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DEPARTMENT OF MINES, MINING AND GEOLOGY

J. H. AUVIL JR., Director

STRATIGRAPHY, PALEONTOLOGY, AND ECONOMIC GEOLOGY OF PORTIONS OF PERRY AND COCHRAN QUADRANGLES, GEORGIA

BY

S. M. PICKERING JR.

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19 Hunter Street, S.W.
Atlanta, Georgia, 30334
404/522-7076

August 15, 1970

His Excellency, Lester G. Maddox
Governor of Georgia and
Commissioner Ex-Officio
State Division of Conservation
Atlanta, Georgia 30334

Dear Governor Maddox:

I have the honor to submit herewith Bulletin 81 of the Department of Mines, Mining and Geology entitled, "Geology of Portions of Perry and Cochran Quadrangles, Georgia," by Samuel M. Pickering, Jr., a member of this staff.

The report is an expansion of work done for a Master's thesis at the University of Tennessee and was partially supported at small expense by this Department.

The report covers work on rocks in middle-central Georgia just below the fall line in an area previously unreported in detail and should serve as an excellent guide to future workers in this area. Deposits of commercial interest such as cement-grade limestone, iron ore, high-silica sand, fullers earth clay, chemical-grade limestone, and road material are described, located and analyzed in this report. The stratigraphy developed in this work will be of inestimable value to water research in this area.

Very respectfully yours,

J. H. Auvil, Jr.

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INTRODUCTION

Location

The area described in this report covers approximately 250 square miles and includes portions of Pulaski, Houston, Dooly and Bleckley Counties, Georgia. The Ocmulgee River flows from north to south near the eastern edge of the area. Towns included are Hawkinsville, Hartford, Klondike, Hayneville, Grovania, Clinchfield, Elko, and Unadilla.

The area studied is located in the southern part of the Perry and the western part of the Cochran U. S. Geological Survey 15 minute Quadrangles (fig. 1). The portion of the area in the Perry Quadrangle lies between Big Indian Creek, Flat Creek, and the southern boundary of the map. The eastern portion of the area occupies the western one-third of the Cochran Quadrangle south of the Bleckley-Twiggs County line.

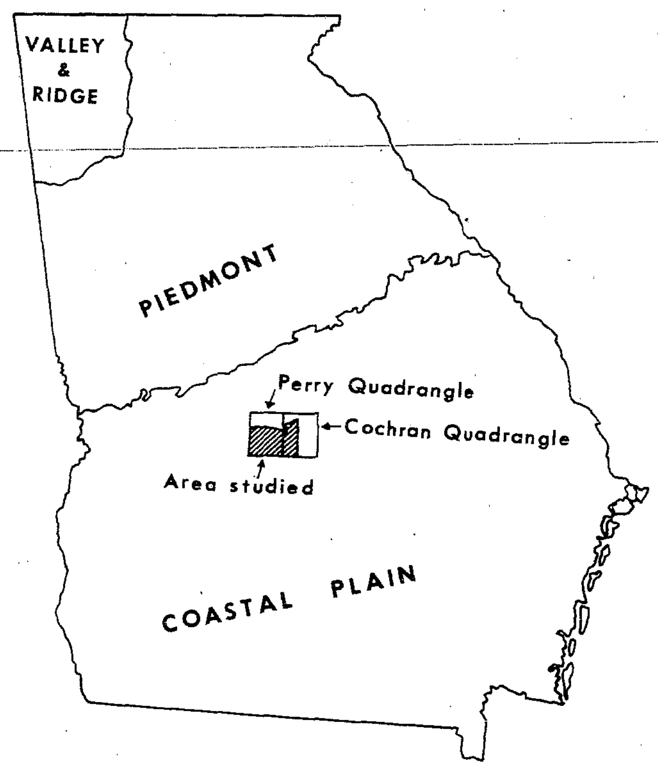

Figure 1. Location of Perry and Cochran Quadrangles and of area studied.

Purpose

The purpose of the investigation leading to this report was to solve problems resulting from past differences in stratigraphic interpretations and geologic mapping, and to outline the mineral and ground water resources of the area. In the past all geologic mapping in this portion of middle Georgia was by reconnaissance methods only, and the work was done by geologists who were using regional stratigraphic nomenclature over very large areas. The reconnaissance mapping has led to diverse interpretations of the classification of the rock units in the area. The resulting differences in geologic maps (fig. 2) contrast considerably with the large-scale mapping for this report (pl. 1). In order to identify and describe the stratigraphic units in a suitable manner, it was necessary to investigate the fossils in the formations mapped, resulting in considerable new paleontologic information included in this report.

The economic geology considered includes that relating to iron ore, agricultural and cement limestone, fuller's earth, silica sand, brick clay, and ground water.

Previous Work

The first geologic map of the Coastal Plain of Georgia with an extensive descriptive text was published in 1911 (Veatch and Stephenson, 1911). More up-to-date correlation and a different geologic map were offered by Cooke (1943). The most recent regional mapping on the Coastal Plain of Georgia was that of the Tertiary area by MacNeil (1947). LeGrand (1962) included geologic mapping of Houston County in his report on the Macon area. Fossil collections from the area of this thesis have been reported in various publications (Dall, 1916), (Cooke, 1943), (Richards, 1955, 1956), (Pickering, 1961).

Carver (1965, 1966), University of Georgia, has done work on the brick clay and the stratigraphy of Pulaski County.

A comparison of past geologic mapping in the area studied is shown in fig. 2.

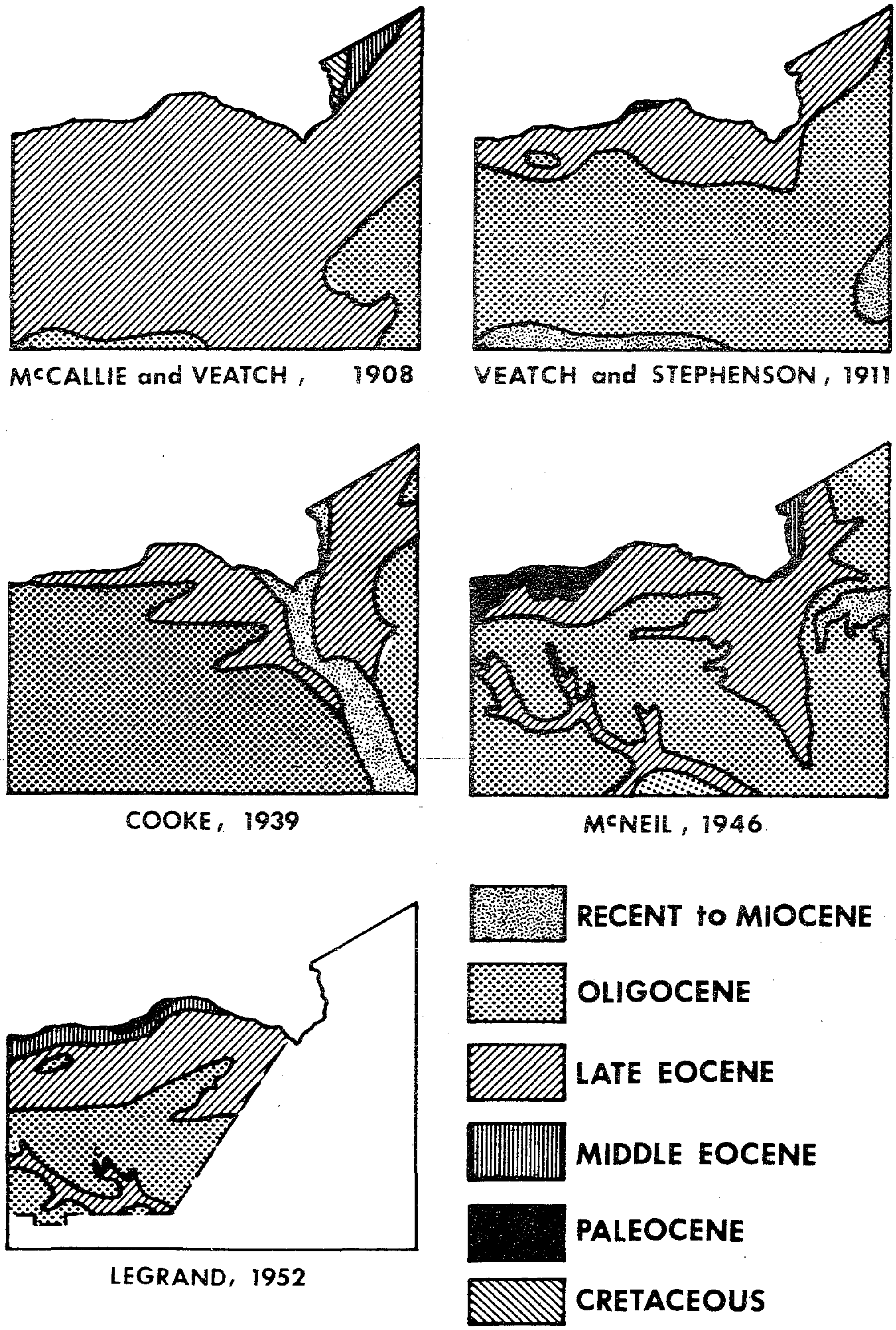

Figure 2. Previous geologic mapping of the area studied.

Acknowledgments

Much of the work for this report was done as a thesis toward the completion of the Master of Science degree at the University of Tennessee, under partial financial assistance by the Georgia Department of Mines, Mining and Geology. The writer is grateful for the assistance rendered by fellow staff members of the Department of Mines during the investigations described herein. A. S. Furcron, former Director of the Department of Mines, introduced the writer to the area and was a constant source of information and encouragement. J. H. Auvil, Department of Mines Director, supplied valuable data and advice on the economic geology of the area. James W. Furlow and William E. Marsalis, staff geologists, visited the area with the writer and assisted in stratigraphic interpretation. Staff geologist Martha A. Green kindly reviewed and proofed the manuscript.

S. M. Herrick, U. S. Geological Survey, answered innumerable questions concerning microfossils and stratigraphy. S. H. Patterson, U. S. Geological Survey, was most helpful in proofing and arranging the manuscript for publication.

R. E. McLaughlin, Department of Geology and Geography, the University of Tennessee, visited the study area, reviewed the manuscript in thesis form, and gave needed advice on paleontology, paleoecology, and biostratigraphy. Other members of the thesis committee, H. J. Klepser and L. T. Larson, offered helpful criticism during the completion of the thesis.

The writer is grateful to Carl Vardaman, artist, and to David Crawley and Tom Lemaster, draftsmen, for the fossil plates and maps included in this publication and to Judy Norris for composition of type copy for this manuscript.

Acknowledgement is made to the Clinchfield Penn-Dixie Cement Company and especially to B. B. Nall and J. G. Phillips for access to samples from Company exploration drill holes.

STRATIGRAPHY

General Discussion

The Perry and Cochran quadrangles are underlain by sedimentary rocks which dip gently southeastward. The contact of Eocene and Oligocene rocks is inclined 10 to 15 feet per mile to the southeast, a dip which is not measurable at a single outcrop. The uppermost Cretaceous sediments, which are not exposed in the area mapped, dip nearly 25 feet per mile as determined from elevation and depth information listed in logs of water wells (Herrick, 1961). The axis of a structure referred to as the Chattahoochee Anticline was illustrated by Sever (1965) to pass approximately through the center of the area investigated. Particular attention was given to the possibility that the dip of the rocks in the area investigated might reverse to the northwest or even to the northeast, but no such reversal was found. The conclusion follows that the Chattahoochee Anticline does not extend as far as the Perry-Cochran area discussed herein.

Physiographically, the area studied lies on the Dougherty Plateau and Tifton Upland (LaForge, 1915) of the Coastal Plain province of Georgia (fig. 3). The most important physiographic feature is a prominent north-facing escarpment extending approximately east-west across the northern portion of the area. This scarp has generally been regarded as a cuesta capped by the Ocala Limestone (Cooke, 1943; Connell, 1954). Detailed mapping (pl. I, in pocket) shows that the Ocala crops out at the base of the cuesta in the valley of Big Indian Creek and has disclosed that the escarpment is capped by the resistant Flint River Formation and a layer of unconsolidated Neogene undifferentiated clastics. Big Indian Creek and the other streams of the area flowing eastward are consequent streams whose trends were determined by the regional strike of the outcropping rock units.

Solution features occur throughout the area. Sinkholes resulting from solution of the original limestone of the Flint River Formation are evident on topographic maps by closed depression contours throughout the area underlain by that formation.

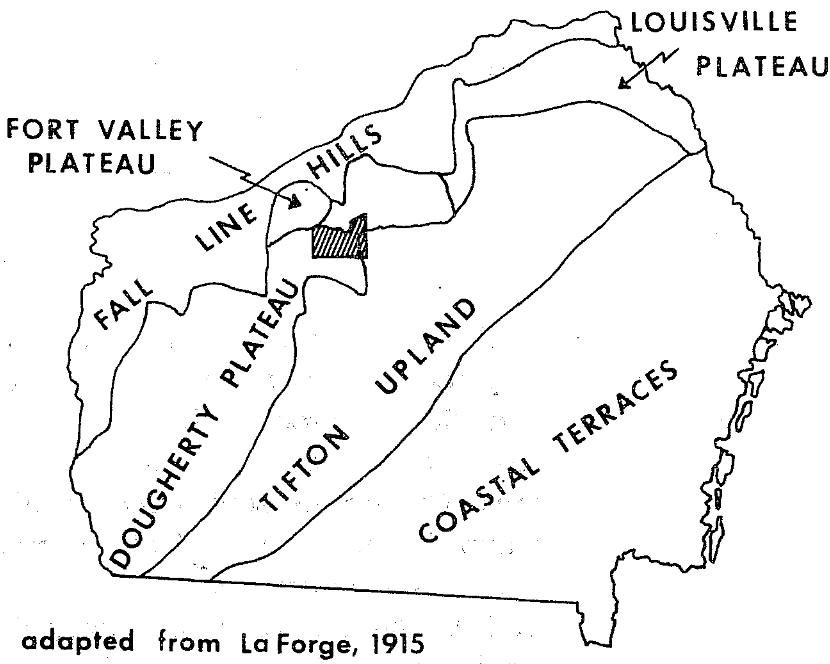

Figure 3. Physiography of the area studied on the Georgia coastal plain.

The formations in the area studied represent two transgression-regression cycles of marine, transitional, and terrestrial deposition. In general, the rocks are less clastic down dip away from the original shoreline. Owing to the presence of facies fossils which are not stratigraphically limited, some previous investigators have correlated units which are not comparable except for lithologic characteristics. The stratigraphic units used in the present study are described in detail in the following paragraphs.

McBean Formation

The Middle Eocene McBean Formation has been observed at only a few exposures in the area mapped, along drainage ditches in the new west quarry of the Clinchfield Penn-Dixie Portland Cement Company (fig. 5). These sediments are lithologically and biostratigraphically similar to the type McBean Formation of east Georgia. The author regards the top of the McBean in the study area as the top of the highest bed of micaceous, lignitic silt. Herrick (1961) referred to these sediments in the subsurface of Pulaski County as the Middle Eocene Lisbon Formation, an Alabama equivalent to the McBean.

