Paleogene Carbonate Facies and Paleogeography of the Dougherty Plain Region

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30th Annual Field Trip
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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS AND TABLES

CHAPTER 1 -- INTRODUCTION

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Conventional wisdom on the geologic nature of the Georgia Coastal Plain appears to derive directly from the work of geologists in the first half of this century, principally C.W. Cooke, and primarily from his summary work published in 1943. Most southeastern geologists are aware that the region is underlain by a seaward-thickening wedge of sediments, which dip very gently in the same direction they thicken. More sophisticated views might include the fact that the sediment is primarily terrigenous clastics, and that a sublinear low in structure contour and isopach maps in the southwestern corner of the state represent a structural/ depositional/paleogeographic feature called the Suwannee Strait or Gulf Trough. This is all rather bland stuff.

Personally, we are a bit surprised and disconcerted by the dawning realization that we are no longer young Turks. The children we brought to south Georgia in diapers are grown, or nearly so, and we recall our first joint trip to visit Paleogene outcrops as having just ended. We can still almost taste the ice-cold beer that officially closed it down. We are beginning to glimpse what we suspect is a common perceptual disorder among historical geologists. We spend the time of our lives, without really understanding where it goes and why there's so little of it, trying to make sense of events so remote in time, and requiring such vast quantities of it, that we can't really understand that either.

There are, of course, rewards we receive in exchange for our Turkhood. Part of ours is to have been part of a small group of people who have added interesting flesh to the bones of Coastal Plain geology. We have asked two of our colleagues in this group to join us in summarizing the work of the past decade-and-a-half in this volume.

Paul Huddlestun has been largely responsible for re-vamping the lithostratigraphic framework in which we view the Paleogene rocks of the region (e.g., Huddlestun, 1981, 1993; Huddlestun and Hetrick, 1979; McFadden, et al., 1986). Much of his work has focused on the control exercised by the Suwannee Strait/Gulf Trough on the distribution of lithologies, identifying deposits of pelagic origin within the Strait and shelf deposits flanking it, for example. We have invited Paul to contribute a short article to this guidebook summarizing the lithostratigraphy of the carbonate facies of southwestern Georgia. This is included as Chapter 2 of this guidebook.

Jon Bryan has concentrated on both biostratigraphic constraints on the ages of Paleogene rocks in the region (Bryan, 1991; Bryan and Huddlestun, 1991), the facies relationships among them (Bryan, 1992, 1993), and Paleogene paleogeography of the area (Bryan, 1993). Our own pertinent research has also focused primarily on the geographic distribution of carbonate facies and associated biofacies in the Paleogene of southwestern Georgia, and on the paleogeography implied by those distributions. We have published on both the Eocene (Carter, 1987, 1989, 1990; Carter, et al., 1989; Carter and McKinney, 1992) and on the Oligocene (Carter and Manker, 1987; Manker and Carter, 1987, 1989), and have accumulated a fair amount of unpublished data on the Paleocene as well. Because of the interest Jon shares with us on the depositional environments and paleogeography of these deposits, we have asked him to collaborate on a summary chapter on these topics. This is presented as Chapter 3 of this guidebook.

In addition to historical geologic interest, these limestones also provide both economic opportunity and environmental problems to humans. The abundant groundwater they contain, along with the level land and rich soils developed on them, make farmland in the Dougherty Plain among the richest in the country. A small, sporadically active mining industry exists. The karst-related geomorphic processes in operation make sinkhole development a continuous concern to land-use planners. During the flooding of July, 1994 much of the population of southwestern Georgia was negatively affected by floodwaters; residents of the Dougherty Plain were additionally hit with sinkhole collapse during and subsequent to the actual flooding. Chapter 4 of this guidebook is a summary of karst processes in the aftermath of flooding, and the first fieldtrip stop will examine one of the main sinkholes in the Albany area. We thank James A. Hyatt and Peter M. Jacobs of Valdosta State University for this contribution.

The field trip is designed to allow participants to examine as many types of facies and as many paleogeographic features as possible. Unfortunately, the primary paleogeographic feature of the region, the Suwannee Strait, which exerted the principal control on facies distributions, occurs only in the subsurface. However, we will visit outcrops of high energy, near-shelf-edge (or Suwannee Strait-edge) facies of Paleocene and Oligocene age, mid-shelf, low energy deposits of Eocene age, and nearshore deposits of both Paleocene and Eocene age.

PHYSICAL GEOGRAPHY OF THE FIELD TRIP AREA

Figure 1-1 is a map illustrating the general physiographic features of southwestern Georgia. The west-facing Pelham Escarpment separates the Tifton Upland to its east from the Dougherty Plain to its west. The former is capped by Miocene and younger terrigenous rocks of varying degrees of lithification. The latter is underlain at the surface by primarily Late Eocene carbonates of the Ocala Limestone, with younger rocks removed by post-Miocene erosion. The Pelham Escarpment has a maximum relief near the southwest corner of the state of about 55m, but relief decreases regularly toward the northeast, where the escarpment becomes virtually impossible to define in the vicinity of Dooly County. Our proposed origin of the escarpment is summarized below. As the Dougherty Plain rises southeastward toward the Pelham Escarpment, in the downdip direction, the Oligocene carbonates of the Bridgeboro and Suwannee Limestones and their equivalents come to lie at the surface. The strata dip gently southeastward into the Gulf Trough (or Suwannee Strait). As the Plain rises toward the Fall Line Hills to the northwest (updip), progressively older rocks are encountered. These are primarily terrigenous rocks of Early and Middle Eocene, Late Paleocene, and Cretaceous age, but also include carbonates in the Clayton Formation of Early Paleocene age.

The Pelham Escarpment serves as a clear line of separation between the Tifton Upland and the Dougherty Plain, but the boundary between the Dougherty Plain and the Fall Line Hills is not so easy to define. The original definition of the latter seems to have included the stipulation that the hills were underlain by Cretaceous rocks (Brantley, 1916, p. 2). However, Cooke (1925, p. 19-20) included areas underlain by pre-Ocala Paleogene rocks as well. The dashed line on Fig. 1-1 approximates the boundary by this definition. All the field trip stops which illustrate Eocene and Oligocene carbonates are in the Dougherty Plain and on the Pelham Escarpment. Those illustrating the Clayton Formation are in the Fall Line Hills *sensu* Cooke, 1925. Their approximate locations are indicated on Fig. 1-1.

Figure 1-2 is modified from Beck and Arden (1983), and summarizes the relationship between

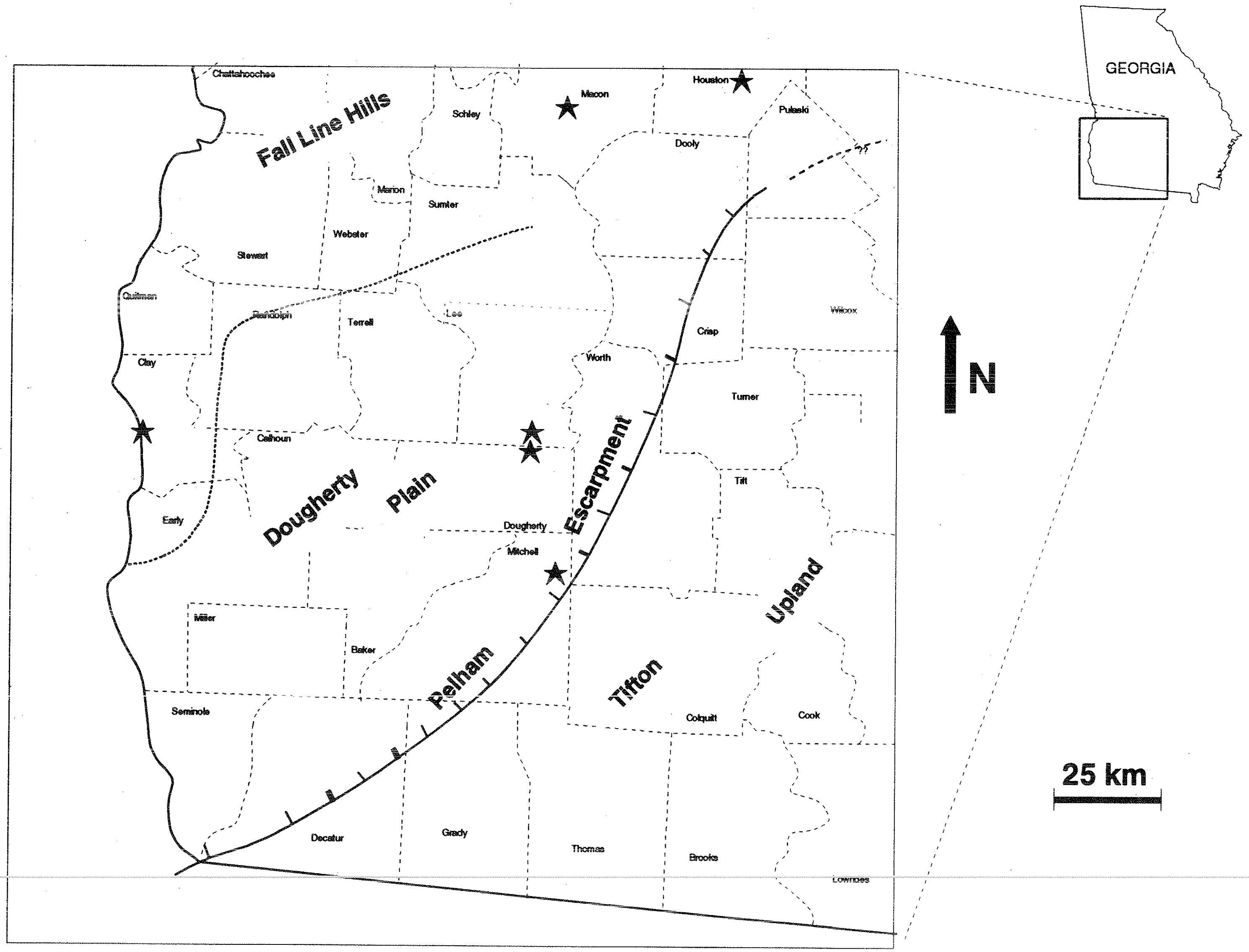

FIGURE 1-1 -- County map of southwestern Georgia showing locations of major physiographic features in the vicinity of the Dougherty Plain. Stars indicate field trip stops.

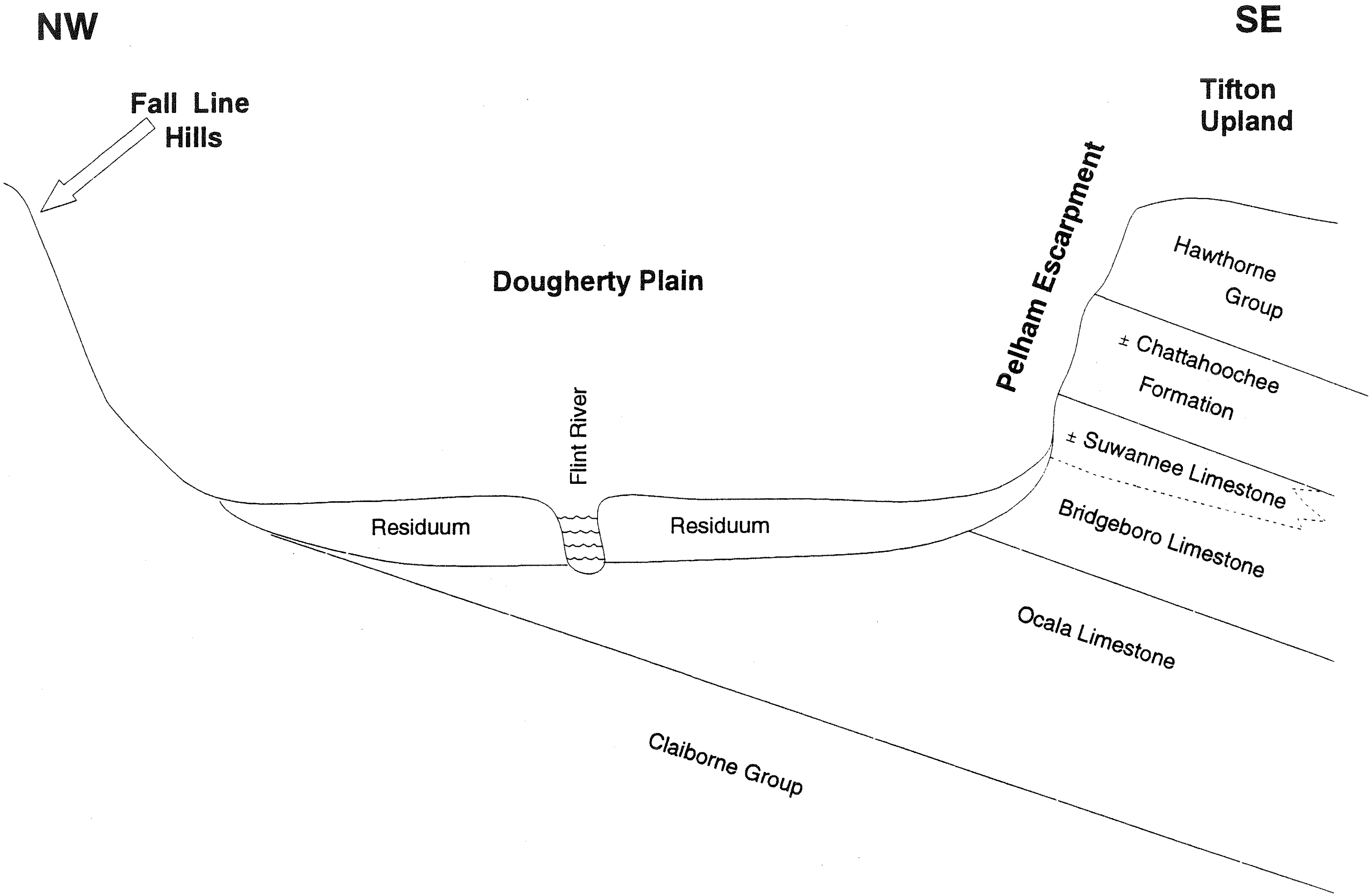

FIGURE 1-2 -- Schematic cross section of the Dougherty Plain region showing the relationship of surface topography to underlying geology. Modified from Beck and Arden, 1983.

bedrock geology and physiography in the region. Two things should be mentioned about the rocks shown on the Pelham Escarpment. First, the Chattahoochee Formation is present in the vicinity of Climax Cave in northeastern Decatur County, but missing from the quarry at Bridgeboro in Mitchell County and all points north. Second, the Suwannee Limestone is only known to occur at Rockhouse Cave in central Crisp County. Most of what Beck and Arden called "Suwannee Limestone" is, in fact, Bridgeboro Limestone, and this is the unit in which the numerous caves along the escarpment have their horizontal passages developed. Of course, Beck and Arden were simply following standard stratigraphic nomenclature of the time, in which all Oligocene carbonates in the region were called "Suwannee".

Herrick and LeGrand (1964 -- as quoted in Beck and Arden, 1983, p. 22) interpreted the Dougherty Plain as a solutionally lowered plain with continuing retreat of the Pelham Escarpment resulting from headward solution of the Bridgeboro limestone and undermining of the Miocene clastics on the Tifton Upland. The result was "an eastward, down-the-dip retreat of the entire solution scarp". Herrick and LeGrand apparently considered that the Dougherty Plain originated entirely by the retreat of the Pelham Escarpment, presumably with Miocene "overburden" carried away concurrently with being undercut and lowered. We assume, given that Late Eocene carbonates and Oligocene chert have long been known to occur in the Fall Line Hills at Rich Hill, Crawford County (off the map one county to the north of Macon County in Fig. 1-1) that they were postulating a minimum of about 75 km of post-Miocene scarp retreat.

Beck and Arden (1983, p. 26) questioned the exact mechanism of undercutting of the scarp, though not the overall process of "down-the-dip retreat". They pointed out that most of the drainage along the escarpment is influent, and that there is no evidence for, nor a satisfactory model to allow for the former existence of effluent springs along its course. They modified the hypothesis by calling upon cave development driven by inflowing streams to undermine the edge of the escarpment.

Though recognizing the importance of erosion in the development of the Pelham Escarpment, Carter and Manker (1987) questioned the need to hypothesize significant retreat. Pointing out the relationships of various Lower Oligocene facies to the edge of the Suwannee Strait and to the escarpment, they proposed that its origin was related to, and its present position approximated, the original "back-reef" slope of the Bridgeboro algal build-up on the northern edge of the Suwannee Strait. (See Chapter 3, herein.) That is, the present scarp is, in part, a depositional feature and not entirely an erosional one. They further postulated the former existence of a contemporaneous friable, course clastic facies in the Dougherty Plain, now almost completely destroyed. Erosion of this friable sand, rather than solution of a >75 km wide band of Limestone, accounted for the existence of the Dougherty Plain in their model.

ACKNOWLEDGMENTS

We wish to thank Patricia Beck for invaluable assistance with logistical arrangements for the trip. Yonnie Williams assisted with the road log and with relocating stop two of day two, and read portions of the field guide with a useful critical eye. She also did the original sketches for Figure 3-6. Debbie Standridge helped type portions of the field guide. Various landowners deserve our thanks for access to their land and, in some cases, for taking time to accompany us to their sites. Particular thanks go to Laura Leary (Bridgeboro Quarry), John Cole (Bridgeboro Quarry), and Bill Barrett (Medusa Quarry).

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CHAPTER 2 -- LITHOSTRATIGRAPHY OF THE LIMESTONE AND RELATED FORMATIONS OF THE DOUGHERTY PLAIN

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INTRODUCTION

The purpose of this section in the 1995 Georgia Geological Society field trip is to present a useful outline of the lithostratigraphy of the carbonate and related rocks of the Dougherty Plain. Only one lithostratigraphic unit, the Muckalee Limestone Member of the Williston Limestone, is a new unit. The Williston and Crystal River Limestones of the Ocala Group, and the Altamaha Formation have not hitherto been recognized on the Dougherty Plain. The possible presence of the Bucatunna Clay on the Dougherty Plain was discussed by Huddlestun (1993). The name Flint River formation has been abandoned (MacNeil, 1944b, 1947a, 1947b; Huddlestun and others, 1974; Huddlestun, 1993) and the Suwannee Limestone as has been applied on the Dougherty Plain is now recognized as Bridgeboro Limestone. Figure 2-1 illustrates the units discussed in this chapter, and their stratigraphic correlations.

STRATIGRAPHY

Ocala Group

The Ocala Group consists of relatively shallow-water, granular to bioclastic, variably macrofossiliferous limestone and dolostone. Commonly, larger Foraminifera are abundant in the Ocala Group and, in the upper part or in discrete beds, commonly produce a larger foraminiferal coquina.

The Ocala Group is subdividable into the lower Williston Limestone (with the Muckalee Limestone member, new name) and the upper Crystal River Limestone. This subdivision of a lower and an upper Ocala in Georgia was established by Applin and Applin (1964) on the basis of the first occurrence of the

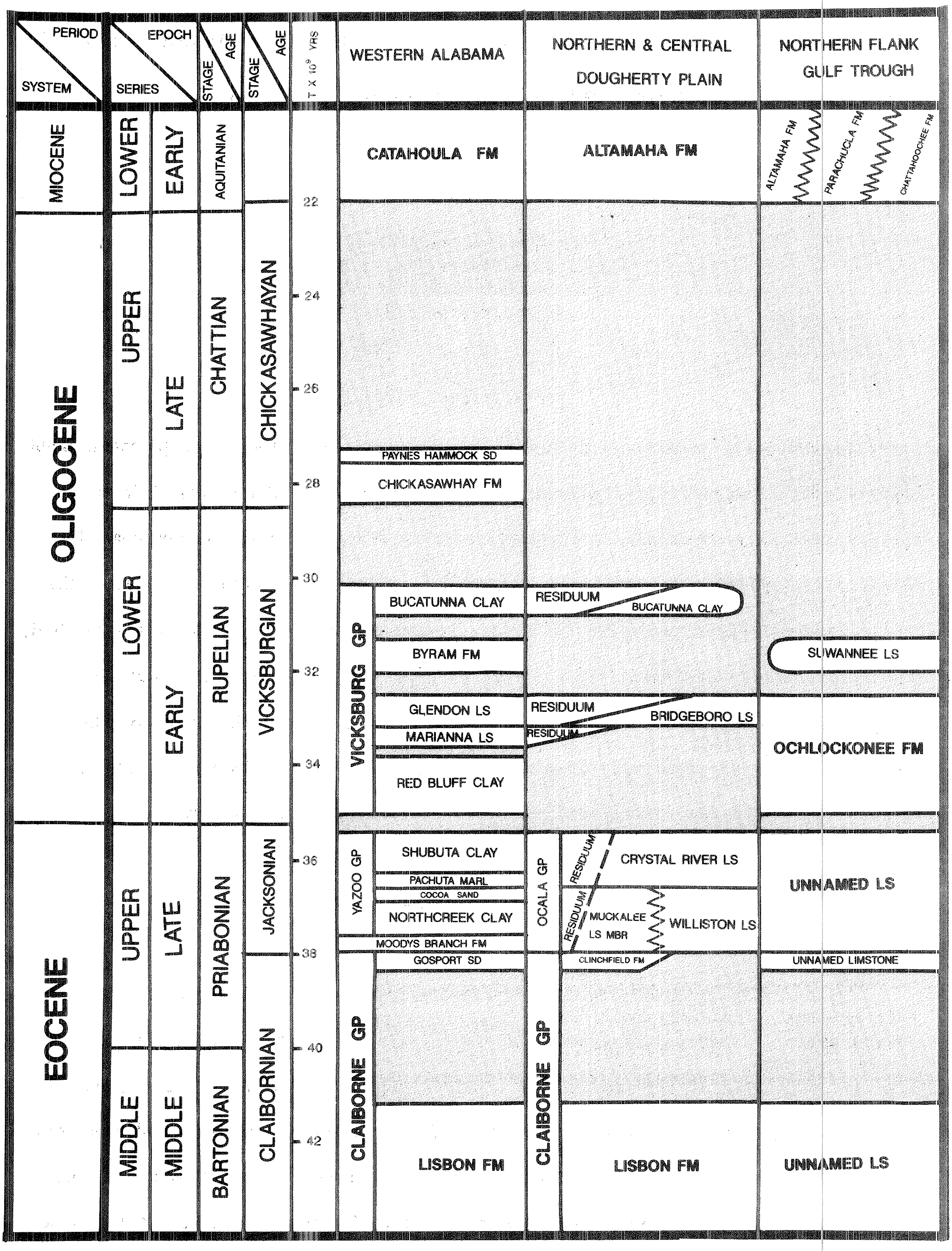

FIGURE 2-1 -- Correlation chart, Dougherty Plain.

foraminifer *Amphistegina pinarensis* within the Ocala. The subdivision can also be made on the basis of lithology where the lower part of the Ocala Group is granular and not especially fossiliferous (Williston Limestone), and the upper part is more coarsely fossiliferous and chalky (Crystal River Limestone). *Amphistegina pinarensis* appears to be restricted to the Williston Limestone.

In well-cuttings, the top of the Ocala Group is generally recognized on the first occurrence of Eocene larger Foraminifera. Lithology changes in well-cuttings at the top of the Ocala Group commonly include lighter colored, almost white limestone, greater chalkiness, greater abundance of fossils and greater diversity of fossils. Lithologically the basal Oligocene limestones are lithologically similar to the Ocala Group limestones and, in many wells, the lithologic distinction between the Oligocene limestones and the Ocala in well-cuttings is subtle. As a result, the best consistent way to identify the top of the Ocala Group is on the basis of the contained fauna and especially larger Foraminifera.

The Ocala Group is Late Eocene in age (Huddlestun and Hetrick, 1986).

Williston Limestone

Definition -- The Williston Limestone was named by Vernon (1951) as a lower member of the Ocala Limestone in Citrus and Levy Counties, Florida. The Williston was elevated to formation of the Ocala Group and expanded upon by Puri (1957). Huddlestun and Hetrick (1986) recognized the formation in Georgia.

