geological Society (GGS) 1975 trip, are shown in Figure 19.

Mileage **cum.**	**Inc.**	
0.0		Leave Ramada Inn, Phenix City, Ala. Turn left (northwest) on U.S. 280-27. We are about 1.5 miles west of Chattahoochee River (from Creek words "Charta" = stone and "uchee" = red), driving toward Fall Line.
1.4	1.4	Junction U.S. 80. Turn left (west) on U.S. 80.
1.9	0.5	**STOP 1.** Large borrow area on north side of U.S. 80 (behind car wash) exposes upper part of Tuscaloosa Formation overlain by Pliocene (?) gravel sequence. Phenix City 7½' Quadrangle, sec. 9, T. 17 N., R. 30 E.

The base of this section in the Tuscaloosa Formation is approximately 45 m (150 ft) above the unconformable contact with crystalline basement (here probably hornblende-biotite gneiss). The primary sedimentary structures, lateral variability, and composition of the Tuscaloosa at this locality (Fig. 20) are typical of the unit in this region.

Lithologically, the section here is most like the Gordo Formation of the Tuscaloosa Group, as described from western Alabama. Characteristics are high-angle,

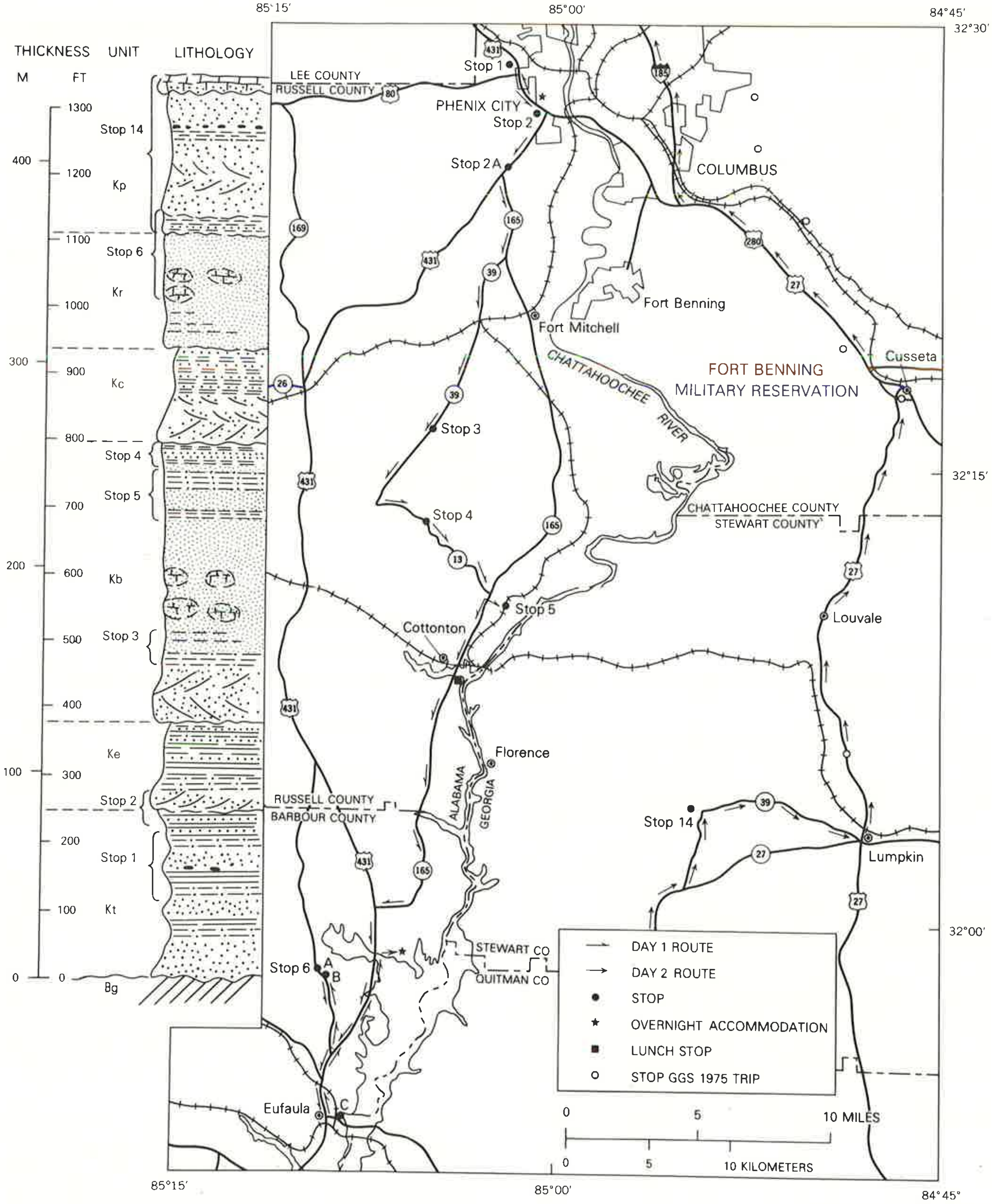
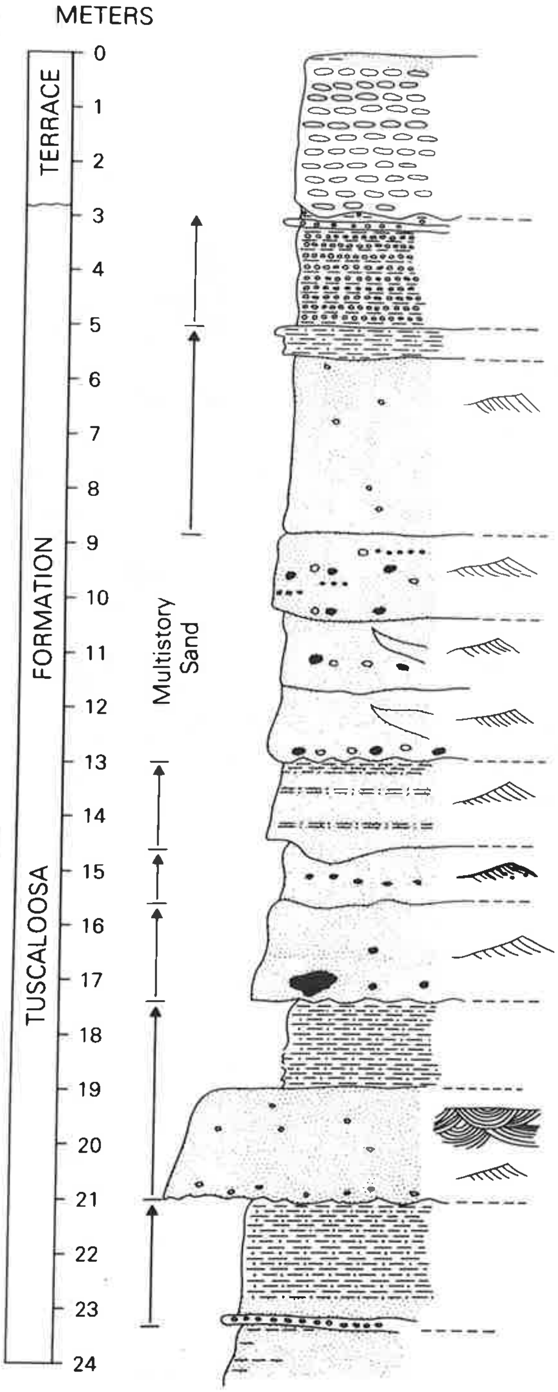


Figure 19. Field trip route and location of stops on first day, and completion of field trip route on second day. Inset shows approximate stratigraphic position of each stop.

STOP 1 LOCALITY 65

Top of Section 450 ft (137.2m)



14 COBBLES, round to discoid polycrystalline quartz; thin sandy soil at top; sediment is heavily iron stained and weathered.

13 VERY COARSE GRIT in clay matrix, poorly bedded; iron stained and locally iron oxide cemented.

12 SILTY CLAY, massive, iron oxide indurated; pale olive (10YR 6/2) mottled to moderate reddish brown (10YR 6/6).

11 FINE to MEDIUM SAND, local quartz pebbles and pods of grit; low-angle, thin (5–20cm thick) crossbed sets; micaceous, weathered Kspar. Grayish yellow (5Y 8/4) to light red (5R 6/6) at top.

10 COARSE SAND to GRIT with abundant quartz pebbles and clay clasts, large crossbed set trending 115°. Note reduction rinds on clay clasts.

9 MEDIUM to VERY COARSE SAND, with rounded quartz pebbles and clay clasts, trough crossbedded, and channeled; heavy-mineral laminae, sparse Kspar grit.

8 Variably stained pale orange (10YR 8/2).

7 MEDIUM to VERY COARSE SAND, crossbedded, fines upward through interbedded sand and clayey silt to blocky clay at top. Pale yellowish green (10Y 8/2).

6 MEDIUM to COARSE SAND, small-scale crossbeds delineated by clay clasts and clay laminae; Kspar epimatrix.

5 MEDIUM to VERY COARSE SAND, clay clasts to blocks, crossbed sets trend 130°; thin (±2cm thick) clay at top; pale yellowish green (10Y 8/2) to white micaceous quartz sand.

4 SILTY CLAY to CLAYEY SILT, massive-blocky, mottled. Poorly exposed; pale olive (10Y 6/2) at base and top mottled to reddish brown (10R 4/6).

3 FINE to MEDIUM SAND with local coarse Kspar grit and quartz pebbles; indurated to tightly cemented and case hardened. Multistory sand with scour and fill, thin crossbed sets; Kspar epimatrix, heavy-mineral laminae; very pale orange (10YR 8/2).

2 CLAYEY SILT AND SILT CLAY grades upward from indurated coarse grit bed at base through well-sorted, very fine sand; slickensided--color-mottled, small hematitic nodules. Pale olive (10Y 6/2).

1 CLAYEY FINE SAND, very poorly sorted, faint heavy-mineral laminae; micaceous (both biotite and muscovite); pale yellowish green (10Y 8/2).

Figure 20. Stratigraphic column for Tuscaloosa Formation at Stop 1. Lateral relationships of lithologic units highly variable. Arrows at left show fining-upward sequences. Section measured by J. Reinhardt and J. Estabrook, 9/78.

unimodal crossbed sets (trending south and southeast); scour-fill structures, intraformational clay-clast conglomerates, extreme variability in composition (percentages of potassium feldspar, muscovite, and heavy minerals) and sorting of sand. Six rather complete fining-upward sequences (arrows, Fig. 20) have been identified and can be traced upward through this 21 m (70 ft)-thick Cretaceous section.

The Cretaceous (Tuscaloosa) section is capped by a 3 m (10 ft)-thick upper Tertiary high-level gravel terrace. The base of the gravel is approximately 75 m (250 ft) above the present Chattahoochee River. Topographic position of this unit and paleontological data from elsewhere (Voorhies, 1970) suggest a late Miocene or early Pliocene age for this deposit. The quartz gravels are packed tightly in a clayey sand matrix and are

Figure 21. Sand-clay contact near base of section at Stop 1. Clay was moderately dewatered and extremely cohesive when coarse sand was deposited, as shown by ragged contact and distribution of clay intraclasts.

well rounded, mostly discoid to elongate. Deeply iron-stained cobbles and a leached A_2 soil zone cap the section.

Composition, sedimentary structures, and geometry of sedimentary units in the Tuscaloosa are consistent with a meandering stream-point bar model for sedimentation. Beds with coarse-grained sediments above highly eroded bases (Fig. 21), representing channel fills, and with fine-grained, color-mottled gradational tops, representing floodplain deposits, are well displayed. These characteristics differ sharply from those of coarse deposits of a degrading fluvial system, represented by the gravel terrace sequences, resulting from downcutting of the Chattahoochee River.

2.4 0.5 Junction U.S. 280-431. Turn right (southeast) on U.S. 80 East. Drive through recent strip development. Abundant exposures of Tuscaloosa sand and clay.

4.2 1.8 Turn right on ramp for U.S. 431. Continue to right, along U.S. 431 (south).

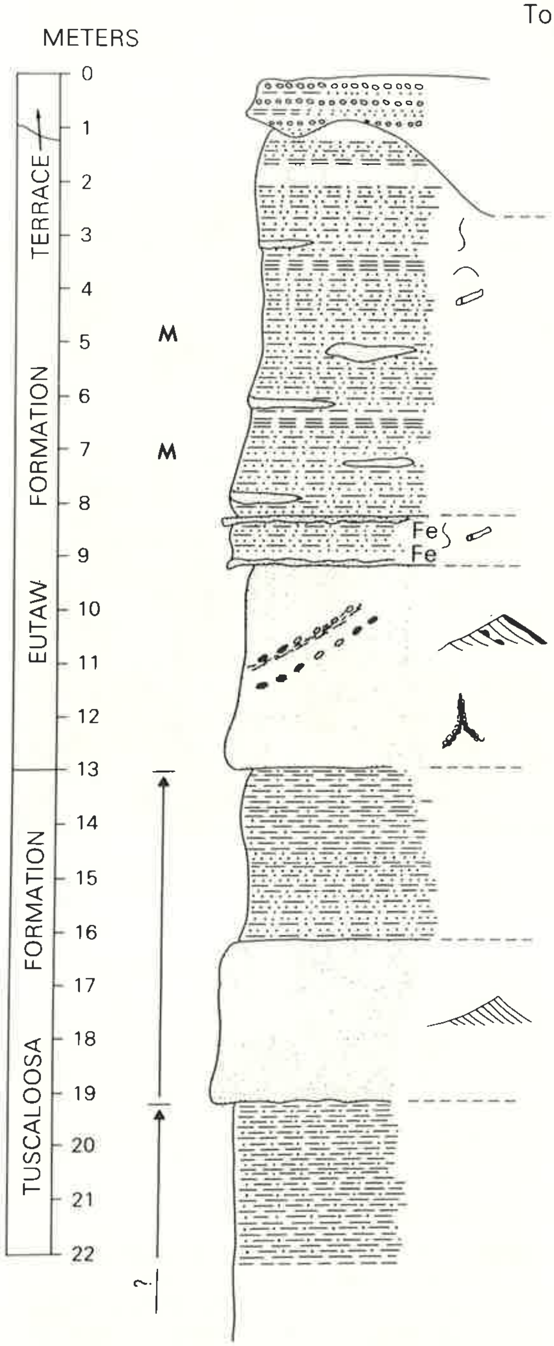
4.5 0.3 **STOP 2.** Borrow area 100 m west of U.S. 431 exposes upper part of Tuscaloosa and updip basal part of Eutaw, cut by NW trending, gravel-filled channel. Phenix City 7½' Quadrangle, sec. 22, T. 17 N., R. 30 E.

Only a partial section (south of the Pliocene channel) is shown in the measured section (Fig. 22). Additional section in the Tuscaloosa can be measured north of the channel. Lithologically and stratigraphically, the Tuscaloosa here is roughly equivalent to the top of the section near Stop 1. Abundance of color-mottled clay, suggesting subaerial weathering and soil development, is perhaps more striking at this locality than at Stop 1. The Tuscaloosa-Eutaw contact appears to be remarkably planar, with very little reworking of Tuscaloosa lithologies into the base of the Eutaw.

Our discussion will focus on the two distinct Eutaw lithologies and their arrangement at this locality. The basal part of the Eutaw is a crossbedded, medium to very coarse sand and grit; compositionally and texturally, it is immature. Conspicuously different from Tuscaloosa features are: 1) polydirectional crossbed sets (most south and southwest), 2) interbedded, thinly bedded clay, and 3) abundant burrows, especially *Ophiomorpha*. A well-preserved channel (Fig. 23) near the southern margin of the exposure cuts the basal sand and displays 1) clay drapes along the channel margin, and 2) abundant clay clasts of thinly bedded rather than massive clay and sparse burrows. Overlying and contrasting carbonaceous sand and clay are highly bioturbated, consequently very poorly bedded, and contain pods of bored wood, carbonaceous debris, and abundant bivalve molds.

STOP 2 LOCALITY 48

Top of Section 500 ft (152.4m)



7 LARGE PEBBLES to SMALL COBBLES; sandy clay matrix; deeply iron stained-weathered. Channel axis is to north of section and trends southeast

6 VERY FINE SAND to SILT; CLAY interbeds disrupted by burrows; poorly bedded overall; thin (1–3cm thick) clean quartz sand lenses. Abundant bivalve molds and carbonaceous debris. Abundant muscovite; jarosite on fractured surfaces. Brownish gray (5YR 4/1)

5 CLAYEY SAND, Kspar and quartz grit; very poorly sorted and bounded by iron-oxide cemented crusts-beds; bioturbated-carbonaceous debris. Grayish orange (10YR 7/4)

4 COARSE SAND, CLAY laminae-clay clasts on high-angle bedforms; crossbed sets 50cm thick trend 250°–260°. Abundant *Ophiomorpha nodosa* (200/sq. m). Very pale orange (10YR 8/2)

3 SILTY CLAY, blocky, compact and massive. Gradational to clayey sand near base. Very light gray clay becomes color mottled to light olive gray (5Y 6/1) and grayish red (5R 4/2) at top

2 FINE to COARSE SAND, low angle, 10–20cm thick, crossbed sets trend 95° Internal ± 1m thick fining-upward sequences; locally abundant muscovite, ilmenite, rutile, sparse monazite. Very pale yellowish orange (10YR 8/4)

1 SILTY CLAY, massive to blocky, slightly micaceous; moderate reddish brown (10YR 4/6) reduced to pale yellow near top

Figure 22. Stratigraphic column at Stop 2. Lateral relationships as shown in Figure 23. Fining-upward sequences shown in Tuscaloosa. Section measured by J. Reinhardt and J. Estabrook, 9/78.