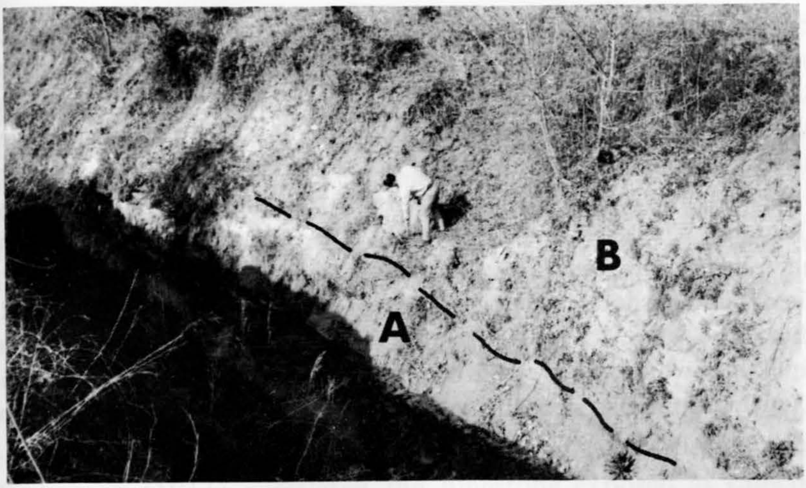

Figure 4. McBean Formation (A) overlain by Clinchfield Sand (B) in drainage ditch at locality 11.

Clinchfield Sand

Cooke (1943) correlated the sand beneath the Ocala Limestone at Clinchfield, Georgia, with the type Gosport Sand of Little Stave Creek, Alabama. MacNeil (in Furcron, 1944; MacNeil, 1947) continued the use of the term Gosport for sand beneath the Ocala throughout central Georgia as did LeGrand (1962), in the Macon area and Herrick (1961). Vorhis (1965) orally proposed a change in nomenclature for this unit from Gosport Sand to Clinchfield Sand. The writer has visited typical outcrops of the Gosport Sand at Little Stave Creek and Claiborne Bluff, Alabama, and agrees with Vorhis that a change in nomenclature is advisable. The type Gosport is a grey to tan, silty sand and underlies the Moody's Branch Marl, not the Ocala Limestone.

The Clinchfield Sand is a medium-grained, well sorted (fig. 4), poorly consolidated quartz sand. The sand is massive and no bedding or cross-bedding may be observed. Accessory minerals present are detrital carbonate, ilmenite, leucoxene, muscovite, hornblende, zircon, staurolite, epidote, and monazite. The total content of heavy minerals is less than one percent. The Clinchfield

Sand grades upward into the Ocala Limestone, through a zone of sandy limestone lenses and sand beds approximately five feet thick. In this report the top of the Clinchfield Sand is placed at the highest bed of unconsolidated sand. The author has observed the Clinchfield Sand in outcrop as far from the study area as Rich Hill, in Crawford County, and Irwinton, in Wilkinson County, Georgia. Wherever seen, lithology and top and bottom criteria have been consistent; therefore, formational status for the Clinchfield Sand is here suggested. Logs of water wells (Herrick, 1961) show the sand to be 10 to 20 feet thick, and it is of similar thickness where penetrated by 12 holes drilled by the Penn-Dixie Cement Company (in the vicinity of locality 10, pl.2). The log of a Penn-Dixie test hole presented here as figure 5.

Depth	Lithology	Formation
0- 8 ft.	Cream to light tan fossiliferous limestone, sandier at depth.	Ocala Limestone
8-24 ft.	Light tan fine grained fossiliferous sand with zones of abundant oyster fragments.	Clinchfield Sand
24-42 ft.	Light grey fine grained sand.	Clinchfield Sand
42-46 ft.	Grey micaceous, lignitic sandy fossiliferous silt.	McBean Formation
64-54 ft.	Blue-grey glauconitic silty clay.	McBean Formation

Figure 5. Log of test hole 11, Penn-Dixie Portland Cement Company, Clinchfield, Georgia. Elevation 273 ft.

The area underlain by Clinchfield Sand is characterized by rather flat, gullied topography. Big Indian Creek and several of its tributaries have cut through the Ocala Limestone and flow on the Clinchfield Sand. The flood plains are choked with loose sand, and the streams show a braided, meandering pattern. Reworked Clinchfield Sand forms dunes along Big Indian Creek at locality 5. The best exposure of Clinchfield Sand in the type area is in a series of pits in the north end of the old east Penn-Dixie Quarry

Ocala Limestone

Dall (1892) first described and named the Ocala Limestone from type outcrops in Marion County, Florida. Veatch and Stephenson (1911) correlated the limestone exposed at Clinchfield, Houston County, Georgia, with the rocks in Florida then regarded as belonging to the Vicksburg Group. Cooke (1915) demonstrated that the Ocala near Bainbridge, Georgia, belongs to the Jackson Group, and Shearer (1917) mapped it at Clinchfield and throughout the area studied as Jackson. Stose, Cooke, Crickmay, and Butts (1939) mapped the Jackson as having an eastern, or "Barnwell" facies, and a western, or Ocala facies. The area under investigation lies on the eastern edge of this Ocala facies. MacNeil (1947) reverted to mapping the entire Upper Eocene outcrop as "Jackson undifferentiated" and "indistinguishable Jackson and Oligocene." Herrick (1961) regarded the Ocala as a separate unit of the "Barnwell Formation" and considered the Ocala the downdip facies equivalent of the Barnwell. Herrick and Vorhis (1963) have divided the Ocala into upper and lower divisions. Their lower Ocala is the lower Jackson limestone which crops out in the central portion of Georgia. Their upper Ocala is a downdip subsurface facies equivalent of the younger Twiggs Clay and possibly the Cooper Marl.

The Ocala Limestone is a calcarenite to calcirudite composed largely of fragments of organic debris. The limestone is 89 to 97 percent calcium carbonate and the remaining 3 to 4 percent is chiefly clay and quartz sand. In fresh exposure the Ocala Limestone is composed of alternating beds of hard and soft limestone.

The soft limestone is a fossil hash of organic particles in a soft matrix of fine, calcareous silt. The hard limestone is a coquina of large fossil fragments in a partly recrystallized matrix. In weathered outcrop the entire formation develops case hardening and much of it is recrystallized.

Bedding in the Ocala Limestone is even and ranges from six inches to four feet in thickness. Cross-bedding in the soft limestone may be observed at several places at locality 11, the west quarry of Clinchfield Penn-Dixie Cement Company.

Minor solution cavities parallel to bedding and lined with crystalline calcite occur in the Ocala Limestone at location 23, the main Georgia Lime Rock Company quarry.

The top of the Ocala Limestone is regarded as the base of the lowest fuller's earth clay bed of the Twiggs Clay (fig. 6). The Ocala has been measured to be from 26 to 42 feet thick in the area studied.

Figure 6. Ocala Limestone (A) and Twiggs Clay (B) at the old Clinchfield Penn-Dixie Cement Company east quarry, locality 10.

The outcrop area of Ocala Limestone in the area under consideration is moderately sloping land below the steep valley walls of Big Indian Creek valley. Major solution features present elsewhere in the Ocala are lacking; the relatively impermeable overlying Twiggs Clay apparently has protected the Ocala from ground water solution in this area. The influence of the Twiggs Clay on the weathering of the Ocala is borne out by the extensive chertification and solution of the Ocala in southwest Georgia, where the Twiggs is missing.

Twiggs Clay

Outcrops of the clay overlying the Ocala in Georgia were first called Congaree Clay (Sloan, 1907). Veatch and Stephenson (1911) applied the South Carolina term Barnwell Sand (Sloan, 1907) to the Twiggs Clay and overlying red sands of uncertain age. Cooke and Shearer (1918) redefined the Congaree Clay as the Twiggs Clay from type outcrops at Pikes Peak in Twiggs County, Georgia. Cooke (1943) described outcrops of Twiggs Clay from across east Georgia and referred to them as the eastern facies of the Jackson. In this same publication, Cooke described Twiggs Clay beneath the Ocala Limestone at Clinchfield. Numerous test holes drilled at Clinchfield in connection with the present work disclosed that the Clinchfield and McBean Formations underlie the Ocala (fig. 5).

Many authors have placed the Twiggs Clay in member status in the Barnwell Formation (Cooke and Shearer, 1918; Cooke, 1943; MacNeil, 1947; Herrick, 1961; Herrick and Vorhis, 1963). However, the writer has observed the Twiggs Clay to be lithologically distinct in outcrop and subsurface for more than 800 square miles. In this area, the easily distinguished top and bottom of the unit reflect obvious lithologic changes. For these reasons the writer recommends the change of the rock unit status of the Twiggs Clay from that of member to that of formation.

The Twiggs Clay is a green-gray to blue-gray, blocky, hackly clay. The principal clay mineral present is montmorillonite; and at fresh exposures, there is usually enough calcium carbonate present as microfossils and silt to clay size particles to effervesce with 10 percent hydrochloric acid. Sandy and silty zones in the clay are common at localities 12 and 24. The clay in outcrop is much broken with typical hackly fractures of no particular orientation (fig. 7). These fractures are commonly coated with manganese and iron oxides.

Figure 7. Outcrops of Twiggs Clay may be recognized by characteristic irregular fractures.

The Twiggs Clay typically weathers to a fluffy, light tan soil. Distinctive light gray to tan opaline chert nodules mark the soil derived from the lower portion of the Twiggs. Weathering and resultant slump is so severe that natural outcrops of the Twiggs Clay away from major streams have not been observed, although road cut and dam construction exposures are common.

The top of the Twiggs Clay is considered to be the top of the highest clay bed with an uneven, hackly fracture. The formation has been measured at 30 to 58 feet thick in the area mapped.

The Twiggs Clay outcrop belt is one of active erosion. The clay weathers to an unstable, gently rolling hillside; and gullying and soil creep are very active where even moderate slope is present. Ground water moves along the top of the relatively impermeable clay, and springs commonly mark the top of the formation.

Cooper Marl

The Cooper Marl in the area mapped is rather resistant to erosion and underlies hummocky terrain. The marly limestone weathers slowly and is quite coherent. Thus, high banks and bluffs of relatively unweathered Cooper Marl are prominent along major streams which cut into the unit (fig. 8). Away from streams the

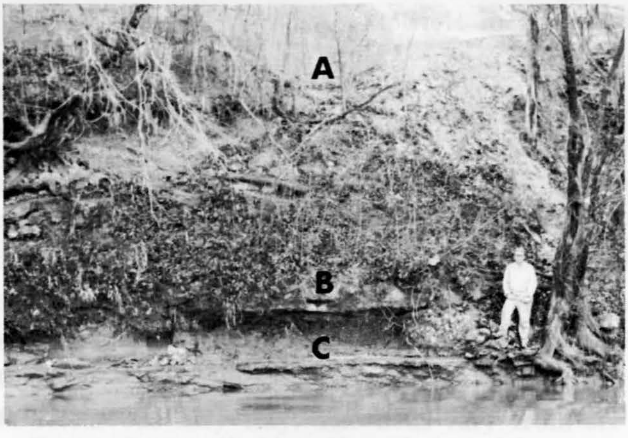

Figure 8. Cooper Marl upper marl (A) and lower limestone (B) overlies Twiggs Clay (C) at Taylor's Bluff (locality 19) on the Ocmulgee River.

Cooper is covered by talus and slump from the topographically more prominent Flint River Formation, and outcrops are not common. Downdip, in the southern part of the area studied, the Cooper is more calcareous, and small sinks and solution slump structures due to volume change in weathered Cooper Marl are evident.

The Cooper Marl was named by Tumoney (1848) from type exposures along the Cooper River in South Carolina. Cooke (Stose, Cooke, Crickmay, and Butts, 1939) mapped the Cooper along the length of the escarpment south of Clinchfield and as a patch in East Georgia. Cooke (1943) recognized the unit in Jenkins County in East Georgia and in Bleckley, Pulaski, and Houston Counties. In his publication, Cooke placed the Cooper, which he regarded as a formation, within the Jackson "Formation." Connell (1955) stated that he visited Cooke's exposures of Cooper Marl and that he was convinced that the Cooper does not exist in Georgia. LeGrand (1962) included this formation as part of sediments of Jackson age and did not differentiate it as a separate unit. Herrick (1961) and Herrick and Vorhis (1963) recognized the Cooper Marl in the subsurface of eleven counties in central and eastern Georgia. Carver (1966) describes the Cooper Marl from several of Herrick's (1961) well logs. The writer finds the Cooper marl in the study area to be quite similar lithologically to exposures of Cooper near the type locality in South Carolina.

The Cooper Marl was accorded formational status by Cooke (1943) and is used in this sense in the present report. The formation is 0 to 37 feet thick in the area studied.

Byram Formation

The Byram Formation crops out in the area mapped only in the southeastern portion of the Cochran quadrangle along the west bank of the Ocmulgee River. There the formation is almost continuously exposed in a series of low bluffs. The Byram Formation was named for type exposures along the river near the town of Byram, Mississippi. Brantley in 1916 described the exposures discussed in the present report and referred to them quite accurately as Glendon Limestone but cited no paleontologic evidence for this correlation. In 1962 Herrick and Sever described the Byram Formation in a well in Coffee County, Georgia, where it is present as a unfossiliferous tan saccharoidal dolomite. The first paleontological evidence for the presence of the Byram Formation in Georgia was obtained from the above mentioned exposures along the west bank of the Ocmulgee River in the Cochran quadrangle, Georgia (Herrick, Pickering, and Sachs, 1966). The Byram Formation has never before been mapped in outcrop in Georgia.

Herrick, Pickering, and Sachs in 1966 divided the Byram Formation in its Ocmulgee River outcrop area in the Cochran quadrangle into Units A and B. The upper unit, or Unit A, is

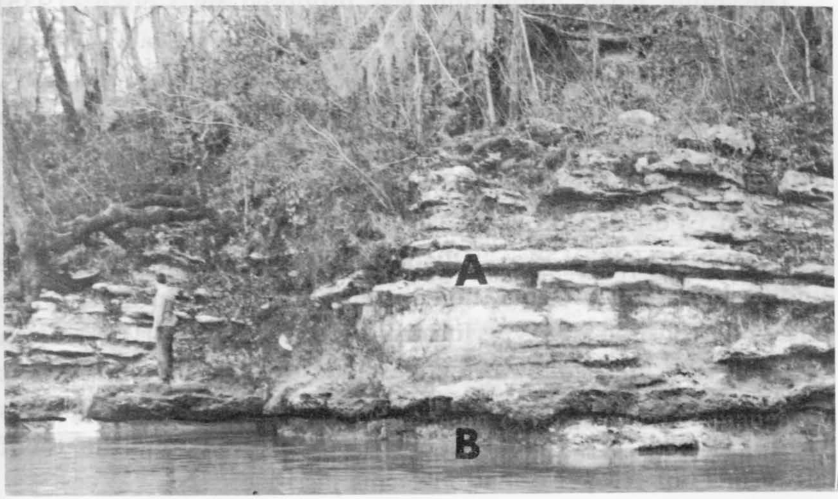

Figure 9. Unit A (shown by A) overlies Unit B (at B) of the Byram Formation at locality 38 on the Ocmulgee River.

composed of alternating beds of light tan crystalline limestone and tan calcareous silty clay. The beds vary from six inches to three feet in thickness. The lower unit, or Unit B, is a massive white to pale cream plastic chalk which is a very pure calcium carbonate. The total thickness of the two units is approximately 40 feet. The top of the Byram Formation in the area studied is regarded as being the top of the highest limestone bed beneath the chert of the Flint River Formation. The rather limited extent of the Byram Formation outcrop area in the mapped portions of the Perry and Cochran Quadrangles is shown on Plate I. Outcrops of Byram above the Cooper Marl were not observed north or west of Hawkinsville; it is inferred that erosion or solution has removed these sediments from most of the area mapped, or that the Byram was deposited only in the southeastern corner of the area. The boundary between the Cooper Marl and the Byram Formation is conformable, and appears to represent almost continuous deposition. Where the Byram is not present, the top of the Cooper is cut by an unconformity.