Lithology -- The Williston Limestone in Georgia characteristically consists of granular, fairly even textured, moderately to well-sorted, fine- to coarse-grained, chalky to well-washed and clean, sparingly to nonmacrofossiliferous calcarenite that locally may contain abundantly macrofossiliferous beds or lenses. The calcarenite particles or grains consist generally of bioclastic debris in varying stages of comminution, much being nondescript and unidentifiable as to origin. In general, the finer granular calcarenite is chalky in appearance with much interstitial, very fine grained paste that evidently formed from the trituration of larger particles. The coarser granular calcarenite is generally more mealy in texture, more porous, and better washed with less, even little, interstitial, fine-grained calcite. In addition, the coarser arenitic bioclastic particles show less comminution and more particles can be identified as to origin.

Whereas in the type area of the Williston Limestone in Florida the granular component of the

Williston consists predominantly of Foraminifera, especially miliolids, the foraminiferal/miliolid quality of the limestone is not pronounced in Georgia. It is not unusual that miliolids influence the texture and lithology but rarely do they dominate and control the lithology of the Williston in Georgia as they do in Florida. The occurrences of macrofossils is sporadic with scattered, thin intervals of limestone being richly fossiliferous, either with molluscan molds or larger Foraminifera. Larger Foraminifera are prominent at scatter intervals but rarely rival in abundance the larger Foraminifera of the Crystal River Limestone. Furthermore, the most conspicuous larger Foraminifera of the Williston are the genera *Nummulites* and not, as in the overlying Crystal River, *Lepidocyclina*. In addition, the abundance of *Nummulites* in the Georgia Williston is considerably less than in the type area of the formation in Florida. *Lepidocyclina* in the Williston Limestone in Georgia typically are small and delicate, not commonly large and robust as in the overlying Crystal River.

Bedding in the Williston is generally massive and structureless, and devoid of primary sedimentary and biogenic structures. There are rare or scattered stratigraphic intervals, however, where the Williston is apparently cross-bedded or stratified. Where thinly layered, such as commonly occurs near the top of the formation in southern Georgia south of the Gulf Trough, it is platy, shaley, and fissile, with small fossils scattered along bedding planes.

The Williston Limestone is typically more recrystallized than the Crystal River Limestone and, therefore, tougher and more internally coherent. Intervals of unconsolidated calcarenite, or hard, dense, recrystallized limestone are commonly present in any given section but are volumetrically minor.

Sand, glauconite, and traces of clay mineral are restricted to the updip or shoreward facies of the Williston Limestone. Glauconite occurrence is closely associated with the occurrence of siliciclastics in the formation. In the core Dougherty 1 (GGS-3173) there is an upper calcareous sandstone that is 23.5 feet thick that grades downward into 46 feet (14 m) of Williston Limestone.

Stratigraphic Relationships -- Undifferentiated Williston Limestone in the Dougherty Plain (and in all of Georgia) is a subsurface unit. Only a local lithofacies of the Williston, the Muckalee Limestone Member in the Dougherty Plain, is known in outcrop. The Williston Limestone disconformably overlies the Lisbon Formation and is overlain conformably and gradationally by the Crystal River Limestone in the Dougherty plain area. In the Georgia Geologic Survey core Dougherty 1 (GGS-3173), the entire thickness of the Williston Limestone, from 24.5 feet to 94 feet, is 69.5 feet (21 m).

The Williston Limestone broadly is a shallow water, marine, continental shelf, carbonate deposit.

Muckalee Limestone Member of the Williston Limestone (new name)

Definition -- The Muckalee Limestone Member of the Williston Formation is a new name, proposed here for a stratified, flaggy, variably hard and soft, fossiliferous lithofacies of the Williston Limestone in the Dougherty Plain of southwestern Georgia. Previously the Muckalee Limestone had been referred to the Vicksburg Formation by Veatch and Stephenson (1911, p. 313, 314), Jackson Group (Brantly, 1916, p. 11), and Ocala Limestone (Brantly, 1916, p. 148; Cooke, 1943, 1959; Glawe, 1974). All of the limestone described by Brantly (1916) from the vicinity of Spring Creek in Calhoun county in the west, through the vicinity of Armena to Kinchafoonee Creek in Lee County in the east (p. 132-134, 142-152) includes the Muckalee Limestone of this report.

The Muckalee Limestone is recognized as a member of the Williston Limestone because of its occurrence in the Williston stratigraphic position, its limited geographic distribution, and the typical Williston low frequency of larger Foraminifera. It is distinguished from the typical Williston Limestone in being persistently and prominently bedded and more conspicuously fossiliferous. Lithology intermediate between typical Williston lithology and Muckalee lithology is present in the Georgia Geologic Survey core Doughty 1 (GGS-3173) taken approximately 10 miles (16 km) west of Albany in Dougherty County.

Type Section -- The name Muckalee is taken from Muckalee Creek in Lee County, Georgia, from an old limestone quarry near which I first recognized the limestone as lithostratigraphically distinctive. The type locality of the Muckalee Limestone Member of the Williston Formation is designated here as an active limestone quarry of Martin Marietta Company on the north side of Fowltown Creek, approximately 2 miles (3.2 km) northeast of the old community of Armena and 1 mile (1.6 km) north of the community of Oakland in Lee County, Georgia. The type locality is approximately 10 miles (16 km) northwest of Albany, Georgia. The type section or unit stratotype (holostratotype) of the Muckalee Limestone at the type locality are those limestones conformably overlying the Clinchfield Sand or the Lisbon Formation (on topographic highs) where the Clinchfield is absent. The exposures of limestone along Muckalee Creek in the vicinity of

Leesburg, Lee County, are all Muckalee Limestone.

Lithology -- The Muckalee Limestone Member of the Williston Limestone is a stratified limestone that contains varying but minor amounts of impurities. Chemical analyses by Brantly (1916, p. 133, 144-152) indicate that the limestone sampled by him ranges from approximately 97% to 99% pure. Being an updip and presumably a relatively nearshore facies of the Williston Limestone, the principal subordinate lithic components include very fine grained quartz sand and clay. No dolomite, gypsum, chert, or glauconite are known to occur in unweathered Muckalee Limestone. Furthermore, the sand and clay components of the limestone appear to be irregular in their distribution with some areas (e.g., the Spring Creek area west of Arlington, Calhoun County, being almost free from impurities (Brantly, 1916, p. 132-133).

Although granular and calcarenitic, this lithic component of the Muckalee Limestone is not as conspicuous as in typical Williston lithology. Bedding in the Muckalee Limestone is characteristically prominent, crude, flaggy and lenticular. In outcrop the limestone has the appearance of having been constructed of small, superposed lenses of limestone, generally ranging in thickness from a few inches (roughly 5 cm) to less than 1 foot (30 cm), and not more than 10 feet (3 m) in length. As a result, the bedding planes are discontinuous, merge, and diverge. The appearance of the lenticular bedding is enhanced by the variable and alternating had/soft quality of the member, resulting in the bedding on an exposed surface standing out in bold relief, in contrast to the massive, structureless bedding style of typical Williston Limestone.

The Muckalee Limestone is more conspicuously macrofossiliferous than typical Williston Limestone, with more conspicuous *Lepidocyclina* and moldic mollusk-rich intervals. *Nummulites*, commonly prominent in the Williston Limestone, is rare in the Muckalee Limestone.

Clay is locally conspicuous, as at the type locality or in the vicinity of Leesburg. The clay occurs as thin, discontinuous, horizontal layers or laminae throughout the limestone section. The clay typically is noncalcareous, waxy, and pale green. Quartz sand is rare in the Muckalee Limestone and occurs in scattered trace amounts at or near the base of the member. However, 23.5 feet (7 m) of calcareous sandstone is present at the top of the Williston Limestone in the core Dougherty 1 (GGS-3173), 10 miles (16 km) south of the type locality of the Muckalee Limestone Member near Armena.

Stratigraphic Relationships -- In its area of known occurrence, the Muckalee Limestone Member of the Williston Limestone is principally an outcropping unit and is directly overlain by residuum. It is not known to occur in the subsurface of the Dougherty Plain and, therefore, appears to occur as a narrow band or belt across the inner edge of the Dougherty Plain from the vicinity of Muckalee Creek in Lee County, southwestward to the vicinity of Spring Creek in Calhoun and Early Counties. It overlies with apparent conformity and gradation, a variable thickness of white, friable, calcareous, fossiliferous sandstone bearing local concentrations of *Periarchus lyelli* (*Scutella* bed) that is referred to here as the Clinchfield Sand. Where the Clinchfield Sand is locally absent, the Muckalee Limestone disconformably overlies the Lisbon Formation. The Muckalee Limestone is not known to be overlain in outcrop by the Crystal River Limestone.

No complete section of the Muckalee Limestone Member is known at this time. Its thickness at the type locality northeast of Armena is approximately 30 feet (9 m). The maximum thicknesses of limestone reported by Brantly (1916) in the Armena-Kinchafoonee Creek area (here assigned to the Muckalee Limestone) in Lee County, ranges from 20 to 30 feet (6 to 9 m).

The depositional environment of the Muckalee Limestone is interpreted to be inner neritic, marine, carbonate, continental shelf.

Crystal River Limestone

Definition -- The Crystal River Limestone was named by Puri (1957) for the upper part of the Ocala Limestone in peninsular Florida that had been referred to undifferentiated upper Ocala Limestone by Vernon (1951) in Citrus and Levy Counties, Florida. Huddlestun and Toulmin (1965) and Huddlestun (1965) extended the name into Alabama, and Huddlestun and Hetrick (1986) extended the name into Georgia.

Lithology -- The Crystal River Limestone is principally a limestone in Georgia with known dolomite and dolostone occurrences restricted to the region south of the vicinity of the Gulf Trough and Altamaha River. Other than local traces of glauconite, sand, and clay, no other lithic components are known to occur in the Crystal River Limestone in Georgia.

There are five types of limestone lithology in the Crystal River Limestone in Georgia: (1) a

Lepidocyclina/larger Foraminifera coquina, (2) moldic, molluscan-rich limestone, (3) miliolid-rich limestone, (4) chalky, fine- to medium-textured, massive bedded, finely bioclastic calcarenite reminiscent of the chimney rock of the Marianna limestone and (5), coquinoid bryozoan limestone. The formation generally consists of mixtures of these five end members in varying proportions, but the most common and characteristic lithology of the Crystal River consists of mixtures of the *(1) Lepidocyclina*/larger Foraminifera coquina and the (4) massive bedded, chalky calcarenite. Any of the five lithology types may form the dominant lithology in particular beds so it is not accurate to say the Crystal River Limestone is invariably a richly fossiliferous limestone.

Typical Crystal River Limestone is present in the shallow subsurface of Dougherty County and probably elsewhere in the Dougherty Plain. However, exposures of Crystal River Limestone along Lake Blackshear in Crisp County and at Muckafoonee Creek in Albany are not typical. The Crystal River limestone at these sites consist of macrofossiliferous limestone with a variably calcilutitic to calcarenitic matrix. The limestone is neither rich in mollusks nor larger Foraminifera.

Stratigraphic Relationships -- The Crystal River Limestone is that component of the Ocala Group that crops out discontinuously along the Flint River, from the highway US 280 crossing of Lake Blackshear between Cordele and Americus, southward to Decatur and Seminole Counties. It gradationally overlies the Williston Limestone, and is overlain disconformably (or paraconformably) by the Bridgeboro Limestone in the Dougherty Plain in western Georgia.

The Crystal River Limestone is correlative with the Tobacco Road Sand of the Barnwell Group of the Fall line Hills area of eastern Georgia and western South Carolina, and with the Pachuta Marl and Shubuta Clay of the Yazoo Group (Formation) of western Alabama and Mississippi.

The depositional environment of the Crystal River Limestone is broadly that of an open-marine, carbonate continental shelf.

Bridgeboro Limestone

Definition -- The Bridgeboro Limestone was named by Huddlestun (1981, 1993) for algal (rhodolithic) limestone in southern and southwest Georgia that had previously been called Suwannee Limestone (Owen, 1963; Glawe, 1974). Manker and Carter (1987) and Bryan (1991) adopted the name and supplied detailed descriptions and paleoenvironmental analyses of the formation. Bryan and Huddlestun (1990) established the age and correlation of the Bridgeboro Limestone.

Lithology -- The Bridgeboro Limestone is a rhodolithic limestone and it is the abundance of rhodoliths in a matrix of variably bioclastic calcarenite that distinguishes this formation. The abundance of rhodoliths varies from bed to bed. In some beds the rhodoliths are packed close together and impart a rubbly appearance to the bed. In other beds the rhodoliths do not dominate the lithology so completely, and the limestone takes on a more massive, uniform appearance. However, whether the rhodoliths are common or rare in a specific bed, they are always present in typical Bridgeboro deposits. The observed size of the rhodoliths range from less than 0.5 inch (1 cm) to as much as 5 inches 13 cm).

The matrix lithology of the Bridgeboro Limestone typically consists of a fairly uniform, even-textured, granular calcarenite. The calcarenite particles generally consist of very fine- to medium-grained bioclastic debris most of which is unidentifiable as to origin. Recognizable particles consist of fragments of Bryozoa, Foraminifera, echinoderms, rhodoliths, and rare calcitic mollusk fragments. Some scattered beds or lenses contain more coarsely bioclastic calcarenitic limestone in which the larger foraminifer *Lepidocyclina* is conspicuous. In some beds at the type locality of the Bridgeboro Limestone, the matrix lithology consists of a fine-grained calcarenite which is lithologically similar to the Marianna Limestone.

Degree of consolidation of the calcarenite ranges from soft and unaltered to indurated. Most commonly, however, the matrix is only lightly to moderately recrystallized and is rather soft and easily eroded. Because of the typically soft nature of the calcarenite matrix and the hard, resistant rhodoliths, core recovery in the Bridgeboro Limestone is characteristically poor. Commonly the only sediments recovered are small rhodoliths and rhodolith fragments.

Other than rhodoliths and bioclastic debris, the Bridgeboro Limestone is only moderately fossiliferous. Macrofossils that do occur consist of mollusk molds and casts, *Chlamys anatipes, C. duncanensis* scattered occurrences of the echinoid *Clypeaster cotteaui*, Bryozoa, and rare molds of colonial coral heads. The colonial coral heads are more commonly found near the top of the formation, where they get rather large and abundant. Other than rhodoliths, the only fossil that has been identified to date and that is moderately common in the formation is *Lepidocyclina*. At the type locality, *Lepidocyclina* ranges in abundance from common to rare and is spotty in distribution. Some zones or small lenses contain abundant *Lepidocyclina*.

The Bridgeboro is a relatively pure limestone and there are few other subordinate lithic components of the formation. Irregularly occurring clasts and smeared out clasts of very fine grained sand and films of greenish waxy clay are present at the type locality but elsewhere, quartz sand and clay minerals are not apparent in the formation. Clay and chert occurrence near the top of the formation is common but results largely from weathering and solution.

Stratigraphic Relationships -- The Bridgeboro Limestone (and residuum) that crops out on the Dougherty Plain on the northern flank of the Gulf Trough extends from the vicinity of Dublin in Laurens County, in the northeast, southwestward to at least Decatur County, a distance of approximately 100 miles (160 km). The Bridgeboro Limestone has not yet been traced southwestward into Jackson County, Florida. However, it is exposed in a limestone pit in northeastern Washington County, south of Chipley, Florida (formerly Duncan Church beds in Florida [Puri and Vernon, 1964]) and is present in the Florida Geological Survey core Hunt 1 (W-10954) in southern Washington County, Florida.

The band of Bridgeboro Limestone in the Dougherty Plain appears to be no more than 20 to 30 miles (32 to 48 km) across at the most. In the Ocmulgee River area, it grades laterally northwestward into the Marianna and Glendon Limestones. Farther southwest, in Worth and Dougherty Counties, the outcrop belt of the Bridgeboro Limestone occurs in the Dougherty Plain where its former presence is indicated by the occurrence of rhodolith-bearing chert rubble and boulders. I presume the Bridgeboro Limestone originally graded northwestward into the Marianna Limestone and Glendon Limestone on the Dougherty Plain, but those formations have subsequently been stripped off the plain or have been dissolved or altered to chert. It is possible that siliciclastic Shellstone Creek beds of Huddlestun (1993) could have been present in the Marianna-Glendon stratigraphic position on the inner Dougherty Plain and the Bridgeboro Limestone could have graded directly into the Shellstone Creek. Other than scattered outliers, the Oligocene occurs today only as a residuum over the Dougherty Plain.

In the type area of the formation, the upper contact relationships are ambiguous and the Bridgeboro Limestone occurs at the top of the local section or is overlain by residuum. At the type locality, the pinnacled top of the Bridgeboro Limestone appears to be overlain by residuum of the Bucatunna Clay. At Climax Cave in Grady County, Georgia, the Bridgeboro occurs at the top of the Oligocene section and is disconformably overlain by the Lower Miocene Chattahoochee Formation (Huddlestun, 1988). At Rockhouse Cave near Cordele in Crisp County, on the other hand, the Bridgeboro Limestone is disconformably overlain by the Suwannee Limestone and a 6 inch (15 cm) thick bed of dark chert that occurs in the stratigraphic position of the Suwannacoochee Dolostone of Huddlestun (1993) separates the two formations.

The Bridgeboro Limestone is at least 65 feet (20 m) thick at the type locality. Although the pinnacled and weathered top of the formation is exposed there, the lower contact is not, and the complete thickness of the formation at the type locality is not known. Owen (1963) reported roughly 100 feet (33 m) of Suwannee Limestone (Bridgeboro Limestone of current usage) near the type locality of the Bridgeboro.

Age -- The age of the Bridgeboro Limestone is Early Oligocene, Vicksburgian (Rupelian). All of the principal macrofossils of the formation are known to occur only in Vicksburgian formations in the type provincial Oligocene in Mississippi and Alabama.

Bryan and Huddlestun (1990) produced evidence that the Bridgeboro Limestone at its type locality (which is the upper part of the formation) is correlative only with the Glendon Limestone of Mississippi and Alabama. The Bridgeboro Limestone occurs within the *Cassigerinella chipolensis-Pseudohastigerina micra* Zone of Stainforth and others (1975), and within Zones P18-P19 of Blow (1969).

Suwannee Limestone

Definition -- The Suwannee Limestone was named by Cooke and Mansfield (1936) for Oligocene limestone cropping out on the Suwannee River between Ellaville and White Springs in Hamilton and Suwannee Counties, Florida. The name subsequently was extended into western Florida and across Georgia (Cooke, 1945) to the Dougherty Plain (Owen, 1963; Glawe, 1974). Huddlestun (1988) restricted the name Suwannee to limestone of typical Suwannee lithology as exposed on the Suwannee River. This effectively removed the name Suwannee Limestone from all known outcropping limestone (and chert) on the Dougherty Plain.

Lithology -- Typical Suwannee Limestone consists of very pale orange (10 YR 8/2), even-textured, and mealy (medium- to coarse-grained), granular, calcarenitic limestone. The grains generally consist of roughly equidimensional, rounded, nondescript calcareous pellets that may be largely algal or fecal in origin (also see Randazzo, 1972), miliolid Foraminifera, and fine, nondescript bioclastic debris. The grain-size of the pellets is variable, ranging from fine (on the Wentworth scale) with much intragranular calcite "paste", to generally coarse and relatively well-sorted, with little calcite "paste". The Suwannee Limestone is soft to indurated and recrystallized, massive-bedded and structureless to rudely but distinctly bedded, and sparingly macrofossiliferous. Quartz sand or silt is not apparent in the formation and conspicuous interstitial clay is rare in the formation as a whole.

The granular quality of the Suwannee Limestone is more pronounced than in other Tertiary limestones of Georgia, Florida and Alabama. The granularity of the Suwannee Limestone commonly remains evident where the limestone has been entirely converted to chert, leaving only "ghosts" of the pellets and Foraminifera within the translucent chert, or where the limestone has been completely recrystallized by calcite and is lacking in porosity.

The Suwannee Limestone characteristically contains few macrofossils, and large sections (e.g., along the Suwannee River) may be entirely devoid of macrofossils or visible bioclastic debris. In other places the Suwannee may be moderately macrofossiliferous with scattered concentrations of *Rhyncholampas gouldii* or rich concentrations of molluscan molds (typically with low diversity). Although *Lepidocyclina* occurs in scattered beds in low or moderate abundance, I know of no abundant occurrences of larger Foraminifera in the Suwannee Limestone in cores or outcrops.

Stratigraphic Relationships -- Typical Suwannee Limestone overlies the Bridgeboro Limestone immediately east of the Gulf Trough in southwestern Georgia (McFadden and others, 1986; Huddlestun, 1993), and north of the Gulf Trough near Cordele in Crisp County (Huddlestun, 1993). However, the Suwannee Limestone or its stratigraphic equivalent is absent at the Bridgeboro type locality where residuum of Bucatunna Clay (?) disconformably overlies the Bridgeboro Limestone. The Suwannee Limestone of Huddlestun (1993) or its residuum is not known to be present on the Dougherty Plain or in the Pelham escarpment.

Huddlestun (1993) concluded that the age of the Suwannee Limestone is Early Oligocene, Vicksburgian (Rupelian) and is most likely correlative with the Byram Formation of Mississippi. The principal macrofossils of the formation are known to occur only in the Vicksburg Group in the Vicksburgian type area in Mississippi and also in Alabama. None are presently known to occur in the Chickasawhay Formation.

Bucatunna Clay

Huddlestun (1993) suggested that the weathered gray clay overlying the pinnacled Bridgeboro Limestone at its type locality is an outlier of the Bucatunna Clay. This is a reasonable correlation because the clay at the Bridgeboro lime pits is lithologically compatible with Bucatunna clay lithology and it occurs in the proper Bucatunna stratigraphic position, i.e., overlying the Glendon Limestone (or Glendon-equivalent). If this identification is correct, it means that the Bucatunna Clay, typically developed in Mississippi and western Alabama, was formerly more widespread in the eastern Gulf Coastal Plain and may have occurred throughout the western Georgia Coastal Plain. The easternmost definite occurrence of the Bucatunna Clay is in the vicinity of Florala, Alabama. Unfortunately there are no other known clay beds in the Bucatunna stratigraphic position in eastern Alabama or Georgia.

Undifferentiated Residuum

Most Oligocene residuum consists of moderate reddish brown (10 R 4/6), variably cherty clay with associated blocks or inclusions of variably fossiliferous chert and local concentrations of ironstone. Much of the fossiliferous chert on the Dougherty Plain was derived from the Bridgeboro Limestone because the silicified rhodoliths are prominent in the chert. Most of the Bridgeboro residuum is found east of the Flint River but some silicified Bridgeboro residuum also occurs immediately west of the river. I have seen no silicified Suwannee Limestone on the Dougherty Plain. Elsewhere in Georgia, the characteristic granular and mealy texture of the Suwannee is still apparent where the limestone has been either completely recalcitized or silicified.

Both Cooke (1935, 1943) and MacNeil (1944a, 1944b) included gravel in the concept of the Flint River formation. However, it is my observation that the Oligocene deposits of the Southeastern United States are devoid of quartz gravel and quartz pebbles. The gravel identified by Cooke (1935, 1943) and

MacNeil (1944a, 1944b) occurs in high terrace, fluvial deposits of the Chattahoochee and Flint Rivers across the entire southern part of the Dougherty Plain and is stratigraphically unrelated to the Oligocene or Eocene residual deposits.

Sand residuum on the northern Dougherty Plain is identified here as Miocene Altamaha Formation that has been let down onto the Dougherty Plain by dissolution of the underlying Oligocene limestones. MacNeil (1944a, 1944b) also thought that the sand and clay residuum were emplaced during the weathering of the Oligocene carbonate deposits from overlying Miocene deposits. However, it does not appear to me that disaggregated Altamaha sediments were incorporated into the Oligocene residuum during dissolution of the Oligocene limestones. Much of the Oligocene clay residuum on the Dougherty Plain that is not sandy may have been derived from the weathering and leaching of the Bucatunna Clay.