Characteristics of the basal part of the Eutaw indicate that a high-energy marine environment transgressed an unconsolidated (Tuscaloosa) shoreline. Crossbedded sand containing *Ophiomorpha* and the channel form and filling suggest deposition within a tidal channel adjacent to an estuarine or open lagoonal complex. The apparent marine regression seen here is consistent with the general pattern seen elsewhere in the Eutaw.

7.1 2.6 Turn left on Alabama Route 165.

ALTERNATE STOP 2A. Roadcut along NE side of U.S. 431-Alabama 165 intersection exposes another Tuscaloosa-Eutaw contact; Eutaw exhibits offshore facies from base to top of exposure. Phenix City 7½' Quadrangle, sec. 32, T. 17 N., R. 30 E.

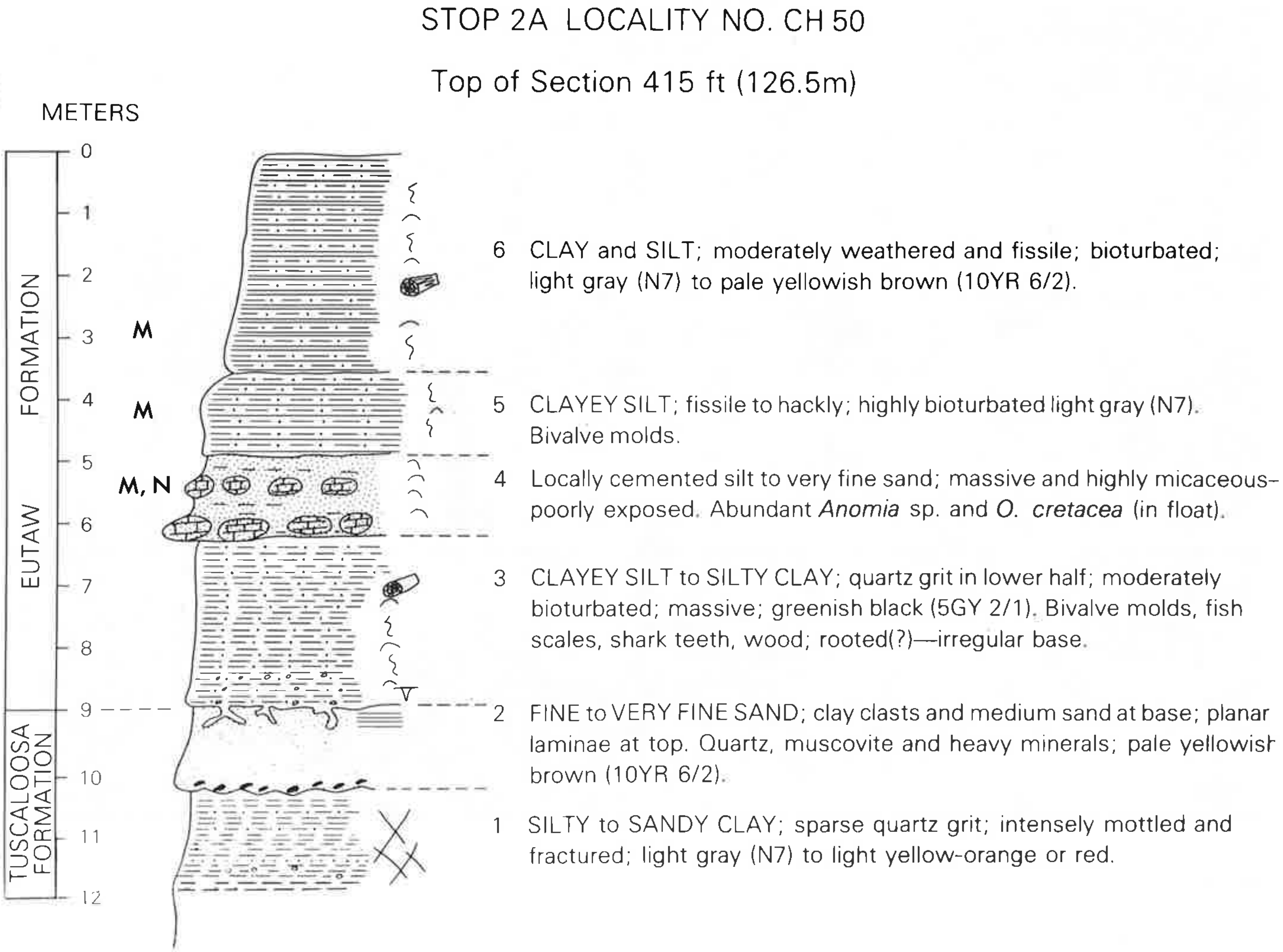
Figure 23. Well-preserved channel, immediately above Tuscaloosa-Eutaw contact. Coarse barrier-bar sand (bed 4) is overlain by carbonaceous back-barrier clay and fine sand (beds 5 and 6). Numbers correspond to units in measured section (Fig. 22).

This stop illustrates the Tuscaloosa-Eutaw contact slightly (about 3.2 km, 2 mi) downdip. The gradient on the contact between Stop 2 and here is nearly 9.5 m/km (50 ft/mi). A basal, coarse, Eutaw sand is conspicuously absent except as floating quartz grit, and the contact is more difficult to define here (Fig. 24) than at Stop 2. The Eutaw contains an increasing amount of calcitic shell debris, predominantly *Ostrea cretacea*, and phosphate, including teeth, 3 to 6 m above the contact. Eutaw sediments are very poorly bedded and contain only sparse, abraded wood and carbonaceous debris, in marked contrast to Stop 2.

The apparent contact between the Tuscaloosa and Eutaw has been badly disrupted (Fig. 25). Possibly, the activity of vegetation during the gap in sedimentation between Tuscaloosa and Eutaw deposition created the structures in the contact zone. Perhaps equally plausible, the disruption occurred by action of pine roots much more recently.

		Continue south on Alabama 165.
9.9	2.8	Exposures of coarse, poorly bedded, deeply weathered gravel (Pliocene) along east side of road. Deeply weathered sand in adjacent exposures is probably basal part of Blufftown Formation.
10.3	0.4	Turn right at Y-intersection, Russell County 39.
14.2	3.9	Uchee (Red) Creek. Excellent exposures of Eutaw clay containing abundant joints and sandstone dikes, along entire length from U.S. 431 to Alabama 165. Extremely wide floodplain and abrupt cuesta on south side.
15.0	0.8	Basal part of Blufftown Formation, composed of crossbedded, coarse, quartz sand, seen best on east side of road. Exposures become progressively more deeply weathered toward top of cuesta.
16.5	1.5	Stop at intersection. Continue south on Alabama 39, which approximates a dip-slope of the Blufftown Formation.
18.1	1.6	Ihagee Creek
18.3	0.2	**STOP 3.** Roadcut showing transition upward from well-sorted, nearshore quartz sand to shelly marl in lower part of Blufftown Formation. Fort Mitchell 7½' Quadrangle, sec. 24, T. 15 N., R. 29 E.

This section (Fig. 26) probably can be correlated with Planter's Landing on the Chattahoochee River (Stephenson, 1911, p. 132). It has been included for those who would like to collect calcareous macro- and microfossils near the Santonian-Campanian boundary. Indurated ledges are poorly developed concretionary horizons and contain abundant *Exogyra ponderosa* valves. General absence of stratification in these sediments results from both lower sedimentation rates and more biogenic reworking than in most other sections seen today. Changes in composition and sorting, from predominantly fine quartz sand at the base, upward to micaceous, slightly glauconitic clayey silt to



6 CLAY and SILT; moderately weathered and fissile; bioturbated; light gray (N7) to pale yellowish brown (10YR 6/2).

5 CLAYEY SILT; fissile to hackly; highly bioturbated light gray (N7). Bivalve molds.

4 Locally cemented silt to very fine sand; massive and highly micaceous-poorly exposed. Abundant *Anomia* sp. and *O. cretacea* (in float).

3 CLAYEY SILT to SILTY CLAY; quartz grit in lower half; moderately bioturbated; massive; greenish black (5GY 2/1). Bivalve molds, fish scales, shark teeth, wood; rooted(?)—irregular base.

2 FINE to VERY FINE SAND; clay clasts and medium sand at base; planar laminae at top. Quartz, muscovite and heavy minerals; pale yellowish brown (10YR 6/2).

1 SILTY to SANDY CLAY; sparse quartz grit; intensely mottled and fractured; light gray (N7) to light yellow-orange or red.

Figure 24. Measured section in Tuscaloosa and Eutaw Formation at Alternate Stop 2. Section measured by J. Reinhardt and J. Estabrook, 9/78.

marl, reflect changes in sediment supply and current energy in the basin during a marine transgression.

18.5	0.2	Stop sign at junction Seale Road. Continue south on Russell County 39.
21.9	3.4	Stop sign. Turn left (east) on Russell County 13.
24.4	2.5	**STOP 4. Roadcut and drainage ditch exposing upper pat of Blufftown along south side of road. Omaha 7½' Quadrangle, sec. 12, T. 14 N., R. 29 E.**

The basal part of the Cusseta Sand is at a higher level toward the bend in road (south and east of section in Fig. 27). Key features at this stop are 1) apparently transitional characteristics of the Blufftown-Cusseta boundary somewhat downdip of the type Cusseta, 2) well-preserved and well-displayed lower shoreface sediments in upper part of the Blufftown, and 3) small-scale pillow structures below the weathering profile on upper bench in this section.

The upper part of the Blufftown in this downdip section (relative to the type Cusseta) is considerably more marine in aspect and less carbonaceous. Primary sedimentary structures here are characterized by moderate lateral continuity of bedding and bed forms, and rather low-amplitude bed forms. Sedimentation units, alternately dominated by physical and biological components, constitute the entire section (Fig. 28). Iron-diffusion banding (Liesegangsbande) is pervasive within well-laminated, well-sorted quartz sand units.

Deformation structures (Fig. 29) in the upper part of the measured section are similar to detached load structures (pillows) seen elsewhere in the Cretaceous section, especially near the Eutaw-Blufftown contact and in the upper part of the Ripley Formation (Stop 6). These structures seem to have resulted from soft-sediment deformation that involved reverse density gradients, produced after a more competent, tightly packed, laminated sand was loaded on a less competent, highly bioturbated, clayey sand. The structures formed when sediments were jarred prior to dewatering.

		Continue east on Russell County 13.
25.7	1.3	Exposures of crossbedded Cusseta Sand on north side of road. Large-scale bedforms and abundant *Ophiomorpha* and clay clasts.
26.3	0.6	North side of road, exposure of fine-grained Cusseta Sand cut by large Pliocene (?) channel. Abundant iron banding and cementation.

Figure 25. Eutaw-Tuscaloosa contact at Alternate Stop 2. Whether root mottling is modern or Cretaceous is unclear. Shovel handle is 50 cm (20 in) long.

27.2	0.9	Stop sign at intersection Alabama 165. Turn right (south). Proceed to LUNCH STOP (additional mileage omitted from road log).
28.6	1.4	Turn left at flashing yellow light at Alabama Kraft entrance No. 1 (Russell Co. 4).
28.9	0.3	**STOP 5.** Railroad cut along Southern Railroad Spur (Mahrt station) into Alabama Kraft Paper immediately north of overpass. Transgressive phase of cycle in upper part of Blufftown Formation. Omaha 7½' Quadrangle, sec. 29, T. 14 N., R. 30 E.

Exposures at this locality represent a sequence, not well preserved in updip exposures, of the upper part of the Blufftown Formation. Documentation for the preservation of transgressive phases in Cretaceous cycles (see text) is based partly on vertical sequences at this locality.

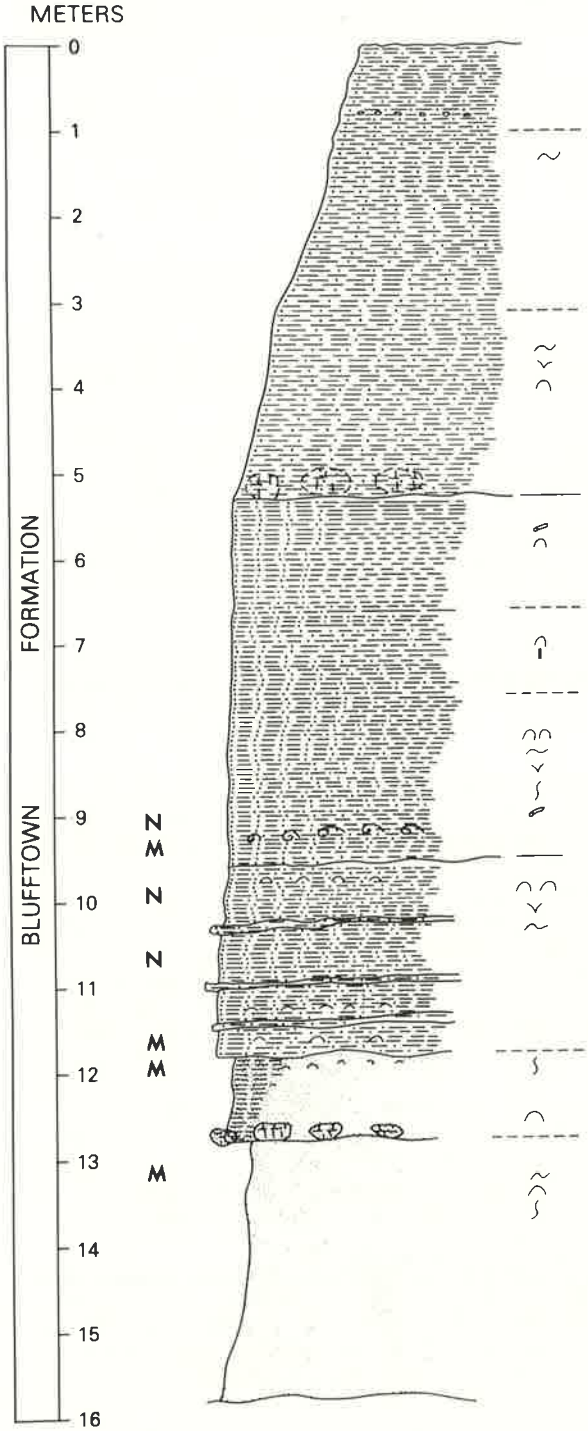
Four distinct lithofacies are stacked vertically and show considerable continuity within limits of the exposure (Fig. 30). Units exposed in the basal 4 m (beds 1 and 2) are characterized by alternations of cross-laminated to crossbedded sand and carbonaceous silt or clay; burrows are sparse and fossil molds absent. Well-developed, small-scale channels and inclined bedforms (Fig. 31) indicate considerable current activity within this somewhat restricted back-barrier environment. The transition to crossbedded sand containing *Ophiomorpha* (Fig. 32) is not well exposed and is somewhat obscured by weathering.

Preservation of this key transitional environment, thought to be part of a barrier-bar complex, is less impressive here than elsewhere in the Cretaceous section (e.g., Stop 2). This difference may be a function of rates of sea-level rise during the time interval. Lithologic character and lateral continuity of the barrier destructional unit are perhaps most variable of the units exposed here. The base is sharp and somewhat scalloped (Fig. 33). Locally, this unit is rather well bedded, but typically, it is thoroughly bioturbated and massive; the unit is very poorly sorted throughout. The transition to massive marine silt and clay is sharp, delineated by a thin, indurated to iron-cemented bed (Fig. 33). Compositionally, open-marine lithologies vary from clayey fine sand to sandy silt and clay; burrows are poorly defined, and primary physical sedimentary structures are absent.

		Return via access road to Alabama 165.
29.3	0.4	Stop sign. Turn left (south) on Alabama 165.
31.5	2.2	Hatchechubbee Creek, which has been flooded by Walter F. George Reservoir.
31.7	0.2	Hatchechubbee Creek Landing (operation by U.S. Army Corps of Engineers).
37.2	5.5	Basal part of Cusseta Sand cut by Pleistocene (?) channel on north side. Now ascending Cusseta cuesta.
39.4	2.2	Pass Russell County 50. Several levels of Pliocene to Pleistocene terraces exposed along this east-west road.