Flint River Formation

The Flint River Formation was proposed by Cooke (1935) for deposits of chert and red clay above the Ocala Limestone along the Flint River between Hales Landing and Red Bluff, Georgia. MacNeil (1947) and LeGrand (1962) prefer the term Suwannee Limestone for the rocks Cooke refers to as Flint River. The Suwannee is an Oligocene limestone of Florida and extreme southern Georgia. Herrick (1961), Pickering (1961), and Herrick and Vorhis (1963) use "Oligocene residuum" or "Oligocene undifferentiated" to avoid the Suwannee-Flint River problem. The author has visited the type locality of the Flint River Formation and can find no distinction between the residual Oligocene chert exposed there and the chert exposed in the study area. Cooke's (1935) original description fits the unit quite well, and the use of his term Flint River Formation seems justified.

The Flint River Formation in outcrop is composed of boulders and dornicks of chert (fig. 10); nodules, geodes, and large concretionary masses of limonite, hematite, and goethite (fig. 11); iron- and chert-cemented sandstone and conglomerate; stiff to plastic varicolored clay; and manganiferous sand. No carbonate mineral was observed at outcrops of the Flint River Formation in the area mapped.

The silica in the Flint River Formation occurs as tripoli, chalcedony, porcelaneous chert, and silicified breccia. A residual origin of the chert due to silicification of weathering limestone is indicated by the preservation in silica of such features as originally calcareous megafossils and microfossils; oolites; pseudomorphs of microscopic carbonate rhombs; and preserved solution cavities.

Figure 10. Bedding preserved from the original limestone of the Flint River. Formation is exposed in southwestern Houston County.

Residual chert from the Flint River Formation does not have the black exterior and chalky white interior of much of the residual chert from the Ocala Limestone or the nodular shape and soft, opaline nature of chert from Twiggs Clay.

The iron enrichment of the Flint River Formation is secondary. The iron was probably precipitated from the ground water which dissolved the original limestone. The precipitation was induced by the change in pH occurring as calcium carbonate became dissolved in ground water and replaced by silica. Thus, limonitic geodes as seen at localities 28, 30, 32, and 33 and crusts of radiating fibrous needles of goethite lining solution cavities in chert were formed. In general, all weathering surfaces at the top of the original limestone became coated with encrustations of limonitic material. The iron enrichment is thought to represent a horizon of abrupt vertical change from low to high pH at the level of the water table during the weathering of the original Flint River Formation limestone.

Figure 11. Iron ore (A) overlies chert (B) of the Flint River Formation at an exposure in western Pulaski County.

The cherty and limonitic residuum from the Flint River Formation in the southeastern portion of the area studied is free of quartz sand. To the northeast a more sandy facies is evident. At localities 1, 2, and 14 the formation is represented by iron-cemented sandstone and at localities 3 and 4 by chert-cemented sandstone and conglomerate.

There is an extensive bed of manganiferous sand and clay at the base of the residuum of the Flint River Formation. The sand contains bedded manganese which may be of primary origin.

The Flint River Formation, due to its residual nature, varies considerably in thickness. Maximum thickness measured is 46 feet. The Flint River Formation was probably 50 to 100 feet thick before weathering and solution.

The outcrop area of the Flint River Formation holds up the steepest portions of the rather gently sloping valley sides in the area studied. An escarpment of the Flint River Formation just south of Clinchfield is the most prominent physiographic feature of the area. In the southern portion of the area mapped, the Flint River outcrop belt is pitted with sink holes which are evident on topographic maps but difficult to discern in the field.

Neogene Clastics

Cooke (1935) in his original description included younger sand, clay, and conglomerate beds in his Flint River Formation. He later (1943) tended to exclude these clastic sediments from the formation, and the present author has followed this policy (Pickering, 1961). Various writers have placed these relatively young clastic sediments into units named Lafayette, Altamaha, Hawthorne, and Alum Bluff. The only clues to their age is their superposition over the weathered upper Oligocene Flint River Formation and from the anomalous Potassium-Argon age determination of more than 30 million years from a tektite found on the material in nearby Dodge County (Furcron, 1961). The sediments are lithologically similar to blanket sands and clays assigned to several geologic units of the Coastal Plain. Probably all parts of the Neogene from Miocene to Recent are represented by the sediments. Herrick (1961) refers to this material simply as residuum.

The Neogene clastic sediments of the area studied are predominantly tan, brown, or red sand, clay, and gravel characteristically bleached to light tan at the surface. Cross-bedding and channel-filling commonly occur near the base of the unit.

The sediment is coarser and more poorly sorted near its base. Well rounded pebbles of vein quartz are common just above the unconformable contact with the Flint River Formation (fig. 11). The Flint River Formation was weathered very nearly to its present condition before deposition of the Neogene clastics. This is demonstrated at locality 22 where the unconformable contact between the formations cuts through the residual iron enrichment zone of the Flint River Formation and fragments of goethite geodes are present in the Neogene sediments. The Neogene sediments vary greatly in thickness; they have been measured to be as much as 68 feet thick.

The Neogene clastic material of the area studied caps the interstream divides, which are characterized by gently rolling upland with few gullies.

BIOSTRATIGRAPHY

General Discussion

Fossil species observed to be characteristic of the formations mapped and studied are listed (Table I) and discussed in the following sections. Illustrations of selected species are included in the appendix.

TABLE I - BIOSTRATIGRAPHY

vr - very rare
r - rare
c - common
a - abundant
va - very abundant

	McBean	Clinchfield	Ocala	Twiggs	Cooper	Byram	Flint River
VERTEBRATES							
Lamna appendiculata		c	r	c	r		
Carcharias cuspidata	r	a	r	a	c		
Galeocerdo latidens		a	r	c	r		
Sphyrna sp. ?		r					
Carcharodon megalodon		r	vr				
Myliobatis sp.	r	a	c	a	a		
Pristis sp.		vr					
Basilosaurus sp. ?		r	vr	vr			
Eosiren sp. ?		c	r	r			
ECHINOIDS							
Phyllacanthus mortoni		r	c				
Gagaria mossomi							r
Gagaria chickasawhay						vr	
Oligopygus wetherbyi			vr				
Clypeaster rogersi						a	
Clypeaster cotteaui							r
Periarchus lyelli	vr	c	r				
Periarchus lyelli pileus-sinensis		c	a	c			
Periarchus quinquefarius					c		
Periarchus quinquefarius kewi					r		

TABLE I - BIOSTRATIGRAPHY (cont.)

vr - very rare
r - rare
c - common
a - abundant
va - very abundant

	McBean	Clinchfield	Ocala	Twiggs	Cooper	Byram	Flint River
ECHINOIDS (cont.)							
Laganum ocalanum			c				
Laganum floridanum		vr	c				
Wythella eldridgei			vr				
Cassidulus gouldi							c
Paraster armiger			vr				
Paraster americanus					r	vr	
Macropnuestes mortoni		vr	r				
Brissopsis blanpiedi					vr		
PELECYPODS							
Glycymeris cookei							c
Glycymeris suwaneensis							r
Pecten suwaneensis							r
Pecten deshayesi ?	vr						
Amusium ocalanum		vr	r				
Chlamys spillmani clinchfieldensis		c	a	c			
Chlamys cocoanus					c		
Crassostrea gigantissima ?		a	c				
Ostrea sellaeformis	vr						
Gryphaeostrea plicatella					c		
Ostrea mauricensis						vr	r
Lima halensis							r
Crassatellites paramesus							va
Phacoides wacissanus							c
Venus (Chione) bainbridgensis							c
GASTROPODS							
Agaronia alabamensis	r						
Xenophora humilis						c	
Lyria mansfieldi						vr	
Cerithium cookei						c	

TABLE I - BIOSTRATIGRAPHY (cont.)

vr - very rare
r - rare
c - common
a - abundant
va - very abundant

	McBean	Clinchfield	Ocala	Twiggs	Cooper	Byram	Flint River
CORALS							
Flabellum cuniformae				r	a		
Trochocyathus sp.							r
FORAMINIFERA							
Spiroplectammina mississippiensis					r	r	
Textularia subhauri					r		
Textularia hockleyensis				c			
Textularia adalta					c	c	
Gaudryina jacksonensis					r		
Karreriella sp.					vr		
Liebusella byramensis					r	r	
Quinqueloculina vicksburgensis						r	c
Quinqueloculina monroei						r	
Pyrgo sp.					vr		
Pyrgo byramensis						r	r
Uvigerina vicksburgensis						r	
Uvigerina jacksonensis					c		
Angulogerina byramensis						c	
Discorbis assulata				r	r		
Discorbis arcuatocostata						c	
Mississippina monsouri						c	
Valvulineria jacksonensis			c	c	a		
Valvulineria paucilocula						c	
Gyroidina vicksburgensis						c	
Eponides jacksonensis				r	r		
Eponides advena						c	
Eponides byramensis					r	c	
Pararotalia parva						c	
Pararotalia mexicana var.							a
Siphonina sp.	r						
Siphonina byramensis					r	a	

TABLE I - BIOSTRATIGRAPHY (cont.)

vr - very rare
r - rare
c - common
a - abundant
va - very abundant

	McBean	Clinchfield	Ocala	Twiggs	Cooper	Byram	Flint River
FORAMINIFERA (cont.)							
Siphonina jacksonensis				r	c		
Cibicides americanus	c		r	c	c	r	
Cibicides mississippiensis				c	r		
Cibicides lobatalus				r	a		
Cibicides planoconvexus	r			c	c	r	
Cibicides westi	r						
Planulina byramensis						c	
Planulina cocoaensis				vr	r		
Planulina cooperensis					c		
Planorbulina mediterranensis						r	
Lepidocyclina ocalana		r	a	vr			
Lepidocyclina undosa							a
Lepidocyclina mantelli						a	
Nummulites floridensis		vr					
Robulus alato-limbatus			r	r	c	r	
Robulus alatolimbatus			r		c	r	
Marginulina cocoaensis					c		
Dentalina jacksonensis					r		
Dentalina cocoaensis					c		
Nodosaria latejugata					c		
Lagena laevis					c		
Lagena hexagona				vr	r		
Guttulina problema					r		
Globulina gibba globosa					c		
Nonion advenum	r		c	a	vr		
Nonion inexcavatum	r		r	r			
Nonion vicksburgensis						c	
Hantkenina alabamensis					vr		
Bulimina jacksonensis					c		
Bolivina jacksonensis				r	c	r	

TABLE I - BIOSTRATIGRAPHY (cont.)

vr - very rare
r - rare
c - common
a - abundant
va - very abundant

	McBean	Clinchfield	Ocala	Twiggs	Cooper	Byram	Flint River
FORAMINIFERA (cont.)							
Reusella eocena		c					
Reusella oligocenica						r	
Reusella byramensis					r	c	a
Asterigerina subacuta						c	
Alabamina mississippiensis						c	

McBean Formation

The oyster, *Ostrea sellaeformis*, occurs near the top of the McBean Formation at the only outcrop observed. This oyster is regarded as being characteristic of Middle Eocene sediments wherever found (Veatch and Stephenson, 1911) (Cooke, 1943). The foraminifer *Cibicides westi* was found in drill cuttings from several of the Clinchfield Penn-Dixie Cement Company test holes by Herrick. It was found in material from the outcrop in the ditch at locality 11 by the author. *Cibicides westi* is regarded as being characteristic of Middle Eocene sediments wherever found (Herrick, 1961; Herrick and Vorhis, 1963).

Clinchfield Sand

The Clinchfield Sand in the area under consideration contains a megafauna very similar to that of the Ocala Limestone. The echinoids *Periarchus lyelli*, *P. lyelli pileus-sinensis*, and *Laganum floridanus* have been observed in this unit, generally in the limy beds at the top. The characteristic Ocala pecten *Chlamys spillmani clinchfieldensis* is common locally in the Clinchfield, generally in the more calcareous portions. An oyster which Stenzel (personal communication) identified as *Crassostrea gigantissima* occurs at the top of the Clinchfield but not in the overlying Ocala. Shark, stingray, porpoise, whale, and sawfish teeth, along with whale and manatee bones are abundant in the Clinchfield at localities 9 and 10.

The microfauna of the Clinchfield Sand is presently being studied by S. M. Herrick, U. S. Geological Survey, from samples provided by the author; a Moodys Branch equivalence for the Clinchfield Sand has been suggested by Herrick (personal communication, 1966). The presence of *Periarchus lyelli* indicates possible correlation with the *Periarchus lyelli* zone of the Moodys Branch Marl of peninsular Florida (Toulmin, 1955).

As noted in a previous section, Clinchfield Sand has been regarded without proof as being of Claiborne age, the equivalent of the Gosport Sand of Alabama (MacNeil, 1946; LeGrand, 1962; Herrick, 1961). However, both the similarity of the megafossils observed in the Clinchfield to those of the Ocala Limestone of Jackson age and the resemblance of the microfauna to that of the Moodys Branch Marl indicate a Jackson age for the Clinchfield.

Ocala Limestone

Fragments of a regular echinoid resembling *Phyllacanthus mortoni* have been observed at locality 11 near the base of the Ocala. This echinoid has also been observed in the Ocala at Lee County, Florida (Cooke, 1941).

Periarchus lyelli pileus-sinensis is very common in the Ocala at many outcrop localities (fig.12). This echinoid is common in the Ocala Limestone of Florida, Alabama, and Georgia (Cooke, 1941).

Figure 12. *Periarchus lyelli pileus-sinensis* in Ocala Limestone at locality 11.

The echinoid *Wythella eldridgei* was found at locality 11. It has not previously been found in Georgia north of Dougherty County. It is considered to be characteristic of the Ocala Limestone (Cooke, 1959). Typical Ocala pelecypods encountered at many localities in the study area are *Chlamys spillmani clinchfieldensis* and *Amusium ocalanum*. The large foraminifer *Lepidocyclina ocalana* is abundant at most outcrops and has frequently been mentioned in the literature as being characteristic of the Ocala.

The very large irregular echinoid *Macropneustes mortoni* is relatively common in fragmented form at most Ocala outcrops; one intact individual was recovered at locality 11. This echinoid has been found only in the Ocala Limestone of Florida, Georgia, and Alabama (Cooke, 1959).