Stratigraphic Relationships -- Undifferentiated Oligocene residuum is known to occur on the Dougherty Plain. It is overlain by, and locally protrudes through, the Altamaha Formation in the northern part of the plain, and is overlain by a mantle of high river terrace sands of the Chattahoochee and Flint Rivers in the southern part of the plain.

Based on the conclusions of Huddlestun (1993) concerning the age of the Oligocene deposits in Georgia, all of the Oligocene residuum is considered here to be Early Oligocene, Vicksburgian in age.

Altamaha Formation

The Altamaha Formation has not hitherto been recognized on the Dougherty Plain. However, most exposures of weathered sand on the northern part of the Plain north of the latitude of Albany, and on both sides of the Flint river, consist of medium- to coarse-grained, moderately sorted, prominently stratified sand. The Altamaha generally is not so deeply weathered so as to mask its lithology and bedding characteristics. However, locally the Altamaha Formation has been severely fractured, folded, and blocks of Altamaha have been rotated. For the most part, during dissolution of the Oligocene carbonates and the letting down of the Altamaha Formation, the Altamaha appears to have been mechanically competent and rigid, even brittle.

This brief commentary on the Miocene Altamaha Formation is required in this field trip guidebook because it has been commonly mapped or included in the Oligocene residuum (Cooke, 1939; MacNeil, 1947a, 1947b; Georgia Geological Survey, 1976; Huddlestun, 1993). It is, however, distinct from the Oligocene and does not appear to have been incorporated into the severely dislocated and reconstituted Oligocene residual sediments.

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CHAPTER 3 -- FACIES AND PALEOGEOGRAPHY

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PREVIOUS RESEARCH

Tertiary paleogeographic research in the southeastern Coastal Plain has a long history. Among the earliest geologists to draw paleogeographical conclusions from rocks in the area was Raphael Pumpelly, who, in a paper on unconformable relations in the area published in 1893, suggested that "... The Gulf Stream after the creation of the Central American barrier, found its way back to the Atlantic sweeping over southern Georgia and northern Florida, and supplying the food needed to build up the great organic beds of the Chattahoochee and Chipola." It is unclear what connection Pumpelly envisioned between his proposed path of the Gulf Stream and the location of the Suwannee Strait. Indeed, it is not clear that he was aware of the existence of the strait. The first reference to its existence seems to be in the work of Dall (1892) a year earlier, who coined the term "Suwannee Strait" for an inferred former deep-water feature separating peninsular Florida from the remainder of the Gulf and Atlantic Coastal Plains. Dall did not explicitly outline the evidence on which he based his inference, but apparently it was the geographically distinct outcrop areas of the argillaceous Hawthorne Formation (which he stated lay within the Strait) and the sandy Altamaha Grit (which he placed on the northern flank of the Strait). Both formations are Miocene. Whether he was aware of Dall's work or not, Pumpelly was presumably only inferring the necessity of a current to supply nutrients for the corals he found so abundantly in the rocks of the region. Though his title refers to the "Chattahoochee" strata, many of the coral-rich rocks he referred to are actually Oligocene Bridgeboro Limestone, rather than Miocene Chattahoochee Formation, as the term is presently used. In any case, these are the earliest works of which we are aware in which a physical paleoenvironment was inferred and its geographic implications explored.

The first paper explicitly concerned with paleogeography of the region was Vaughan's (1910) work on the history of the Florida Platform. Vaughan discussed the implications of carbonate stratigraphic packages to episodes of submergence and exposure in the region. He recognized the "pre-Vicksburg" origin of the Platform itself. It is critical to recall that Vaughan included the Ocala as well as some of the overlying limestones in his "Vicksburgian", in contrast to the current meaning of Vicksburgian as exclusively Lower Oligocene. Furthermore, his "Chattahoochee" apparently included the Bridgeboro Limestone, as several of his coral localities of "Chattahoochee" age are certainly Bridgeboro. In addition, he suggested a tropical climate for Florida and southern Georgia during the Paleogene. He inferred a west-to-east current regime in and near the Suwannee Strait. He recognized subsidence of the Florida platform of up to 1000 feet (~300m), contemporaneous with deposition of shallow water limestones, which, he noted, must have kept pace with the subsidence, in, perhaps, one of the earliest applications of the notion of stratigraphic "accommodation". He recognized the fact as well as the implication of transition from pure carbonate to more clastic rich sediments from the time of Ocala to the time of Suwannee deposition. Of most interest to us is the fact that Vaughan reconstructed the regional Paleogene geography, and assigned names to its principal features. He pointed out that the Florida platform would have been separated from the American mainland by the Suwannee Strait, and named this offshore bank "Orange Island".

After Vaughan, little attention was directed toward paleogeography of the coastal plain until after the second World War. Most geologists during this interval concentrated on establishing stratigraphic correlations and interpreting structural features in the region, because interest was focused on oil exploration. Such work is, of course, fundamental to paleogeographic reconstruction, and continues today. But actual sedimentologic and paleogeographic work dating from the period between Vaughan and the Second World War is essentially lacking, though some attention was paid to general environments of deposition of strata (e.g., Rainwater, 1960). Most paleogeographic insights from this time arose as by-products of stratigraphic and petroleum-centered research. Stratigraphic correlation problems between the northern Gulf Coast and Florida, resulting from faunal dissimilarity, were recognized and attributed to biogeographic differentiation (e.g. Applin and Applin, 1944; Richards and Palmer, 1953; Cole and Applin, 1964). Similarly, broad outlines of the history of transgression and regression were constructed, principally as a framework for stratigraphic research (e.g., Stephenson, 1928). The Suwannee Strait, originally recognized as a paleogeographic feature by Dall (1892), was conceptually attached to a group of stratigraphically recognized features (collectively, the Gulf Trough, the Suwannee Channel, and the Chattahoochee, Tallahassee, and Apalachicola Embayments) in southwestern Georgia and northwestern Florida. Huddlestun (1993, p. 106) provides a thorough discussion of the history of understanding of this feature, and of the distinction between the Suwannee Strait as a paleogeographic feature and the Gulf Trough/Suwannee Channel as a stratigraphic one.

By the mid 1950's interpretations of the environmental and paleogeographic implications of stratigraphic, paleontologic, and petrologic observations were beginning to creep back into the literature. Moore (1955) recognized that the distinctive foraminiferal faunas of temporally equivalent strata within and on the flanks of the Apalachicola embayment represented distinct biofacies. His interpretation of the depth tolerances of the constituent genera allowed him to conclude that the Apalachicola embayment strata were deposited in water at least 100 feet deeper than nearby strata outside the embayment, approximately 20 km away. In the 1960's, refinements of models of major transgressions and regressions affecting the region, and their paleoenvironmental implications, were elucidated by Rainwater (1964) and MacNeil (1966). Interestingly, given the modern concentration on sequence stratigraphic research in the region, no consensus arose about whether these transgressions and regressions resulted from local isostatic and sediment supply effects, or from eustatic sea-level changes.

It was the work of Cheetham (1963) that first explicitly approached the problem of paleogeography in the southeast. Cheetham interpreted faunal disjunction of bryozoan faunas and their inferred depth distributions in direct relation to their association with the Suwannee Strait, the Florida Bank, and the former American continental shelf in Georgia and Alabama.

The same year, Herrick and Vorhis (1963) published a compendium of isopach and structure contour maps which beautifully illustrated stratigraphic thickenings and depressions associated with the

Gulf Trough.

Chen (1965) provided isopach maps which also illustrated the location of the Gulf Trough, at least for the Paleocene, and superimposed upon them Krumbein and Sloss style facies maps. The distribution of lithofacies was neatly related to the position and influence of the Suwannee Strait for the Paleocene. However, lack of good stratigraphic control on the Eocene position of the Strait, coupled with an over-simplified view of its control on lithofacies at the time ("clastic" vs. "non-clastic") led Chen to infer erroneously that the Suwannee Strait had migrated northwestward during this time. McKinney (1984a) later took this at face value and suggested that carbonate suppression by clastics (Walker, *et al.* 1983) could explain this paleogeographic mobility. Chen (1965) was apparently the first author to note the association of Paleocene and Eocene "reef-like limestone" with the southern edge of the Suwannee Strait in Florida. However, he did not provide any description of these limestones, nor did he recognize any major reef tract in the region.

Later isopach/facies maps by Cramer (1974) also illustrate the location of the trough, for the entire Tertiary. However, Cramer's more generalized facies maps do not show any obvious relationship between rock type and the Gulf Trough.

Randazzo and Saroop (1976; later summarized in Randazzo, 1982) produced the first microfacies-based lithologic study in the region, in which they concluded that the Middle Eocene to early Late Eocene rocks in Citrus and Levy Counties, Florida were deposited in very nearshore environments, and that water depths progressively deepened over the Florida Bank through the remainder of the Late Eocene. Randazzo, *et al.* (1990) have further documented the paleoecologic and paleoenvironmental conditions of the peritidal facies of the Middle Eocene Avon Park Formation. Ivany, *et al.* (1990) described the unique and exceptionally well preserved fossil seagrass beds of the Avon Park.

Coleman (1983) outlined the lithofacies distributions of Lower Oligocene rocks in westernmost Alabama and Mississippi. His work, though far from our area, concerns us because it served as a model for interpreting coeval rocks eastward in Alabama and into the region of this field trip (Bryan, 1993).

The following summary of Paleogene facies and paleobiogeography is derived primarily from a few recent publications, as follows. Manker and Carter (1987; later summarized in Manker and Carter,

1989) were the first to propose that the distribution of a specific lithofacies (the algal bioherm of the Bridgeboro Limestone) was directly controlled by the action and position of the Suwannee Strait. They later proposed (Carter and Manker, 1987) that a modern physical geographic feature (the Pelham Escarpment) reflected original depositional topography as controlled by this relationship. Carter (1989; 1990) related biofacies distributions of Eocene echinoids, with minor lithofacies support for his contentions, to the position and actions of the Suwannee Strait. Carter and McKinney (1992) later used these relationships to discuss the efficacy of the Strait as a paleobiogeographic boundary. Bryan (1991a; 1993) examined the paleoenvironmental, paleoecological, and paleogeographical aspects of Paleocene and Oligocene rocks in the eastern Gulf Coast, among other things. Huddlestun (1993) placed his discussion of the Oligocene strata of southern Georgia into a conceptual framework of regional paleogeography and facies relationships.

PALEOCENE CARBONATES

Only the lower Paleocene (Midwayan/Danian and lowest Selandian) has an appreciable content of carbonate sediments in our area, and even these are clastic-rich. Farther west in southwestern Alabama lie the reef limestones of the Sabinian/upper Selandian Salt Mountain Limestone (see Bryan, 1991b for discussion). Equivalent strata in Georgia are all clastic. Most of the Lower Paleocene carbonates of Alabama and southwestern Georgia are assigned to the Clayton Formation, and members thereof, which is a heterogenous package of carbonate and clastic rocks. The bulk of the formation in the type area, where it was originally named the "Clayton Limestone" is actually calcareous orthoquartzite, though good shelf carbonate facies do occur nearby (e.g., the McBryde Limestone Member, Toulmin, 1977).

Most carbonates in the Clayton Formation are open shelf calcarenites and calcilutites. Judging from the inferred substrate preferences of the modestly diverse echinoid fauna, the former facies is probably dominant. There are at least two other carbonate facies which we will encounter on the trip, weather permitting.

One of these facies is an algal-rich rock which probably occupied a setting near the Paleocene shelf edge. The Paleocene paleogeographic reconstruction of Huddlestun (1993, Fig. 49, reproduced as

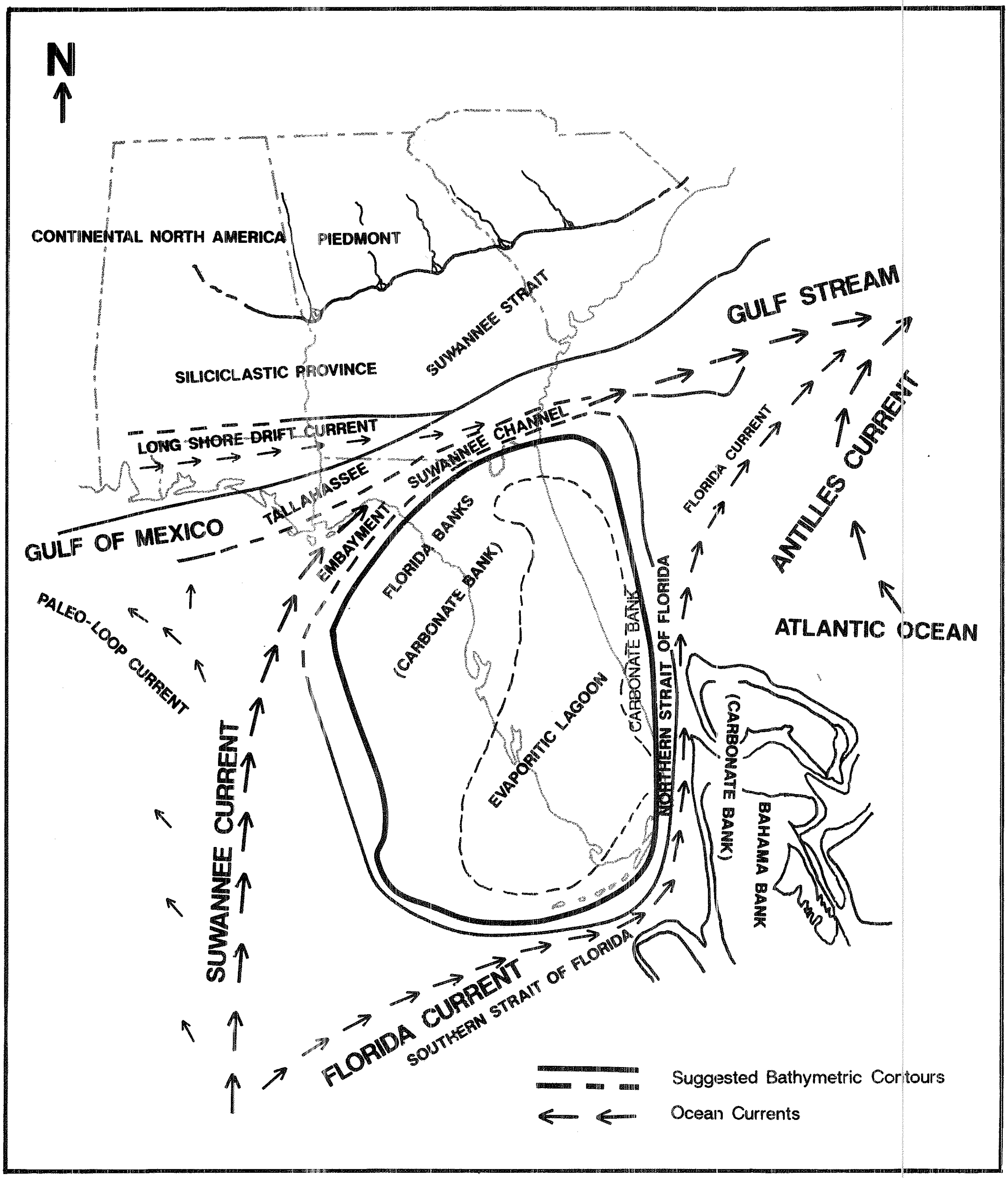

FIGURE 3-1 -- Paleogeography and current distribution of the eastern Gulf Coast during the Midwayan (Early Paleocene/Danian). (From Huddlestun, 1993)

Figure 3-1 herein) shows the Suwannee Strait trending nearly east/west across northwestern Florida and southern Georgia, with strong east-flowing currents paralleling its northern edge. The most offshore exposed Clayton carbonates are algal rhodolith bearing rocks, known from two localities (Figure 3-2). Near Rutledge, Crenshaw County, Alabama, this facies has been considered part of the Porters Creek Formation (Copeland, 1966). Below the W.F. George Dam on the Chattahoochee River in Henry County, Alabama and Clay County, Georgia it has been assigned to the Clayton Formation. These would lie within the region of strong "longshore currents" on Huddlestun's map (Fig. 3-1). Though we currently know too little of this facies to state with certainty that it is a shelf-edge build-up, its general similarity to the better exposed and better known Oligocene Bridgeboro Limestone tempts us to think of it as an analogous facies. The Bridgeboro Limestone is discussed in some detail below. Rhodoliths in the Paleocene rocks are less numerous, much larger, and often more flattened than are typically found in the Bridgeboro, so we infer that the depositional setting of the two, while similar, was not identical.

The other carbonate facies in the Clayton is an oyster bank from a nearshore setting. On the Flint River near Montezuma, Macon County, Georgia, is a thick lime-rich bed dominated by the Paleocene oyster *Ostrea crenulimarginata* (Veatch and Stephenson, 1911; Toulmin, 1977). This bed is completely surrounded and infiltrated by clastic sediments, primarily sand, but is rich enough in oyster shells to be considered a true limestone. Thin oyster and coral biostromes scattered within the Late Paleocene Tuscahoma Sand along Abbey Creek and its tributaries in Henry County, Alabama probably represent a similar facies. Figure 3-2 includes our interpretation of the general paleogeographic setting of all these Early Paleocene carbonate facies.

EOCENE CARBONATES

Carbonate rocks are essentially lacking in Lower and Middle Eocene strata, with only isolated stringers and beds ever encountered. The Upper Eocene, in contrast, is dominated by carbonate rocks over most of the eastern Gulf Coast region, from eastern Mississippi to central Georgia. Within the area of this field trip, Upper Eocene carbonates are assigned to the Ocala Limestone (in Florida -- Scott, *et al.*, 1991) or Ocala Group (in Georgia -- Huddlestun, 1981) including the Tivola Limestone. In addition, the Clinchfield Sand is extremely calcareous, bearing abundant sand sized carbonate fossil fragments as well

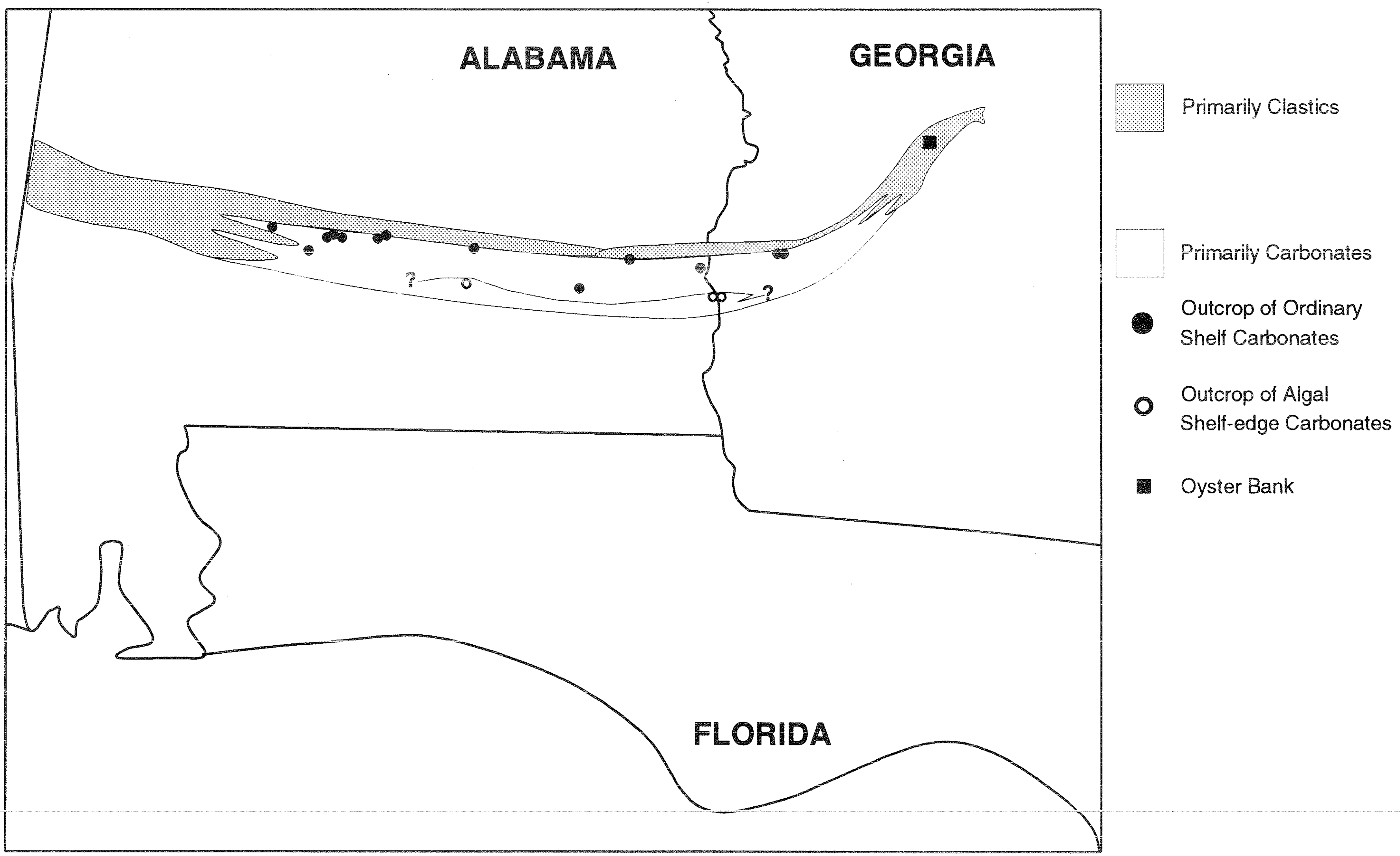

FIGURE 3-2 -- Outline map of southern Georgia and Alabama showing outcrop area of the Clayton Formation and equivalents. Note the occurrence of algal rhodolith bearing carbonates along the southern edge of the outcrop band.

as calcite cement.

The various carbonate facies of these units were deposited on the North American continental shelf proper, and the area covered by this field trip was separated from peninsular Florida by the Suwannee Strait, which strongly influenced the distribution of facies. The position of the Strait axis changed rather dramatically between the Paleocene and the Late Eocene (Huddlestun, 1993), to a position as indicated on Figure 3-3 (reproduced from Huddlestun, 1993, Fig. 51). Eocene shelf-edge and pelagic facies in and adjacent to the Suwannee Strait are entirely in the subsurface, and so will not be visited. Sediments from mid-shelf and shoreward settings will be examined.