STOP 3 LOCALITY 83

Top of Section 400 ft. (129.9 m)



9 SILT, massive and deeply leached; predominantly quartz; includes soil zone transitions from A_2–B_2

8 SANDY CLAY, blocky and bioturbated; fine quartz sand, sparse Kspar, weathered glauconite. Light gray (N7) to light greenish gray (5G 8/1)

7 VERY FINE SAND to SILT, massive, bioturbated; quartz, muscovite, glauconite; gypsum in fracture fills; weathered concretions near base. Light greenish gray to greenish gray (5GY 8/1–6/1)

Traverse 40MN (to fresher section)

6 SILTY CLAY, bioturbated, fissile, micaceous and moderately carbonaceous. Medium gray (N5) to light brownish gray (5YR 6/1)

5 SILT and CLAY, compact, bioturbated, fractures-fissile; micaceous. Medium gray (N5)

4 SILT to SILTY CLAY (MARL), massive bioturbated; moderately abundant quartz, glauconite, muscovite (especially in burrow fills). Calcite preserved in shells, sparse carbonaceous debris. Grayish olive green (5GY 3/2)

Traverse 5MN to fresher section

3 MARL, locally indurated, crudely bedded; muscovite, quartz, glauconite. Very abundant *Exogyra ponderosa* throughout. Dark gray (N3)-dark grayish green (5G 4/1)

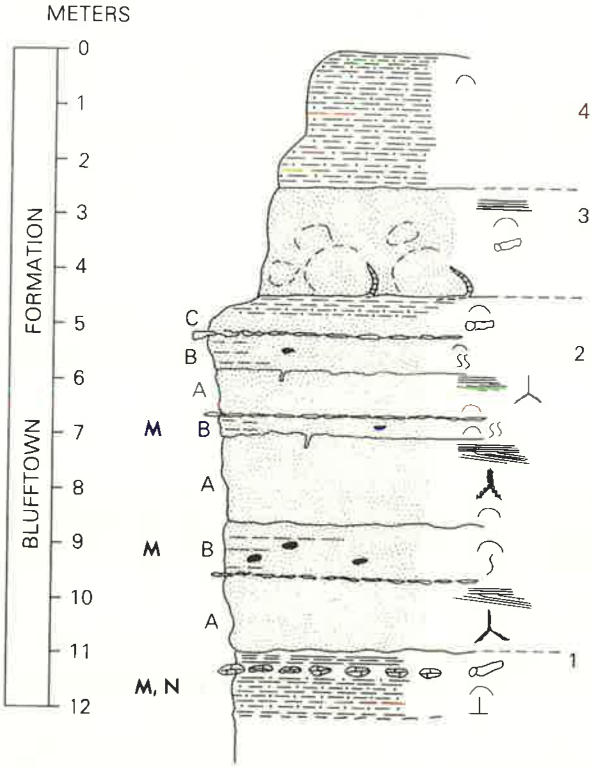
2 FINE SAND, burrowed, small *E. ponderosa* valves; quartz, heavy minerals, sparse muscovite. Very pale orange (10YR 8/2)

1 FINE to VERY FINE SAND, friable, massive, burrowed; quartz, sparse heavy minerals, glauconite(?)

Figure 26. Measured section in upward transition from sand to marl in lower part of Blufftown Formation at Stop 3. Section measured by J. Reinhardt and J. Estabrook, 9/78.

STOP 4 LOCALITY 585

Top of Section 450 ft. (137.2m)



4 CLAYEY SILT, massive and deeply weathered; soil zone at top; moderate reddish brown (10R 4/6). Very abundant bivalve molds; probably bioturbated

3 FINE to VERY FINE SAND; planar laminated and highly deformed by clay injections-dikes; laminated sand as enclosed pods and blocks. Yellowish gray (5Y 7/4). Abundant bivalve molds and carbonaceous debris

2 Alternating intervals consisting of:

A. FINE to VERY FINE SAND, well-sorted, planar to low angle cross stratified, extensive Liesegangsbände. Clay lined burrows especially *Asterosoma*. Pale yellowish green (10Y 8/2)

B. CLAYEY VERY FINE SAND, massive—bioturbated, scattered clay clasts and chips. Extremely abundant shell molds bedded as lags. Grayish yellow to olive gray (5Y 3/2)

C. VERY FINE SAND to SILTY CLAY, very poorly bedded light brownish gray (5YR 6/1) clayey sand to brownish black (5YR 2/1) micaceous clay. Abundant bivalve molds and carbonaceous debris

1 SILTY CLAY to MARL, thinly bedded clay at top of fissile, micaceous and olive gray (5Y 3/2). Fresh to leached shells throughout; quite carbonaceous at top

Figure 27. Measured section at Stop 4, showing transition from inner shelf to lower shoreface lithologies in upper part of Blufftown Formation. Section measured by J. Reinhardt and J. Estabrook, 3/78.

42.6	3.2	Enter Barbour County, Alabama.
42.7	0.1	Barbour Creek, with exposures of basal part of Cusseta (slightly below creek level) equivalent to Woolridge Landing section on Chattahoochee River.
42.8	0.1	Twin Springs rest stop. Artesian water piped from base of Pleistocene sand (lowest terrace).
47.9	5.1	Stop at junction U.S. 431. Turn left (south).
48.9	1.0	Lakepoint Resort Park, Alabama State Park system, on Lake Eufaula.
53.8	4.9	Turn right, Barbour County 37.
57.4	3.6	**STOP 6B.** Proceed without stopping to:
57.6	0.2	**STOP 6A.** Series of roadcuts on both sides of Barbour County 37, exposing upper part of Ripley Formation transition from inner shelf to nearshore facies in Providence Sand. Eufaula North 7½' Quadrangle, sec. 32, T. 12 N., R. 29 E. to sec 5, T. 11 N., R. 29 E.

This locality affords an opportunity to see changes in sediment composition, bedding characteristics, and macrofossil composition from marine to marginal marine sediments. Unfortunately, much of the Ripley Formation is badly weathered in most roadcuts, and access to stream cuts is difficult for a large field trip. The transition seen between Stops 6A and 6B (Fig. 34) includes a unit mapped as the Perote Member of the Providence Sand by Eargle (1950).

The lowest exposures stratigraphically (Stop 6A, below the covered interval) on the east side of Barbour County 37 are somewhat glauconitic and approach a marl, compositionally. Diagnostic of the Ripley and much of the middle part of the Blufftown are calcite-cemented ledges and spheroidal concretions (Fig. 35). Weathering leached the aragonitic fossils, but moderately abundant calcitic forms, especially oysters, remain. *Thallassinoides*-type burrows and other biogenic structures are best seen near the boundaries between cemented and noncemented or indurated intervals.

While walking from Stop 6A to 6B, notice the extremely large load structure directly ahead. Although the mechanism for soft-sediment deformation seen at Stop 4 probably is similar, differences in scale may be due to differences in lithology and bedding characteristics, and possibly sedimentation rate.

Contrasts between Stops 6A and 6B center on: 1) biogenic content and activity, 2) bedding characteristics, and 3) sediment composition. In the transition from Ripley to Providence, carbonaceous, laminated to thinly bedded clay is a characteristic component; locally, leaf beds are present. Sand intervals are persistent laterally and contain abundant interbedded clay. Shell molds are abundant only locally and burrows are rather sparse. Quartz sand is noticeably coarser and more abundant than below; glauconite is not present here, and is found only in trace amounts in less weathered sections. Muscovite is moderately abundant

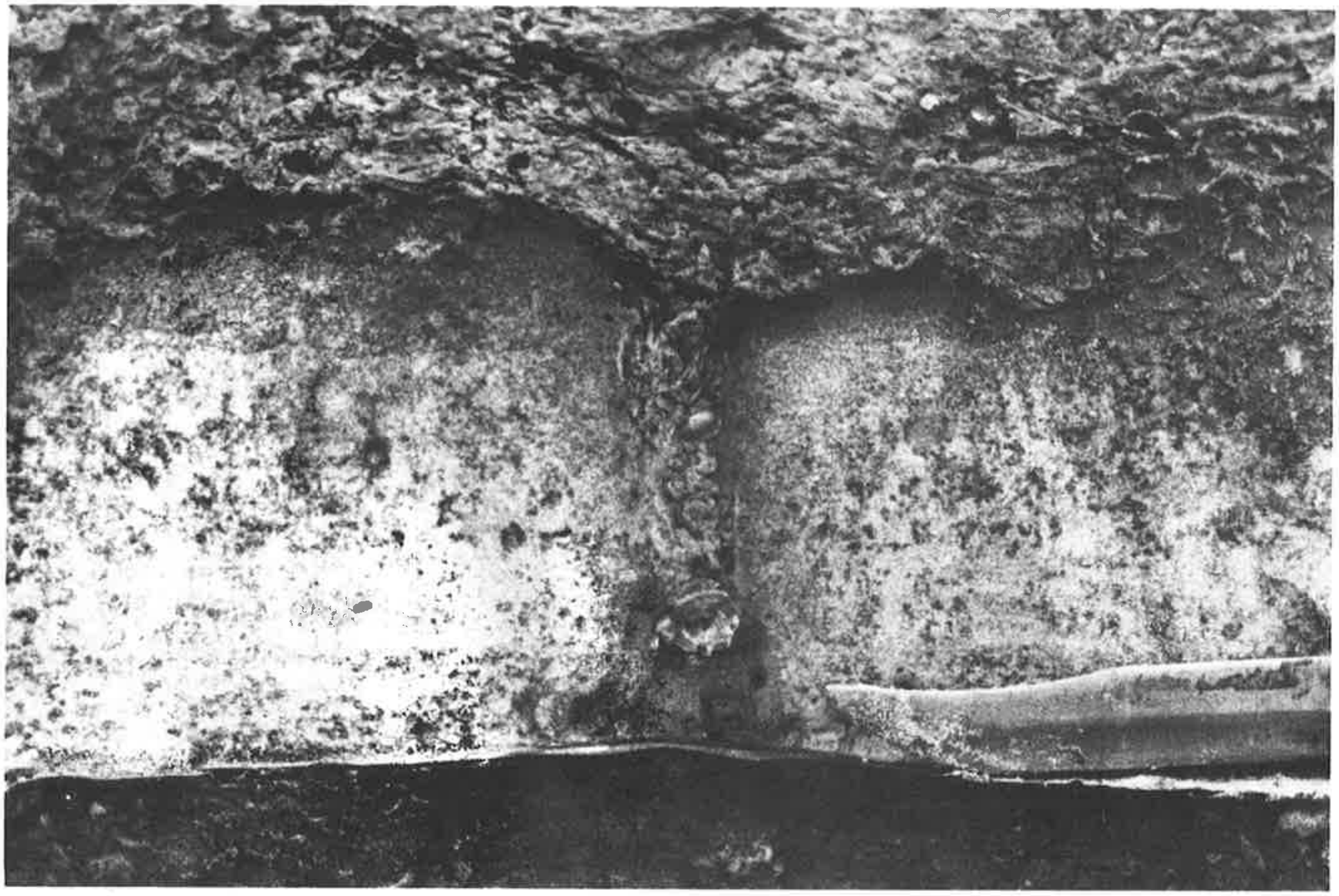
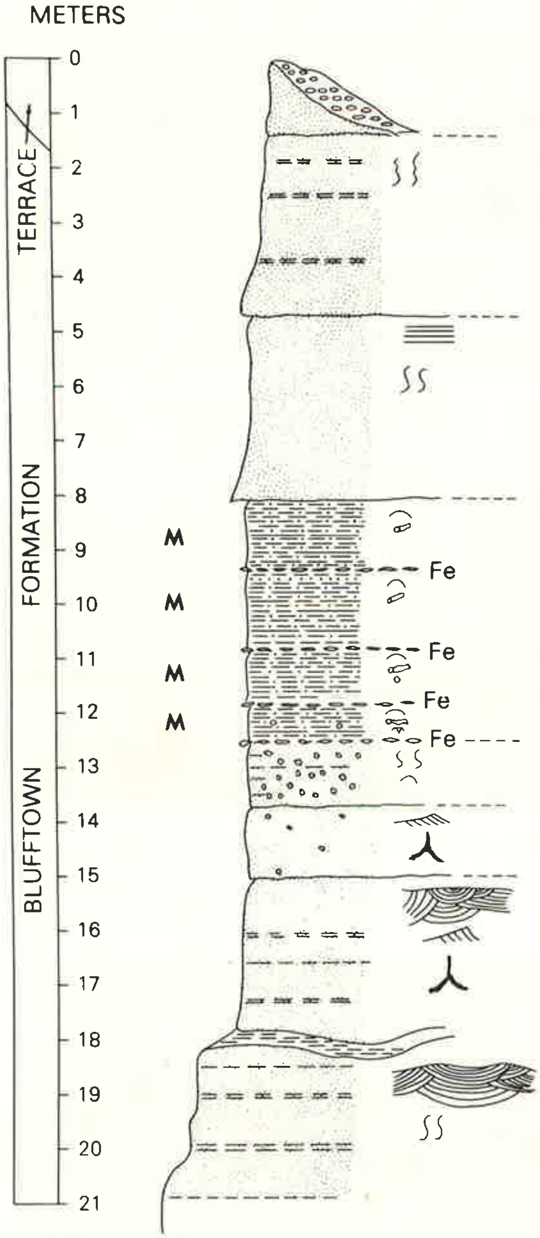


Figure 28. Lithologic contact in upper part of Blufftown Formation, between planar laminated sand (below) and fossiliferous, bioturbated sand (above). Vertical burrows and wavy top suggest shallow subtidal bar forms alternating with runnels containing a dominant organic component. Knife blade about 3 cm (1.2 in) wide.

Figure 29. Collapse structures (pillows) similar to those at Stop 4. These structures are along access to River Bend Park, GA, 16 km (10 mi) along strike east of Stop 4, near Blufftown-Cusseta boundary.

STOP 5 LOCALITY 113

Top of Section 415 ft (126.5m)



8 VERY FINE SAND CUT BY COARSE GRAVEL (PLIOCENE?)

7 VERY FINE SAND; poorly bedded-burrowed; clayey matrix-clasts from disrupted clay interbeds; weathered to pale reddish brown (10R 5/4)

6 VERY FINE SAND; planar bedded—laminated and sparsely burrowed, micaceous; very light gray (N8) and locally iron stained. Abundant carbonaceous debris and bivalve molds

5 SILTY CLAY; locally clayey sand; fissile to blocky and planar bedded; abundant muscovite; brownish black (5YR 2/1) to brownish gray (5Y 4/1). Iron oxide indurated to cemented interbeds (Fe); sparse quartz grit and small pebbles at base. Very abundant bivalve molds, carbonaceous debris; locally fish scales, shark teeth.

4 CLAYEY FINE SAND; small quartz pebbles throughout slightly micaceous; massive and bioturbated; pale to moderate yellowish brown (10YR 6/3). Bivalve molds.

3 MEDIUM to VERY COARSE SAND; pods of small pebbles; 30–40 cm crossbed sets, ripple crosslaminated at top; iron-stained to dark yellowish orange (10YR 6/6). Abundant *Ophiomorpha nodosa*.

2 FINE SAND interbedded with micaceous SILT and interlaminated carbonaceous clay; ripple crosslaminated, scour and fill throughout; irregularly weathered at top from light olive gray (5Y 6/1) to pale yellowish orange (10Y 8/0). *Ophiomorpha.*

1 FINE to VERY FINE SAND interbedded and interlaminated with SILT and CLAY; extreme lateral variability from scour and fill channeling. Sand is micaceous light olive gray (5Y 6/1); clay is carbonaceous brownish black (5YR 2/1). Locally abundant vertical to inclined burrows; abundant carbonaceous debris—no macrofauna.

Figure 30. Measured section in upper Blufftown Formation at Stop 5. Section measured by J. Reinhardt, 9/76.

throughout, but is somewhat coarser in 6B than in 6A. The poorly bedded sand above the Perote Member of the Providence (Fig. 36) represents a sharp contrast to the equivalent interval to be seen in the Providence Canyons (Stop 14) tomorrow.

		Retrace route along Barbour County 37.
61.1	3.5	Junction U.S. 431. Turn right (south) toward Eufaula.
62.0	0.9	Junction U.S. 82. Proceed south. Cuts along south side Chewalla Creek, southeast of road, expose upper Ripley strata as seen at Stop 6B.
62.5	0.5	Enter Eufaula, Alabama. Drive through center of Antebellum district.
63.6	1.1	Turn left (east) at U.S. 82, east toward Lake Eufaula.
64.2	0.6	Turn left to Eufaula Landing at Lake Eufaula.

STOP 6C. Upper part of Ripley Formation, Eufaula North 7½' Quadrangle, sec. 33, T. 11 N., R. 29 E.

If time and water level on Lake Eufaula permit, we shall walk down to Eufaula Landing and along the lakeshore to see additional upper Ripley and basal Providence lithologies, including hardground cobbles (Fig. 37), burrowed sandstone beds, and slightly leached shell marl. These exposures, which complement Stops 6A and 6B, represent the same stratigraphic interval.

		Return to Eufaula, Ala., center along Main Street.
66.0	1.8	Turn right (north) on U.S. 431.
73.4	7.4	Turn right, Lakepoint State Resort Park, for overnight accommodations.

END FIRST DAY ROAD LOG.

ROAD LOG AND STOP DESCRIPTIONS—SECOND DAY

The route and location of stops for this field trip, as well as stops on the Georgia Geological Society (GGS) 1975 trip, are shown in Figure 38.