Twiggs Clay

Foraminifera found in the Twiggs Clay in the study area differ from those in the underlying Ocala Limestone and the overlying Cooper Marl. The presence of the Twiggs Clay of *Nonion advena* and *Textularia hockleyensis* is the chief difference.

The irregular echinoid *Periarchus lyelli pileus-sinensis* occurs in limestone beds in the Twiggs Clay at localities 6, 12, and 24. This echinoid has been noted by the author from limestone beds in the Twiggs Clay at outcrops across the eastern part of Georgia.

Cooper Marl

The foraminifera assemblage of the Cooper Marl is very distinctive. Some of the representative forms common at most outcrops of the Cooper Marl sampled are: *Planulina cooperensis*, *Marginulina cocoaensis*, *Siphonina jacksonensis*, *Dentalina jacksonensis*, *Bolivina jacksonensis*, *Liebusella byramensis*, *Uvigerina jacksonensis*, and *Bulimina jacksonensis*.

Cooke and MacNeil (1952) based a change in age of the Cooper Marl in South Carolina from Eocene to Oligocene on the presence of the pelecypod *Chlamys cocoana*. This pecten is abundant at most outcrops of the Cooper Marl in the area studied and is present in the Red Bluff Formation of early Oligocene age in Alabama (Cooke, 1952).

The echinoids *Periarchus quinquefarius* and *P. quinquefarius kewi* occur in the Cooper Marl at localities 7, 13, and 25. These echinoids are known otherwise only from the Sandersville Limestone of east Georgia. The exact age of the Sandersville is not known, and the presence of this unusual echinoid may provide a means of establishing correlation with the Cooper Marl.

The echinoid *Paraster americanus* may be found at localities 16 and 17. This species has not been previously encountered in the Cooper Marl; it occurs in Vicksburg (Middle Oligocene) sediments of Mississippi (Cooke, 1942; Clarke and Twichell, 1915).

The echinoid *Brissopsis blandpedi* also occurs at localities 16 and 17 and has not been noted from Georgia before. It is known only from the Glendon Limestone of Middle Oligocene age in Mississippi (Cooke, 1942).

BYRAM FORMATION

The first biostratigraphic evidence for the presence of the Byram Formation in Georgia was obtained from the west bank of the Ocmulgee River at locality 33 (Herrick, Pickering, and Sachs, 1966). The correlation of these sediments with the Byram Formation in Mississippi was based primarily on this work. Of the 77 species of foraminifera identified from these sediments at locality 33, 58 are listed in the literature as occuring in the Byram Formation in Mississippi. Also the irregular echinoid *Paraster americanus*, which was found in Unit B, occurs in the Mint Spring member of the Byram Formation in Mississippi. The writer has noted a similar suite of fossils from the type locality of the Jacksonboro Limestone of Screven County, Georgia (Dall and Harris, 1892), and correlation with this unit is here suggested.

Flint River Formation

Foraminifera assemblages of the Flint River Formation may be distinguished from those of the Cooper Marl and the Byram Formation in the area studied by the presence of abundant miliolids (*Quinqueloculina* and *Pyrgo*) and *Pararotalia mexicana var*. These forms are characteristic of the Flint River Formation in Georgia (Herrick, personal communication, 1966).

Pecten poulsoni, present in most Flint River Formation outcrops in the area mapped, is also found in Flint River Formation outcrops at Bainbridge, Georgia (Dall, 1916).

Glycymeris cookei and *G. suwannensis* are present at all major outcrops of the Flint River Formation in the area studied and have been noted from the Flint River Formation of southwest Georgia (Dall, 1916).

The regular echinoid *Gagaria mossomi* was observed at localities 16 and 17. This echinoid has previously been found in Florida in the Upper Oligocene Suwannee Limestone (Cooke, 1941).

The irregular echinoid *Cassidulus gouldi* is common at almost all outcrops of the Flint River Formation. The Flint River Formation of central and west Georgia and the Suwannee Limestone of Florida contain *Cassidulus gouldi* in abundance (Cooke, 1943).

Neogene Clastics

The Neogene clastic sediments of the area mapped are not generally fossiliferous, but a few fragments of oysters were found in the purple clay included in these rocks at locality 31. The fragments cannot be further identified. Since they are stained and enclosed in sandy clay near the base of the unit, it can be concluded that they are fossil remains rather than recent exotic material.

PALEOECOLOGY

McBean Formation

The carbonaceous nature of the top of the McBean Formation and the presence of plant fossils and oysters indicate that the environment of deposition was probably quite near shore, and very possibly, in brackish water conditions. The abundant glauconite encountered further down in the formation in the test holes drilled at Clinchfield is an indicator of reducing conditions.

Clinchfield Sand

The environment of deposition of the Clinchfield Sand is one of high energy. The quartz grains are abraded and rounded and are rather well sorted. Fossil fragments in the sand are likewise broken and abraded. The less resistant minerals of the heavy mineral suite, such as feldspar and hornblende, have been weathered and somewhat altered.

The formation is more limy near its upper contact, and there are beds of limy sandstone near the base of the overlying Ocala Limestone. These beds are characterized by their extensive large oyster assemblages, indicating a shallow water environment. Many of the oysters are scattered at random through the sediment with little orientation of the separate valves. Broken shells are more common than whole ones. At locality 10, on the west side of the Clinchfield Penn-Dixie Portland Cement Company silica pit, "reef-like" accumulations of articulated oysters in their growth positions are encountered. Associated with these oyster beds are abundant small pelecypods (*Cardium*, *Venericardia*., *Glycymeris*, and others). These pelecypods are also often articulated.

The fauna of the limy sandstone beds represents a benthonic biotic community with few exotic elements. Some individuals have been drilled by boring gastropods. A general killing of the fauna appears to have resulted from the silting episode which provided the succeeding sedimentary cover. Where a lithologic change indicates the introduction of more favorable environmental conditions, as at the base of the limestone beds, an abundance of species is present.

Ocala Limestone

The Ocala varies from a calcisiltite to a calcirudite and is composed predominantly of broken bryozoan fragments. This sort of clastic accumulation represents a high energy environment of strong bottom currents. Some portions of the calcirudite are quite winnowed and well sorted, and there is no fine matrix surrounding the coarse fossil fragments. Commonly, however, a matrix of silt-size carbonate particles occurs in the Ocala. No unfragmented bryozoa have been observed in living position in the Ocala.

Almost all the fossil material in the formation appears to have been transported from original living positions by strong bottom currents. The large, flat echinoids occur in sedimentary concentrations in large numbers in all orientations The pectens are seldom articulated and are buried at all angles to bedding. Their hinge areas are seldom unbroken. The coin-sized, large foraminifera have been winnowed into helter-skelter masses and are often fragmented. Large manatee, whale, and crocodile bones are usually whole, probably due to their greater strength.

Usually, the faunal elements observed in the Ocala Limestone are clearly exotic. The remains seem not to have moved a great distance for they are little abraded. Possibly the Ocala in the area studied represents a region of accumulated animal debris from nearby banks and reefs. The Ocala is a very extensive formation, and paleoecological work on a larger scale is needed.

Twiggs Clay

The typical argillaceous portions of the Twiggs contain no megafossils, but articulated ostracod and unfragmented foraminiferal shells are common. Small pelecypods were observed at locality 11 with bright color patterns, indicating a photic, shallow water environment. The clay is thick-bedded and indicative of quiet, low energy, bottom conditions with rapid sedimentation. Such conditions do not favor prolific bottom life. Some of the microfossils may represent forms whose remains accumulated as sediments from water zones above the bottom. For others, death probably resulted from silting and rapid burial.

Cooke (1943), LeGrand (1962), and King (1962) stated that the Twiggs Clay is a bentonite or a weathered volcanic ash. The clay is a mixture of the clay mineral montmorillonite with silt-size particles of calcium carbonate, mica, and quartz. Foraminifer tests, which are abundant in the sediment, are generally remarkably well preserved. The writer finds it most difficult to believe that the sediment was once a volcanic ash embedding consistently abundant benthonic foraminifers or that the ash could have weathered so completely as to destroy any glass and volcanic minerals and leave the delicate hyaline foraminifer tests intact and shiny. No textural or structural features suggesting ash deposition were observed in the field or the laboratory. Numerous samples of Twiggs Clay from many localities were washed, screened, and examined by the author for microfossils; no glass shards were observed. In the writer's opinion, the Twiggs Clay was precipitated as colloidal particles formed by the action of salt water on normal terrestrial clay minerals.

There are limestone beds in the Twiggs Clay which represent a reef-like environment. Echinoid shells encountered in these beds lie upright in a life position. Corals occur attached to each other and to pelecypod masses. Pelecypods are articulated, and the larger foraminifera lie flat. No fragmentation of fossils in these beds has been observed. These reef-like beds of limestone may end abruptly in massive Twiggs Clay.

Cooper Marl

The Cooper Marl shows more facies change in the area studied than any other exposed formation. Thus, the fauna of the Cooper is more varied than the fauna of other formations studied.

The echinoid *Periarchus quinquefarius* is found in the Cooper Marl at its updip edge, at localities 7 and 13. The formation at locality 5 is a very glauconitic silt with white calcareous clay pockets which are highly fossiliferous. The echinoid tests occur as broken and whole individuals in the pockets and in the silt. At locality 13, *Periarchus quinquefarius* is found in sandy limestone with little clay. Six miles downdip at locality 25 there is another occurrence of this echinoid, in rock similar to that at locality 6, but just off the flank of a calcarenite reef-like structure. *Periarchus quinquefarius* has been observed in the Cooper Marl of central Georgia and east Georgia and the Sandersville Limestone of east central Georgia in fine-grained calcarenite. The occurrence of this form in such varied lithology, and the fact that it has not been found in any other formation, indicate that *Periarchus quinquefarius* may be a good fossil for correlation between the Sandersville and the Cooper.

Chlamys cocoana, a small pelecypod, is common at most outcrops of Cooper Marl throughout the area, regardless of facies. Since it is also found in the Red Bluff Clay of Alabama and is restricted to the Cooper and Red Bluff, this fossil may offer reasonable correlation with the Alabama section.

The coral *Flabellum cuniformae*, which has been cited often as a guide fossil to the Late Eocene, is found in the Cooper Marl at all outcrops of rather pure calcarenite. Apparently it could tolerate no silt or clay suspended in the water. *Flabellum cuniformae* occurs throughout the Upper Eocene-Lower Oligocene of the Southeast wherever clean calcarenite occurs. For this reason the use of this fossil for correlation seems unsupported by field evidence.

Bryozoans occur abundantly in the Cooper Marl north of a line between locality 19 and Elko but have not been observed south of this line.

The echinoids *Paraster americanus* and *Brissopsis blanpiedi* occur in large numbers (fig. 13) in the Cooper Marl at localities 16 and 17. They seem to have preferred a soft, somewhat sandy

Figure 13. *Brissopsis blanpiedi* in place in Cooper Marl at locality 16.

bottom and are generally found just beneath a zone of abundant worm borings. The worm workings may indicate a sediment unusually rich in organic matter.

The pelagic, deep water foraminifer *Globigerina sp.* is absent in the updip Cooper Marl but present at downdip exposures. This is thought to be due to deeper water conditions downdip. Agglutinated foraminifera such as *Textularia sp.* are more abundant in more clastic lithologies, no doubt owing to the greater availability there of test construction materials.

Byram Formation

Unit B of the Byram Formation consists predominately of medium- to fine-grained carbonate fragments and abundant tests of smaller foraminifera. The carbonate fragments are rather angular and the foraminifer tests are not abraded or broken indicating their deposition was probably in rather quiet water. The coin-shaped large foraminifera, *Lepidocyclina mantelli*, occurs most abundantly in a well defined bed approximately three feet in thickness in which it is scattered helter-skelter at all orientations, but the fragile test is generally unbroken. It is not known whether the random orientation of the tests of *Lepidocyclina mantelli* represents their mode of life in the bottom sediment or whether they were carried in by a gentle bottom current which did not fragment them. As the bed of concentration of these larger foraminifera is remarkably continuous over 200 yards distance the former hypothesis seems more tenable.

The massive nature of Unit B and the lack of apparent bedding indicates that deposition was probably continuous and the environment rather similar through the entire unit. Echinoids, gastropods, and corals are generally found in their living positions throughout the unit.

The rhythmic alternating nature of the lithology of Unit A suggests that environmental conditions fluctuated regularly during deposition, probably due to varying availabilities of clastic silt and clay. The base of each of the tan clay beds of Unit A contains a very great abundance of fossil material indicating that probably the influx of silt and clay killed large numbers of organisms by clogging their breathing apparatus. Most of the fossil remains observed in Unit A were in their approximate living positions, indicating a probable life assemblage rather than a sedimentary accumulation of miscellaneous fossil material. Corals were observed to be considerably more abundant in the lower bed of limestone than in any other part of the unit. This limestone bed is also the thickest bed probably indicating that deposition occurred over a longer period of time during which corals could become more firmly established.

Flint River Formation

The Flint River Formation is sandy in the northwestern exposures but contains no sand to the southeast. This feature may indicate a major source of terrestrial clastic sediments from a northwest direction, possibly a large river. The presence of large oysters in chert-cemented sands in the Flint River Formation may indicate brackish water.

There is a definite association between the echinoid *Cassidulus gouldi* and various types of ostracods. Casts of this echinoid are often filled with ostracods, which are quite rare in the Flint River as a whole. Apparently these echinoids died unburied, and ostracods entered their tests and fed on the interior soft parts until burial rendered their escape impossible. Thus casts of *Cassidulus gouldi* often show abundant ostracods on the surface (fig. 14).

Figure 14. Ostracods preserved on the silicified mold of the interior of *Cassidulus gouldi*

Large foraminifera, mainly *Lepidocyclina undosa* and *Lepidocyclina favosa*, are common at most outcrops of the Flint River Formation. At locality 26 there is a large boulder illustrating an unusual assemblage of vast numbers of these large protozoans (fig. 15). The tests are scattered helter-skelter at all angles in a volume of two to three cubic yards. This assemblage may be the result of rapid burial of an unusually productive bottom community, or it may represent a preserved "swash line" concentration of individuals. The tests are not broken or fragmented.

Figure 15 Foraminifer tests concentrated in Flint River Formation chert.

Pelecypod shells in the Flint River Formation are disarticulated and broken in local, lens-like concentrations of spectacular numbers. This may indicate "swash line" beach type deposits. The abundance of *Quinqueloculina*, *Pyrgo*, and *Reussella* tests also seems to indicate near-shore conditions. Alga-like masses with associated small solitary corals, gastropods, and regular echinoids, indicate that shallow, clear water conditions with high associated energy may have produced true reef development. The fauna of the Flint River Formation appears to have tropical to subtropical affinities, further substantiating this premise.

MINERAL RESOURCES

Iron

There is a zone, 0 to 10 feet thick, of limonite-hematite enrichment in the residuum of the Flint River Formation. This zone is near the top of the residuum and is a mappable horizon (Pickering, 1961). The iron concentration is intermittent and, where present, generally overlies the chert of the Flint River Formation. Where there are good concentrations of iron in the residuum, chert is usually not as prominent as where there is no iron enrichment.