Precious little lithologic study has been directed toward these rocks in Georgia, and while more has been done in Florida, it is all within a very restricted area of the west-central part of the state. Carter (1989) included the results of a Sedimentary Petrology class project on the microfacies of these strata in Georgia, but it was based upon a very small number of thin sections. Randazzo and Saroop (1976) reported on a microfacies analysis of Middle and early Late Eocene strata encountered in six cores from a small area in west-central Florida. They concluded that the earliest Late Eocene in the region recorded a transition from tidal flat to shallow subtidal deposition. Zachos (1978) also recognized this transition in his microfacies analysis (covering a somewhat larger area and including somewhat younger Late Eocene strata). Both Fenk (1979) and Sharpe (1980) used microfacies analysis to postulate progressive deepening throughout the entire Late Eocene in central Florida. It is possible to infer from faunal data in Cheetham (1963) a progressive deepening of water in the entire region throughout the Late Eocene, though the depth tolerances of bryozoan species is too great to be certain about this. McKinney (1984b) was able to relate the morphologic changes within an evolving echinoid lineage to progressively greater environmental stability during the Late Eocene, which, in turn, resulted from increasing water depth through this time. Carter (1989; 1990) related an upsection increase in the proportion of mud-tolerant echinoid species through Upper Eocene strata to increased water depth through the interval. The best hypothetical cause for this deepening is the Late Eocene eustatic sea level rise (lower T4) postulated by Haq, *et al.* (1987). Bryan (1993) pointed out that such deepening over a carbonate shelf during eustatic rise indicated that the water depths must have been sufficient to cause them to behave as drowned

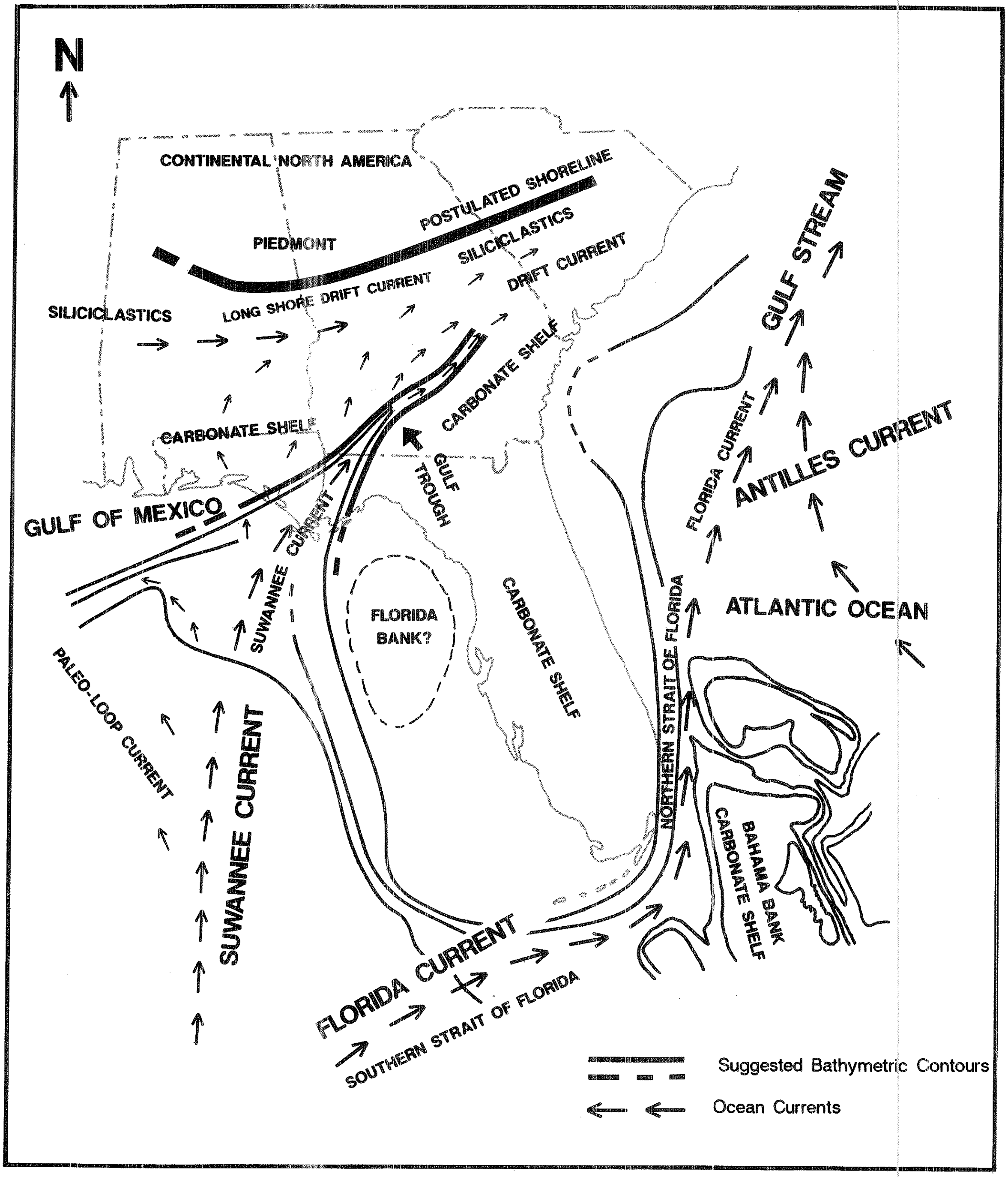

FIGURE 3-3 -- Paleogeography and current distribution of the eastern Gulf Coast during the Jacksonian (Late Eocene/Priabonian). (From Huddlestun, 1993) shelves. Otherwise a different set of transgressive carbonate systems tract facies would be expected (James, 1984).

From lithostratigraphy (Huddlestun, 1993), bryozoan paleoecology (Cheetham, 1963), and echinoid paleoecology (Carter, 1990) the Florida platform has been interpreted as a north-sloping ramp during the Late Eocene, though Cheetham (1963) envisioned a rather complicated evolution of this ramp into a rimmed platform during the interval. Carter (1989) interpreted the south Georgia continental shelf to have been a rimmed bank at the time, based upon the geographic distribution of echinoid assemblages which preferred relatively low energy, muddy substrata (in a broad band whose offshore edge was at some distance from the Suwannee Strait) and those which preferred relatively high energy, sandy substrata (both near the Suwannee Strait edge and also shoreward of the central muddy band). The summary figure (Fig. 3-4) is modified from Carter and McKinney (1992) who combined the inferred paleogeography of the Florida bank and the continental shelf. It should be noted that the nearest exposed Eocene carbonates to the inferred position of the edge of the Suwannee Strait is still some tens of km distant on either flank. Thus conclusions about the nature of this edge based on surface data alone are suspect. Using lithofacies distributions in the subsurface, Huddlestun (1993 -- Fig. 56) derived an interpretation consistent with that based upon echinoid distributions. That is, the south flank lay in substantially deeper water in the late Late Eocene than the north flank, which lay at the edge of a basically flat shelf.

In Georgia, only the central muddy facies of the Ocala and the nearshore sandy Clinchfield and Tivola Formations are well exposed, and fieldtrip stops are planned to allow examination of both. Eocene shelf edge facies will not be seen on the field trip.

OLIGOCENE CARBONATES

In many respects the Oligocene of the eastern Gulf coast represents the most interesting package of strata in the region. Controversy exists about exact correlations. For example, some authors (Hunter, 1976) would include the *Rotularia vernoni* zone of the uppermost Ocala Limestone of Florida (traditionally Late Eocene) with the Lower Oligocene Bumpnose Limestone, and even the authors of this chapter

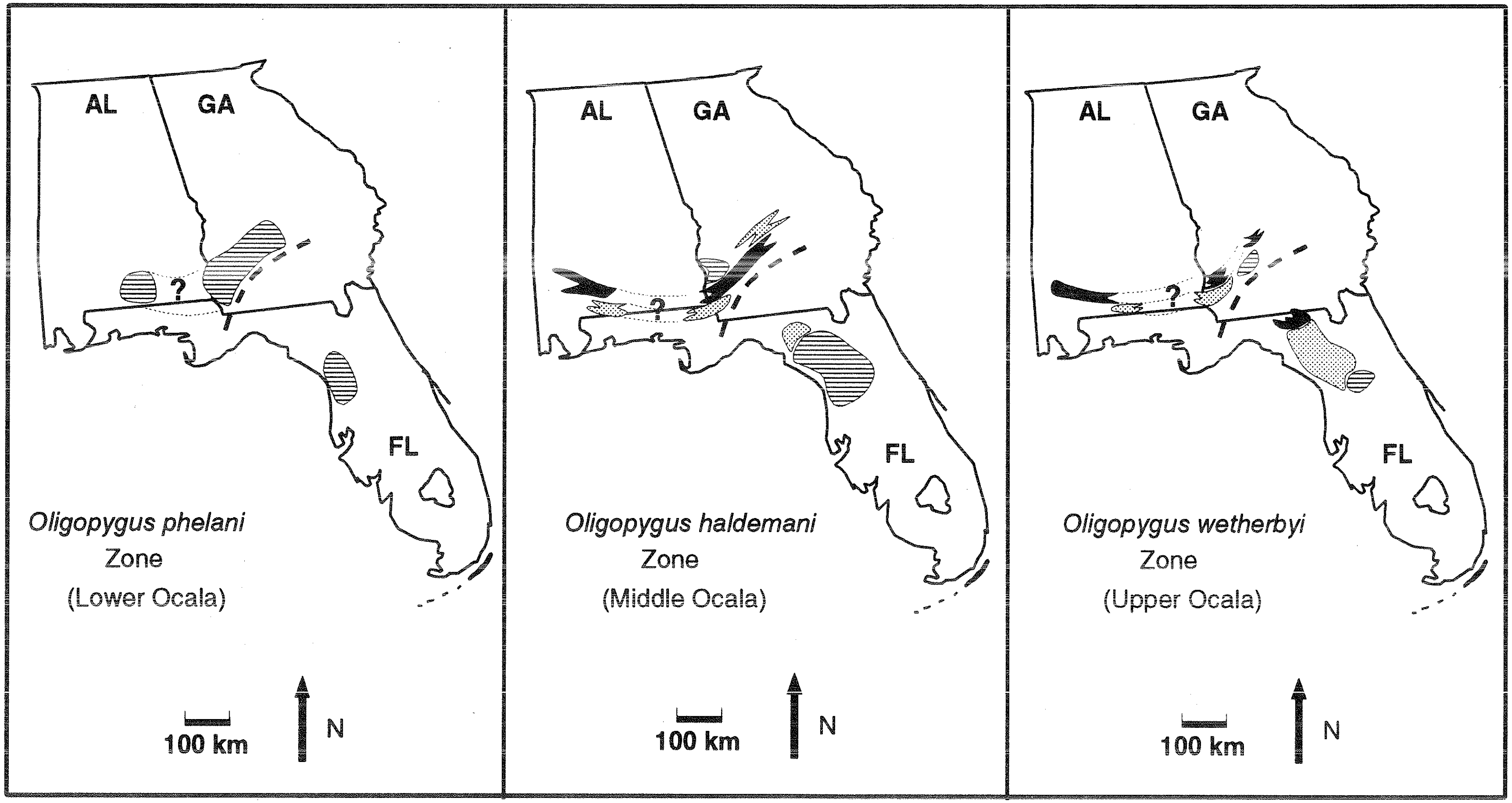

FIGURE 3-4 -- Summary of carbonate facies in the Late Eocene of the eastern Gulf Coast. Patterns indicate where collections allow control on sediment type. Solid pattern indicates areas in which echinoid collections contain >50% mud-tolerant species. Collections from dotted areas have between 0 and 50% mud-tolerant species. Collections from lined areas have no mud-tolerant species. Thin dotted lines indicate inferred continuity of these areas as bands paralleling the Suwannee Strait and continental shelf edge. Heavy dashed line approximates the axis of the Suwannee Strait. (Modified from Carter and McKinney, 1992).

disagree on this point. While the Suwannee Limestone has long been considered to be Late Oligocene in age (e.g., J.G. Carter, 1989) and equivalent to the Chickasawhay Limestone of Mississippi and Alabama, it has more recently been placed in the Vicksburgian Stage (Early Oligocene) by Huddlestun (1993) and Bryan (1991a) based on lithostratigraphic and biostratigraphic criteria. Furthermore, Jones *et al.* (1993), using $^{87}Sr/^{86}Sr$ stable isotope geochronology, report dates from three Suwannee Limestone localities in both northern and central Florida ranging from 33.6 to 35.3 Ma, placing the Suwannee well within Early Oligocene time. Hammes (1992), also using $^{87}Sr/^{86}Sr$ geochronology, indicates that all Suwannee deposition in southwestern Florida occurred between 36 and 31Ma. Stratigraphic controversy aside, the most interesting aspect of the rocks for this field trip is the wonderful variety of exposed lithofacies, and their paleogeographic connection to the Suwannee Strait.

Lower Oligocene limestones within the Suwannee Strait apparently resulted from dominantly pelagic deposition in deep water, though sea-level lowstands probably introduced shallower-water sediments into its axis (Huddlestun, 1993). These facies all lie in the subsurface, and it is the shallow bank facies of the northwest flank of the Strait which provide the most interest for us.

These facies comprise the Bridgeboro Limestone and its Florala Member near the shelf edge, the equivalent Marianna and Glendon Limestones, the possibly partly equivalent (and demonstrably partly younger) Suwannee Limestone, and the residuum developed from all these rocks (and others) on the Dougherty Plain. The latter were named the "Flint River Formation" by Cooke (1935), a lithostratigraphic unit whose validity was questioned by Huddlestun (1993), who called them simply "undifferentiated residuum". Unfortunately, unaltered Marianna and Glendon are very poorly exposed in Georgia and only the residua are common. Nor is the Florala exposed in the state. Only the Bridgeboro and Suwannee are easily seen as non-residual exposures.

In northern peninsular Florida, only the Bridgeboro (subsurface only) and Suwannee Limestones are common, with two thin, areally restricted carbonate units (Ellaville Limestone and Suwannacoochee Dolostone -- Huddlestun, 1993) occurring in the extreme northern part of the Peninsula. To the west, in southern Alabama and the Florida panhandle, the Marianna, Glendon, Bridgeboro, and Florala are all well exposed. It was for this area and southwestern Georgia that Bryan (1991a; 1993) constructed his model of overall facies relationships.

The Bridgeboro Limestone is the most distinctive of the Oligocene lithofacies in the region. Manker and Carter (1987) pointed out that its geographic distribution parallel to both flanks of the Suwannee Strait was consistent with it representing a shelf-edge buildup or reef (Fig 3-5). They discussed two main lithofacies within the unit: 1) algal rhodolith calcirudite and 2) algal calcarenite. Manker and Carter, 1987 neglected to discuss a third facies which occurs at the very top of the Bridgeboro at the type locality, because its precise age and facies relationship to the other two was not clear at the time. The algal rhodolith calcirudite consists of a densely packed (averaging 294/m^2 in cross-sectional counts) accumulation of large (5cm mean diameter), typically spherical, concentrically laminated rhodoliths constructed overwhelmingly by the rhodophyte *Archaeolithothamnium.* Between the rhodoliths is a calcarenite of primarily fragmentary algal debris. By comparison with modern rhodolith shape (Bosellini and Ginsburg, 1971), the spherical, concentric structure was interpreted to indicate frequent movement of the rhodoliths by currents in the Suwannee Strait affecting its edges. Prager and Ginsburg (1989) subsequently pointed out that much of the rolling of Recent rhodoliths on the Florida shelf edge is actually accomplished by burrowing echinoids (similar in form to species known to occur in the Bridgeboro) and by fish. They questioned the necessity, and even ability, of currents to move such large objects frequently. The estimates of required current velocity for rolling derived by Prager and Ginsburg (1987) were actually overestimated because they treated the nodules as solid quartz spheres, and chose velocities which would "entrain" (implicitly, to suspend and transport) them, rather than simply rolling them. We have estimated the physical density of Recent rhodoliths from the southern Gulf of Mexico (collected by K. Smith of the University of South Florida) between 1.5-1.6 g/cm^3. Thus, with a density only 60% that of quartz, and with irregular rather than perfectly spherical surfaces, and requiring slight rolling rather than suspension in order to become coated, we suspect that ordinary storm and possibly tidal currents might actually move the rhodoliths. We do not question the importance of organic processes in moving rhodoliths, simply the supposed rarity of current-driven movements. The frequent (though not universal) occurrence of rhodolith facies on the edges of deepwater straits with strong currents suggests some genetic relationship between the currents and the nodules. The fauna associated with the rhodolith rich

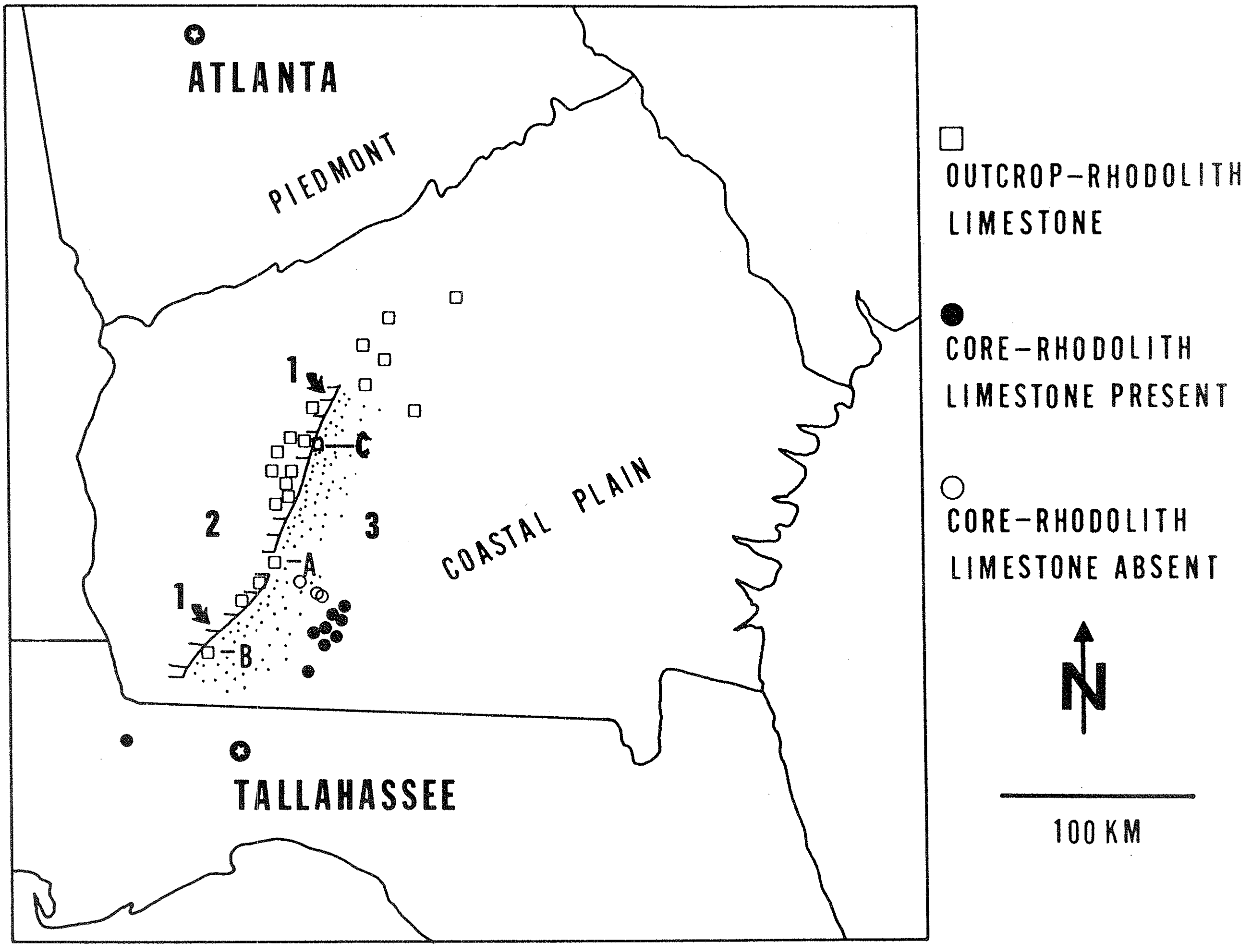

FIGURE 3-5 -- Locations of cores and outcrops containing Bridgeboro Limestone. Major sampling areas are (A) Bridgeboro Quarry, (B) Climax Cave, and (C) Rockhouse Cave. General physiographic features are (1) Pelham Escarpment, (2) Dougherty Plain, and (3) Tifton Upland. (Modified from Manker and Carter, 1987).

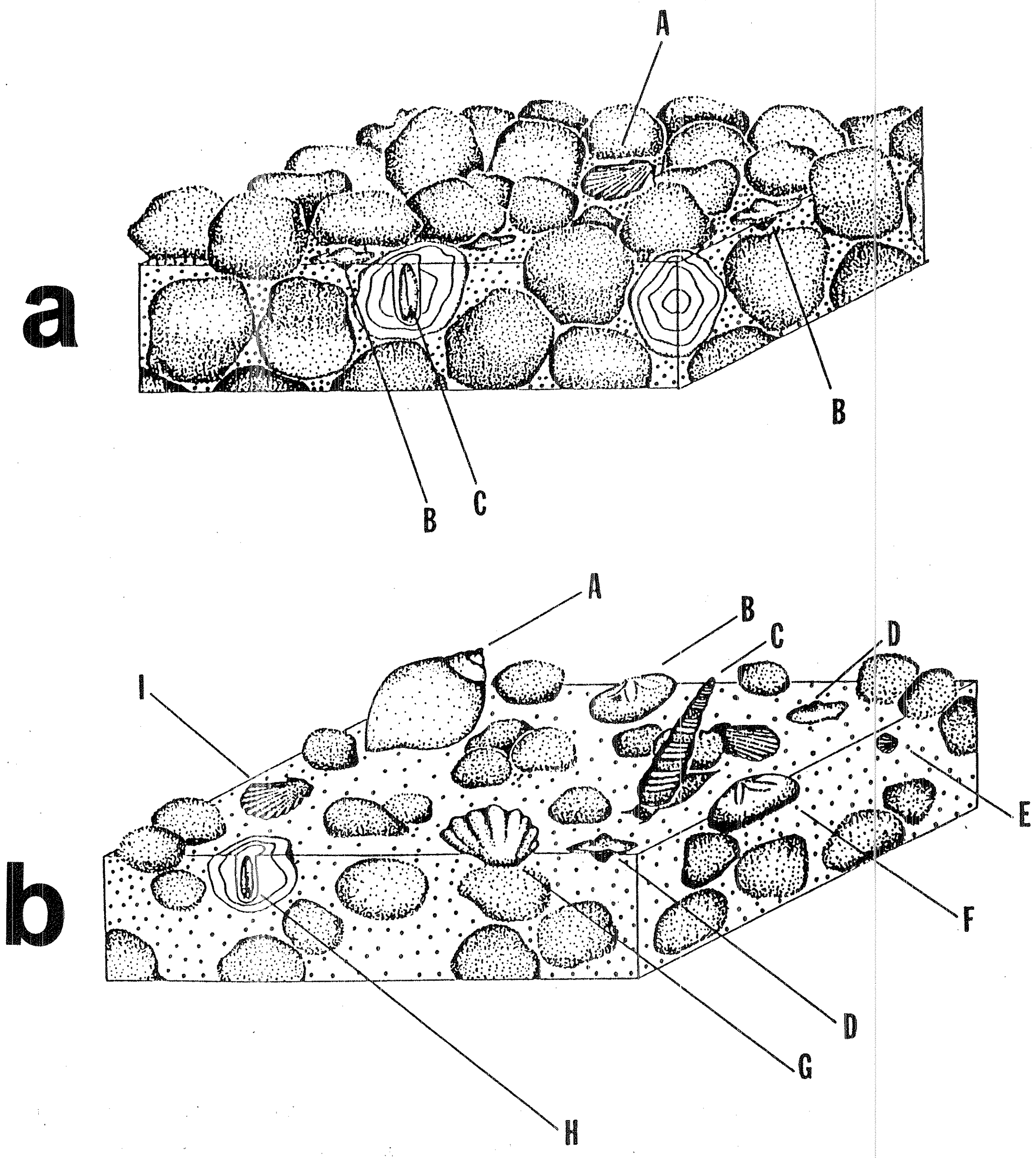

FIGURE 3-6 -- a) Paleoecologic reconstruction of lower, rhodolith-dominated community from Bridgeboro Quarry. Note the extreme dominance by rhodoliths and the low diversity of associated taxa. A) *Chlamys duncanensis*, B) *Lepidocyclina* sp., C) *Lithophaga nuda*.

b) Reconstruction of upper, rhodolith-poor beds at Bridgeboro Quarry. Note the lower rhodolith dominance and the higher diversity of associated taxa compared to Fig. 3-6a. A) *Ampullina flintensis* B) *Clypeaster cotteaui*, C) *Cerithium hernandoensis*(?), D) *Lepidocyclina* sp., E) *Glycymeris cookei*(?), F) *Rhyncholampas gouldii*, G) oyster, H) *Chlamys duncanensis*. (From Manker and Carter, 1987).

facies is of moderate to low diversity, and is dominated by taxa with clear adaptations to coarse, and even mobile, substrata (Fig. 3-6a).

The second major facies known from the Bridgeboro is algal calcarenite. These loose, coarse sands generally include a few small rhodoliths, and are identical with the matrix of the rhodolith calcirudite facies. The two facies might be considered end members of a spectrum, were not the possible intermediate lithologies absent (or at least exceedingly rare). Associated fauna in the calcarenite facies are of slightly higher diversity and seem well adapted to burrowing in or living on loose sand (Fig. 3-6b).