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0.0		Leave Lakepoint Resort Lodge.
1.1	1.1	Turn left (south) on U.S Highway 431.
7.2	6.1	Entering Eufaula, Alabama; beautiful homes built mostly in 1850-1870.
8.2	1.0	Junction with U.S. 82 in Eufaula; continue south on U.S. 431.
10.3	2.1	Crossing Barbour Creek; good Cretaceous outcrops to west.
11.0	0.7	Turn right (west) on Alabama 30; will be traveling across weathered outcrops of Providence Sand.

Figure 31. Laminated sand-clay couplet characteristic of back-barrier facies at base of section (Stop 5). Starved ripple forms occur at sand-clay interface.

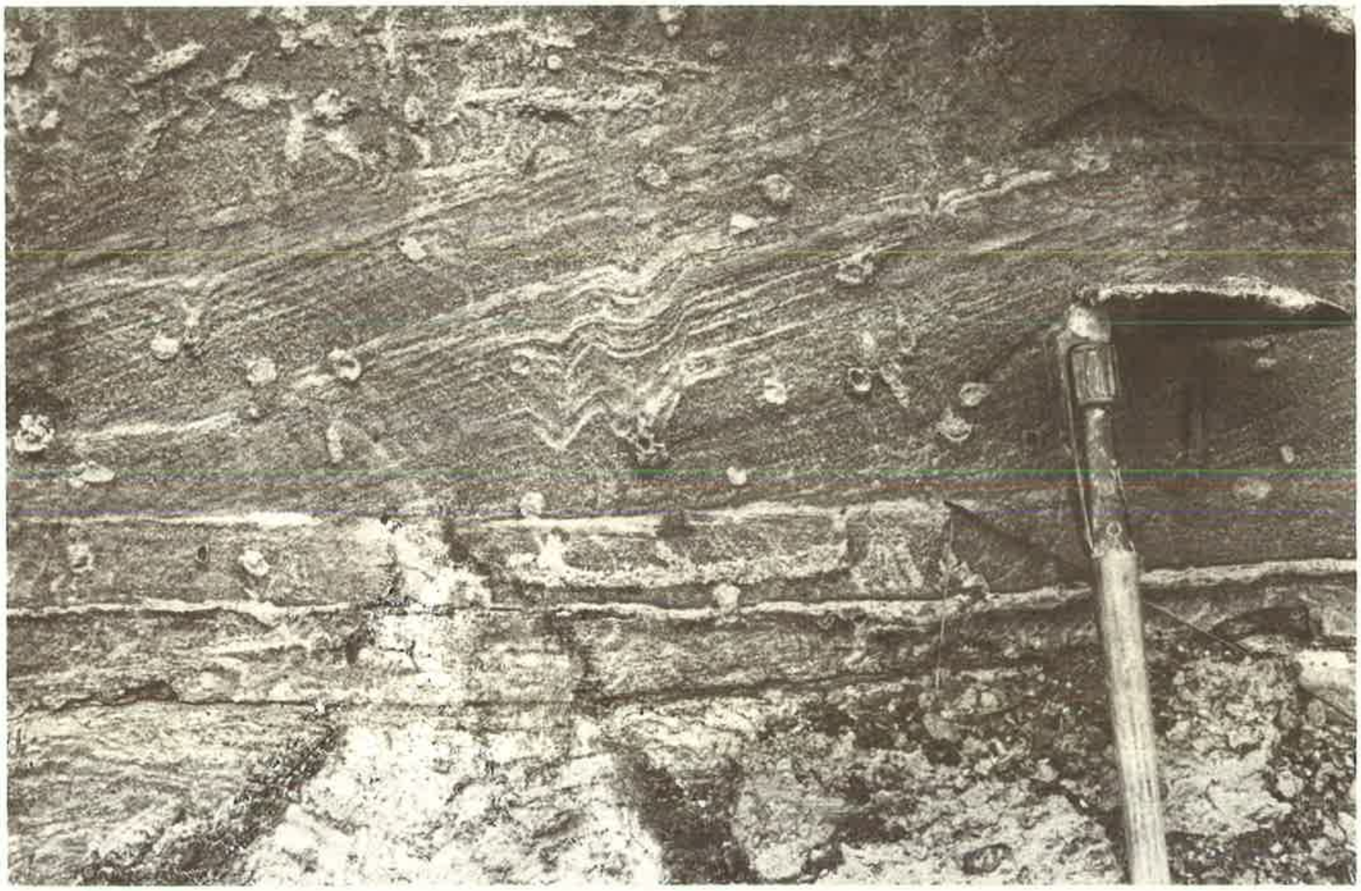


Figure 32. ***Ophiomorpha*** **and associated collapse structures in crossbedded sand representing barrier-bar environment within transgressive cycle. Entrenching tool for scale.**

22.8	11.8	Turn right (north) on Barbour County 79.
23.1	0.3	Roadcuts through lower part of Clayton Formation on both sides; most of lower Clayton is well-sorted, fine- and medium-grained sand; contact with Providence Sand exposed at north end of east cut.
23.5	0.4	Roadcuts exposing Providence Sand.
24.1	0.6	Roadcut exposing laminated, carbonaceous Perote Member of Providence.
26.1	2.0	Turn left (west) on Barbour County 28; Perote-Ripley contact exposed in cut on right, at intersection.
26.7	0.6	Roadcuts exposing Providence Sand for next 8 km (5 mi).
32.4	5.7	**STOP 7A.** Walk 275 m (300 yds) northeastward along railroad tracks. Exposure in railroad cut in type area of Clayton Formation, Clayton, Barbour County, Ala. Clayton North 7½' Quadrangle, sec. 34, T. 11 N., R. 26 E.

This stop illustrates updip, shallow marine lithologies of the Clayton, near its northern limits of exposure. The outcrop section contains two sand sequences separated by a silty clay interval. The sands probably are of inner neritic origin, representing nearshore subtidal sand sheets and associated bars. Sands are massive to crossbedded, fine to medium grained, and generally well sorted. Shells, particularly the calcitic *Ostrea crenulimarginata* and silicified specimens of *Turritella aldrichi*, are abundant locally. Molluscan molds, particularly of species of *Turritella*, also are abundant. Many shell banks are indurated to calcareous sandstones because of dissolution and redeposition of shell carbonate. Shelly pockets usually are 1 to 2 m (3.2–6.4 ft) thick and pinch out laterally. Sixteen species and varieties of mollusks were reported by Harris (1896) from the shell beds. Much of the covered interval between the top of the sandy Clayton in the railroad cut and the overlying outcrop of Porters Creek Clay seems to be calcareous cemented shelly sands.

Dark-gray, laminated, carbonaceous silty clay in middle of section (Fig. 39) contains numerous entire plant leaves and low-diversity dinoflagellate and sporomorph assemblages. This laminated clay, called the "leaf bed," probably is of restricted-marine origin, either lagoonal or tidal flat.

Altitude of railroad tracks through the cut is 161 m (528 ft). Similar sands, although lacking shells and containing increased amounts of fine gravel, occur in hilltops for 8 km (5 mi) north-northwest of Clayton, cropping out to altitudes of 198 m (650 ft); these strata represent deposition at or near the shoreline. South and southeast of Clayton, the Clayton Formation becomes marine carbonate, as at Stop 11, except for a thin basal sand presumably reworked from the underlying Providence Sand.

Walk back to intersection of road and railroad, and then 137 m (150 yds) westward along road.

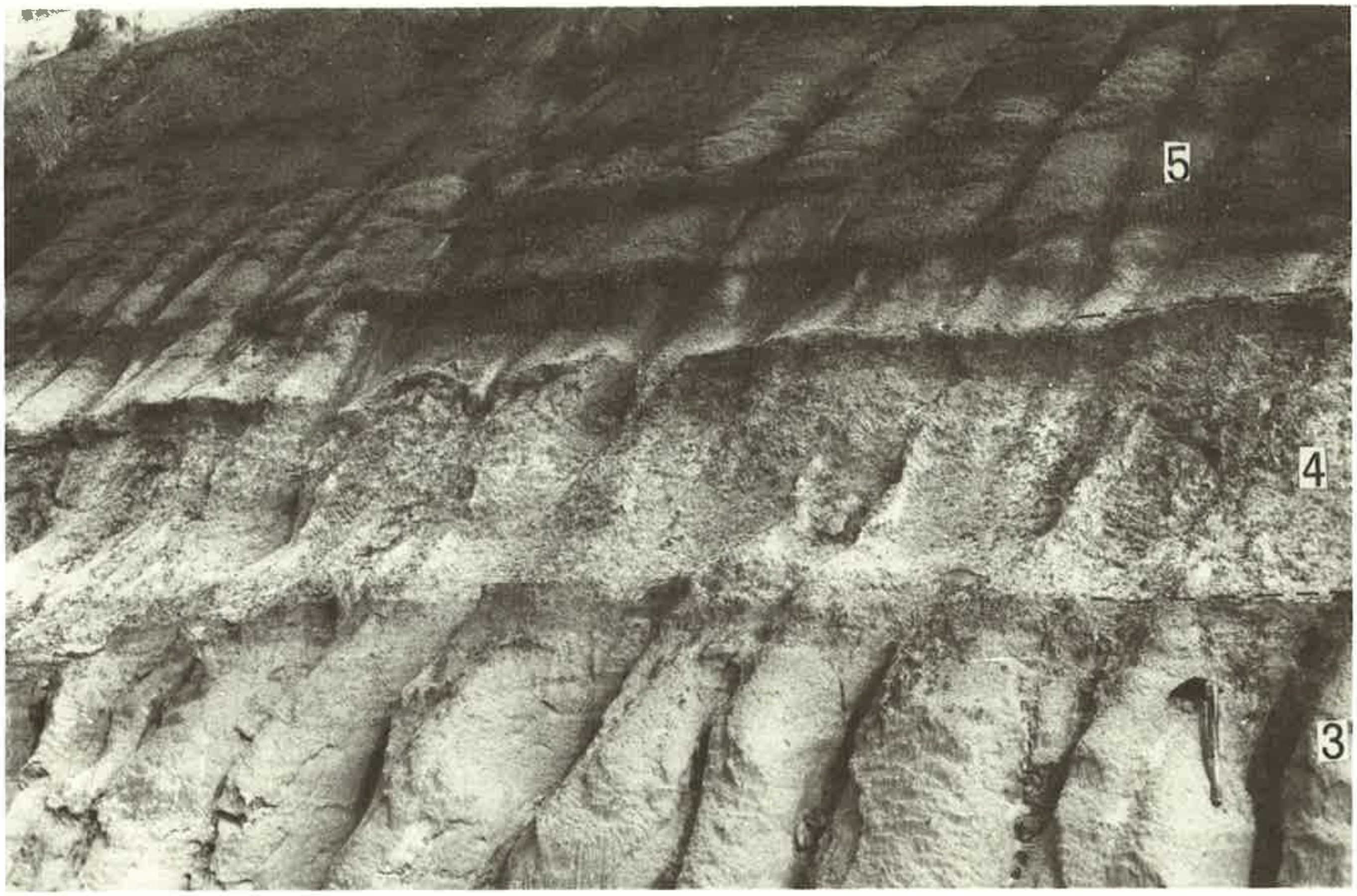


Figure 33. Transition upward from well-sorted barrier-bar sand (bed 3) through poorly sorted sandy clay (4), representing barrier destruction, into offshore marine clay (5). Numbers at right correspond to units on measured section (Fig. 30). Entrenching tool for scale.

STOP 7B. Exposure of Porters Creek Clay in roadcut and ditch, Barbour County, Ala. Clayton North 7½′ Quadrangle, sec. 33, 34, T. 11 N., R. 26 E.; sec. 3, 4, T. 10 N., R. 26 E. Corehole 102 drilled 3 m (10 ft) west of ditch outcrop.

The outcrop and accompanying corehole yielded 9 m (29.5 ft) of olive-black clay and silt. Because of lithologic similarity, these strata were placed in the Porters Creek Clay. This exposure is the only one presently known of this unit in the Chattahoochee Valley area; it probably represents an outlier of the Porters Creek, which is thick and widespread farther west in Alabama.

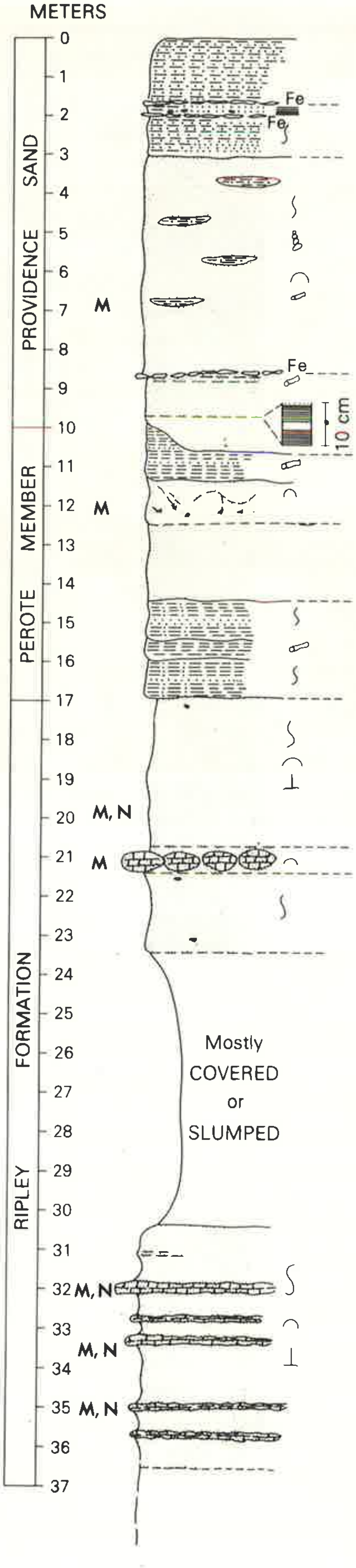
The lower part of the section, as seen in corehole 102 (Fig. 40), is massively bedded glauconitic shelly clays. These beds have a diverse foraminiferal assemblage, which contains as much as 35 percent planktic foraminifers; these characteristics suggest deposition in inner neritic environments. Higher in the corehole, the clay becomes laminated and micaceous; shells are sparse, and diversities of foraminifers and dinoflagellates are low. In the uppermost part of the corehole and in outcrop, calcareous microfossils are absent. These biologic criteria suggest a shallowing upward to probable restricted-marine conditions of deposition.

Biostratigraphic data from calcareous nannofossils indicate that these beds correlate with the uppermost Matthews Landing Marl Member of the Porters Creek in western Alabama. Thus, these beds are younger than any others reported so far for the Clayton.

		Back into bus and straight ahead on Oak Avenue into Clayton.
33.0	0.6	Turn left (south) on Armory Street.
33.1	0.1	Turn right (west) on College Street.
33.5	0.4	Turn right (north) on Midway Street (Alabama Highway Business North 51).
34.5	1.0	Turn left (south) on Alabama 51. Exposure of weathered Clayton Formation at intersection; outcrops of Providence Sand to north along decline in road.
34.8	0.3	Roadcuts on both sides; east cut exposes Clayton Formation, which has blocky clay unit in middle.
35.5	0.7	Turn left (east) on U.S. 30.
36.5	1.0	Blocky clays of Clayton Formation visible in ditch on south side of road.
39.0	2.5	Turn right (south) on Barbour County 67 (Bud Gary Road).
39.8	0.8	Turn left (east) at road fork onto Barbour County 24.

STOPS 6A–6B LOCALITY 113

Top of Section 385 ft (117.3m)



12 CLAYEY SAND, massive and deeply weathered; includes soil and colluvium on slopes.

11 CLAYEY SAND AND VERY FINE SAND interbedded with iron oxide cemented ledges; local clay clasts, planar laminated to bioturbated.

10 VERY FINE to MEDIUM SAND, massive, even bedded, lensoid silty clay pods, highly bioturbated throughout, progressively more weathered toward top. Abundant bivalve and gastropod molds, especially near the base; carbonaceous debris is locally abundant. Irregular iron oxide crusts and nodules especially near the base.

9 FINE SAND, thin to medium bedded, locally finely laminated; interbedded with thinly bedded laminated clay (inset). Very pale orange (10YR 8/2) sand

8 CLAY, finely laminated with interbedded and interlaminated very fine sand. Dark yellowish brown (10YR 4/2).

7 FINE to MEDIUM SAND, massive, micaceous, disrupted clay blocks (deformation structures; bivalve molds; yellowish gray (5YR 7/2).

6 VERY FINE SAND, well-sorted, massive, friable, extremely weathered.

5 SILTY CLAY, interbedded with micaceous FINE quartz SAND. CLAY, compact interval is olive gray (5Y 6/2). Sand is bioturbated; clay is carbonaceous.

4 VERY FINE SAND to MARL; weathered, locally abundant clay chips, massive-bioturbated; sparse muscovite, glauconite (weathered). Abundant calcitic shells throughout-especially oysters. Greenish gray (10GY 5/2).