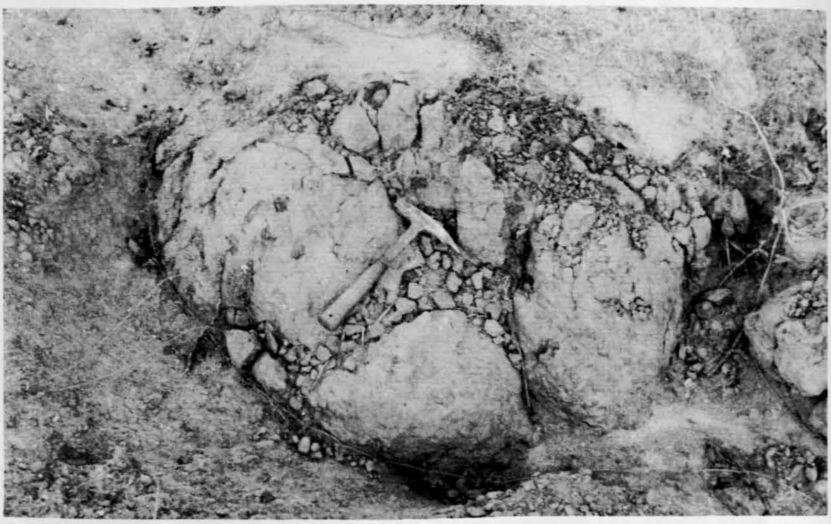

Figure 16. Limonite occurs as large spherical concretions, such as at this outcrop 3 mi. west of Hawkinsville on Old Pinehurst Road.

As discussed earlier, limonitic enrichment, in the form of concretions, geodes, dornicks, and iron-cemented sandstone, apparently was produced by the replacement of limestone during solution and silicification (Haseltine, 1926; Pickering, 1961). Limonite geodes line chertified solution cavities at localities 28, 30, 32, and 33. It is suggested the iron was not derived from iron minerals originally present in the limestone but from iron-rich ground water solutions derived from rocks of the piedmont area.

Iron mining, in the area studied, began in 1961 (Pickering, 1961) and was almost continuous to 1965 at localities 29, 30, 31, and 39. Average ore grade has been 51 percent iron, with desirably low phosphorus. It is shipped to Birmingham, Alabama, to raise the quality of the low-grade Clinton-type hematite ore.

Mining was accomplished by a small (¾-yard) power shovel and front-end loader. It was trucked about 5 miles to a single log washer, cleaned, and trucked 7 miles to the railhead at Unadilla.

Limestone

The Ocala Limestone has been quarried in the area mapped since 1912 (Brantley, 1916). For many years all of the stone was used for agricultural lime, for road metal, and for aggregate. In 1941 Penn-Dixie Cement Company began production of Portland Cement from the Ocala Limestone, Twiggs Clay, and Clinchfield Sand. Production has been continuous since that time, and localities 10 and 11 have been quarried for this purpose. Georgia Lime Rock Company is quarrying the Ocala for agricultural limestone at locality 23.

The Ocala Limestone has been reported to be 89 to 97 percent calcium carbonate (table III) in the outcrop area studied (Brantley, 1916). Thickness is generally about 40 feet along the Big Indian Creek valley; but locally, solution or erosion has reduced thickness to less than 15 feet.

The Cooper Marl has been quarried for agricultural limestone at localities 16, 17, 21, and 25, where the formation is a soft calcareous marl. Small operations should be able to compete favorably for local lime requirements, as the rock is easily worked and overburden is negligible. Production could be resumed at many places along the banks of the Ocmulgee River.

Fuller's Earth

Twiggs Clay throughout the area mapped consists of a plastic gray-blue to green fuller's earth in the area of Pike's Peak in Twiggs County and Wrens in Jefferson County, Georgia. Fuller's earth is mined and sold for a variety of purposes. As a part of the Department of Mines, Mining and Geology Georgia Minerals Exploration Program test holes are being cored in the Twiggs Clay throughout its area of outcrop in South Georgia and tests are being made to determine economic feasibility. Several test holes have been cored for areas underlain by Twiggs Clay in the Perry and Cochran quadrangles; test results will be published when available.

The Twiggs Clay may also be well adapted to the manufacture of rock wool insulation or light weight aggregate; tests for these commodities are presently being made.

The Twiggs Clay, which is being removed as overburden in large tonnages from limestone quarrying operations in the area studied, is presently being used in only small quantity as an additive in the manufacture of Portland Cement. It is hoped that additional research by the Department of Mines in cooperation with the Georgia Institute of Technology will reveal some use for this product which is now being discarded.

High Silica Sand

The Clinchfield Sand in its area of outcrop is generally highly iron stained and would be very difficult to beneficiate to an acceptable high silica sand product. However, where the formation has been protected from staining by the overlying Ocala Limestone it is relatively free from objectionable iron, and attrition scrubbing will produce a silica product which is quite low in iron. Large acreages of Ocala Limestone have been removed by quarrying operations in the area south of Big Indian Creek. In these quarry areas Clinchfield Sand is in a relatively unstained condition with very little overburden and is readily accessible to available mining and loading equipment and to rail transportation facilities.

The Clinchfield Sand does contain from two to six percent calcium carbonate in the form of coarse- to fine-grained organic debris. Most of this carbonate material is very fine-grained and can be removed by screening. In order to produce a salable high silica product, however, the remaining carbonate would have to be removed by some method, probably froth flotation.

Only a portion of the Clinchfield Sand is sufficiently coarse-grained to be used as a raw material for glass manufacture; however, the remaining fine-grained quartz sand would have a considerable market potential for the manufacture of sodium metasilicate and the making of silica-lime bricks. This fine-grained sand could also be crushed and sold for silica flour.

It may be readily calculated that if the average thickness of the Clinchfield Sand is only fifteen feet there is a minimum of more than 325,000,000 tons of silica sand available for mining in presently active quarry areas in Houston County.

Construction Sand

There are very large tonnages of construction grade sand available in Pleistocene high terrace deposits along the east bank of the Ocmulgee River throughout the area studied. This material has been mined from several small pits along Georgia Highway 126 about three miles north of Hartford but is not presently being used in any way. If the building industry in the area should require the production of large quantities of construction sand, these deposits should be of great use.

SUMMARY AND CONCLUSIONS

The exposed Tertiary rocks of the area studied may be divided and mapped lithologically and paleontologically as seven distinct formations overlain by a series of undivided Neogene clastics. These formations are, in ascending stratigraphic order: McBean Formation, Clinchfield Sand, Ocala Limestone, Twiggs Clay, Cooper Marl, Byram Formation, and Flint River Formation. Regional dip is from ten to fifteen feet per mile to the southeast.

Study of the paleontology in the area mapped reveals that the sand under the Ocala Limestone has a late Eocene fauna. Further it has been concluded that this sand should be referred to as the Clinchfield Sand Formation. The Alabama term "Gosport Sand" is not applicable to this unit.

The Ocala Limestone is a distinctive formation and is not a ridge-forming unit as has been previously assumed by some authors. The Flint River Formation holds up the "Ocala Escarpment" just south of Clinchfield.

Formational status has been suggested for the Twiggs Clay. The Twiggs has been shown not to exist beneath the Ocala; it was there confused in the past with the McBean.

The Cooper Marl is present in central Georgia and is the lithologic equivalent of the Cooper Marl of South Carolina. Examination of fossils encountered in the Cooper Marl shows possibilities for correlation with the Sandersville Limestone of east central Georgia, a unit of previously undetermined age.

Detailed study of the paleontology of the Cooper Marl has shown the presence of a number of forms regarded as Oligocene in other states. Further substantiation is therefore given to recent suggestions that the Cooper Marl is of Early Oligocene age. The Cooper is not present along the "Ocala Escarpment" where it has been previously mapped. Updip, the Cooper Marl is indeed a typical marl containing about equal proportions of sand, clay, and carbonate but downdip, this formation is represented almost entirely by limestone.

The Byram Formation has been mapped and described along the Ocmulgee River south of Hawkinsville.

The Flint River Formation is represented by the residual products of an Oligocene limestone. It is the approximate updip faunal equivalent of the Suwannee Limestone of Florida and south Georgia. The Flint River Formation is sandy and conglomeratic to the northwest. South of this area there is a belt of calcarenite to calcirudite which has been silicified to loose, porous tripoli. South of this belt much of the chert in the formation is compact, nonporous chalcedony and jasper.

The interstream divides are capped with a blanket of sand, clay, and conglomerate which cannot be subdivided. The age of this material can be only assigned to the undivided Neogene.

Reported for the first time as a result of this study are: *Periarchus lyelli*, *P. lyelli pileus-sinensis*, *Laganum floridanum*, *Chlamys spillmani clinchfieldensis*, and *Crassostrea gigantissima* from the Clinchfield Sand; and the echinoids *Paraster americanus*, *Periarchus quinquefarius*, *P. quinquefarius kewi*, and *Brissopsis blandpiedi* from the Cooper Marl.

Paleoecological study has shown that the Clinchfield Sand was deposited in shallow water under high energy conditions. Change in environment to lower energy conditions led to deposition of sandy limestone beds near the top of the Clinchfield. The number of species present at this change of environmental conditions is relatively large, and all often appear in living position.

The Ocala Limestone is shown to be a high energy bioclastic accumulation of transported organic debris.

The Twiggs Clay has a shallow water pelecypod fauna and no indication of volcanic ash accumulation as previously thought.

The Cooper Marl shows clear facies change from more clastic clay marl updip to fine-grained limestone downdip.

The Flint River Formation shows a sandy facies at the northwest edge of the area studied, a coarse bioclastic facies across the central portion, and a compact, fine-grained facies along the southwest edge. Areas resembling true reefs are present with a typical alga-coral-gastropod-regular echinoid assemblage.

The youngest sediments of the area are a complex blanket of sands, clays, and conglomerates of Neogene age. The sedimentary features of this material indicate a terrestrial or deltaic origin.

High silica sand from the Clinchfield Sand in the Perry and Cochran quadrangles was sampled by drilling at Clinchfield, and an analysis of this material is included. Measured sections of limestone from the Ocala Limestone and the Cooper Marl in the area have present or future economic potential as agricultural lime and for cement manufacture. Iron mining in the area is described, and other possible economic mineral resources are enumerated and described.

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TABLE II

Chemical Analysis of Typical Channel Samples of Outcropping Formations

	McBean Formation	Clinchfield Sand	Ocala Limestone at Clinchfield	Twiggs Clay at Clinchfield	Twiggs Clay at Taylor's Bluff	Cooper Marl at Big Creek
Locality	11	10	10	11	19	32
Loss on ignition	7.57	---	41.29	18.91	11.23	37.02
Lime (CaO)	7.14	---	52.32	20.16	10.64	43.87
Magnesia (MgO)	Trace	---	0.40	0.30	0.30	0.40
Alumina (Al_2O_3)	17.64	2.36	1.88	16.52	14.36	7.00
Ferric Oxide (Fe_2O_3)	6.00	0.40	0.64	3.57	2.86	1.60
Phosphorus Pentoxide (P_2O_5)	0.06	---	0.06	0.11	0.19	0.37
Silica (SiO_2)	61.52	91.00	3.32	40.42	60.42	9.64
TOTAL	100.00	99.81	99.91	100.00	100.00	99.90
Calcium Carbonate ($CaCO_3$)	12.74	5.42	93.38	35.98	18.99	78.30
Magnesium Carbonate ($MgCO_3$)	Trace	---	0.84	0.63	0.63	0.84
Total Carbonates	12.74	---	94.22	36.61	19.62	79.14
$CaCO_3$ equivalent theoretical	12.75	---	94.37	36.72	19.73	79.28
BPL	0.13	---	0.13	0.24	0.42	0.81

TABLE II

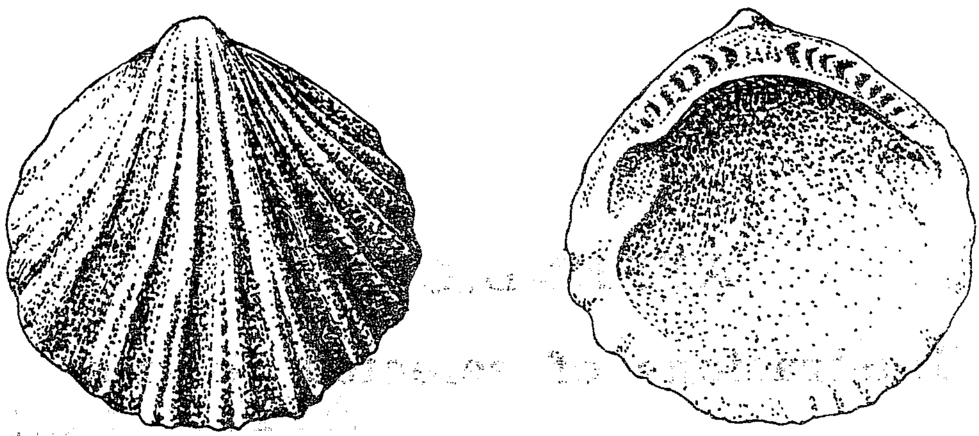
Chemical Analysis of Typical Channel Samples of Outcropping Formations

	Cooper Marl at Opelika Mfg. Co.	Byram Formation Unit B	Byram Formation Unit A Limestone	Byram Formation Unit A Clay	Flint River Formation
Locality	34	37	38	38	15
Loss on ignition	38.72	43.22	42.93	33.22	0.86
Lime (CaO)	48.60	55.14	52.74	39.20	---
Magnesia (MgO)	0.40	Trace	0.50	0.50	---
Alumina (Al_2O_3)	4.24	0.20	1.80	8.71	1.05
Ferric Oxide (Fe_2O_3)	0.90	0.22	0.20	2.29	0.23
Phosphorus Pentoxide (P_2O_5)	0.14	---	0.02	1.00	---
Silica (SiO_2)	7.08	1.18	1.60	14.78	97.86
TOTAL	100.08	99.96	99.79	99.70	100.00
Calcium Carbonate ($CaCO_3$)	86.74	98.41	94.13	69.96	---
Magnesium Carbonate ($MgCO_3$)	0.84	Trace	1.05	1.05	---
Total Carbonates	87.58	98.41	95.18	71.01	---
$CaCO_3$ equivalent theoretical	87.73	98.41	95.37	71.20	---
BPL	0.30	---	0.04	2.18	---