The third facies present at the type locality of the Bridgeboro is a coral-rich bed at the very top of the quarry. Farther to the southwest, in Climax Cave (Fig 3-5), large colonial corals as are found at Bridgeboro are much more commonly encountered, clearly within the Bridgeboro Limestone. Vaughan (1900) reported on a rather highly diverse Oligocene coral fauna near Bainbridge, which he interpreted as a coral reef. This locality is now apparently under the waters of Lake Seminole, unfortunately. Thus, the association of the Bridgeboro with coral reef facies in much of its outcrop area reinforces its interpretation as a shelf-edge facies.

Based upon the near perfect dominance of the rhodophyte *Archaeolithothamnium* in Bridgeboro rhodoliths, Carter and Manker (1987) postulated moderately deep-water deposition for the unit. The occurrence of green algae in the upper strata of the type section led them to suggest depositional shoaling as the algae accumulated, either because of buildup of the facies itself, or because of eustatic sea level lowering (presumably the distinct drop at the Rupelian/Chattian boundary between TA4 and TB1 of Haq, et. al, 1987). Some preference might be given to the former explanation by considering that the Rupelian Bridgeboro is directly overlain by Miocene sediments (Parachucla Formation) at the type section, implying a lack of space for deposition during the Chattian. (i.e., Chattian deposition was not accommodated by either subsidence or post-Rupelian basin volume.) Assuming this to be the case, the Bridgeboro represents a true shelf-edge buildup, but, lacking a rigid framework, not an ecologic reef. Bryan (1991a) estimated water depths of 30-70m during Bridgeboro deposition, based on depths of occurrence of living rhodoliths in the modern Caribbean and Gulf of Mexico.

Bryan (1991a; 1993) has provided a summary of the facies relationships among all the Lower

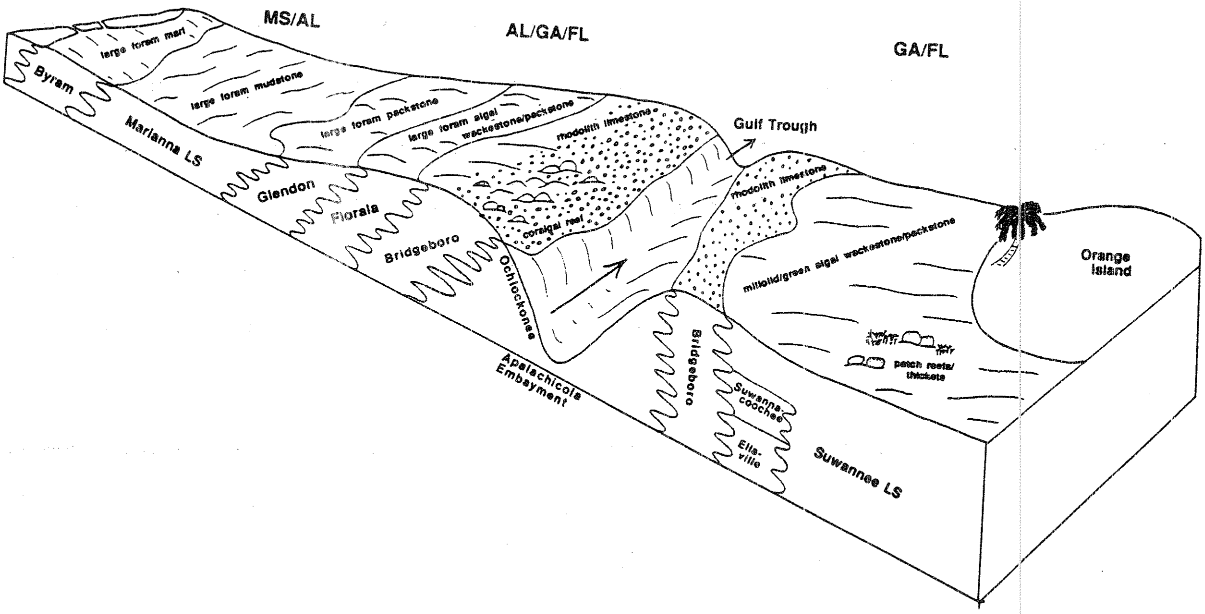

FIGURE 3-7 -- Block diagram reconstruction of Vicksburgian carbonates across the entire eastern Gulf Coastal Plain from Mississippi to Florida, as an extension of Coleman's (1983) model. (From Bryan, 1993).

Oligocene units in the eastern Gulf Coast region, and his interpretation is summarized in Fig. 3-7. The Marianna and Glendon Limestones (and their undifferentiated residua in the Dougherty Plain) are interpreted as open shelf, quiet water deposits. Bryan has omitted the Suwannee Limestone from his model of the shelf to the north of the Strait, but it is known to be present in the subsurface and exposed in Rockhouse Cave (Fig. 3-5). Based upon its stratigraphic position directly overlying the Bridgeboro, particularly in the northern part of the Pelham Escarpment area, we suggest it to have been a post-Bridgeboro high energy shelf and near shelf-edge facies, lacking rhodoliths. We do not intend imply thereby that all the Suwannee is younger than all the Bridgeboro. The latter may have continued to be deposited in the southern Suwannee Strait region after the former began accumulating to the north.

Bryan (1993) interprets the Florala Member of the Bridgeboro as a relatively quiet water back-bioherm (i.e., shoreward) facies of the high energy Bridgeboro shelf-edge buildup, because it lies geographically nearer the paleoshoreline than does the Bridgeboro in southern Alabama and the Florida panhandle. In contrast, Huddlestun (1993) considers the Florala as a "far-offshore, relatively deep and still-water, photic zone..." deposit, and reconstructed it as a down-slope facies rather than a shelf facies. This interpretation was based upon the occurrence of Florala in the Gulf Trough in Georgia, downdip of the Bridgeboro (see Huddlestun, 1993, Plate 3). Thus, both authors have good justification for placing the Florala facies in distinctly different relationships to the Bridgeboro, suggesting that its actual relationship might be more complicated and interesting than either implies. Downdip, into the Suwannee Strait (or Gulf Trough), the pelagic facies of the Ochlocknee Formation appears, with or without intervening Florala, according to both authors.

Across the Suwannee Strait, on its other shallow flank, the Bridgeboro reappears. Its lateral shelf facies equivalents on the Florida Shelf (i.e., toward Vaughan's "Orange Island") are the Suwannacoochee, Ellaville, and Suwannee.

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CHAPTER 4 -- RECENT SINKHOLE DEVELOPMENT ON THE DOUGHERTY PLAIN AT ALBANY, GA.

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ABSTRACT

Flooding of the Flint River following Tropical Storm Alberto in July, 1994 triggered the collapse of at least 312 sinkholes in a mantled karst plain at Albany Georgia. We examine the distribution and dimensions of these sinkholes in order to evaluate their mode of formation; to estimate subsidence associated with new sinkhole development; and to assess the significance of new sinkholes to the evolution of the Dougherty Plain. Sinkhole locations are more clustered than random, with 88% occurring inside the limits of flooding. Inside flooded areas, sinkholes often follow joint-controlled linear trends ($r>0.95$). Sinkholes most often occur in predominantly sandy residuum, although they are not restricted to areas of thin overburden. Sinkhole dimensions are log-normally distributed with respective median circumference, length, width and depth dimensions of $C=5.7$ m, $L=1.8$ m, $W=1.6$ m and $D=0.7$ m. Sinkholes formed by the collapse of overburden into preexisting cavities which were formed by piping of residuum into underlying bedrock joints. As much as 12,670 m^3 of sediment was transported underground as the new sinkhole opened. When averaged over key flooded areas, new sinkholes account for an average surface lowering of between 0.40 and 0.56 mm/km^2. If flood-triggering events are the primary control on the rate of sinkhole development in the Dougherty Plain, new sinkholes could only account for as much as 0.8 to 1.12 m of surface lowering per million years. This implies that new sinkholes are less important to surface lowering than is the subsequent coalescence and lateral growth of sinkholes.

INTRODUCTION

Sinkholes are the most common and arguably the most important landforms occurring on the Dougherty Plain. Sinkholes are potential hazards for land use, they represent groundwater contaminant entry points, and they reflect stages in landscape evolution. Because sinkholes are initiated underground it is difficult to directly observe processes responsible for their formation. However, the surface characteristics of sinkholes, including their distribution, dimensions, and morphology, are useful for assessing the origin and growth of sinkholes (Williams, 1972; Kemmerly, 1982; Ogden *et al.*, 1989) and for understanding important hydrologic and geologic controls on sinkhole development (LaValle, 1968; White and White, 1979). In addition, estimates of sinkhole volume (Hollingshead, 1984; Wilson *et al.*, 1987) provide a measure of the amount of material that has subsided underground (Arrington and Lindquist, 1987).

At least 312 sinkholes were reported to have formed in Albany following flooding of the Flint River in July 1994 in association with Tropical Storm Alberto. Single day precipitation totals for this storm exceeded the 200 year recurrence interval for several stations in the Flint River drainage basin, with rainfall at some stations 3 times larger than any previous daily rainfall on record (T. Mote, personal communication, 1995). The Flint River crested 7 m above flood stage at Albany on July 11, 1994, inundating much of the city. Numerous sinkholes were reported as soon as residents were able to return to their homes. These sinkholes are unusual because (1) a large number formed at one time, (2) they were triggered by flooding associated with Tropical Storm Alberto, and (3) the sinkholes formed in association with raised water levels rather than a drawdown of the water table. Furthermore, field survey data allows us to accurately estimate subsidence associated with sinkhole development.

In this paper we (1) relate the distribution of new sinkholes to the limits of the July 1994 flooding, (2) describe the dimensions and mode of formation of the sinkholes, (3) quantify the volume of material that subsided into the sinkholes, and (4) assess the significance of new sinkholes to the evolution of the Dougherty Plain.

STUDY AREA

Albany, Georgia is located within the Dougherty Plain physiographic region of the southeast Coastal Plain (Figure 4-1). The Dougherty Plain is a gently rolling karst plain located between the clastic-capped Tifton Upland to the southeast and the Fall Line Hills to the northwest (Figure 4-1). Most of the drainage in the Dougherty Plain is subterranean, with overland flow entering sinkholes and draining as

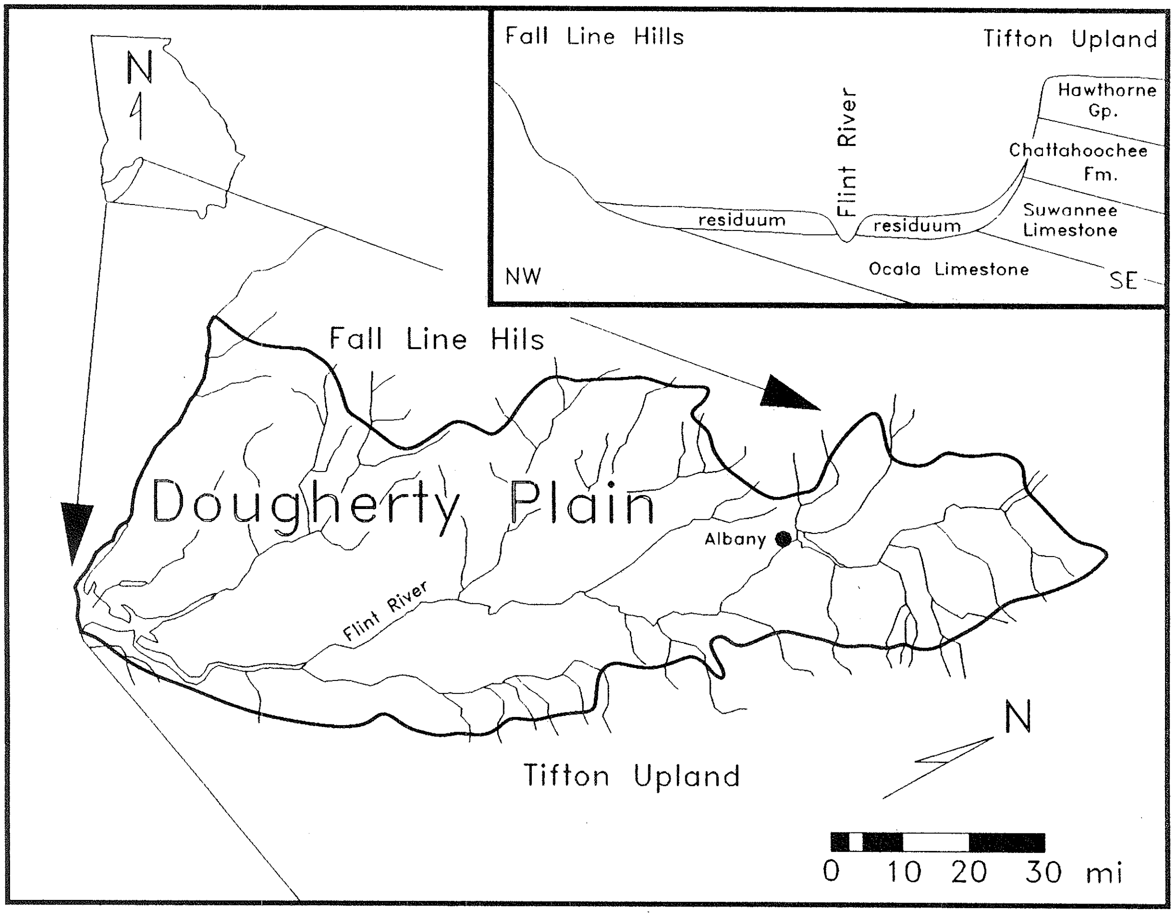

FIGURE 4-1 -- Location of the Dougherty Plain, Flint River, Albany Georgia and surrounding physiographic regions. Inset shows an idealized NW-SE geologic cross-section showing the stratigraphy and dip of bedrock units modified from Beck and Arden (1984).

baseflow to the Flint River. Originating on the Piedmont, the Flint River is the only surface drainage feature which crosses the length of the region, although several tributaries from the northwest have incised surface channels. The Dougherty Plain karst features originated following exposure of the Ocala Limestone surface as the Pelham Escarpment, which separates the Dougherty Plain and Tifton Upland, retreated down-dip (Herrick and LeGrand, 1964; Beck and Arden, 1984).

The Dougherty Plain is underlain by >1500 m of clastic and carbonate rocks of pre-Cretaceous to Quaternary age (Hicks *et al.*, 1987). Only the Ocala Limestone (Late Eocene age) and overlying surficial residuum are important to development of sinkholes in the Albany area (Figure 4-1). Dipping gently to the southeast, the Ocala Limestone outcrops in the few incised river valleys, but is typically covered by residuum and recent alluvium (Wait, 1963; Hicks *et al.*, 1981; 1987; Torak *et al.*, 1991). The Ocala Limestone is part of the upper Floridian aquifer system, which is the primary source of drinking and irrigation water in the region. The Ocala Limestone is densely jointed and highly permeable. Major joint sets trend at 315, 5, and 30 degrees (Brook and Allison, 1983).

Hicks *et al.* (1987) summarized the thickness and textural trends of the residuum and alluvium that mantle the Dougherty Plain. Thickness of unconsolidated deposits varies from 6 to 21 m, with the thickest deposits generally found east of the Flint River. Isolated extreme thicknesses near 120 m are probably ancient sinkhole fills. Grain size varies from sand to clay, but is typically a sandy clay derived from weathering of the Ocala Limestone and overlying clastic sediments.

Most sinkholes found on the Dougherty plain are pre-historic, having formed by subsidence and piping of unconsolidated sediment into the Ocala Limestone (Brook and Allison, 1983; Beck and Arden, 1984). Cavities develop and grow in residuum above joints until the overlying soils can no longer maintain an arch and collapse (Figure 4-2).

FIELD WORK

Sinkholes at Albany were examined less than two months after they were first reported. The locations and dimensions of 77 sinkholes were determined using a Trimble Global Positioning System (accurate to within ± 3m) and a variety of field survey techniques. These data were merged with the GPS

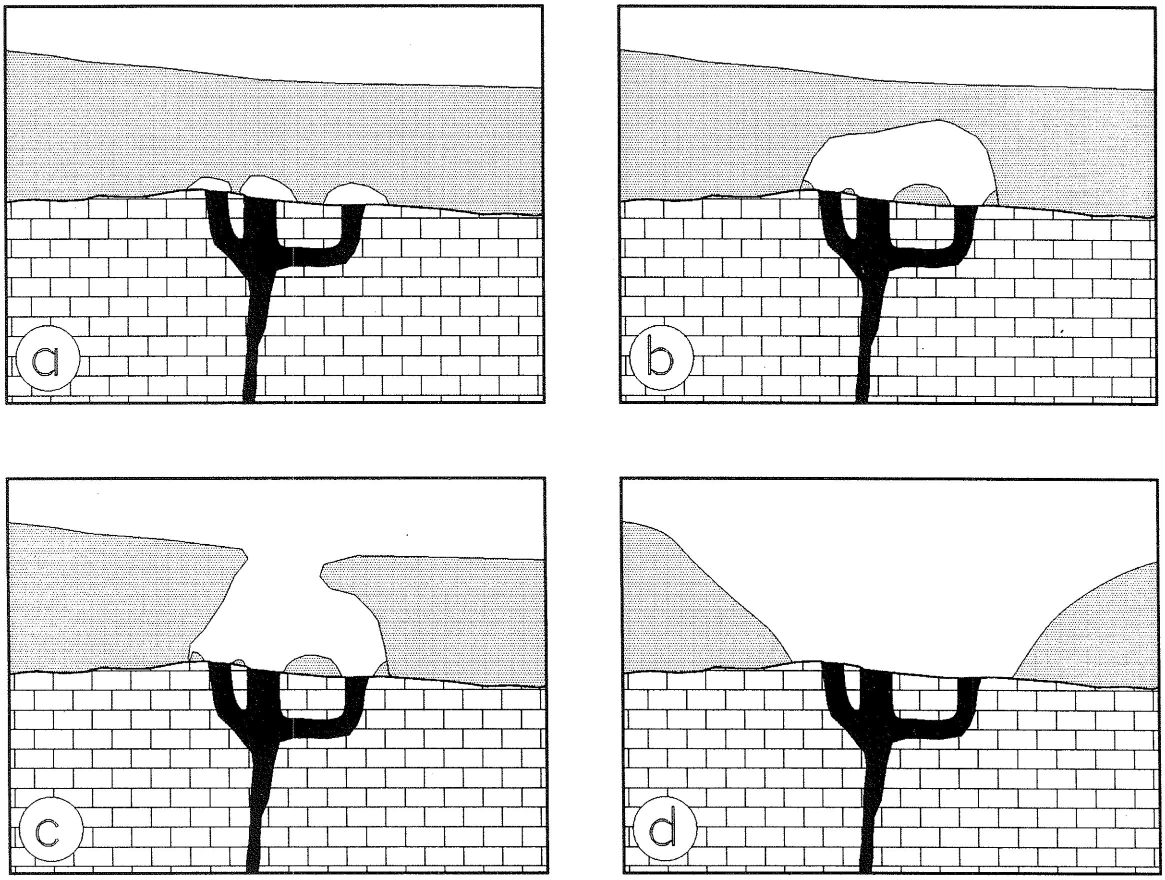

FIGURE 4-2 -- Model of subsidence sinkhole development on the Dougherty Plain adapted from Beck and Arden (1984). *(a)* Initial piping of residuum into underlying joints creates a small cavity at the bedrock-residuum interface. *(b)* Cavity grows by spalling of sediment and coalescence of adjacent cavities until *(c)* the bearing capacity of the overlying soil arch is exceeded and collapse occurs. *(d)* Oversteepened side walls collapse and runoff and colluvial processes transport material downward enlargening the sinkhole and reducing side slopes.

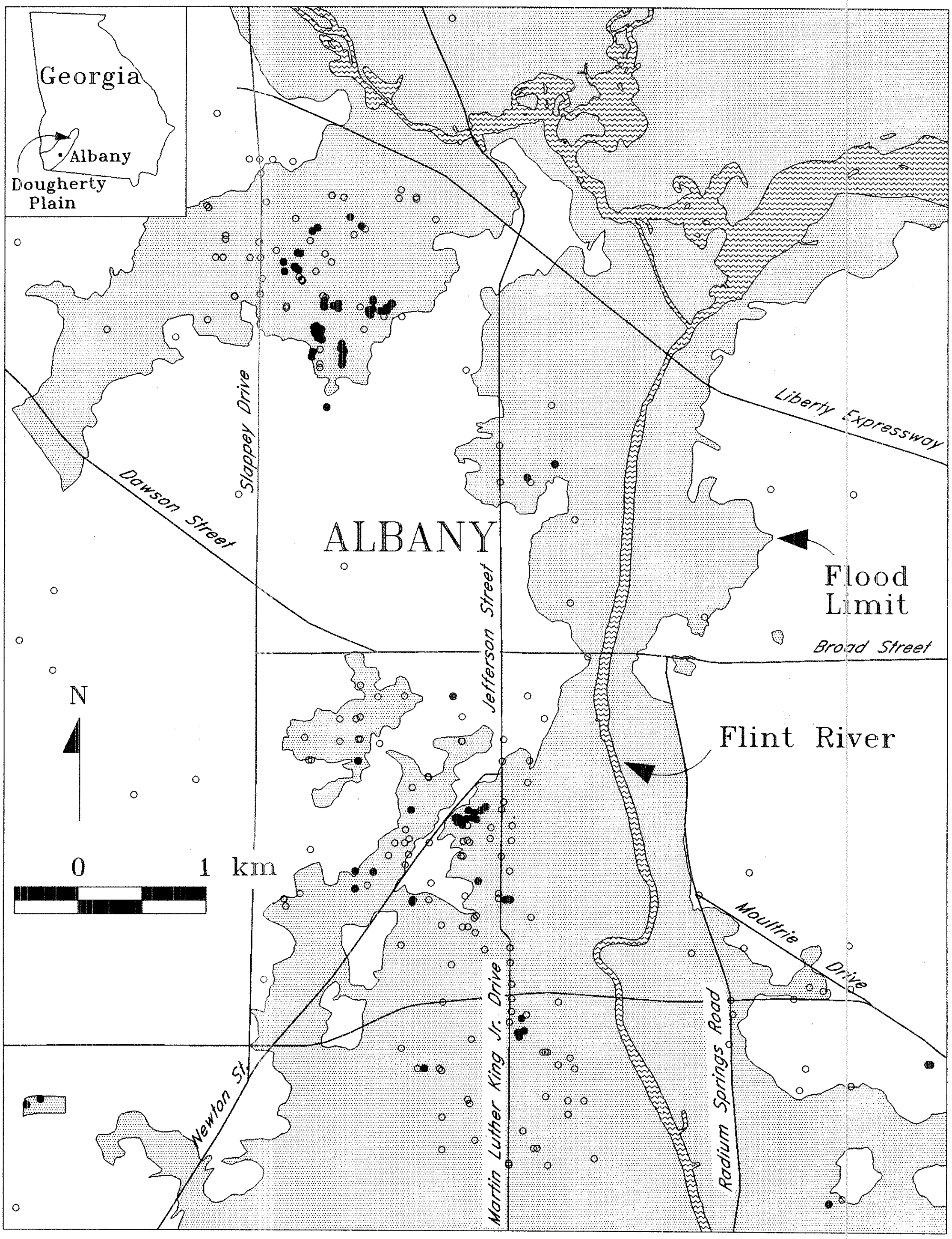

FIGURE 4-3 -- Location of new sinkholes at Albany Georgia. Stippled region shows the limits of flooding caused by runoff from Tropical Storm Alberto. Filled circles identify sinkholes mapped using Global Positioning Systems, while open circles identify the locations of sinkhole addresses reported by residents of Albany. Base map and many of the sinkhole locations were made available by Randy Weathersby (Albany-Dougherty Planning Commission).

locations of an additional 34 sinkholes obtained from the Albany-Dougherty Planning commission and the Georgia Geologic Survey, along with 201 street addresses of sinkholes reported by residents of Albany to the City Engineers Office (Figure 4-3). Sinkhole dimensions including circumference, length, width, and depth, and long-axis orientations were surveyed using a theodolite, a Brunton Compass, a 1.5 m circumference wheel, and tape measures for 77 sinkholes. Depth could not be determined for 24 sinkholes because of fill and other obstructions. Two mutually perpendicular profiles were surveyed across the length and width of the remaining 53 sinkholes to define their three-dimensional form. In the case of 3 large irregularly-shaped sinkholes additional tachiometric survey data were collected to better define their form.