3 FINE SAND, irregular calcite cemented; well preserved burrows, abundant shell debris.

2 FINE to VERY FINE SAND, clay as burrow linings and irregular clasts, massive, well-sorted. Dusky yellow (5Y 6/4).

1 FINE to VERY FINE SAND to MARL; irregularly cemented sand interbeds; crudely bedded to massive; burrowed-bioturbated; micaceous, irregular clay wisps, scattered shell and shell debris throughout, yellowish gray (5Y 7/2).

Figure 34. Measured section in upper part of Ripley Formation and Perote Member of Providence Sand (Stops 6A, 6B). Section measured by J. Reinhardt and J. Estabrook, 11/76.

40.4	0.6	Roadcut exposures of weathered sands and clays of Nanafalia Formation, next mile.
41.6	1.2	Roadcut exposing channeled contact of Clayton and overlying Nanafalia Formations; crossbedded Nanafalia strata contain abundant clay clasts derived from underlying Clayton.
42.8	1.2	Roadcut on north side of road; exposures of kaolinitic clay at top of Clayton Formation and channeled contact with overlying Nanafalia Formation, containing sandy, crossbedded, clay-clast beds of nonmarine origin.
43.9	1.1	Roadcut exposing weathered Clayton section and Nanafalia beds channeled into top of Clayton.
44.3	0.4	Turn right (south) on Barbour County 79.
48.1	3.8	Town of Baker Hill; entering northern edge of Eufaula bauxite district. Turn right (west) on Alabama 131.
50.0	1.9	Turn left (south) on Barbour County 75.
53.3	3.3	Turn left (east) on Barbour County 29.
53.7	0.4	Enter Henry County; road becomes Henry County 29.
53.9	0.2	**STOP 8.** Griffin mine southwest of Baker Hill in Eufaula bauxite district. Henry County, Ala., Lawrenceville 7½' Quadrangle, sec. 4, T. 8 N., R. 27 E.

This abandoned bauxite-kaolin mine exhibits the common, restricted-marine facies of the Nanafalia Formation; these include kaolinitic clay, micaceous crossbedded sand, and carbonaceous clay and silt. Abrupt changes and lenticular patterns of facies are shown in the mine. Carbonaceous clay and silt are abundant in a bed that becomes almost lignitic at the top (Fig. 41). Abundant clay beds and abrupt lateral changes of the Nanafalia suggest restricted-marine deposition in a lagoon or estuary, or a nonmarine origin; presence of low-diversity dinoflagellate assemblages in samples from the carbonaceous clay interval suggest a restricted-marine environment. The dinoflagellate assemblage also suggests correlation with the *Odontogryphaea thirsae* beds, of marine origin, south of Fort Gaines, Ga.

The red sandy horizon at the top of the mine (Fig. 41) is a highly weathered glauconitic sand representing the basal marine transgression recorded by the Tuscahoma Formation. Ferruginous molds of *Ostrea* and *Venericardia* are present about 0.6 m (2 ft) above the base.

The section here shows that the marine transgression is significantly greater than that of the underlying Nanafalia; the latter exhibits a transition from marine to restricted-marine deposits at Fort Gaines, 32 km (20 mi) to the southeast.

		Retrace route north on Henry County 29 and Barbour County 29.
54.5	0.6	Turn right (north) on Barbour County 75.
57.3	2.8	Turn right (east) on Barbour County 16.
59.3	2.0	Turn right (south) on Barbour County 79.
60.7	1.4	Turn left (east) on unnumbered dirt road.
61.0	0.3	Traveling along northern edge of Baker Hill cuesta.
61.6	0.6	Entering area containing large concentrations of bauxite-kaolin mines.

Figure 35. Calcite-cemented concretions and indurated ledges characteristic of glauconitic marls in Ripley and Blufftown Formations. This Ripley locality is correlative with lower part of section at Stop 6A.

61.9	0.3	Mine on north side of road exposes Tuscahoma-Nanafalia contact; dark-gray beds represent basal marine strata of Tuscahoma.
62.0	0.1	Turn right (south) on U.S. 431.
62.7	0.7	Turn left (east) on Barbour County 57.
62.9	0.2	Roadcut on north side exposes contact between laminated clays of Tuscahoma Formation and overlying crossbedded sands of Hatchetigbee Formation.
66.1	3.2	Roadcut exposing sand and clay of Hatchetigbee Formation; a conspicuous channel of possible Tallahatta time-equivalence, or younger, is incised.
66.6	0.5	On north edge of Baker Hill cuesta; Lake Eufaula to northeast.
67.9	1.3	Junction with Alabama 95. Turn right (south) on 95. Tuscahoma and Hatchetigbee section along roadcut on east side.
68.7	0.8	Turn left (east) on Henry County 57.
69.2	0.5	Turn left (north) on dirt road to Mathison mine.

69.5 0.3 **STOP 9.** Mathison mine. Henry County, Ala., Fort Gaines NW 7½' Quadrangle, sec. 13, T. 8 N., R. 28 E.

Extensive face of mine shows continued restricted-marine deposits of Nanafalia Formation, lower marine transgression represented by Tuscahoma, overlain by restricted-marine sediments, and probable restricted-marine deposits at base of Hatchetigbee.

The mine face has deteriorated during the past several years, because of inactivity, and the lowermost 9.1 m (30 ft) is now covered by slumps and higher water levels. Beds formerly exposed lower in the mine were largely lenticular bauxitic clays, abundantly pisolitic in places. These beds have one of the highest alumina analyses of any mine in the Eufaula bauxite district (W. Mathison, 1978, oral comm.). Also present were lenticular, micaceous, crossbedded medium sands similar to those in the Griffin mine (Stop 8). The upper part of the Nanafalia, as exposed, is composed mainly of kaolinitic clays, sparingly pisolitic. At the top of the Nanafalia (Fig. 42) is a micaceous sand unit commonly containing parts of logs 0.3 m (1 ft) in length. Facies patterns of the Nanafalia here suggest, as at the Griffin mine, deposition in a restricted-marine environment such as a lagoon or estuary.

The base of the overlying Tuscahoma Formation is glauconitic sand containing clay clasts, quartz sand, and phosphate pebbles; this unit has a burrowed lower contact; the burrows extend about 0.6 m (2 ft) down into the Nanafalia (Fig. 42). The upper part of the glauconitic sand is shelly and indurated, and contains abundant specimens of *Chlamys greggi*, an important index fossil for the Tuscahoma. Above a relatively thin sequence of laminated silts and clays is an upper glauconitic sand. These glauconitic sands represent marine transgressions, during Tuscahoma deposition into the Chattahoochee Valley area.

Above these lower sands are thinly laminated beds of silt and clay, abundantly carbonaceous, which compose most of the Tuscahoma section (Fig. 42). These carbonaceous, laminated beds have low-diversity dinoflagellate assemblages, suggesting restricted-marine deposition, probably in a lagoon.

The uppermost 3.6 m (12 ft) of the exposure (Fig. 42) consist of low-angle, crossbedded sands of the Hatchetigbee Formation, suggestive of sandbar sequences.

		Return to paved road.
69.8	0.3	Turn left (east) on Henry County 57.
70.6	0.8	Roadcut containing weathered sands of Tallahatta Formation.
73.8	3.2	Intersection; turn left (east) on Henry County 46.
78.6	4.8	Turn left (north) on Henry County 97. Roadcuts in upper part of Nanafalia and lower part of Tuscahoma, for next 2.9 km (1.8 mi).
80.4	1.8	Turn right (east) into Highland Park Public Use Area on Lake Eufaula.

Figure 36. Characteristic sand-clay interbeds in transitional upper Ripley–basal Providence (Perote Member). Lithology well represented in slightly weathered beds at Stop 6B.

Figure 37. Bored phosphatic pebbles and coarse shell rubble in marl matrix from basal Perote Member of Providence Sand, near Stop 6C.

STOP 10. Lunch. Highland Park, Henry County, Ala., Fort Gaines NE 7½' Quadrangle, sec. 26, T. 8 N., R. 29 E.

The area around Highland Park is interpreted as overlying the barrier-bar system that ponded clays of the Eufaula bauxite district in a lagoonal or estuarine environment, to the north-northwest, and passed into open-marine glauconitic sand, silt, and clay of the *Odontogryphaea thirsae* beds of the Nanafalia Formation, seen in outcrop 3.2 km (2 mi) to the southeast (Stop 11). Corehole 124, drilled next to the water pump in the parking lot, penetrated 15.2 m (50 ft) of Nanafalia sand and gravel and a few clay stringers (Fig. 43). Corehole 125, 1.6 (1 mi) southeast of Highland Park, contains only a single 0.3-m (1-ft) -thick bed of marine sediments within the Nanafalia, indicating that the marine facies transition is very close to Stop 11.

Exposed on the west bank of the parking lot are highly weathered clay and sand of the lower part of the Tuscahoma Formation. Roadcuts on Highway 97 north and south of Highland Park show basal glauconitic sands of the Tuscahoma Formation and burrows extending down into the upper part of the Nanafalia Formation, which here consists of crossbedded sands, commonly containing clay clasts. A roadcut 0.5 km (0.3 mi) to the north shows crossbedding characteristic of point bars and *Ophiomorpha*; it probably is an estuarine point bar.

		Continue on park road to junction.
80.7	0.3	Turn left (south) on Henry County 97.
82.6	1.9	Intersection with Henry County 46. Turn left (east).
83.0	0.4	Roadcut exposing intensely burrowed basal part of Tuscahoma Formation.
83.9	0.9	Junction with Alabama 10. Turn left (east).
84.2	0.3	Turn left (north) on Walter F. George Dam access road.
84.3	0.1	Turn right (east) on Franklin Landing boat ramp road.
84.5	0.2	**STOP 11.** Franklin Landing boat ramp on Chattahoochee River. Henry County, Ala., Fort Gaines 7½' Quadrangle, sec. 6, T. 7 N., R. 30 E.

Cut for boat ramp exposes upper part of downdip marine carbonate facies of Clayton Formation and lower part of overlying Nanafalia Formation; exposure includes lowest beds of Nanafalia, which are of restricted-marine origin, and overlying shelly beds of shallow-marine origin.

The Clayton Formation is a fossiliferous limestone. This exposure represents the upper part of the Clayton, which was measured by Toulmin and LaMoreaux (1963) to be as much as 45.7 m (150 ft) thick. The entire Clayton Formation is of inner neritic origin in this area.

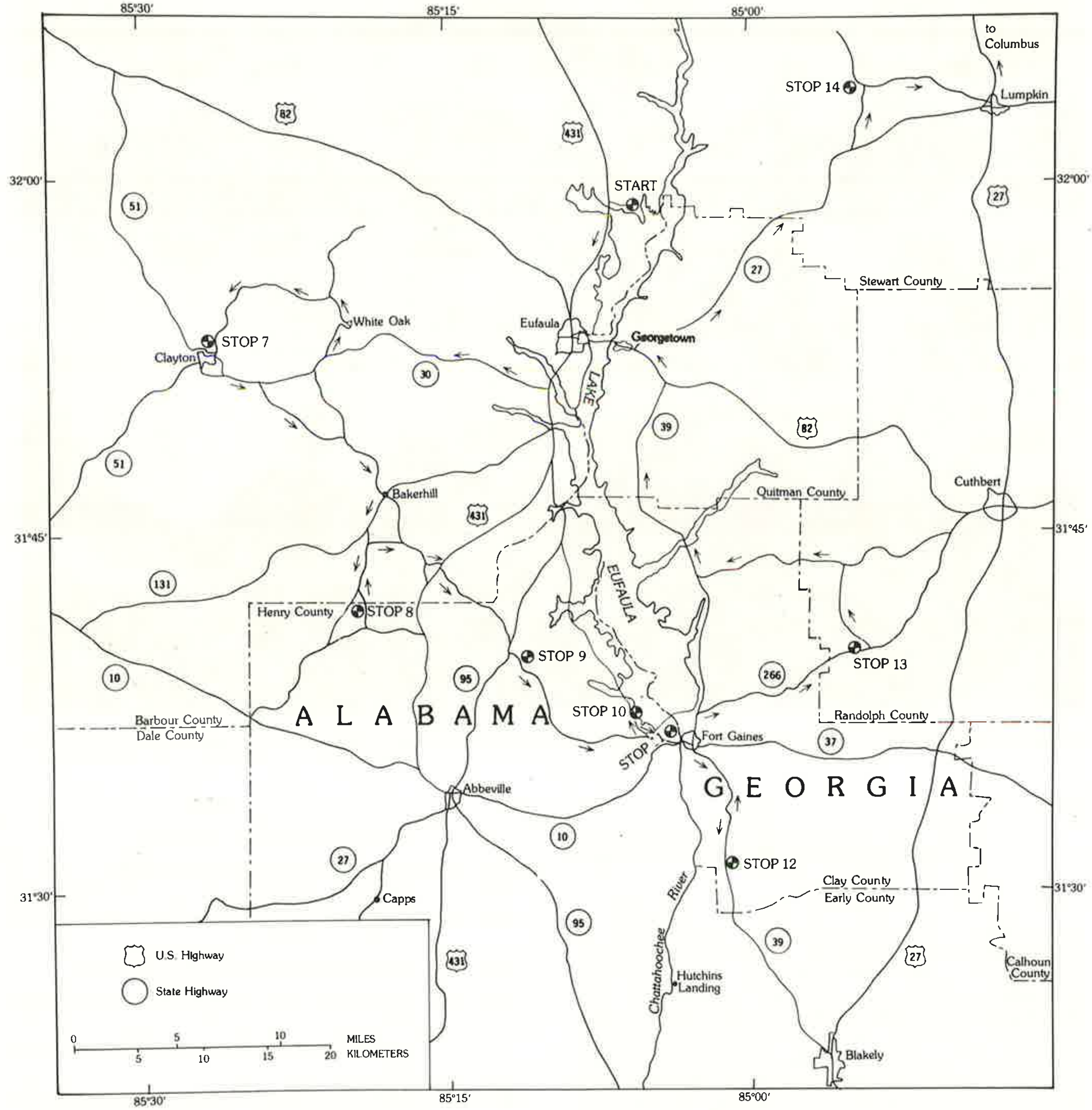
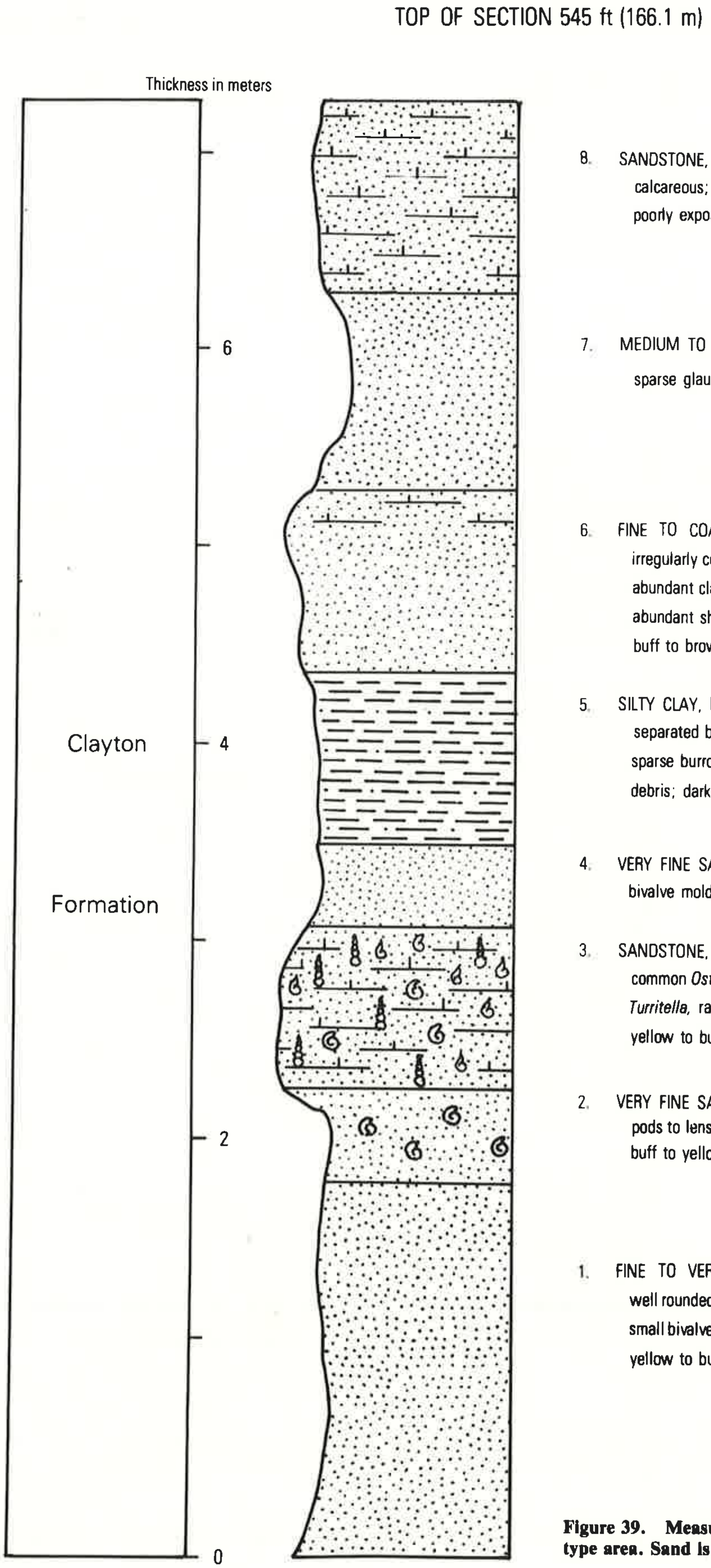


Figure 38. Field trip route and location of stops on second day.