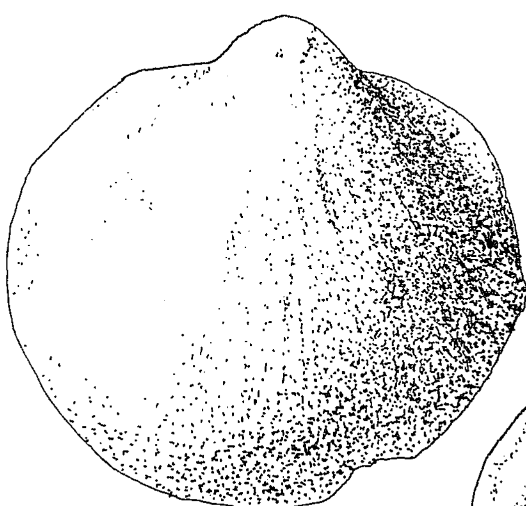
APPENDICES

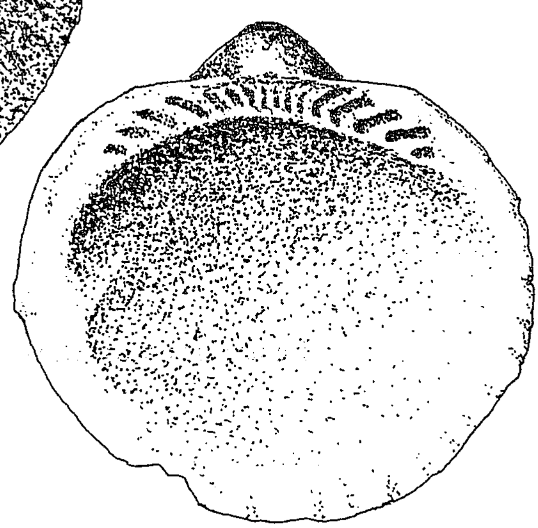
Illustrations of selected fossils

Illustrations by Carl Vardaman

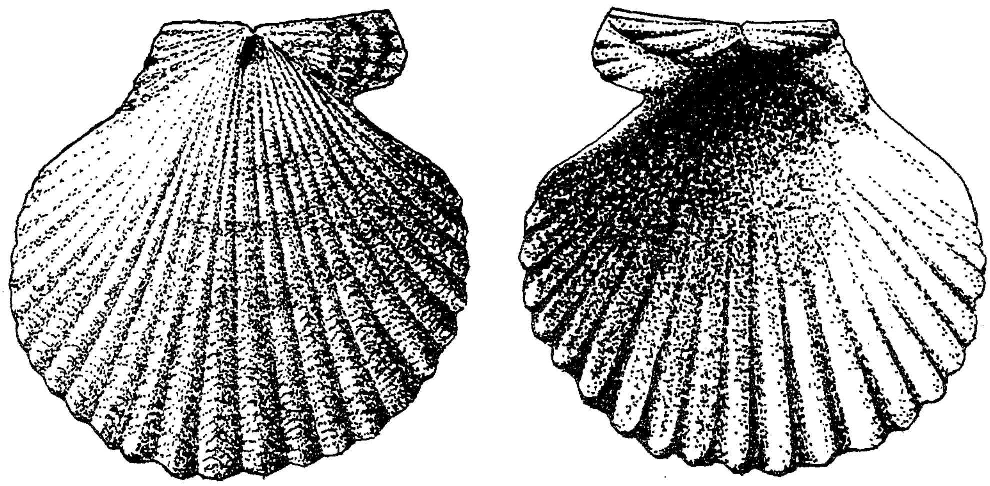


Glycymeris cookei 3X
Flint River Formation

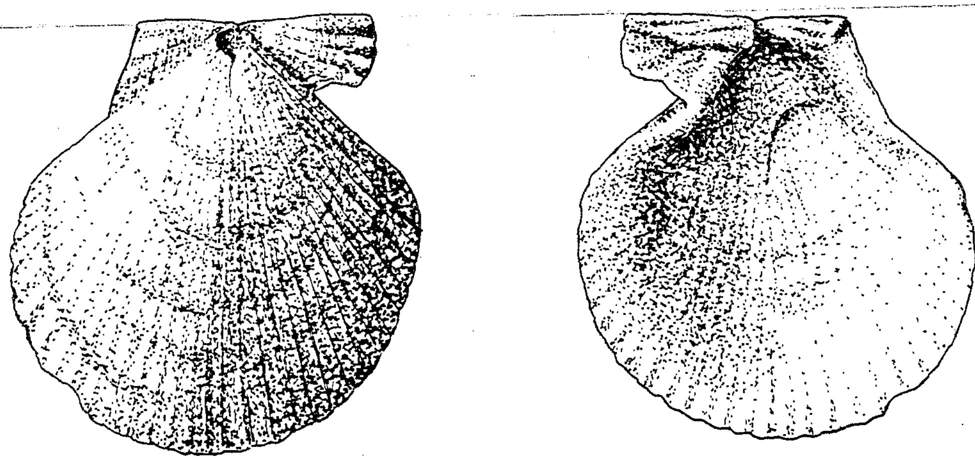




Glycymeris suwaneensis 2X
Flint River Formation

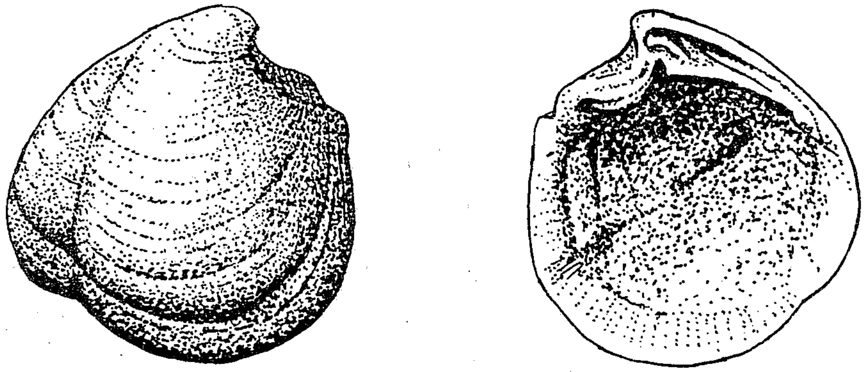


Chlamys spillmani clinchfieldensis 1X
Clinchfield Sand, Ocala Limestone, Twiggs Clay