RESULTS

Sinkhole Distribution, Alignment, and Orientation

New sinkhole locations are compared to flood limits in Figure 4-3. Flood waters crested 0.85 m above the 100 year FEMA flood limit, very nearly reaching the elevation of the 500 year event (R. Weathersby, personal communication, 1995). The new sinkholes are clearly clustered within flooded regions. Eighty-eight percent of all reported sinkholes and 95% of all GPS-mapped sinkholes occur inside flooded areas. Statistical analyses of nearest neighbor distances (Williams, 1972) between sinkholes indicate that sinkholes are more clustered than randomly distributed (Clark-Evans R value of 0.55). Three-quarters of all sinkholes inside flooded areas are located within 500 m of another sinkhole, while the 75th percentile nearest neighbor distance for sinkholes outside flooded areas increases to 1320 m (Figure 4-4). Inside flooded regions, sinkholes are much more prevalent west of the Flint river (13.76 sinkholes/km^2) than they are east (1.89 sinkholes/km^2) or north (0.21 sinkholes/km^2) of the river. These differences likely reflect a combination of the eastward dip of Ocala Limestone, and more frequent reporting of sinkholes in the densely populated portion of Albany west of the Flint River.

The number of sinkholes occurring in different types of residuum (predominantly sand, sand and clay, predominantly clay) and thicknesses of residuum were determined by comparing digitized boundaries from published maps (Hicks *et al.*, 1987) with sinkhole locations in Figure 4-3. The resulting

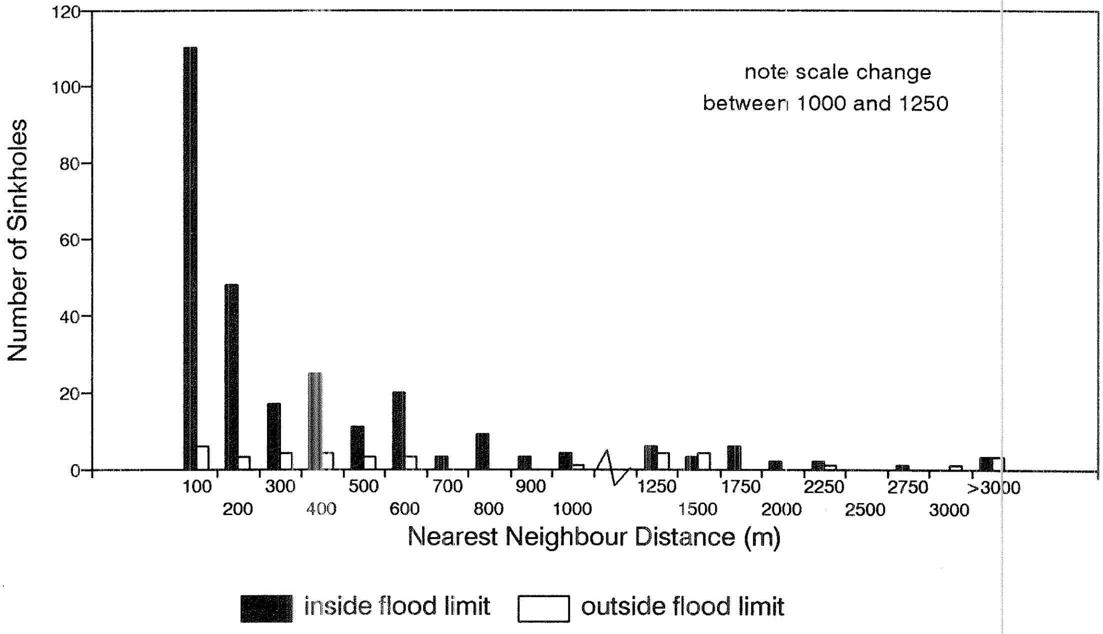

FIGURE 4-4 -- Histogram comparing nearest neighbor distances for sinkholes inside and outside the limits of flooding. Note the high number of closely spaced sinkholes inside the flood limits.

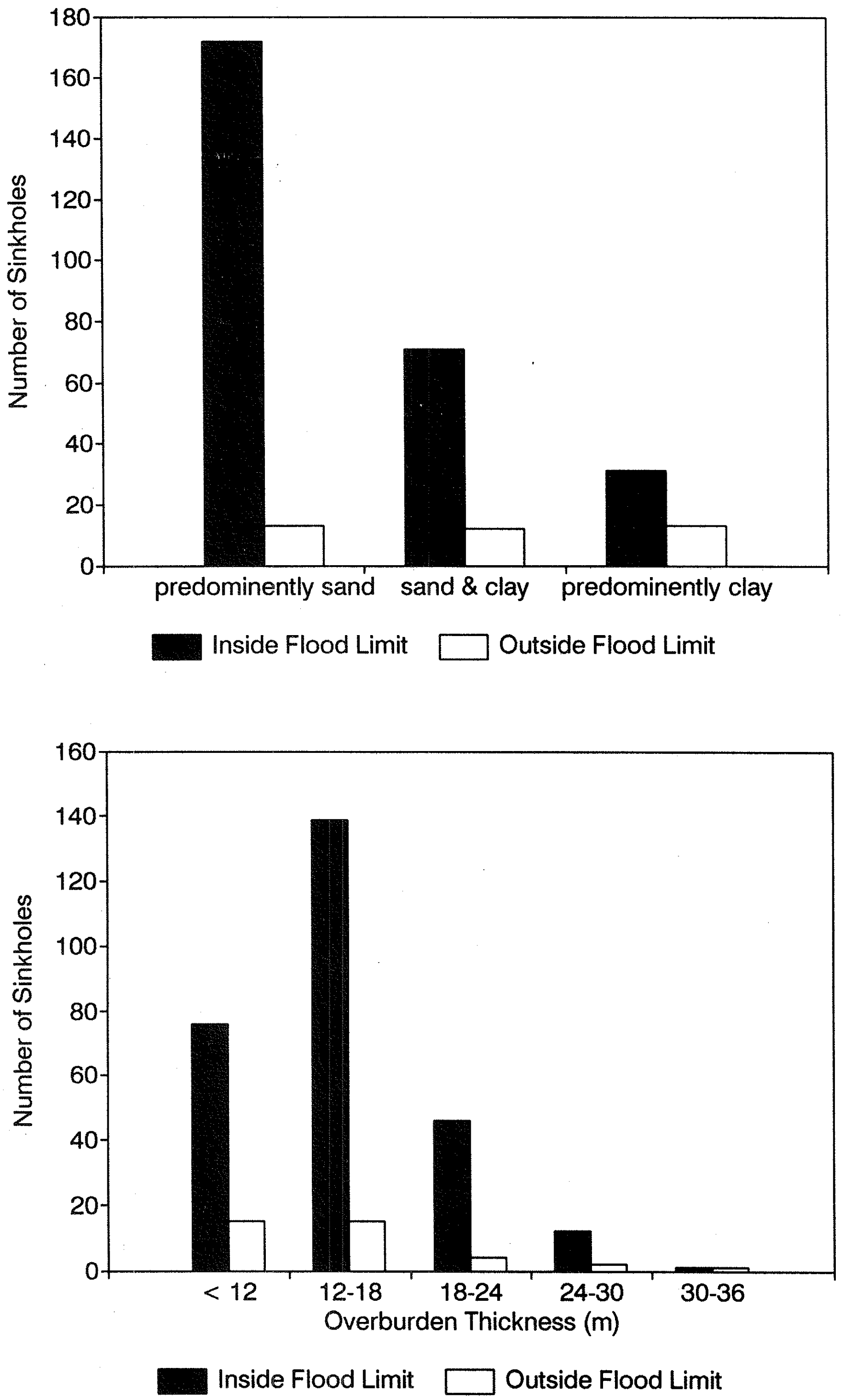

FIGURE 4-5 -- Histograms comparing the number of sinkholes occurring inside and outside the limits of flooding for (*a*) different overburden types, and (*b*) for different overburden thicknesses as mapped by Hicks *et al.* (1987).

histograms (Figure 4-5) show that sinkholes inside the limits of flooding occur predominantly within sandy residuum, while sinkholes located outside the flood limit occur nearly equally in sandy, sand and clay, and clay-rich residuum (Figure 4-5a). Relationships between sinkhole counts and overburden thickness are not as clear. While sinkholes are more frequent in thinner overburden (both inside and outside flood limits) they are not restricted to areas of thin residuum (Figure 4-5b).

The alignment of adjacent sinkhole clusters and the elongation of individual sinkholes often reflect the pattern of joints in underlying bedrock (Brook and Allison 1983; Ogden *et al.* 1989). Several of the GPS surveyed sinkholes occurring inside flooded areas cluster along easily observed linear trends. The linearity of these trends was evaluated by fitting ordinary least squares lines to sinkhole location coordinates. The trends have very high correlation coefficients ($r \geq 0.95$), typically involve 5 to 8 sinkholes per line, and are 51 to 411 m long. The alignment of sinkholes indicates that jointing influenced the location of new sinkholes. Brook and Allison (1983) used the pronounced elongation of old sinkholes to map joint patterns near Albany. However, new sinkholes reported here have low asymmetry values (75% of all new sinkholes have length-to-width ratios less than 1.36) and are not strong indicators of joint patterns. Presumably, with time these new sinkholes will grow and become more elongate.

Sinkhole Dimensions and Volume

In general, most sinkholes are small and shallow. Descriptive statistics based on the circumference, length, width, depth, asymmetry, and volume of 53 sinkholes are summarized in Table 4-1 (24 of the 77 surveyed sinkholes with depth obstructions are excluded from this table). Greater than 75% of all sinkholes have a circumference $\leq$ 8.42 m, length $\leq$ 2.80 m, width $\leq$ 2.25 m, depth $\leq$ 0.94 m, and volume $\leq$ 2.94 m^3. Except for depth, mean sinkhole dimensions are less than their respective standard deviations suggesting that dimensions are log-normally distributed. This was confirmed (α=0.01) for all dimensions except asymmetry using normal score tests (Swan and Sandilands, 1995).

Sinkhole volumes, summarized in Table 4-1, were calculated in three ways depending on sinkhole form. For 3 large irregularly-shaped sinkholes, volumes were calculated using tachiometric survey data and a computer contouring package. However, the majority of sinkholes (n=50) had more regular forms, and volume was determined by approximating the size and shape of the sinkholes with a series of 20 stacked elliptical plates with dimensions defined by sinkhole cross-sectional profile data. The total volume for all 53 sinkholes is 3,829 m^3. The volumes of the 24 sinkholes excluded from Table 4-1 (due to depth obstructions) were calculated using a linear regression model derived from the 53 sinkholes that did not have depth obstructions. While all sinkhole dimensions are strong predictors of volume, stepwise regression reveals that average diameter, calculated as (L + W)/2, is the single best predictor of volume. Based on the regression equation for diameter, (Log Volume = -0.676 + 2.488 (Log Diameter); r^2=0.95), the remaining 24 sinkholes in the field data set account for 174 m^3, bringing the total sample volume for all 77 sinkholes to 4,003 m^3.

			SINKHOLE DIMENSIONS (n=53)			
Group	V	C	L	W	D	L:W
maximum	1791.85	254.94	43.96	20.85	4.09	2.12
minimum	0.01	0.70	0.25	0.25	0.22	1.00
mean	72.25	15.61	4.73	3.09	0.90	1.28
median	0.88	5.73	1.84	1.59	0.66	1.17
stan.dev.	294.37	38.44	9.24	4.58	0.76	0.29
skewness	4.80	5.27	3.61	3.17	2.54	1.53
kurtosis	24.45	30.77	12.43	12.70	7.71	1.29

TABLE 4-1 -- Descriptive statistics for 53 surveyed sinkholes.

This sample volume was used to estimate the total volume of all 311 sinkholes inside the boundaries of Figure 4-3 (1 large sinkhole (V=905 m^3) located outside the boundary of Figure 4-2 was excluded from these calculations). Based on calculations summarized in Table 4-2 our best estimate of total sinkhole volume for the area depicted in Figure 4-3 is between 8933 m^3 and 12,671 m^3. The corresponding volume for sinkholes occurring in the flooded area west of the Flint River, where sinkhole density is highest, is between 7,691 m^3 to 10,638 m^3.

DISCUSSION

Sinkhole Formation

The pronounced clustering of new sinkholes within the flooded region suggests that flooding was the primary triggering mechanism for the new sinkholes at Albany. Collapse associated with raised water levels is usually attributed to a combination of (1) saturation and loss of cohesion in sediments overlying bedrock openings, (2) increased loading due to saturation of the sediment and standing surface water, and (3) liquefaction and piping of sediment downward into underlying cavities (Newton, 1984). Subsequent loss of buoyant support as water levels drop may also initiate failure (Brook and Allison, 1983; Newton 1987). The distribution of new sinkholes at Albany suggests that these mechanisms contributed to sinkhole development.

VOLUME AND SUBSIDENCE CALCULATIONS

1. Volume for 311 sinkholes in Figure 4-3

Upper Limit†	
volume of 76 surveyed sinkholes in Figure 4-3	3098 m^3
multiplication factor to account for larger number of sinkholes in the population	X 4.09
volume of all 311 sinkholes in Figure 4-3	**12671 m^3**
Lower Limit††	
volume of 76 surveyed sinkholes in Figure 4-3	3098 m^3
volume of remaining 311-76 = 235 sinkholes in Figure 4-3	+ 5835 m^3
volume of all 311 sinkholes in Figure 4-3	**8933 m^3**

2. Subsidence for areas depicted in Figure 4-3

area 1 = all of Figure 4-3	7.595×10^7 m^2
area 2 = area of flooded region west of Flint River	1.905×10^7 m^2
subsidence estimates for area 1 (volume estimates ÷ area 1)	**0.13 to 0.18 mm/km^2**
subsidence estimates for area 2 (volume estimates ÷ area 2)	**0.40 to 0.56 mm/km^2**

† sample volume for 76 sinkholes is multiplied by a factor of 4.09 (311 total / 76 surveyed) to account for the larger number of sinkholes in the population.

†† We assume that the sample volume distribution is representative of the remaining 235 sinkholes in the population. Accordingly, we use a log-normal probability density function fit to the sample distribution to calculated expected frequencies for the remaining sinkholes. Expected frequency volumes are summed and added to the sample volume.

TABLE 4-2 -- Summary of calculations used to estimate total sinkhole volume and associated subsidence for regions in Figure 4-3. See text for discussion of these estimates.

The strong alignment of many sinkholes within flooded areas clearly indicates that saturated residuum liquified and was transported into joints in the underlying Ocala Limestone. Liquefaction is favored in saturated non-cohesive residuum (Sinclair et al., 1985). This is indicated by the prevalence of sinkholes within sandy residuum inside the limits of flooding (see Figure 4-5). Furthermore, high-water marks on some buildings indicate that piping of flood-saturated residuum occurred before floodwaters drained completely. Two high-water marks are evident on the collapsed house in Figure 4-6. The first high water mark (arrow number 1 on the right side of the building) is parallel to the original horizontal structure of the building and shows that the house was sitting in at least 2 m of standing water prior to collapse (also note the high water mark on the house in the background). The second high water mark cross-cuts the building, is parallel to the ground surface, and is at an elevation above the ground surface (arrow number 2 in Figure 4-6). Clearly, this house collapsed (*i.e.* the sinkhole formed) after flood waters had begun to drop, but before water levels drained below the ground surface. This strongly supports a combination of flood-induced saturation loading, reduced cohesion and liquefaction of residuum followed by downward piping into a subsurface cavity.

Subsidence

Average subsidence, or surface lowering, associated with new sinkholes is estimated by dividing total sinkhole volume by the area in Figure 4-3 (75 km^2). Subsidence ranges from 0.13 to 0.18 mm/km^2 (Table 4-2). Using the same approach, subsidence for the 19 km^2 flooded region west of the Flint River (where sinkholes are most abundant) varies from 0.40 to 0.56 mm/km^2. These subsidence values together with the recurrence interval of the triggering event ($\approx$500 years based the mapped extent of flooding) are used to estimate the significance of new sinkholes to the development of the Dougherty Plain.

The rate at which sinkholes form is an important control on the long-term lowering of karst plain surfaces. Sinkholes remove clastic overburden which can protect underlying bedrock and slow the rate of weathering. However, the rate at which sinkholes form depends not only on triggering events, but also on the development of cavities within residuum (Figure 4-2), and the presence of highly permeable bedrock drains (White 1988). Because residuum cavities and bedrock drains develop slowly (years to thousands of years) they are more likely to limit sinkhole development than are triggering events. Thus, any estimate of long-term surface lowering based on triggering events must be considered an upper limit on subsidence.

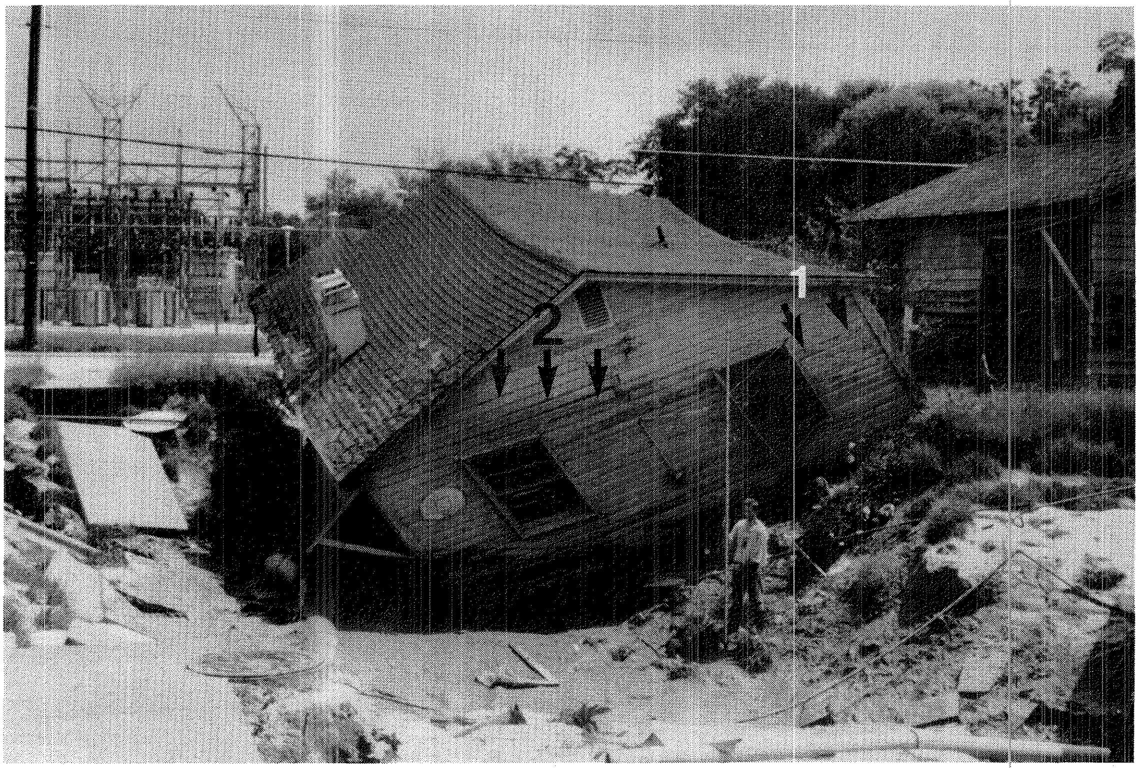

FIGURE 4-6 -- Example of a large sinkhole formed within the limits of flooding at Albany. Note two high-water marks indicated by arrows. High-water mark 1 is parallel to the original horizontal structure of the building indicating that the building stood in ≈ 2m of standing water before collapse occurred. High-water mark 2 cross-cuts the building and is above the surrounding ground surface, indicating that failure occurred before flood waters had drained.

Based on a 500 year recurrence interval for flooding and subsidence values in Table 4-2, we estimate that at most 0.80 to 1.12 m of surface subsidence per million years can be directly attributed to new sinkhole development. These estimates are small (despite representing an upper limit for subsidence) when compared with volume estimates for old sinkholes (*e.g.* Arrington and Lindquist, 1987). However, the real importance of the new sinkholes to surface lowering on the Dougherty Plain stems from their subsequent coalescence and lateral growth, a mechanism capable of transporting substantially more material underground.

CONCLUSIONS

1. Flooding of the Flint River to elevations very near the FEMA 500 year flood limit triggered the collapse of as many as 312 sinkholes. To the best of our knowledge, this is the largest number of sinkholes ever reported to have formed in response to a single triggering event.
2. Eighty-eight percent of the reported sinkholes occur within the limits of flooding; sinkholes are most common in sandy residuum; sinkhole locations often display joint-controlled linear trends; and sinkhole dimensions are small and are log-normally distributed.
3. Flooding triggered failure by saturating residuum over preexisting cavities. This increased the effective weight and decreasing the cohesive strength of soil arches, triggering collapse.
4. Sinkhole volumes, calculated for 76 surveyed sinkholes and estimated from the remaining 235 reported sinkholes, indicates that between 8,933 and 12,671 m^3 of sediment has been transported underground. Subsidence estimates for key flooded areas ranges from 0.40 to 0.56 mm/km^2. When applied over longer time frames, this account for 0.80 to 1.12 m of surface lowering per million years. This small amount of lowering suggests that initial subsidence associated with new sinkhole development is less important to the evolution of the Dougherty Plain than is the subsequent lateral growth and coalescence of sinkholes.

ACKNOWLEDGMENTS

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Assistance in the field and at Valdosta from Jeffrey Tepper and Jay Winkler and statistical advice by Andreas Lazari is greatly appreciated. Many land owners in Albany graciously allowed us to examine sinkholes on their property. We also thank Elizabeth Chainey (Georgia Geological Society) for sinkhole location data and the Albany City Engineer's Office for supplying address locations for many sinkholes. We are particularly grateful to Mr. Randy Weathersby (Albany-Dougherty Planning Commission) for supplying base files and much of the sinkhole location data used to make Figure 4-3.

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CHAPTER 5 -- ROAD LOG

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DAY 1

Begin at Jameson Inn on US 280 near eastern city limit of Americus. Fig. 5-1 illustrates the route followed on the first day.

Mileage	Description
0.0	Turn Left (west) onto US 280.
1.7	Junction GA 377 (Lee St.) in downtown Americus. Turn left (south) on 377. Windsor Hotel across parking lot to right.
14.2	Stop at junction GA 118 (Smithville-Leslie Rd.). Continue south on 377.
21.7	Stop at end of GA 377 at junction with GA 195 (Leesburg-Leslie Rd.). Turn right (south) on 195.
25.2	Cross Muckalee Creek.
28.9	Junction US 19 in Leesburg. Turn Left (south) on 19.
36.3	Cross Kinchafoonee Creek. Entrance (on left) to former site of William's Seafood Restaurant. Turn left into former restaurant site for:

STOP 1 -- Kinchafoonee Creek, north edge of Albany, Dougherty County. Recent karst in the Dougherty Plain.

(James A. Hyatt and Peter M. Jacobs)

This stop illustrates some of the destructive effects of flooding that followed Tropical Storm Alberto in July, 1994. Two features are of interest at this stop: (1) a large, elongate sinkhole on the west bank of Kinchafoonee Creek, and (2) the remnants of Williams Seafood Restaurant.