Karst topography, having relief of as much as 3.6 m (12 ft) near Franklin Landing and as much as 15.2 m (50 ft) elsewhere (Newton, 1965), formed on top of the Clayton (Fig. 45). Micaceous sand and clay, in part carbonaceous, of the "Gravel Creek Sand Member" of the Nanafalia Formation fill these depressions; injection of darker carbonaceous clay into the overlying sheared and faulted sand resulted from slumping of soft sediments. Probably, "Gravel Creek" beds are found only in karst depressions, as Marsalis and Friddell (1975) proposed. "Gravel Creek" beds seem to have been deposited in restricted-marine environments, as suggested by palynomorph assemblages.

The section (Fig. 44) was measured across the river from Franklin Landing, immediately south of the Highway 10 bridge to Fort Gaines. Lowermost shelly beds are dominated by *Odontogryphaea thirsae*, together with lesser numbers of *Ostrea sinuosa*. Beds at Franklin Landing are considered to represent a very shallow, inner neritic, rather than restricted-marine environment because of relatively high benthic foraminiferal diversity (17 species) and almost one percent planktic foraminifers. Higher in the section (Fig. 44), however, fluctuations from very shallow, inner neritic to restricted-marine environments appear, as indicated by marked increase in clay content together



8. SANDSTONE, appears massive;
calcareous; yellow to buff;
poorly exposed

7. MEDIUM TO COARSE SAND, massive;
sparse glauconite, yellow to buff

6. FINE TO COARSE SAND, massive;
irregularly cemented intervals in upper part;
abundant clay matrix, micaceous,
abundant shell molds;
buff to brown

5. SILTY CLAY, laminated,
separated by micaceous silt,
sparse burrows, abundant leaves and carbonaceous
debris; dark gray

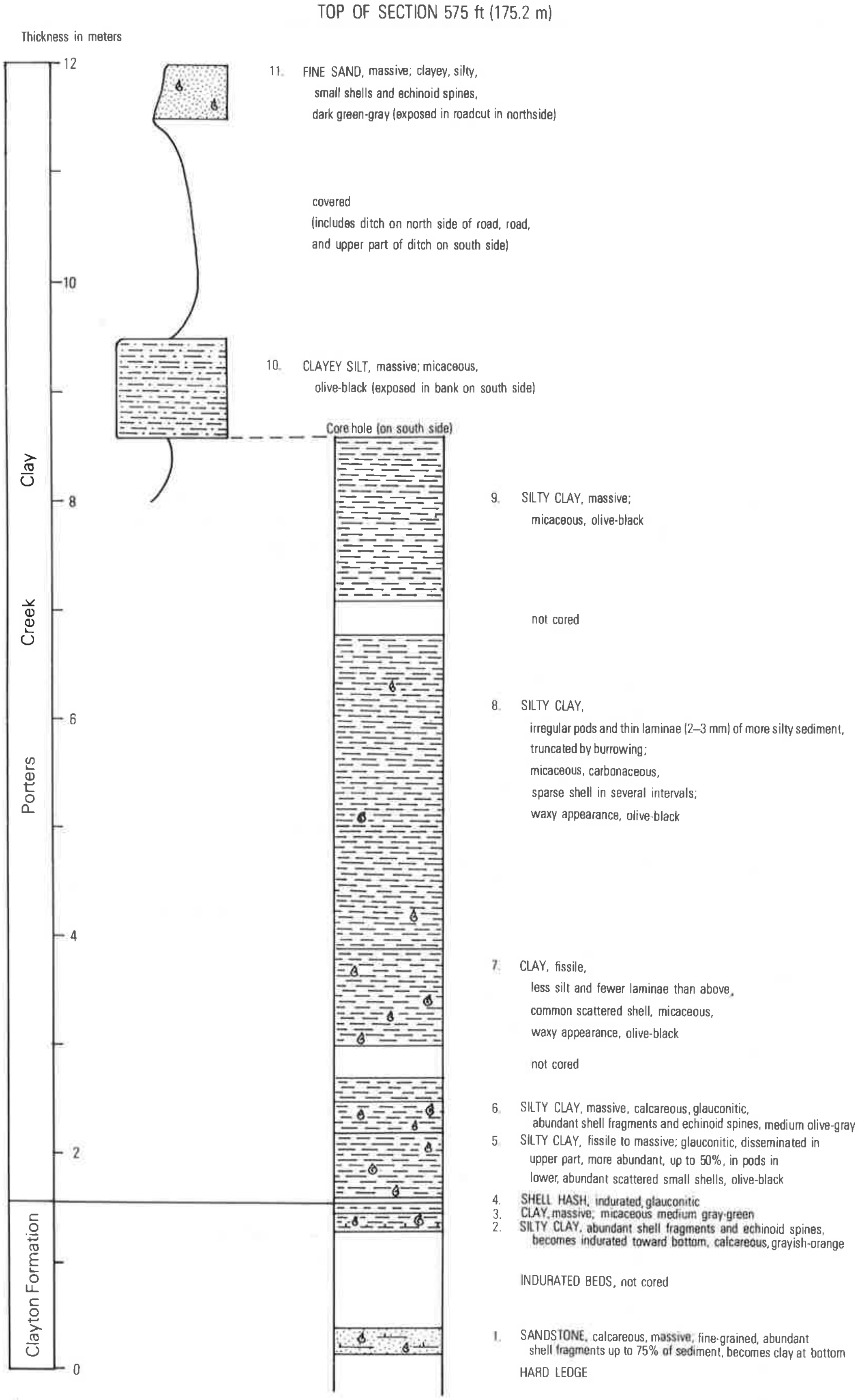
4. VERY FINE SAND, massive; silty, clayey,
bivalve molds, locally oyster shell hash, yellow

3. SANDSTONE, calcareous to sandy limestone, very fine sand;
common *Ostrea crenulamarginata*, small bivalves,
Turritella, random orientation, shells more abundant in upper part,
yellow to buff brown

2. VERY FINE SAND, abundant heavy minerals;
pods to lenses of poorly preserved oysters and molds of *Turritella*;
buff to yellow

1. FINE TO VERY FINE SAND, massive;
well rounded, micaceous, abundant heavy minerals,
small bivalve and *Turritella* molds,
yellow to buff-brown

Figure 39. Measured section of Clayton Formation at Stop 7A, the type area. Sand is dominant.



11. FINE SAND, massive; clayey, silty, small shells and echinoid spines, dark green-gray (exposed in roadcut in northside)

covered (includes ditch on north side of road, road, and upper part of ditch on south side)

10. CLAYEY SILT, massive; micaceous, olive-black (exposed in bank on south side)

9. SILTY CLAY, massive; micaceous, olive-black

not cored

8. SILTY CLAY, irregular pods and thin laminae (2–3 mm) of more silty sediment, truncated by burrowing; micaceous, carbonaceous, sparse shell in several intervals; waxy appearance, olive-black

7. CLAY, fissile, less silt and fewer laminae than above, common scattered shell, micaceous, waxy appearance, olive-black

not cored

6. SILTY CLAY, massive, calcareous, glauconitic, abundant shell fragments and echinoid spines, medium olive-gray

5. SILTY CLAY, fissile to massive; glauconitic, disseminated in upper part, more abundant, up to 50%, in pods in lower, abundant scattered small shells, olive-black

4. SHELL HASH, indurated, glauconitic

3. CLAY, massive; micaceous medium gray-green

2. SILTY CLAY, abundant shell fragments and echinoid spines, becomes indurated toward bottom, calcareous, grayish-orange

INDURATED BEDS, not cored

1. SANDSTONE, calcareous, massive, fine-grained, abundant shell fragments up to 75% of sediment, becomes clay at bottom

HARD LEDGE

Figure 40. Composite measured section, from outcrops and adjacent U.S. Geological Survey corehole 102, of Porters Creek Clay and Clayton Formation at Stop 7B.

with a decrease to 10, or fewer, benthic foraminiferal species and a general absence of planktic specimens.

		Retrace route back to Alabama 10.
84.8	0.3	Junction with Alabama 10. Turn left (east) on 10.
85.1	0.3	Crossing Chattahoochee River, entering Georgia; Alabama 10 becomes Georgia 37.
85.5	0.4	Junction with Georgia 39 in Fort Gaines; town was established in 1840's as a fort to protect settlers on western frontier from Indian attacks; continue east on 37.
85.6	0.1	Turn right (south) on Georgia 39.
86.4	0.8	Roadcut on left, exposing Tuscahoma and Hatchetigbee Formations (GGS Tertiary Stop 6).
87.0	0.6	Roadcut exposing undifferentiated Claiborne (middle Eocene) strata.
90.0	3.0	Roadcut exposing undifferentiated Claiborne (middle Eocene) strata.
92.2	2.2	**STOP 12.** Kolomoki Creek. Clay County, Ga. Fort Gaines 7½' Quadrangle. GGS Tertiary Stop 7.

Roadcut and underlying river section immediately north expose upper part of Tuscahoma Formation, upper part of Hatchetigbee Formation, and Tallahatta Formation and younger undifferentiated Paleogene units. The covered interval of the Tuscahoma and Hatchetigbee Formations (Fig. 46) was examined by corehole 123, drilled 20 m (65.6 ft) east of roadcut.

The Tuscahoma is composed of medium- to dark-gray sand, silt, and clay containing abundant carbonaceous debris. Fine sand is considerably more abundant here than in generally finer grained sections to the northwest, such as the Mathison mine (Stop 9). The exposed upper part of the formation has a complex laminated and cross-laminated pattern suggestive of fluctuating energy conditions, such as those present in a tidal flat system. A low-diversity assemblage of dinoflagellates supports the idea of deposition during other than open-marine conditions.

The Hatchetigbee Formation, as seen in the corehole and partly in the outcrop, contains glauconitic, shelly, very fine sands (Fig. 46). Foraminiferal diversity and percentage of planktic specimens indicate an environment of shallow open-marine waters (but deeper than that of most other post-Clayton formations) and shoaling in the upper half of the section. Upper silt and clay beds are very shallow marine to probable marginal marine. The outcrop section contains shell molds, particularly *Calorhadia;* siliceous shells were reported by Marsalis and Friddell (1975).

The contact between the Hatchetigbee and Tallahatta Formations is marked here, as is common throughout the area, by an indurated thin gravelly sand containing shell fragments. Above basal Tallahatta sands are additional strata of middle Eocene (Claiborne) and younger age, which are undifferentiated here but which were divided into units by Marsalis and Friddell (1975).

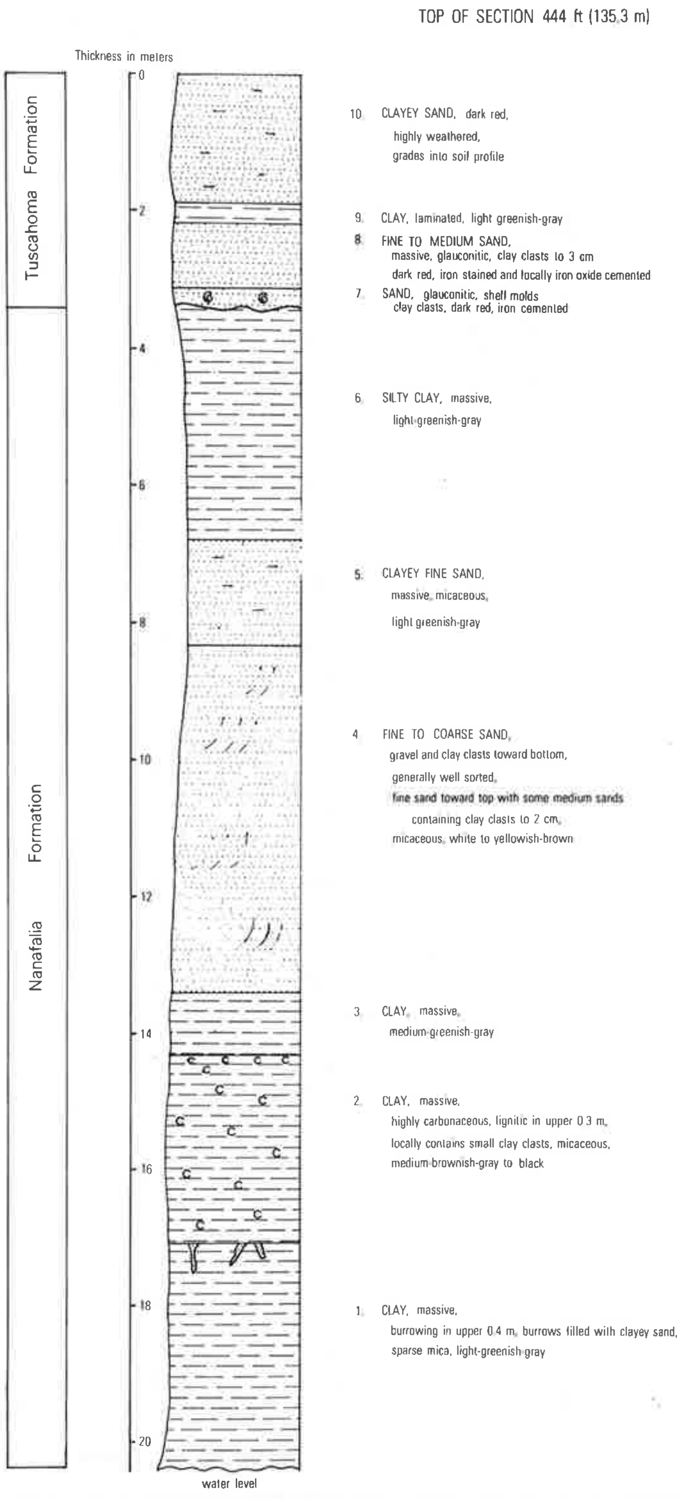
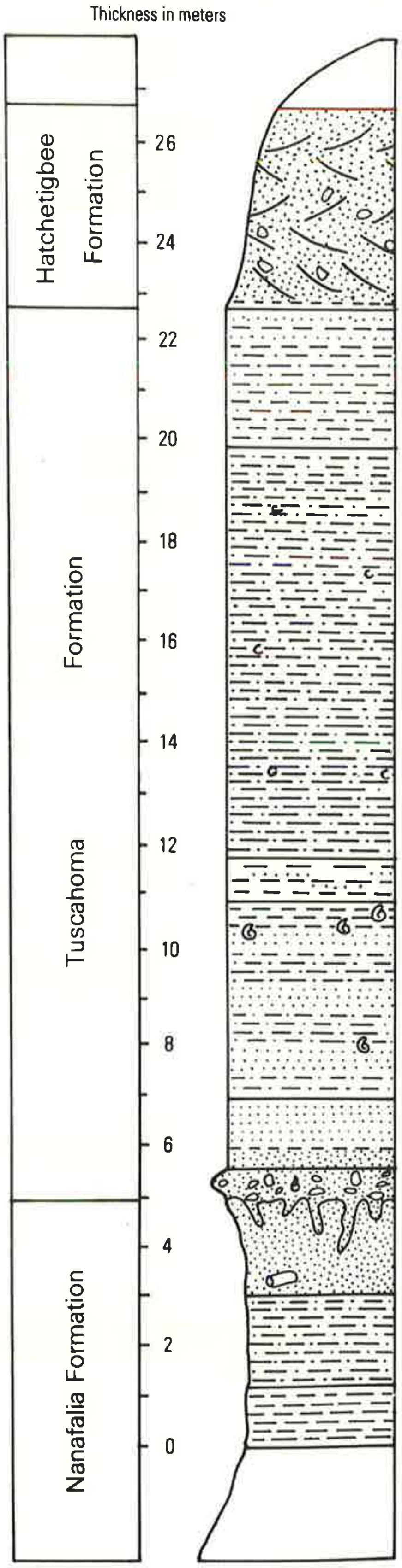


Figure 41. Measured section of Nanafalia and Tuscahoma Formations at Stop 8. Several lithologies characteristic of restricted-marine environments are seen in Nanafalia.