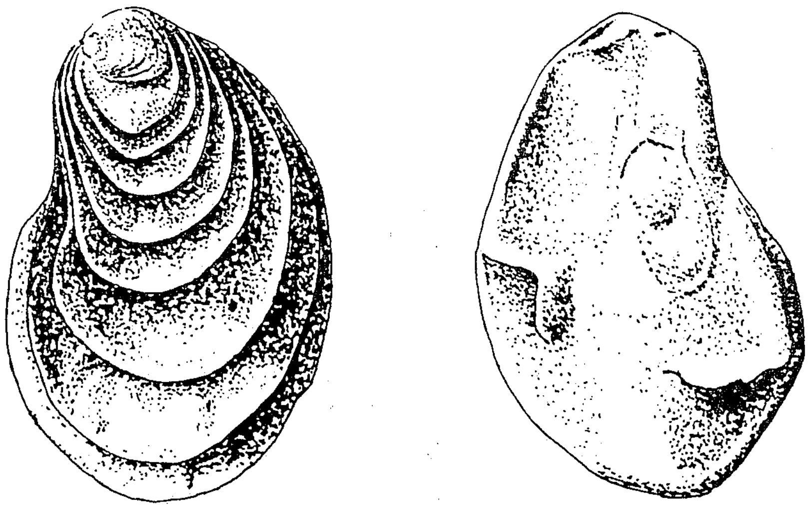
Chlamys cocoana 1.9X

Cooper Marl



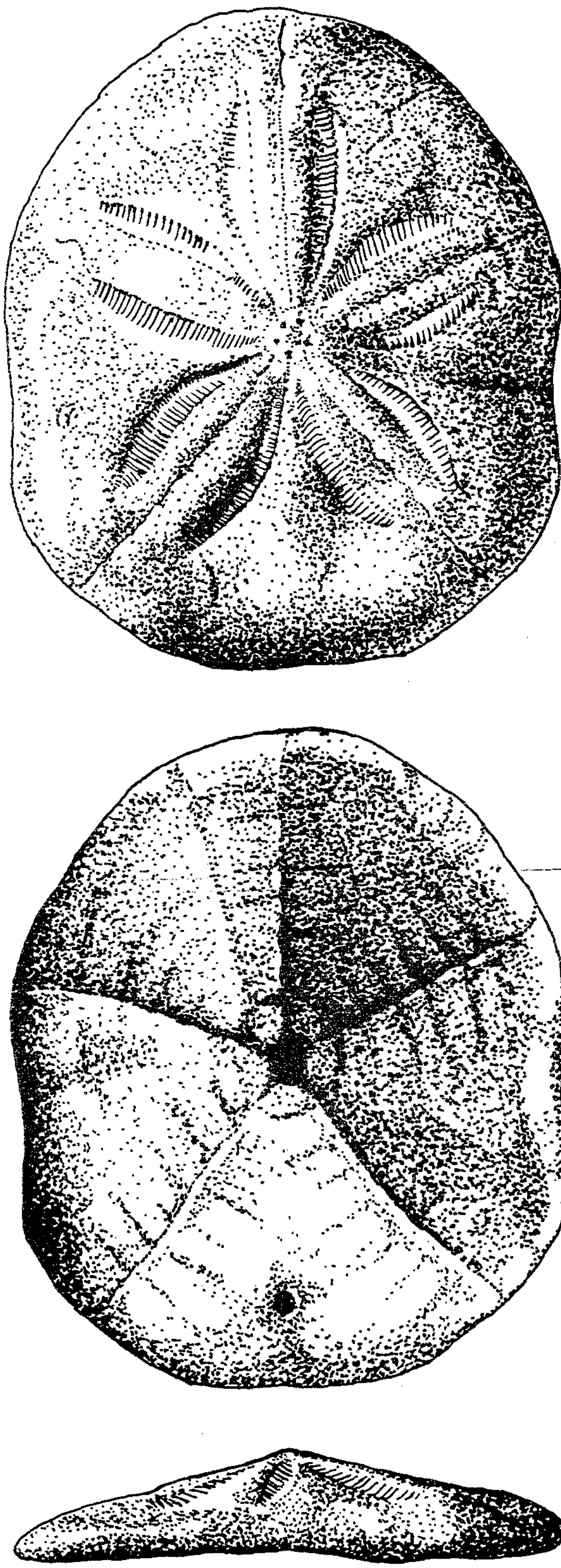
Phacoides wacissanus 1.5X

Flint River Formation

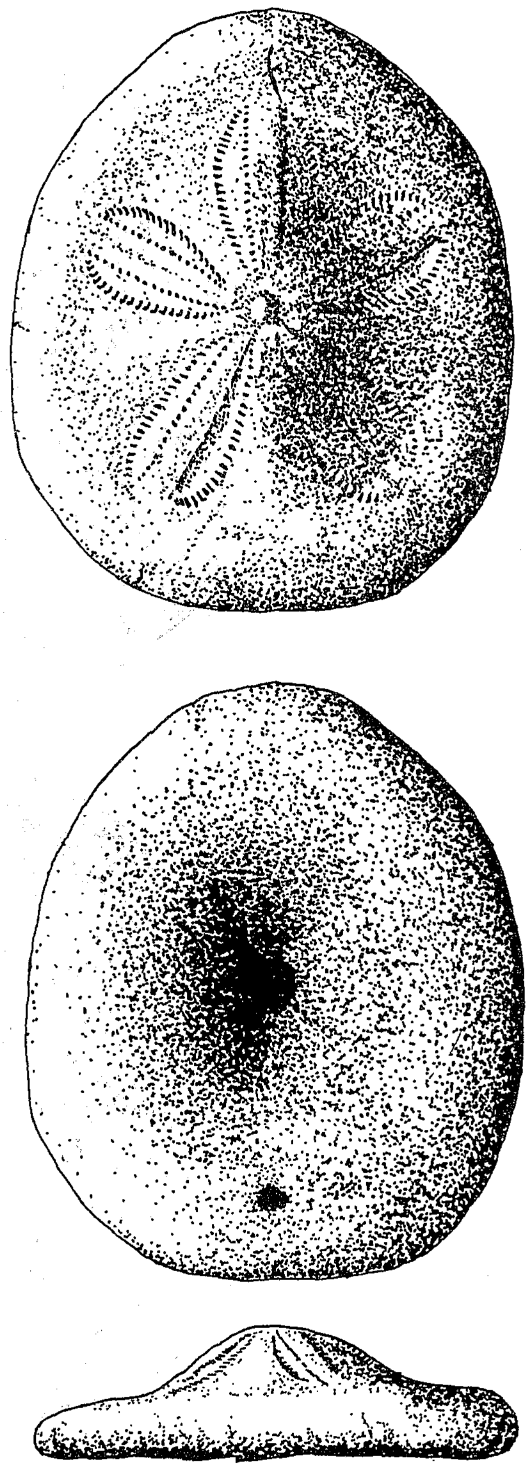


Gryphostrea plicatella 4.5X

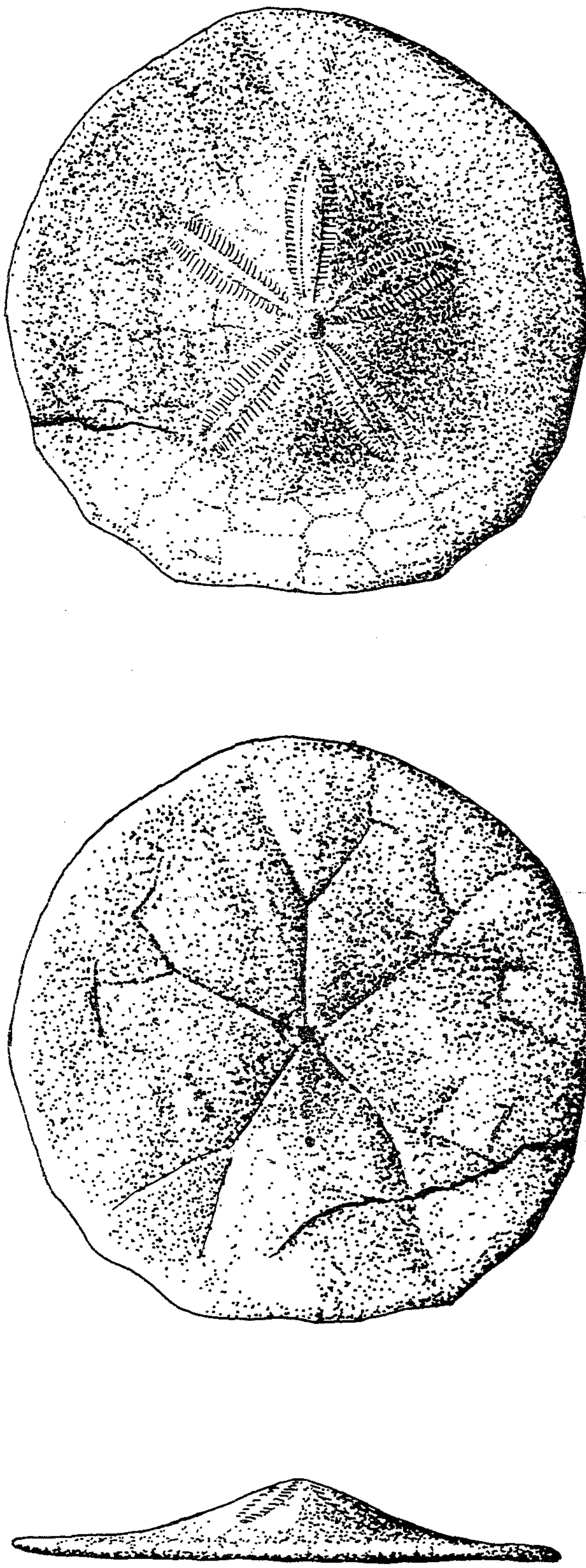
Cooper Marl



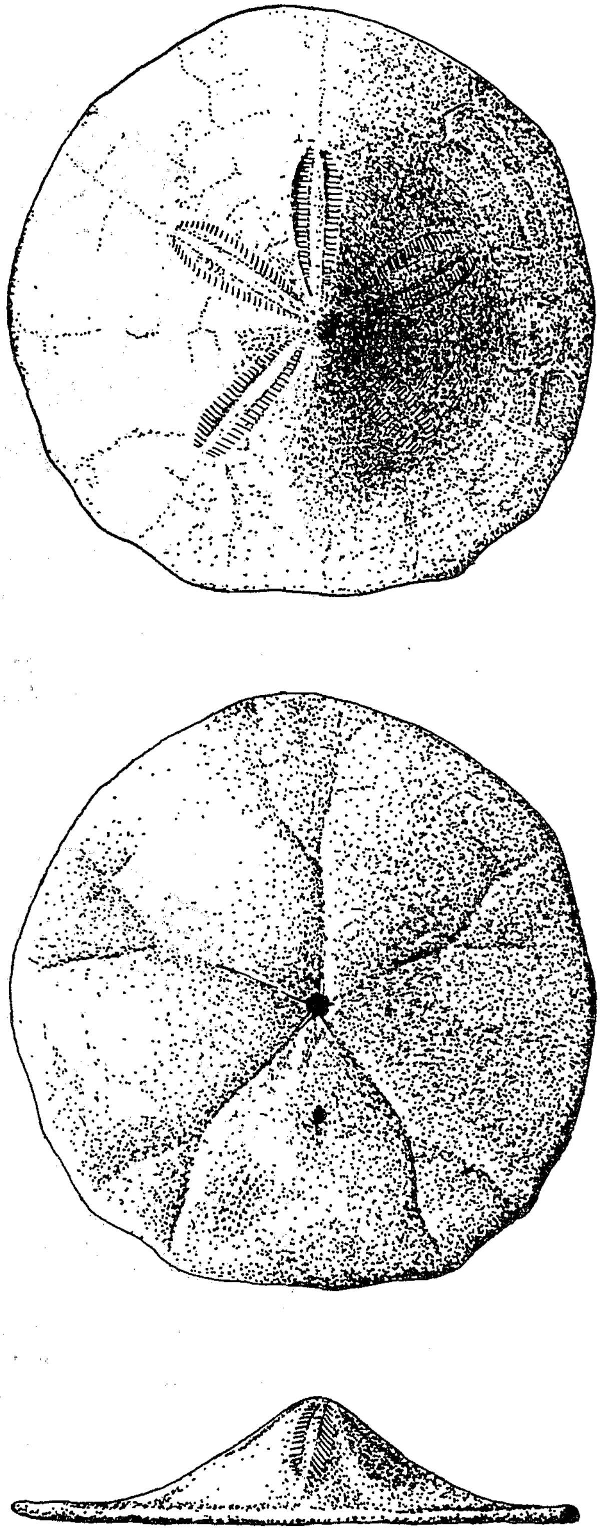
Clypeaster rogersi 1X Byram Formation



Clypeaster cotteaui **1X** Flint River Formation

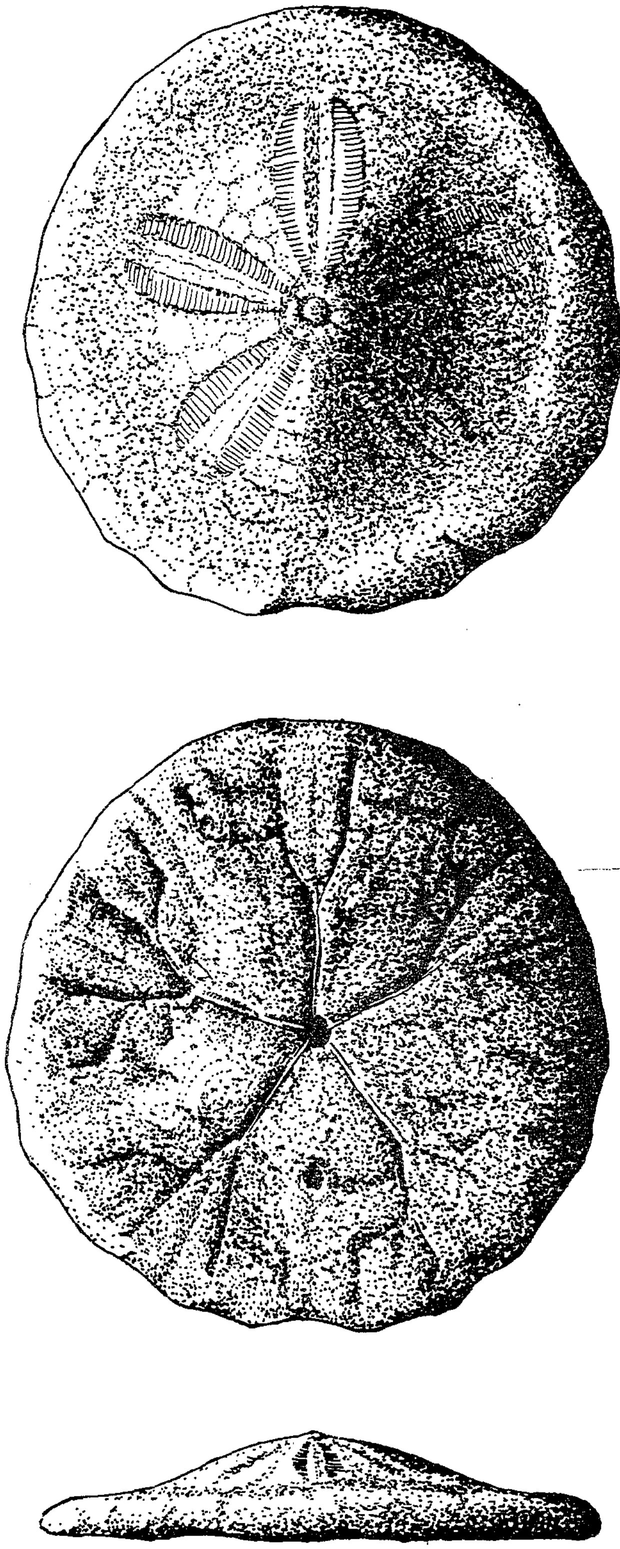


Periarchus lyelli .95X
McBean Formation, Clinchfield Sand, Ocala Limestone

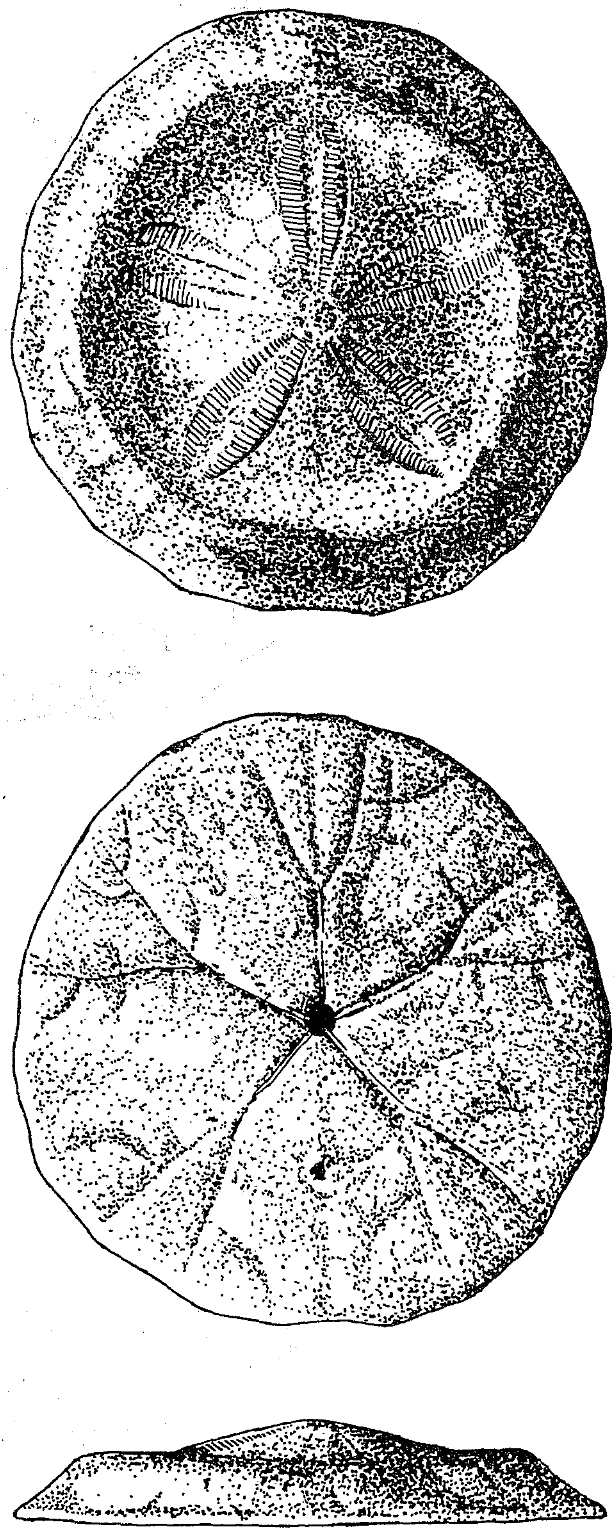


Periarchus lyelli pileus-sinensis **1.1X**

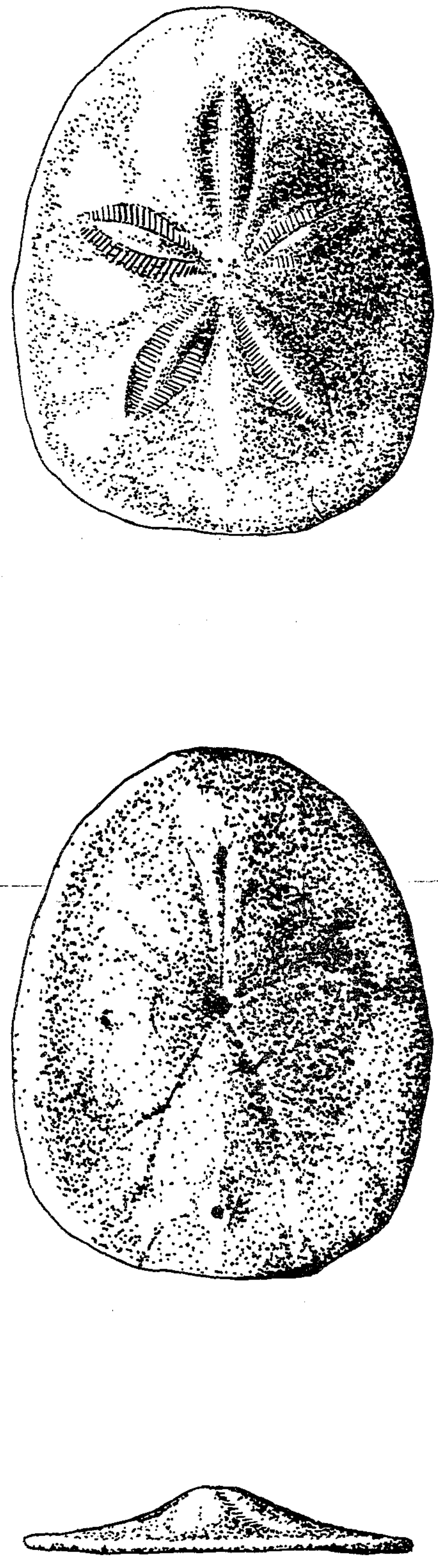
Clinchfield Sand, Ocala Limestone, Twiggs Clay



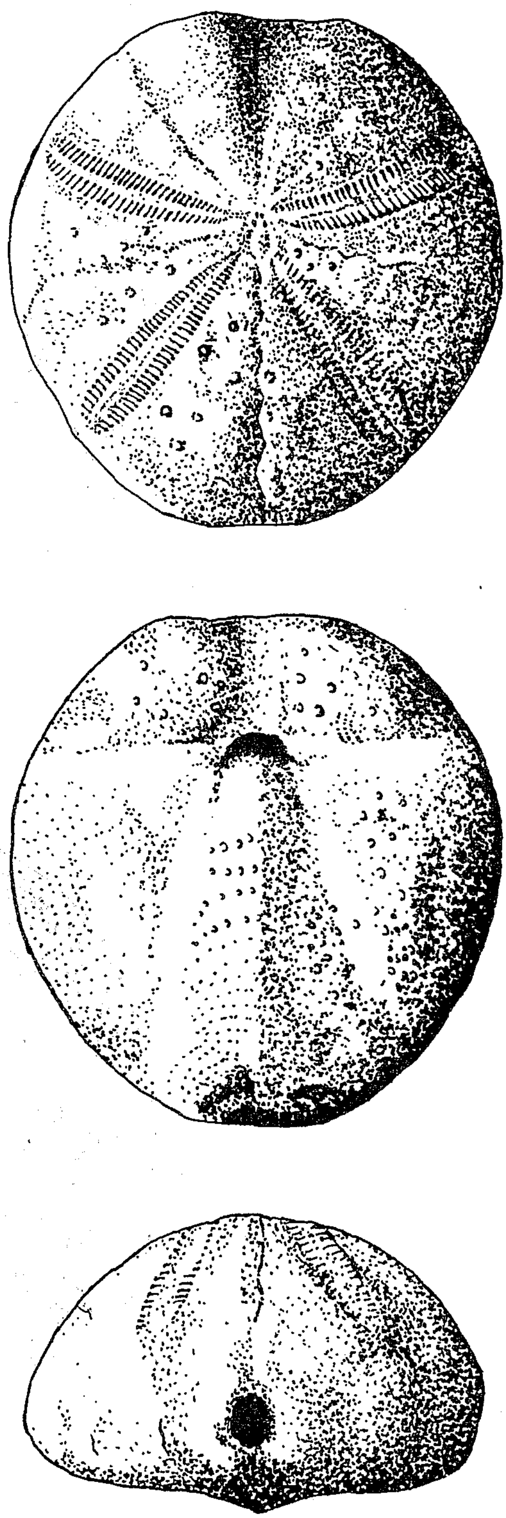
Periarchus quinquefarius **1.1X** Cooper Marl