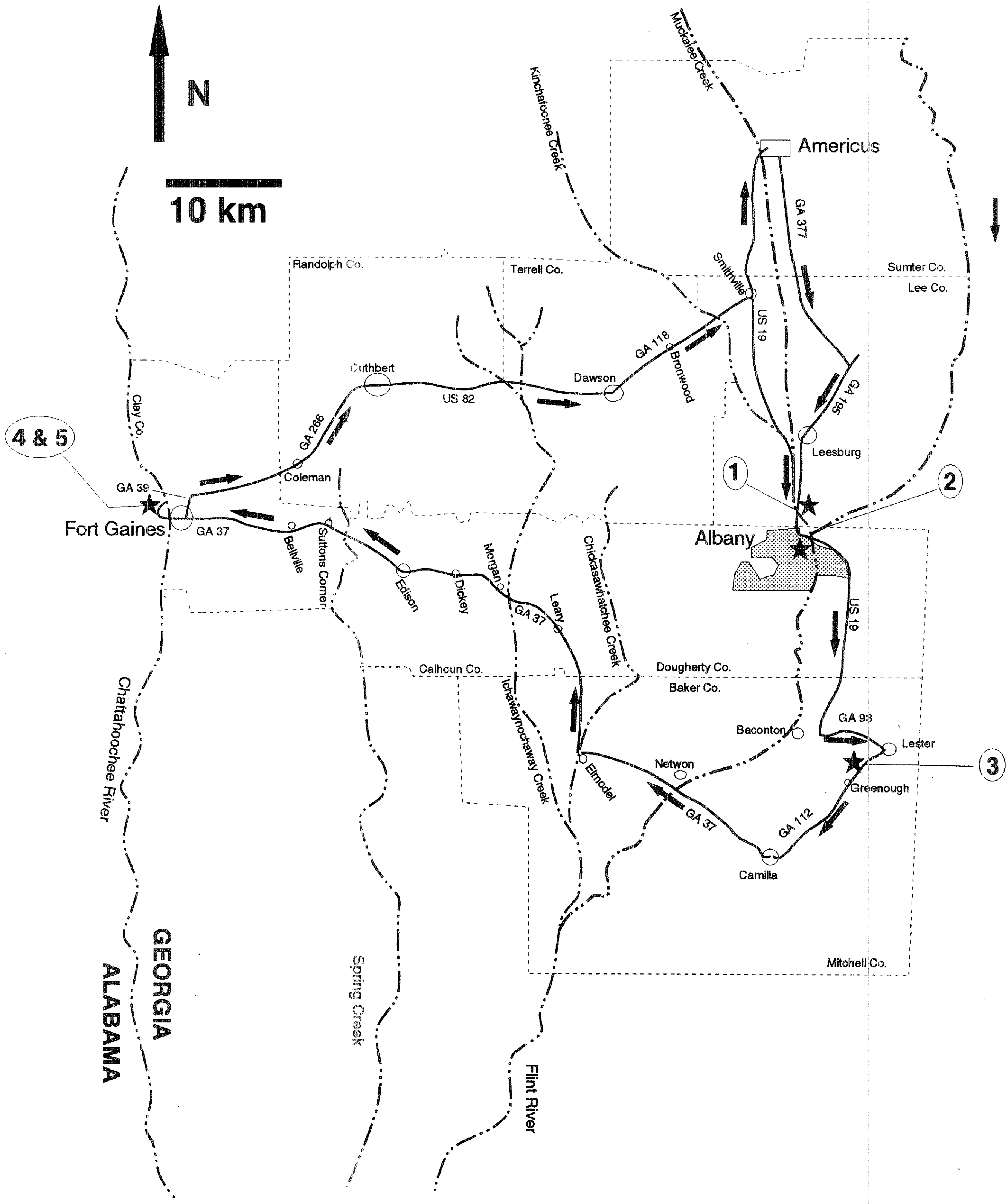

FIGURE 5-1 -- Route of field trip, first day. Arrows indicate route to follow, stops are indicated by stars.

Kinchafoonee Sinkhole

This sinkhole, located ~30m west of Kinchafoonee Creek, is interesting because it is so unlike other sinkholes that were reported following flooding. Most of the 77 sinkholes that we examined in Albany were small (median L=2.4m; W=1.8m; Volume=1.1m^3), shallow (median D=0.7m), circular to elliptical in plan (median L:W=1.17), and were located closer to the limits of flooding than they were to the Flint River or any of its tributaries. An example of a slightly larger than average, but otherwise typical new sinkhole is illustrated in Figure 5-2. In contrast, the sinkhole west of Kinchafoonee Creek is large (L=44m; W=21m; Volume=~905m^3), relatively deep (D=~3.1m), asymmetric (L:W=2.12), and occurs within 30m of Kinchafoonee Creek (Figure 5-3).

New sinkholes at Albany have formed by the collapse of soil into cavities that occur in residuum above solutionally enlarged joints and other openings in the Ocala Limestone (see Figure 4-2). These cavities form over many years to centuries as residuum is washed downward into the bedrock openings by infiltrating groundwater (Brook and Allison, 1983; Beck and Arden, 1984). We argue that flooding triggered collapse by saturating residuum, increasing the effective weight and decreasing the cohesive strength of soil arches overlying cavities. High water marks on some collapsed buildings in sinkholes indicate that subsidence occurred after the peak flooding, but before flood waters drained completely underground (see Figure 4-6).

Presumably the Kinchafoonee sinkhole also formed by subsidence of the locally sandy residuum into underlying bedrock openings. However, water scour marks suggest that the sinkhole collapsed early during the flood, while floodwaters were still flowing rapidly. Scouring is evident on the banks of Kinchafoonee Creek and at both the upstream and downstream ends of the sinkhole (see arrows in Figure 5-3). The alignment of these scour marks implies that overbank flow funnelled through this area. A stand of trees lining the banks of the creek would have helped to focus flow directly over the sinkhole (Figure 5-3). Flow separation at the upstream end of the sinkhole, and flow convergence at the downstream end, would promote turbulence and enhance scouring (Figure 5-4).

Williams Seafood Restaurant

Williams Seafood Restaurant formerly occupied a building located on a large point bar deposit

FIGURE 5-2 -- Example of a typical new sinkhole formed in Albany in association with July 1994 flooding.

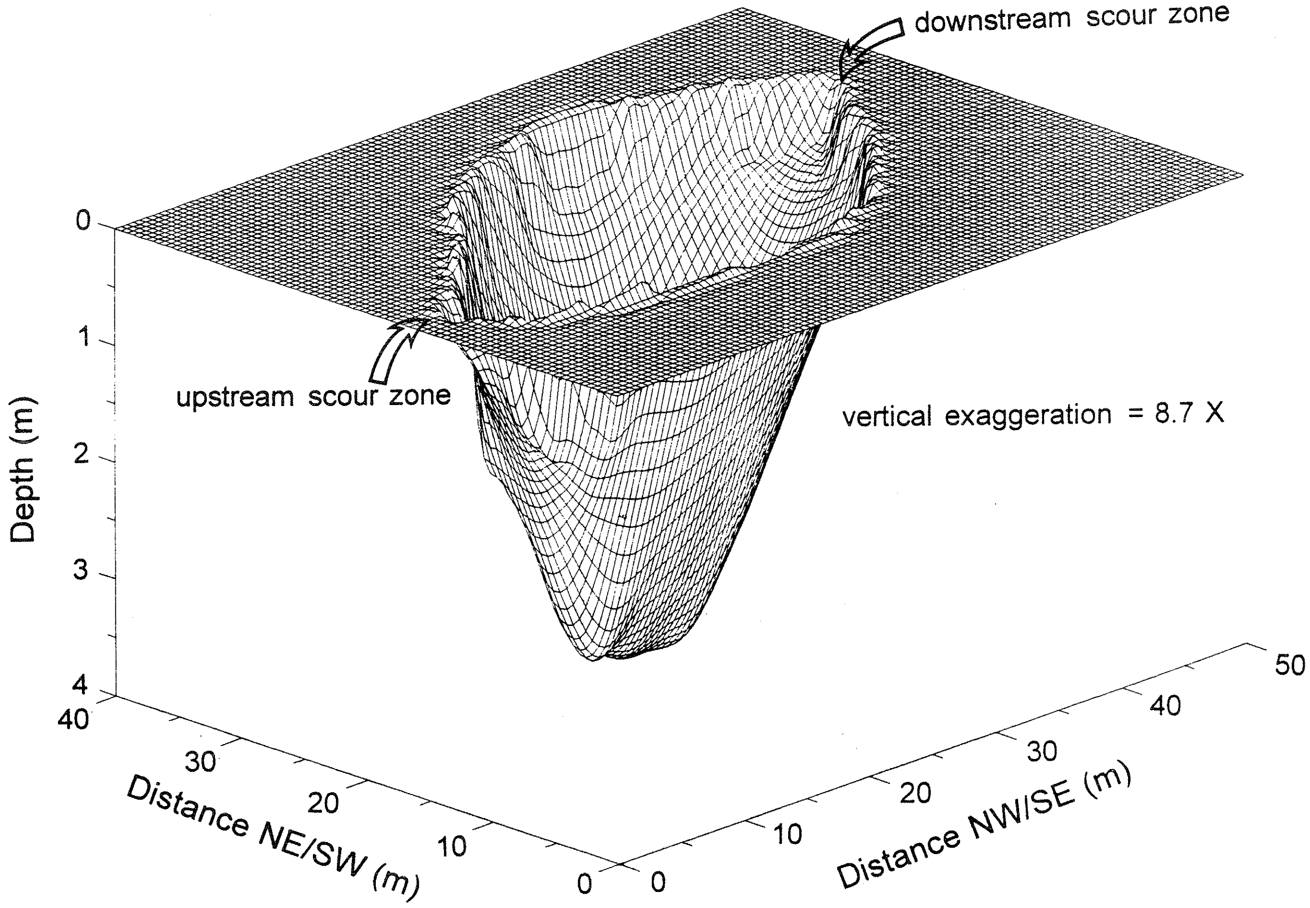

FIGURE 5-3 -- Three-dimensional surface showing the generally elongate form of the sinkhole, and the location of scour marks at both upstream and downstream ends.

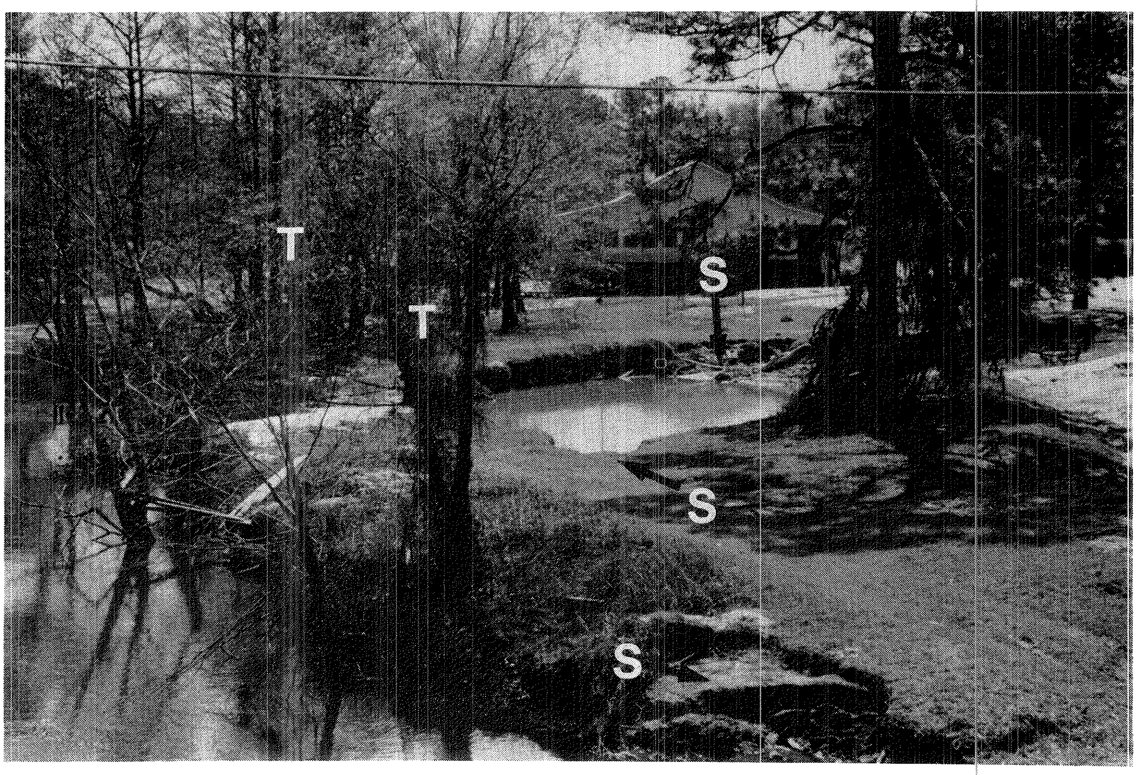

FIGURE 5-4 -- View of Kinchafoonee Creek and stop site 1. Note the alignment of scour marks (S) on the banks of Kinchafoonee Creek, and on the upstream and downstream end of the sinkhole. Also note the stand of trees (T) which helped to funnel overbank flow through the sinkhole area.

~50m south of the Kinchafoonee Sinkhole. High water marks on the building clearly indicate that the structure was inundated during flooding. In addition, substantial structural damage has occurred at the northwest corner and south side of the building.

RESUME FIELD TRIP -- Return to US 19 and turn left (south).

37.0	Junction with Albany bypass, US 19 and US 82. Cross under overpass and bear right onto the bypass for 19S/82E.
39.7	Cross Flint River.
40.5	Exit on Blaylock St. Turn left on Blaylock St. and cross overpass across US 19.
41.6	Entrance on left to Paul Eames Sport Complex. Turn left into it.
41.8	Pavement ends. Continue ahead on dirt road.
42.1	Fork to left, which should be taken.
42.2	Stop. Outcrop is below Georgia Power generating dam visible to right.

STOP 2 -- Lake Worth Dam, north edge of Albany, Dougherty County. Mid-shelf carbonates of the Late Eocene Ocala Group.

(Burt Carter and Phil Manker)

Below the small power generating dam on the north edge of Albany, 0-3m of Ocala Limestone is exposed, depending upon water level. This is probably the Crystal River Formation (Huddlestun, this guidebook). Such a lithostratigraphic correlation places the rock near the middle or in the upper part of the Ocala Group.

We have no measured section from this locality, but the general lithology of the limestone here is wackestone/packstone to poorly washed grainstone, as determined from examination of numerous thin sections. The lower beds tend toward the wackestone/packstone extreme and the top bed toward the grainstone extreme, usually with about 10% of interstitial cavities containing carbonate mud. The upper bench of the exposure, which approximates a bedding plane, contains an abundant and diverse fossil assemblage.

The smooth scallop *Amusium ocalanum* is common at this exposure, suggesting an age near the middle of the Jacksonian, and correlating with the middle Ocala of Florida. The numerous echinoid species known from this outcrop are also consistent with such an age. The common echinoids *Schizaster armiger*, and *Phyllacanthus mortoni*, along with the less common species *Brissopatagus alabamensis*, *Eurhodia patelliformis*, and *Plagiobrissus dixie* all preferred living on muddy bottoms. The common species *Macropneustes mortoni*, the uncommon species *Rhyncholampas conradi* and the rare *Plagiobrissus curvus* all preferred coarser carbonate sand bottoms, though all could apparently tolerate some admixed mud. Large (12 cm wide by 5 cm deep) burrows are interpreted as having been created by *M. mortoni*. Cooke (1943) also reports the molluscs *Eucymba ocalana*, *Cypraea fenestralis*, *Chlamys spillmani*, and *Exputens ocalensis* from this locality.

RESUME FIELD TRIP -- Continue directly ahead on dirt road after stop.

42.9	Return to paved road in Paul Eames Sport Complex. Turn right and exit park, turning right onto Blaylock St. to return to 19.
43.8	Enter access ramp to US 19/US 82. Turn south onto bypass and continue until it becomes Liberty Expressway (still US 19 south).
48.6	Traffic light at intersection of unmarked road. Continue south on 19.
54.6	Cross Mitchell Co. line. Continue on 19.
59.4	Junction GA 93 (Baconton-Lester Rd.). Turn left (east) onto 93 toward Lester.
66.2	Junction GA 112 (Bridgeboro-Camilla Rd.) in Lester. Turn right (south) on 112.
67.8	Entrance to abandoned Bridgeboro Quarry. Pull off beside gate.

<u>STOP 3</u> -- Bridgeboro Quarry, near Camilla, Mitchell County. Shelf-edge carbonates of the Oligocene Bridgeboro Limestone.

(Burt Carter and Phil Manker. Stop description and figures are taken from Manker and Carter, 1989, with slight modification.)

A quarry southwest of Bridgeboro and Lester is the type section of the Bridgeboro Limestone (Huddlestun, 1993). Approximately 21m of limestone is exposed here, and is dominated by a densely packed mass of algal rhodoliths which grew as detached, individual, primary nodules. The number of algal nodules counted in outcrop ranges from 40/m^2 to 294/m^2. Variation in rhodolith density varies both vertically and laterally at the quarry. Throughout the exposed section, but most noticeably in the upper 15m, rhodoliths and the enclosing carbonate sand matrix have in part been replaced by chert. Although silicification occurs in discrete beds 0.5-1.0m thick, these chert beds are generally not continuous throughout the quarry. Lenses and pockets of a yellowish-green swelling clay occur mostly in the upper 15m of the section. X-ray diffraction analysis shows the clay to be a smectite which swells to 17Å upon Glycol solvation (Bowman and Manker, 1982). A measured section is given below, and summarized in Fig. 5-5.

Rhodolith diameters were determined from 278 rhodoliths collected, and range from 2.1 to 8.4cm, with an overall mean of 5.1cm. The mean rhodolith diameter decreases with higher stratigraphic position. Rhodolith shape was also evaluated and is summarized in Fig. 5-6. Most are either compact or compact-bladed. Internally, the nodular algae display a laminar growth pattern and do not appear to have encrusted a foreign object. A moderate number of borings with diameters of approximately 1cm have been observed in the rhodoliths, and were probably generated by the bivalve *Lithophaga nuda*, since the remains of this bivalve have been found inside numerous rhodolith specimens. Smaller borings (approximately 1-2mm in diameter) are also present, and may have been created by sponges or worms.

Thin section analysis shows that most of the rhodoliths collected from the Bridgeboro Quarry are of the genus *Archaeolithothamnium*. This conclusion is based on observation of sporangial sori in the perithallial tissue of the algae. A minor occurrence of *Lithoporella* has been observed in the matrix within some rhodoliths from the quarry and in some from Climax Cave (see Fig. 3-5, location B). Rhodoliths from localities other than Bridgeboro and Climax Cave were also examined microscopically, but in most cases they were replaced by silica, thus making positive identification of the algae impossible. However, the overall morphological features seen megascopically and in thin section were similar to *Archaeolithothamnium* from Bridgeboro.

Twenty-one identified species and at least 12 additional unidentified taxa from the quarry are listed in Table 5-1. It should be noted that rhodolith abundance decreases in the uppermost part of the section exposed in the quarry. This is accompanied by an increase in the diversity of the associated fauna (e.g. 15 species identified, as compared to 7 species identified in the lower, algal dominated part of the section).

The assemblages associated with the algae indicate a Lower Oligocene age (i.e., Vicksburgian)

Measured section at Bridgeboro Quarry

Clay residuum overlies the Bridgeboro at the type section. Huddlestun (1993) questionably considers it to be residual Buccatuna Clay, and reports that it contains silicified Oligocene fossils.

UNIT 12 -- 2.8-3.7m (Cum. Thickn. 21.5-22.4m)
Partly silicified limestone with large solution vugs and scalloped surfaces. Rhodoliths sparse near base, but more densely packed upward, up to 6cm in diameter. Large oysters, corals.

UNIT 11 -- 0.5m (Cum. Thickn. 18.7m)
Rhodolith-poor bioclastic limestone as in Unit 8. Terrigenous clay clasts. *Lepidocyclina.*

UNIT 10 -- 2.9m (Cum. Thickn. 18.2m)
Packed rhodolith limestone as in Unit 1. Rhodoliths more often discoid than below, randomly oriented. Molluscs, *Clypeaster cotteaui.*

UNIT 9 -- 1.7m (Cum. Thickn. 15.3m)
Bioclastic limestone as in Unit 6, argillaceous(?). Few small (<4cm) rhodoliths. Clay clasts and stringers. Abundant molluscs, (*Chlamys duncanensis*, *Anatipopecten anatipes*, *Spondylus* and others), *Clypeaster cotteaui*, *Lepidocyclina.*

UNIT 8 -- 1.7m (Cum. Thickn.13.6m)
Very coarse bioclastic limestone as in Unit 6. More abundant fossils: *Chlamys duncanensis*, *Anatipopecten anatipes*, *Conus*, *Clypeaster cotteaui*, *Lepidocyclina*, corals, molluscs, non-nodular algae. Small clay clasts and stringers.

UNIT 7 -- 0-0.6m (Cum. Thickn. 11.9m)
Bioclastic limestone as below, but noticeably harder. Obvious internal lamination.

UNIT 6 -- 0.5m (Cum. Thickn. 11.9m)
Bioclastic limestone as in Unit 2, but coarser grained. *Chlamys duncanensis* and other bivalves.

UNIT 5 -- 2.45m (Cum. Thickn. 11.4m)
Rhodolith limestone as in Unit 1. Inclined clay-rich bed (?lining channels). *Chlamys duncanensis*, *Lepidocyclina*, two large gastropod species, miliolids, cidaroid echinoid spines.

UNIT 4 -- 0.05m (Cum. Thickn. 8.95m)
Thin, discontinuous green clay bed, similar to clasts below.

UNIT 3 -- 0.6m (Cum. Thickn. 8.9m)
As Unit 2, but rhodoliths smaller (<1cm) and less abundant. Large (up to 0.1m by 0.5m) clasts of green clay and fine, unconsolidated quartz sand slumped into bedding depressions.

UNIT 2 -- 3.4m (Cum. Thickn. 8.3m)
Finely granular bioclastic (algal) limestone, few small rhodoliths (<2cm) becoming more common and larger (<8cm) toward top. Irregular clay clasts.

UNIT 1 -- 4.9m (Cum. Thickn. 4.9m)
Massive to thick bedded limestone. Mostly densely packed rhodoliths up to 10 cm. Thin, discontinuous beds/lenses and clasts of waxy green clay to 10cm. This, lensoid, discontinuous beds of bioclastic, argillaceous(?) limestone extending downward into crevices and cavities. *Chlamys duncanensis*, *Lepidocyclina*, *Ampulina*, oysters, miliolids, turritellid(?)

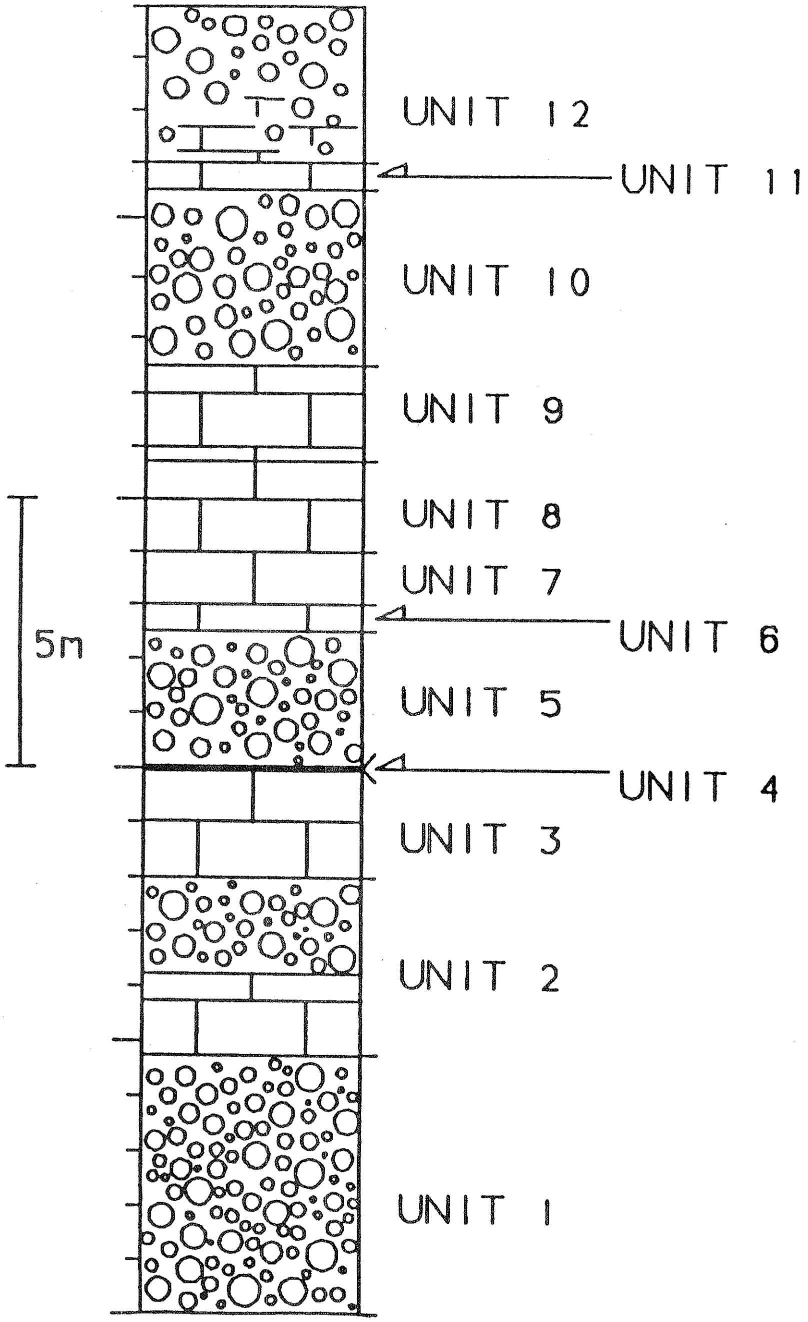

FIGURE 5-5 -- Measured section at Bridgeboro Quarry. From Manker and Carter, 1989.