TOP OF SECTION 426 ft (129.8 m)



Red sandy soil

10. FINE TO MEDIUM SAND, crossbedded,
sets 0.1 m high, dip 10–15° several directions, clay drapes,
fair to poor sorting,
white clay clasts to several cm,
in lowest 1.0 m are several prominent medium-gray clay bands,
medium to dark red

9. SILT TO SILTY CLAY, distinct to indistinct laminations,
some intraformational clay casts,
medium to gray-green

8. SILT TO SILTY CLAY, laminated,
common interbedding of 1 cm thick clays with 1 mm lighter colored silts,
some intervals have 1 cm silt beds and 1 cm clays,
more silt than above unit, silt bed 10 cm thick 3.7 m below top,
small-scale low-angle crossbedding locally common,
abundant carbonaceous debris,
dark gray

7. CLAY, thin laminae of glauconitic sand,
dark gray

6. SILT and SAND, laminated to massive, silts commonly crossbedded,
glauconite common in bioturbated fabric,
Chlamys greggi, shark and ray teeth common near top,
lowest 3.2 m has more abundant carbonaceous debris and rare molds of *Mytilus*
medium gray-green

5. FINE SAND TO SILTY SAND, glauconitic,
dark greenish-gray

4. SANDSTONE, calcareous, quartz pebbles to 10 mm—coarse glauconite,
abundant *Chlamys greggi*—clay clasts abundant at base—burrows into underlying unit

3. FINE SAND, poorly sorted,
large log fragments to 10 cm in diameter; brown

2. CLAYEY SILT,
becomes more clayey toward base
almost indigo blue

1. CLAY, massive, locally bauxitic
medium gray-green

Figure 42. Stratigraphic column of Nanafalia, Tuscahoma, and basal part of Hatchetigbee Formations at Stop 9. This section is near northern limit of Hatchetigbee.

Retrace route to Fort Gaines.

98.8	6.6	Intersection with Georgia 37. Turn left (west).
98.9	0.1	Turn right (north) on Georgia 39, through Fort Gaines.
100.6	1.7	Turn right (east) on Georgia 266.
101.3	0.7	Fork in road; stay right, on Georgia 266.
109.4	8.1	**STOP 13.** Greens Branch. Randolph County, Ga., Coleman 7½' Quadrangle.

Deep ravine exposes upper part of Tuscahoma Formation, entire Hatchetigbee Formation, and lower part of Tallahatta Formation. Hatchetigbee strata show the extent of the earliest Eocene transgression into western Georgia.

The upper part of the Tuscahoma consists of clay and fine sand, laminated throughout and intensely burrowed locally. The sedimentary fabric and low diversity of dinoflagellate assemblages suggest deposition in a restricted-marine environment, probably lagoonal to tidal flat, as is found throughout this region.

The Hatchetigbee is composed largely of glauconitic fine sand; bedding generally is massive except for thin clay laminae in the bottom unit. Shells become more abundant upward through the section, and some of the upper beds are marly (Fig. 47), similar to those of the Bashi Marl Member. Important molluscan index fossils of the Hatchetigbee, including *Venericardia horatiana, V. hatcheplata,* and *Turritella gilberti,* are present. Abundance of fragmented shells suggests very shallow marine conditions, an interpretation supported by low percentages of planktic foraminifers. The sparse planktic assemblages contain, however, species indicative of the lowermost part of the Eocene. Absence of shells in the uppermost unit and the upward decrease in benthic foraminiferal diversity in the underlying beds suggest shoaling toward the top.

The overlying Tallahatta Formation, which forms the waterfall, contains interbedded "plastic" clay and sand. The clay contains only sporomorphs and is considered to be of nonmarine origin.

Continue east on Highway 266.

110.4	1.0	Turn left (north) on Randolph County 15.
110.8	0.4	Roadcuts incised downward through section of weathered Tallahatta sands, Hatchetigbee silt, clay, and sand, and Tuscahoma laminated clay. After crossing stream, road returns upward through section.
115.2	4.4	Junction with Randolph County 164. Turn left (west).
118.6	3.4	Fork in road; stay right.
120.8	2.2	Johnny Moore Hill; exposes Tallahatta at top, downward through Hatchetigbee, Tuscahoma, and Nanafalia Formations. Steep dip at top of section attributed to slumping into solution holes

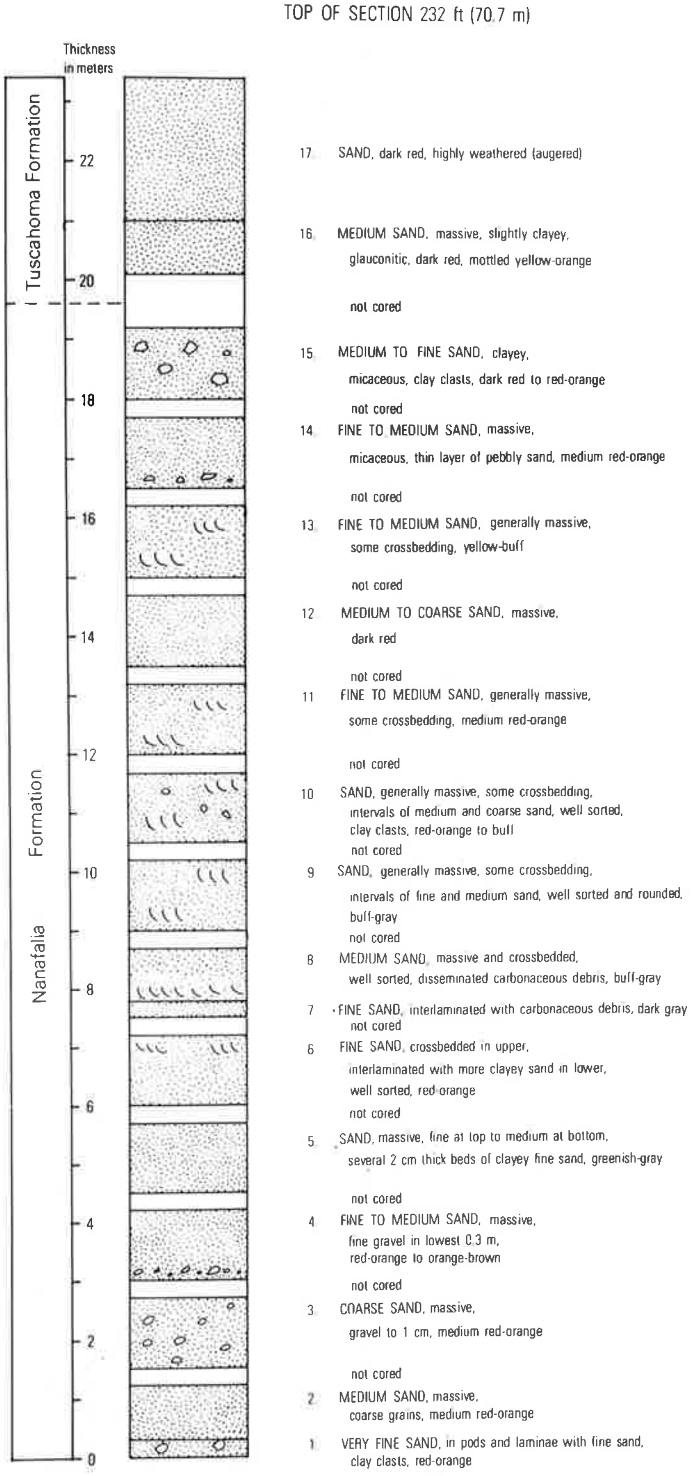
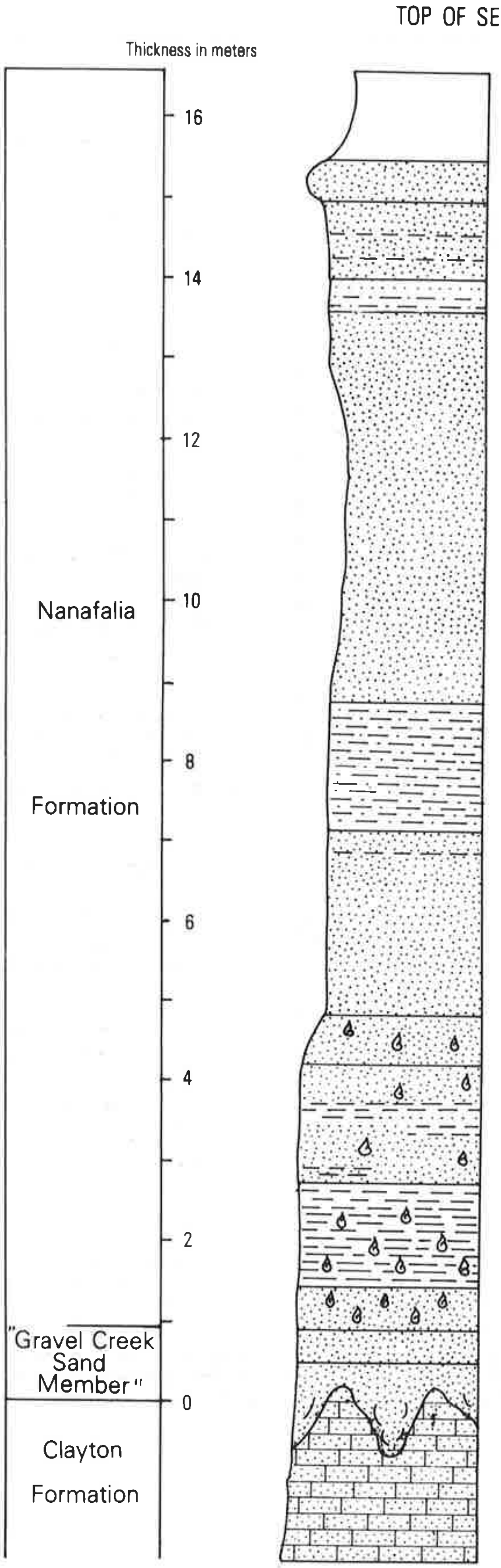


Figure 43. Section in U.S. Geological Survey corehole 124 at Stop 10. Clastic sequence represents barrier, during Nanafalia deposition, that separated marine and restricted-marine environments.



covered

13. SANDSTONE, gray

12. VERY FINE SAND, interbedded with thin silty clay—more sandy toward top; gray

11. SILT, indurated—more sand toward top, abundant molds of small bivalves, medium gray

10. CLAYEY MEDIUM TO FINE SAND, bioturbated and burrowed; micaceous, carbonaceous, medium to dark gray

9. SILT, massive; micaceous, carbonaceous; shell material toward base; dark gray

8. SILTY VERY FINE SAND, clayey toward top; micaceous, carbonaceous; fine shell debris; dark gray

7. VERY FINE SAND, massive; few clay laminae; abundant fine shell debris; few large oysters; medium gray

6. VERY FINE SAND, interbedded with silty clay; clay beds are lensoid, 1–2 cm thick, abundant irregular concretions, abundant fine shell debris; medium gray-green

5. FINE SANDY CLAY, massive; some thin clay stringers; abundant shells, especially *Odontogryphaea thirsae*, glauconitic; medium gray-green

4. VERY FINE SAND, shell debris in lower part, complete shells of *O. thirsae* in upper; wood debris in lower; gray-green

3. FINE- TO MEDIUM SAND, poor sorting; micaceous; large wood fragments to 0.5 m; orange-brown to gray-green

2. SILTY FINE SAND, poorly sorted; micaceous; irregular masses of carbonaceous clay; kaolinitic; white to buff, fills solution pits in top of Clayton Formation

1. LIMESTONE, massive; silt and sand; microfossiliferous, bryozoan and shell fragments; yellow to light gray

Figure 44. Measured section of uppermost part of Clayton Formation and lower part of Nanafalia, 0.8 km (0.5 mi) south of Stop 11. Most of Nanafalia here formed in inner neritic environments.

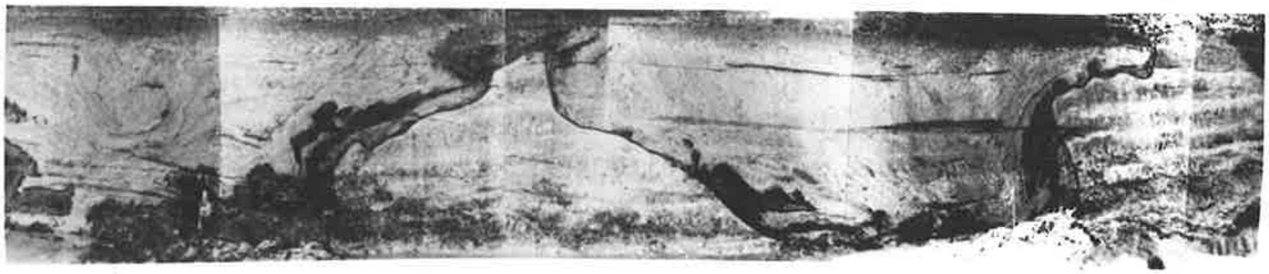


Figure 45. Mosaic of river side of parking lot and boat launching ramp at Franklin Landing (Stop 11), showing karst surface at top of Clayton filled with sediments of "Gravel Creek Sand Member" of Nanafalia. Horizontal alignment of *Odontogryphaea thirsae* beds indicates that they postdate karst formation.

in underlying Clayton limestone, but may be related to faulting present to west. (GGS Tertiary Stop 2).

123.0 2.2 Junction with Georgia 39. Turn right (north) on 39.

134.2 11.2 Junction with U.S. 82. Turn left (west) on 82.

136.5 2.3 Junction with Georgia 27. Turn right (north) on 27.

140.5 4.0 Weathered outcrops of Providence Sand are present from here northward to Lumpkin, as road traverses obliquely to strike of formation.

153.3 12.8 Turn left (north) on unnumbered Stewart County road; ironstone exposures near intersection.

156.5 3.2 Turn left on Georgia 39C.

156.6 0.1 Turn left into Providence Canyons State Park; proceed to overlook.

156.9 0.3 **STOP 14.** (Optional) Providence Canyons State Park, Stewart County, Ga. Lumpkin SW 7½' Quadrangle. GGS Cretaceous Stop 8.

This stop is intended largely as a place to reflect on, and summarize, the geology seen during the past two days. Time permitting, we shall walk to the base of the canyons, to discuss primary sedimentary structures within the Perote and unnamed members of the Providence Sand (Fig. 48). Thickness of the Perote in this area; and transition to the underlying Ripley Formation, were shown in sections by Eargle (1955) and Marsalis and Friddell (1975). These transitions were perhaps better seen at Stop 6, yesterday.

The Providence Sand here is dominated by medium to thickly bedded sand bodies, characterized by an eroded base, complex channel filling, lensoid clay and clay-clast interbeds, and locally abundant *Ophiomorpha*. Although the Providence in this area has been termed "continental facies" by previous workers, the unit belongs in a shallow subtidal to intertidal setting, probably associated with a barrier island complex. Locally, heavy minerals, especially ilmenite and monazite, constitute as much as one-third of the sand, by volume; these concentrations may represent mineable placer deposits comparable with, but on a smaller scale than, the Trail Ridge barrier-sand complex of Pleistocene age in southeastern Georgia and northern Florida.

The Clayton Formation here (seen also Stops 7 and 11) is represented only by an iron-rich residuum; extensive colluvial deposits that mantle most slopes around the canyons are derived from this Clayton residuum. Abundant fossil molds within the iron-cemented residuum, and locally silicified bivalves and gastropods of early Paleocene age, can be found along the Providence-Clayton residuum contact to the east.

Settlement and removal of the primary forest, during the 19th century, contributed to extensive erosion, which is a continuing process over wide areas in the updip Providence Sand outcrop belt in western Georgia. High relief of this area, resulting in part from the early(?) cementation of Clayton residuum, and the thick, highly permeable Providence Sand, resulted in a fragile area environmentally. Although we and the general public can enjoy the aesthetics of Providence Canyon (Fig. 49), we should remember that this scene results in part from poor land use.

Retrace route to entrance.

157.2 0.3 Turn right on Georgia 39C.

157.7 0.5 Extensive flat area, resulting from strip mining of iron oxide residuum formed from weathering of Clayton Formation.

159.3 1.6 Diapirs in Tertiary sediments. Extensive ironstone.

160.8 1.5 Complex structures (offsets in sand arches and clay diapirs) in lower Tertiary sand and clay (probably Clayton and Nanafalia).

161.5 0.7 Greater New Hope Church.

163.8 2.3 Roadcut in thinly bedded, burrowed Providence Sand.

164.7 0.9 Turn left (north) on U.S. 27.

168.1 3.4 Roadcut containing Ripley-Providence contact (GGS Cretaceous Stop 7). Notable is the absence of a carbonaceous unit at base of Providence.

168.5 0.4 Frog Bottom Creek.

176.8 8.3 Community of Louvale. Roadcuts on either side of U.S. 27 are in moderately weathered Ripley Formation (south of Louvale) and in Cusseta Sand (north of Louvale).

183.6 6.8 Hitchitee Creek.

186.2 2.6 Intersection with U.S. 280. Turn left (north) on 280, toward Columbus. Type section of Cusseta Sand is 0.8 km (0.5 mi) north, along railroad cuts at Cusseta, Ga. Roadcuts on northeast side of this intersection were described by Hester (1968) and Marsalis and Friddell (1975). (GGS Cretaceous Stop 6).