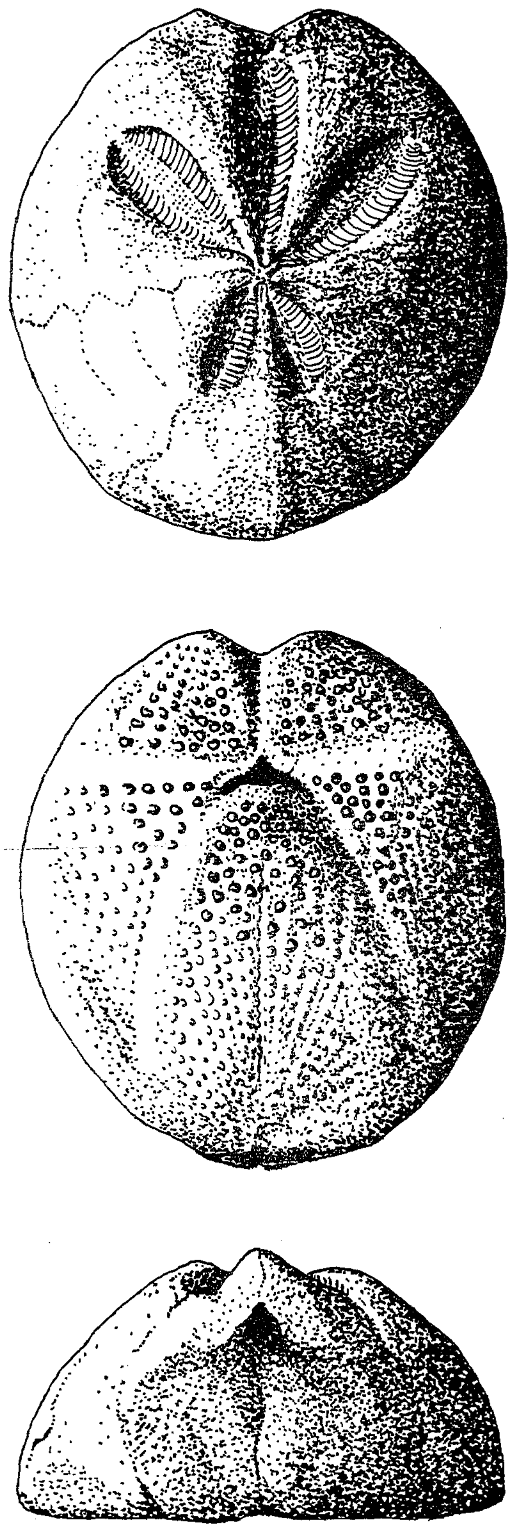
Periarchus quinquefarius kewi 1.3X Cooper Marl



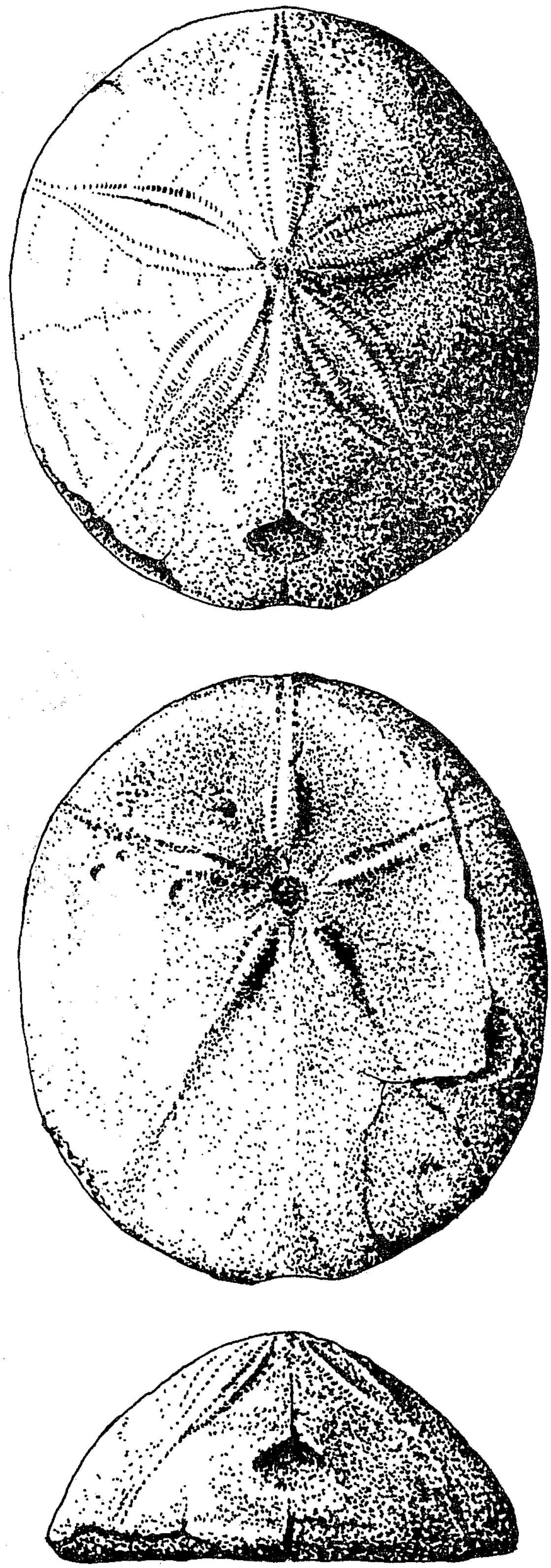
Wythella eldridgi .85X Ocala Limestone



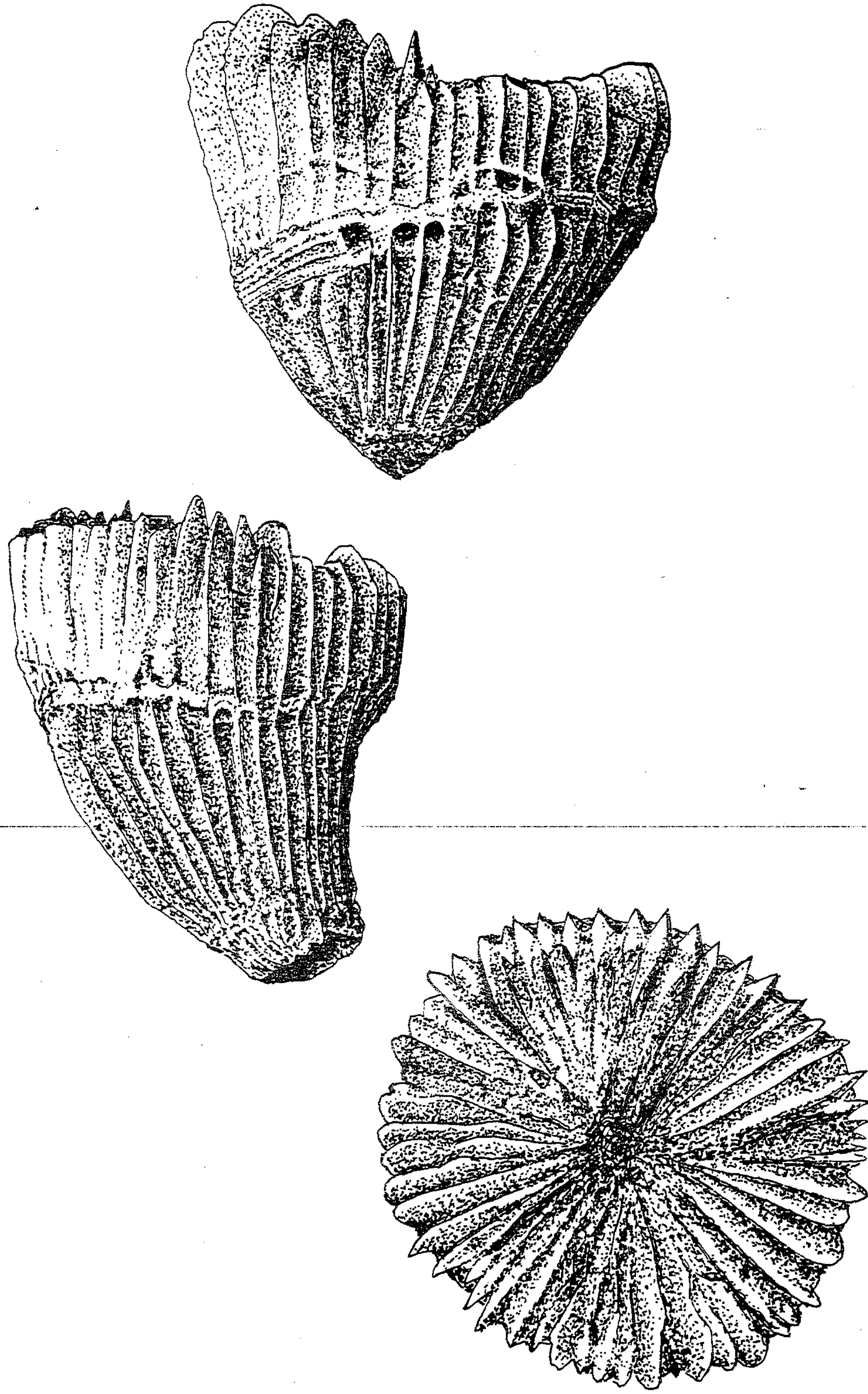
Macropneustes mortoni .7X Clinchfield Sand, Ocala Limestone



Paraster americanus .8X Cooper Marl



Cassidulus gouldi 1.35X Flint River Formation



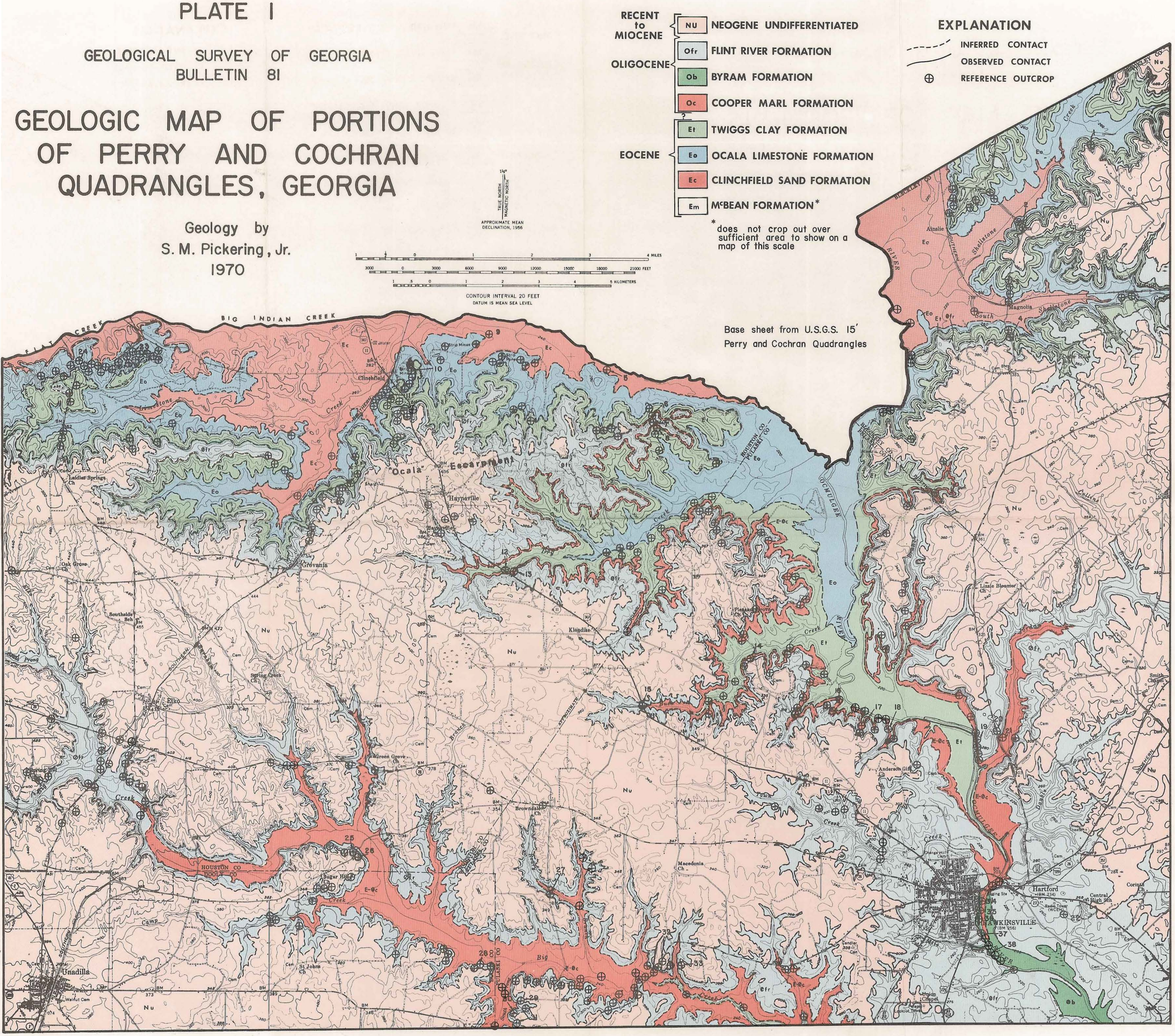
Trochocyathus sp. 1.7X Flint River Formation

PLATE I

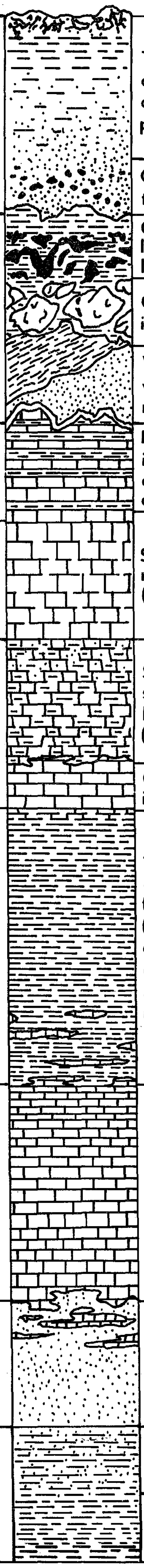
GEOLOGICAL SURVEY OF GEORGIA
BULLETIN 81

GEOLOGIC MAP OF PORTIONS OF PERRY AND COCHRAN QUADRANGLES, GEORGIA

Geology by
S. M. Pickering, Jr.
1970



STRATIGRAPHIC COLUMN
GEOLOGIC SURVEY OF GEORGIA
BULLETIN 81



EPOCH	AGE	FORMATION	LITHOLOGY
RECENT through MIOCENE	UN-DIFFEREN-TIATED	Various, i.e.: "CITRONELLE" "HAWTHORN" "ALTAMAHA" "BARNWELL" "ALUM BLUFF" Probably none valid in this area	Tan to red sandy clay with sparse to abundant "shot iron" pebbles
			Quartz pebbles in tan-red clayey sand
OLIGOCENE	LATE	FLINT RIVER or "SUWANNEE" FORMATION	Ocherous clay and limonite beds and lumps
			Cream to red chert in stiff red clay
			Varved tan clay with white to red sand, manganese enriched
	MIDDLE	UNIT "A" BYRAM FORMATION	Indurated limestone interbedded with chocolate colored clay
		UNIT B BYRAM FORMATION	Soft, cream to white massive chalk (97-98% $CaCo_3$)
	EARLY	COOPER MARL	Soft cream to buff sandy, clayey limestone (83-86% $CaCo_3$)
			Cream to gray indurated limestone
?	?		
EOCENE	LATE	TWIGGS CLAY	Tough blocky green-gray to blue-gray fullers earth (montmorillonitic) clay. More calcareous and with beds of cream limestone toward the base
		OCALA LIMESTONE	Soft cream to buff yellow limestone with indurated layers. Generally thick bedded (87-97% $CaCo_3$)
		CLINCHFIELD SAND	Cream to tan sand with limy oyster shell beds at top. Sand thickness variable
	MIDDLE	McBEAN FORMATION	Sandy, lignitic, glauconitic gray silt
			Stiff olive gray to blue clay with abundant glauconite

PLATE II

S. M. PICKERING, JR.
1970