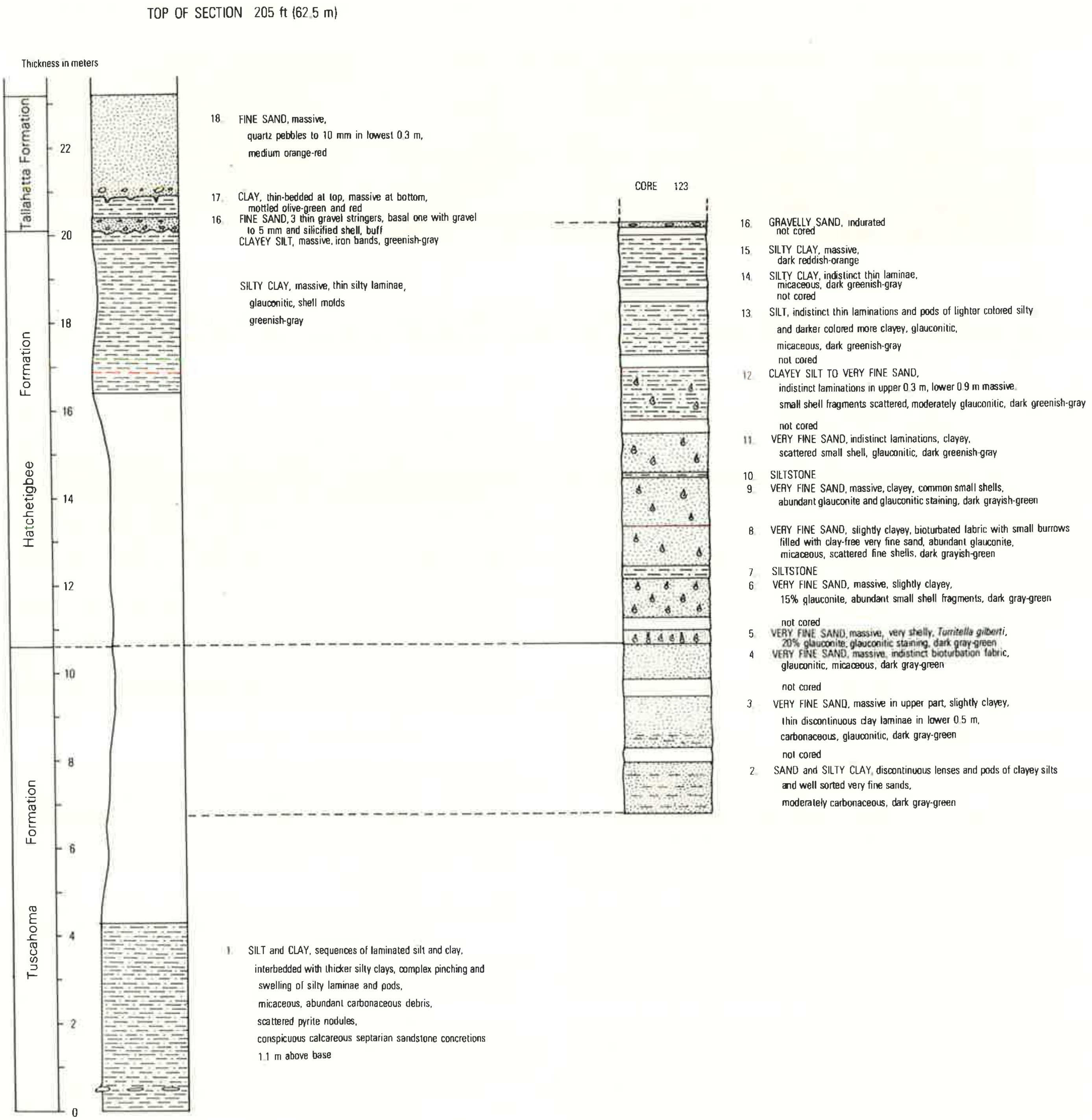


Figure 46. Measured sections from outcrop and adjacent corehole 123 of Tuscahoma and Hatchetigbee Formations at Stop 12. Fossiliferous strata found in lower part of Hatchetigbee corehole.

188.5	2.3	Overgrown exposure on south side of road in Blufftown Formation (GGS Cretaceous Stop 5). Fort Benning Military Reservation on both sides of highway.
193.8	5.3	Basal Blufftown sand exposed in gully on north side of road.
194.8	1.0	Exposure of Eutaw Formation; clean sand pod in channel fill.
195.7	0.9	Upatoi Creek; Chattahoochee-Muscogee County Line.
197.8	2.1	Junction I-185. Proceed north toward LeGrange.
198.6	0.8	Roadcut in Eutaw Formation shows finely laminated silt and thin, fine sand beds.
206.8	8.2	Approximate position of Fall Line. Proceed 160 km (100 mi) to Atlanta for overnight accomodations or connections.

END OF FIELD TRIP

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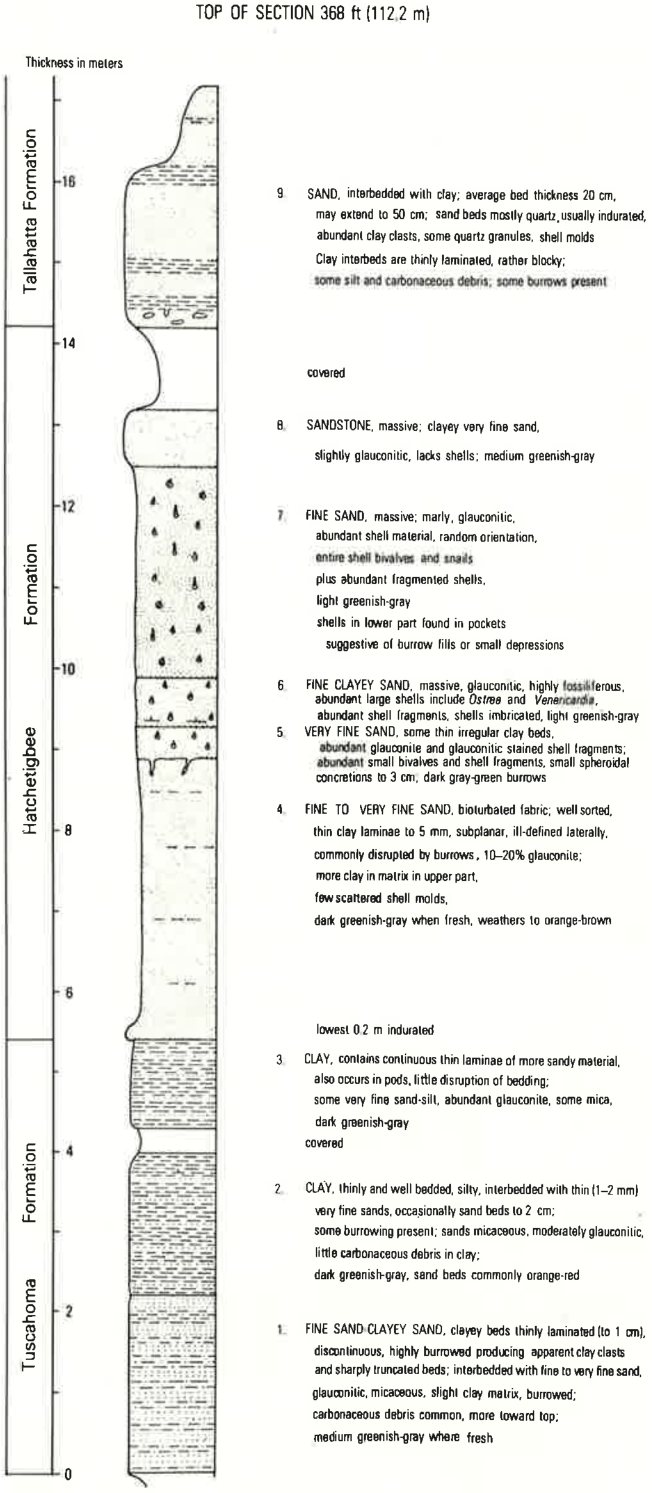
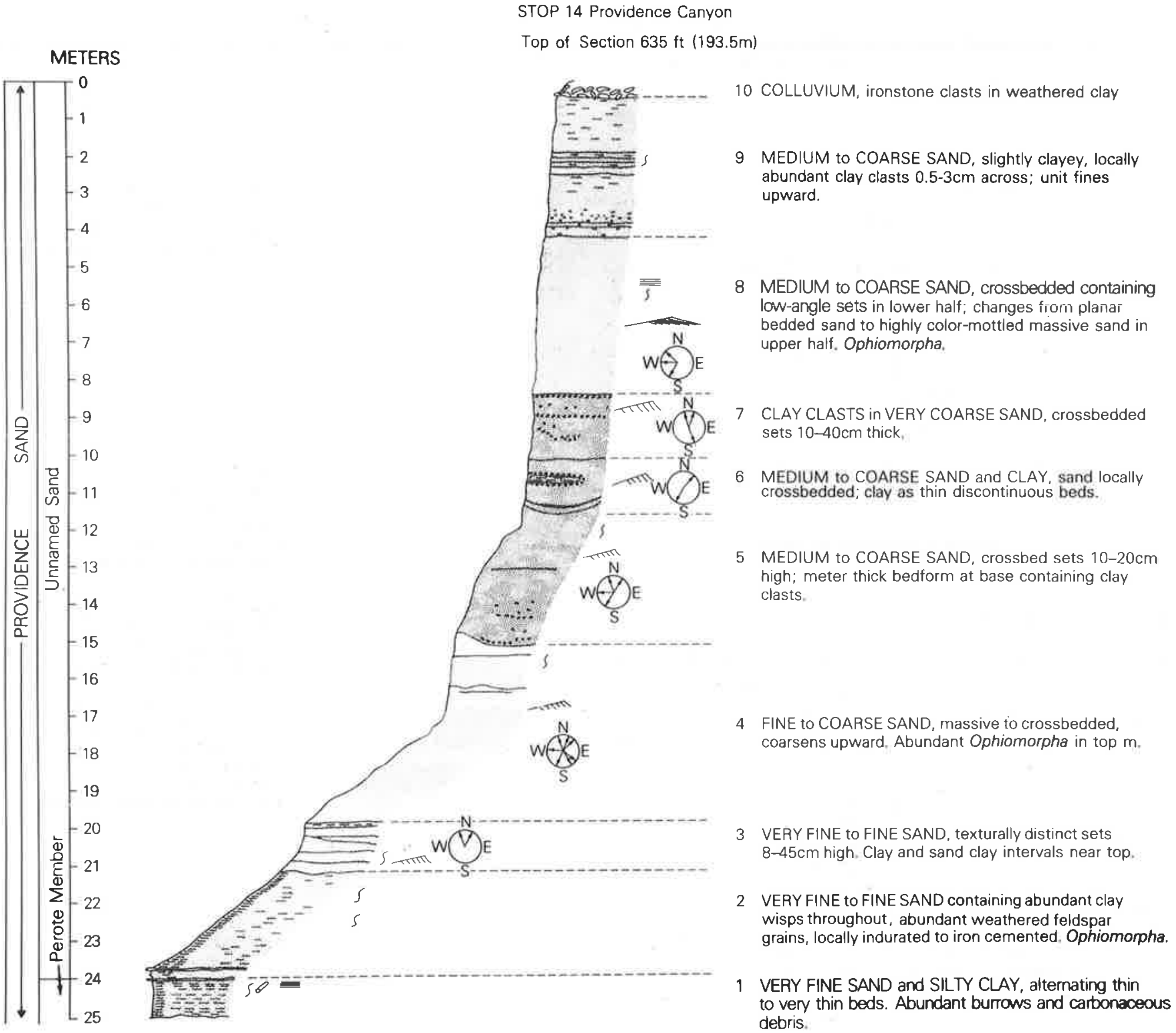


Figure 47. Measured section of Tuscahoma, Hatchetigbee, and Tallahatta Formations at Stop 13. Fossiliferous strata in Hatchetigbee indicate extent of this transgression into western Georgia.



STOP 14 Providence Canyon

Top of Section 635 ft (193.5m)

10 COLLUVIUM, ironstone clasts in weathered clay

9 MEDIUM to COARSE SAND, slightly clayey, locally abundant clay clasts 0.5-3cm across; unit fines upward.

8 MEDIUM to COARSE SAND, crossbedded containing low-angle sets in lower half; changes from planar bedded sand to highly color-mottled massive sand in upper half. *Ophiomorpha.*

7 CLAY CLASTS in VERY COARSE SAND, crossbedded sets 10–40cm thick.

6 MEDIUM to COARSE SAND and CLAY, sand locally crossbedded; clay as thin discontinuous beds.

5 MEDIUM to COARSE SAND, crossbed sets 10–20cm high; meter thick bedform at base containing clay clasts.

4 FINE to COARSE SAND, massive to crossbedded, coarsens upward. Abundant *Ophiomorpha* in top m.

3 VERY FINE to FINE SAND, texturally distinct sets 8–45cm high. Clay and sand clay intervals near top.

2 VERY FINE to FINE SAND containing abundant clay wisps throughout, abundant weathered feldspar grains, locally indurated to iron cemented. *Ophiomorpha.*

1 VERY FINE SAND and SILTY CLAY, alternating thin to very thin beds. Abundant burrows and carbonaceous debris.

Figure 48. Measured section in Providence Sand, Providence Canyons State Park, Stop 14. Section measured and described by Arthur Donovan, 11/79.

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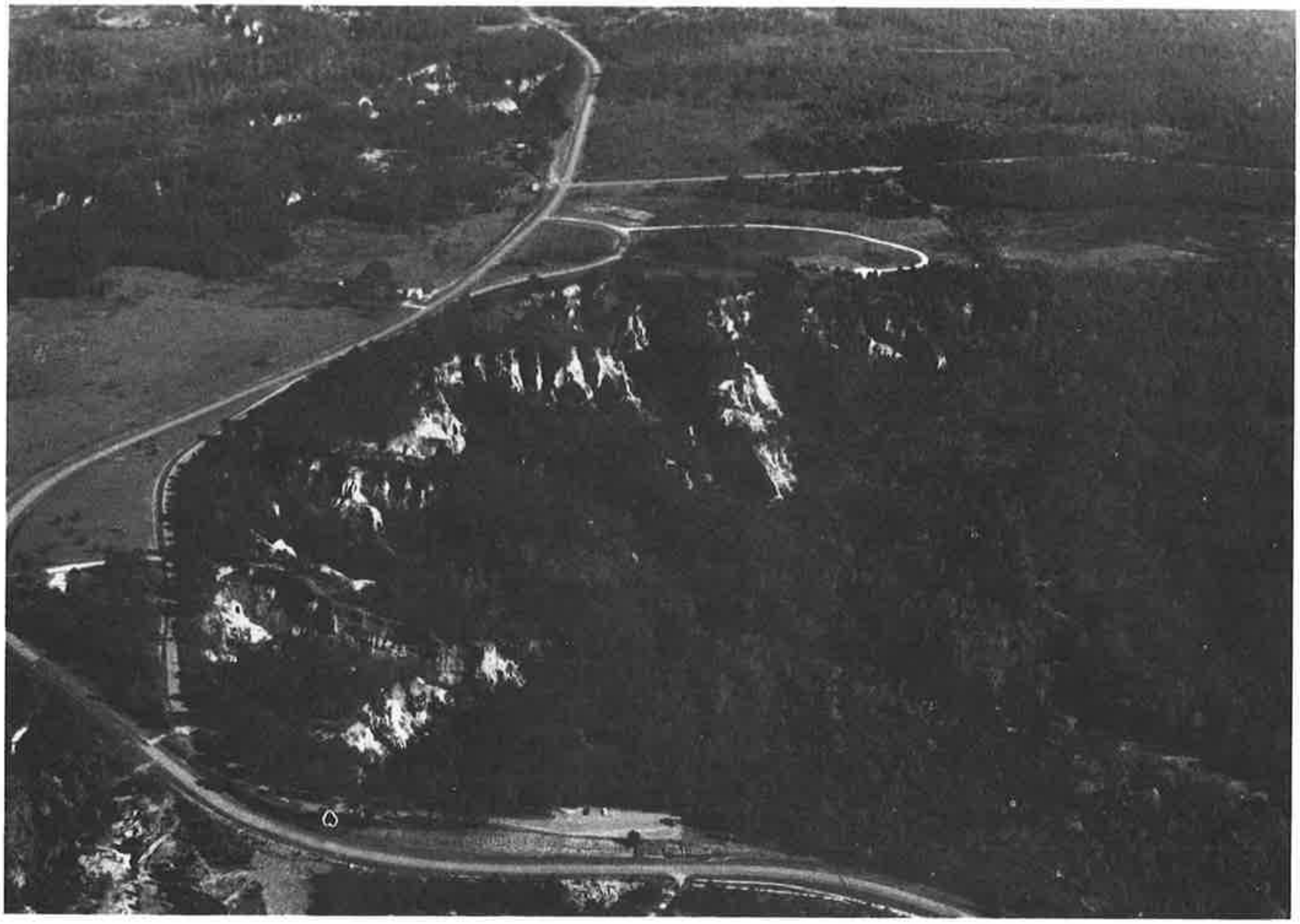

Figure 49. Aerial view of Providence Canyons State Park, showing erosional dissection pattern of area north and south of Georgia Route 39C. View generally to east; interpretative-center parking lot in foreground.

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