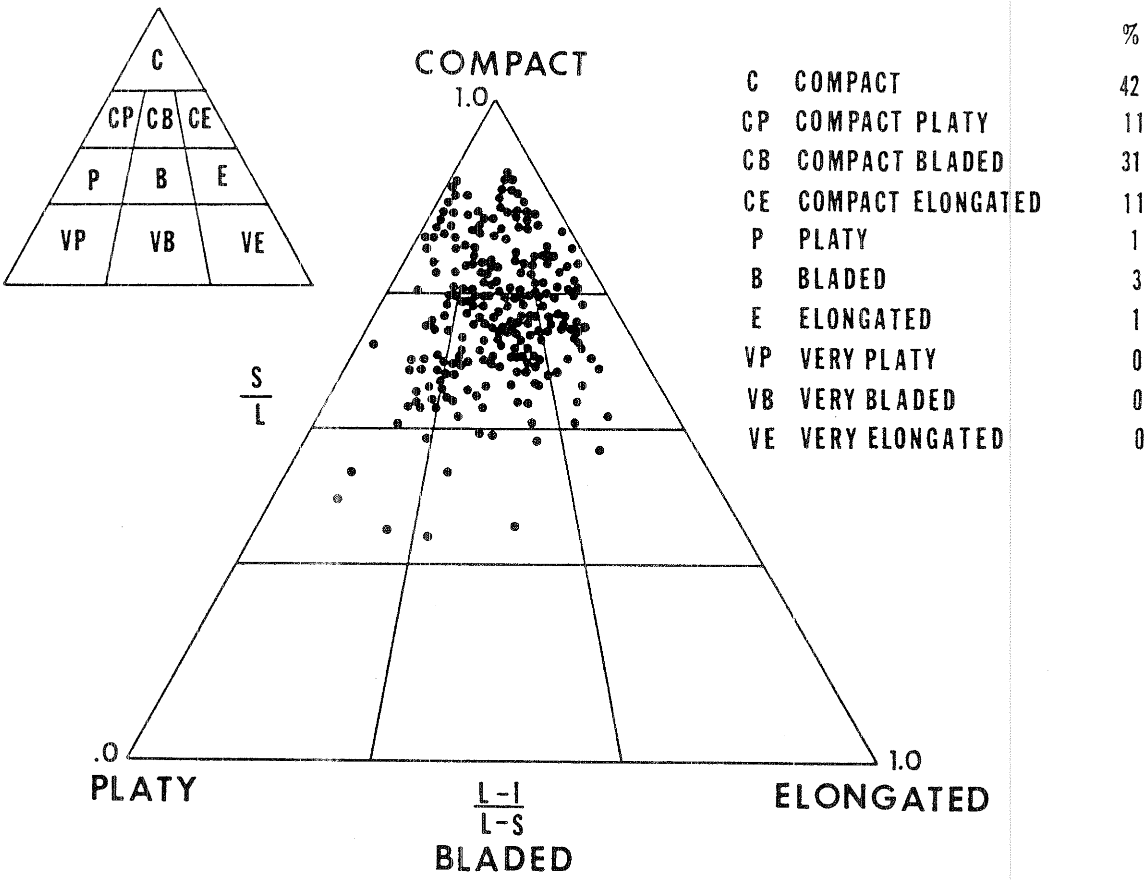

FIGURE 5-6 -- Results of shape analysis of 278 rhodoliths collected from Bridgeboro Quarry. (From Manker and Carter, 1987).

PROTISTA	
Archaeolithothamnium	C
*Lithoporella**	R/R
unidentified melobesiid*	R/R
Lepidocyclina sp.	C
4 species of smaller foraminifera*[1]	R
CNIDARIA	
Trochocyathus(?) sp.	R/R
unidentified colonial coral	R/R
ECTOPROCTA	
**encrusting cheilostomes	R
**?unidentified encruster*	R
ANNELIDA	
sabellarid(?) tubes	U
GASTROPODA	
Cerithium cf. hernandoensis	U
Ampullina cf. flintensis	U
Conus sp.	R
Turritella sp.	R
2 or 3 unidentified species	R?
BIVALVIA	
Lithophaga nuda	C
Glycymeris cf. cookei	U
Chlamys duncanensis	C
C. anatipes	R/R
Ostrea sp. A	U
Ostrea sp. B	R
Lima sp.	R
Phacoides sp.	R/R
?Pitar sp.	R
3 unidentified species	R?
ECHINOIDEA	
undescribed *Prionocidaris(?)*	R/R?***
Clypeaster cotteaui	C
Rhyncholampas gouldii	U
undescribed *Brissus*	R

C	Common. Many individuals from all 3 localities.
U	Uncommon. 3–6 individuals from at least 2 localities.
R/R	Rare but recurrent. 1 individual from each of 2 localities.
R	Rare. Only 1 individual found.
*	Known only from thin section.
**	May be the same species.
***	Spines and disarticulated plates may or may not represent the same species.

[1] Herrick (1961) reports *Prorotalia mexicana* from a core through these strata just south of the quarry.

TABLE 5-1 -- Species encountered *in situ* at Bridgeboro Quarry. (From Manker and Carter, 1987).

for units exposed at the quarry. The echinoid *Clypeaster cotteaui* and the scallop *Anatipopecten anatipes* are only known from the Vicksburgian (Cooke, 1959; Glawe, 1974).

RESUME FIELD TRIP -- Continue south on GA 112 after stop.

70.2	Town Limit of Greenough. Continue on 112.
79.0	City Limit of Camilla. Continue on 112.
79.5	Junction US 19 in Camilla. Cross it and continue on 112.
80.1	Left turn to remain on GA 112.
80.2	Junction GA 37 in Camilla. Turn right (west) on 37.
89.6	Cross Flint River near Newton, entering Baker Co. Continue on 37.
98.1	Town Limit of Elmodel. Continue on 37.
98.8	Cross Chickasawhatchee Creek. Continue on 37.
104.7	Cross Calhoun Co. line. Continue on 37.
108.1	City Limit of Leary. Continue through Leary on 37.
114.4	Cross Ichawaynochaway Creek. Continue on 37.
115.3	City Limit of Morgan. Continue on 37.
119.6	Town Limit of Dickey. Continue on 37.
121.1	Cross Pachitla Creek. Continue on 37.
123.7	City Limit of Edison. Continue on 37.
130.6	Clay Co. line. Continue on 37.
131.7	Junction US 27 in Suttons Corner. Continue on 37.
143.6	City Limit of Ft. Gaines. Continue on 37.
144.7	Cross Chattahoochee River into Alabama. Road number becomes AL 10.
145.1	Entrance to US Army Corps of Engineers park at W.F. George Lock and Dam. Turn right into park.
146.4	Stop beside restrooms below W.F. George Dam. Outcrop is on Chattahoochee River bank below dam.

<u>STOP 4</u> -- W.F. George Dam, Henry County, AL. Shelf-edge carbonates of the Clayton Formation.

(Burt Carter and Phil Manker)

The dam near Ft. Gaines that impounds Lake W.F. George (a.k.a. Lake Eufaula) is constructed on the top of the Paleocene Clayton Limestone. This limestone is visible just below the dam in an Army Corps of Engineers Park. Richard H. Flugeman (in Bryan, 1993) reports that Foraminifera from the Clayton at this locality indicate an age of "likely P1c to P2", making it equivalent to the McBryde Limestone member of the Clayton and the lower Porters Creek Formation of western Alabama, and entirely Danian. Flugeman does indicate that the uppermost Clayton at this site cannot be well constrained in age, and may possibly be as young as P4 in age, suggesting a correlation with the Mathews Landing Marl of Alabama, and keeping open the possibility of an earliest Selandian (= Thanetian) age. Depth tolerances of the Foraminifera led Flugeman to conclude that the lowest Clayton beds at this locality were deposited in water around 18m deep, with deepening upsection to a possible depositional depth of between 18-50m. for the uppermost beds.

Lithologically, the Clayton at this exposure is similar to the Bridgeboro Limestone as examined at the previous stop, though including at least some finer-grained limestones than encountered in the Bridgeboro. Rhodoliths are not as abundant, but tend to be much larger. In addition, they are often flattened in an inverted shallow bowl shape, hence a colloquial name for them of "cow-patty algae". Bryan (1993) reports a fauna of small, attached brachiopods from the undersides of these flat algal colonies, and indicates that they are rather similar to species found in the Salt Mountain Limestone (Selandian) reefal facies of southwestern Alabama. We have done no detailed paleoenvironmental work on these rocks, but the few echinoid species known from this locality include some apparently mud-tolerant forms, suggesting rather quieter water for at least some time during deposition than is ever suggested by sediments or fossils in the Bridgeboro. This might explain why rhodoliths are generally flattened at this locality, rather than rounded. It also suggests that those algal nodules which *are* spherical (and are substantially larger than the average size at Bridgeboro) were rolled by organic rather than hydrodynamic processes (Prager and Ginsburg, 1989).

A great deal of care should be exercised at this stop because 1) the rocks, when wet, can be breath-takingly slick, and 2) it's a long swim to the nearest crawling-out point in either direction. Note that since this is federal land, collecting rocks or specimens is technically not allowed.

RESUME FIELD TRIP -- Retrace route toward park entrance after stop.

147.5	Before exiting park, turn left on road to Franklin Landing boat ramp.
147.6	Stop at outcrop at boat ramp.

STOP 5 -- Franklin Landing, Henry County, AL. Paleocene karst surface on the Clayton Formation.

(Burt Carter and Phil Manker)

Just downstream from the previous stop is the site of old Franklin Landing. A boat ramp constructed here as part of the dam construction project exposed the contact between the Clayton Limestone and the overlying Nanafalia Formation (Selandian). The "*Ostraea*" *thirsae* (now assigned to the genus *Odontogryphaea*) beds and the Gravel Creek Member are both present. Good specimens of the Upper Paleocene guide fossil *O. thirsae* are available, and shark teeth turn up in the Nanafalia with fair frequency as well. The most interesting aspect of this stop, however, is the nature of the formational contact. Across the chain-link fence you can see the extreme irregularity of the contact between the underlying algal-rich Clayton and the terrigenous rocks of the Nanafalia. Note also the iron-stained zone within the Clayton, which is probably a paleosol horizon. The deep depressions on the Clayton's upper surface are pre-Nanafalia sinkholes, infilled with that formation. This is the best, if not the only, exposure of Cenozoic paleokarst in the (nearly) Georgia Coastal Plain.

RESUME FIELD TRIP -- Return to Corps of Engineers park entrance after stop. Turn left (east) onto AL 10 upon exiting and recross Chattahoochee River into Georgia.

148.8	Junction GA 39 in Ft. Gaines. Turn left (north) onto 39.
150.5	Junction GA 266 just past Cemochechobee Creek. Turn right (east) onto 266.
151.3	Bear right to remain on 266.
157.7	Randolph Co. line. Continue on 266.
160.3	Town Limit of Coleman. Continue on 266.
168.9	Junction US 82 (inside Cuthbert). Turn right (east) onto 82.
170.8	Town square of Cuthbert. Pass square and continue east on 82.
182.4	Cross Little Ichawaynochaway Creek at Terrell Co. Line. Continue on 82.
184.9	Cross Ichawaynochaway Creek. Continue on 82.
187.1	Town Limit of Graves. Continue on 82.
190.9	City Limit of Dawson. Route through Dawson is not well marked and requires several turns and/or landmarks whose distances are less than 1/10 mile apart. Leave US82 where it joins GA520 (Corridor Z), continuing straight ahead to the next light. This is the main street through Dawson (formerly, US82). Turn Left (north) onto it. Go to the second traffic light, and turn right onto Lee Street. After one or two blocks this becomes
192.2	GA32, without prior warning. The mileage at this first road sign for 32 should be 192.2.
192.6	Junction GA 118. Turn left (east) onto 118, toward Bronwood.

198.8	Town Limit of Bronwood. Continue on 118.
203.1	Lee Co. line at Kinchafoonee Creek. Continue on 118.
206.9	Junction US 19 in Smithville. Turn left (north) onto 19, which makes a very hard S-bend in the middle of Smithville.
208.2	Sumter Co. line. Continue on 19.
218.8	Traffic light at junction US 280. Continue on 19N/280E.
219.7	Traffic light (second one since the previous mileage) at junction US 280 E. Turn right (east) onto 280.
220.4	Downtown Americus. Windsor Hotel on left. Continue on 280.
221.8	Entrance to Jameson Inn (and Dairy Queen). Turn right into Jameson Inn.

END ROAD LOG, DAY 1.

DAY 2

Begin at Jameson Inn. Fig. 5-7 illustrates the route followed on the second day.

Mileage	Description
0.0	Turn left (west) onto US 280.
0.6	Junction GA 49. Turn right (north) onto 49.
3.8	Road to left leads to Souther Field (Americus airport), where Charles Lindburg made his first solo flight. Continue on 49.
10.2	Railroad crossing at entrance to Mulcoa Corp. headquarters for local bauxite/kaolin mining operations. Continue on 49.
11.0	Turnoff to Andersonville. National Historic Site just beyond at Macon Co. line. Continue on 49.
14.5	Entrance to Cytec Corp. kaolin mine on right. Continue on 49.
18.9	Oglethorpe City Limit. Continue on 49.
20.6	Cross Flint River. Montezuma City Limit at far end of bridge. Continue on 49. Watch for curious left turn to remain on 49 straddling the railroad tracks in downtown Montezuma.
24.3	Road to left (which is easy to miss) leads to public boat ramp. Turn Left. Park at bottom of hill and walk downstream slightly to outcrop.

STOP 1 -- Flint River near Montezuma, Macon County. Nearshore oyster bank of the Clayton Formation.

(Burt Carter and Phil Manker).

Just downstream of a public boat ramp on the Flint River north of Montezuma is an outcrop of Clayton Limestone which represents a strange lithology in this region. The Clayton this far east is almost entirely terrigenous clastics. The carbonate comprising the limestone at this locality is primarily oyster shell, though there are other calcareous organisms and fine carbonate matrix as well. Coarse quartz sand admixed with the carbonate makes this rock look very much like the Clayton at its type locality in eastern Alabama.

Depending upon water level there is 15-20m of mostly covered section below the *in situ* limestone at this stop. At low water the exposed river bank is composed of a light gray, kaolinitic clay, which may continue through the covered interval. Abundant large boulders of limestone occur throughout the covered interval, but none is demonstrably in place. The *in situ* limestone forms a bluff 2-3m in height well above water level. Lichen and plant overgrowth obscure much of it, but a freshly broken surface reveals a

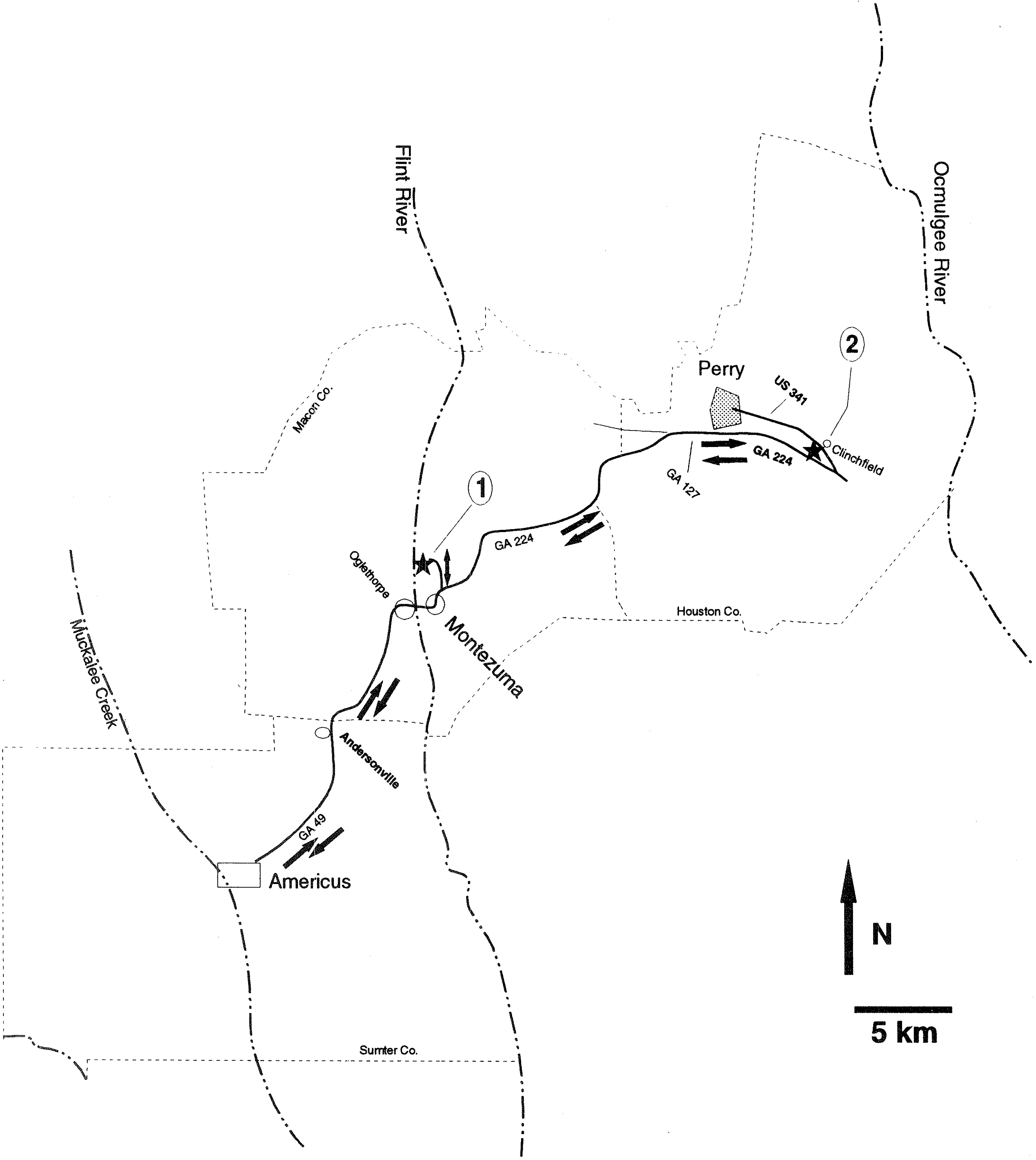

FIGURE 5-7 -- Route of field trip, second day. Symbols as in Figure 5-1.

hard, sandy limestone. The Lower Paleocene guide fossil *Ostrea crenulimarginata* is the most common fossil, though other molluscs, corals, and even shark teeth can be found as well. Collecting is generally easier from the more weathered slumped boulders nearer water level than from the *in situ* outcrop.

Two small cabins used to stand in the level area near the parking spot, which is probably supported by the limestone facies. Flooding during Alberto's rampage removed all trace of one; only the foundation of the other remains.

RESUME FIELD TRIP -- Return to GA 49 after stop. Turn right (south) onto 49. Retrace route into Montezuma.

26.0	Downtown Montezuma. Cross railroad tracks and bear hard left beyond old railroad station onto East Railroad Street, which parallels tracks.
30.7	Stop sign at junction GA 224. Turn left (east) on 224.
44.6	Houston County Line. Continue on 224.
47.6	Y-junction with GA 127. GA 224 "ends" here. (It reappears at Perry.) Continue straight ahead (east) on 127.
49.8	Junction with I-75 and US 41. Cross I-75 on 127/41. Immediately beyond overpass 41 turns left. Continue straight ahead on four lane road, which is now GA 224 S.
58.5	Junction US 341. Turn left (north) on 341.
60.4	Entrance to Medusa Cement Co. Quarry, just before conveyor belt over road. Turn right toward quarry office.

STOP 2 -- Quarry of Medusa Cement Company at Clinchfield, Houston County. Inner shelf carbonates of the Ocala Group (Tivola Limestone).

(Burt Carter and Phil Manker -- Stop description and measured section from Manker and Carter, 1989; section modified for that paper from Huddlestun and Hetrick, 1986.)

This locality is the type section for both the Clinchfield Formation (which we may or may not be able to see, depending upon the company's operations) and the Tivola Limestone. A measured section is given below, and summarized in Figure 5-8. The 13m of Tivola is dominated by ectoproct calcarenite to calcirudite which is usually not well lithified on fresh exposures, but is case hardened on older blocks. Grain sorting is generally not very good, and the fragile, twiggy ectoprocts, though invariable fragmented, are not pulverized. Current/wave energy was apparently strong enough to fragment and transport the debris. Massive colonial ectoprocts, *Periarchus pileussinensis*, *Chlamys spillmani*, and large forams

(?*Lepidocyclina*) are the most common identifiable whole fossils. Other molluscs, echinoids, shark and ray teeth and archaeocetes have also been found. Pickering (1971) includes an exhaustive faunal list of the Ocala (Tivola) in the vicinity.

The greenish clay at the top of the quarry is the Jacksonian Twiggs Clay Member of the Dry Branch Formation. To the east the Tivola thins and undergoes a facies change into the Twiggs, and the Twiggs thins westward and does not occur much farther to the west of the Medusa quarry.

Huddlestun and Hetrick (1986) report 2-3m of Clinchfield Sand which are intermittently exposed by quarrying operations. This unit is a friable, medium to fine, calcareous quartz arenite. Fossils are locally common, but tend to occur as whole skeletons or molds rather than fragmental debris. The bulk of the carbonate is intergranular cement.

Measured section at Medusa Quarry (Modified from Huddlestun and Hetrick, 1986)

Eocene and younger sands at top of quarry (9.3m)
Twiggs Member, Dry Branch Formation (30.7m)
Ocala Group, Tivola Formation:

BED 7 -- 3m (Cum Thickn. 14.3m)
Coarse, rubbly bioclastic limestone. Indurated, thick, vague beds with thin, soft interbeds. *Lepidocyclina*, *Periarchus pileussinensis*, *Chlamys spillmani*, other mollusc molds. Ectoproct debris constitutes bulk of bioclastic grains.

BED 6 -- 0.3m (Cum Thickn. 11.3m)
Soft, ectoproct bioclastic limestone. *Chlamys spillmani*, *Periarchus pileussinensis*.

BED 5 -- 9.6m (Cum Thickn. 11m)
Medium - coarse bioclastic (ectoproct) calcarenite. Quartz sand toward base. Massive to poorly bedded.

Barnwell Group, Clinchfield Formation

BED 4 -- 0.3m (Cum Thickn. 1.4m)
Massive, calcareous, medium-coarse quartz sand. Molds/casts of molluscs.

BED 3 -- 0.2m (Cum Thickn. 1.2m)
Medium calcareous quartz sand. Hard. Few fossils. Clay in upper 5cm.

BED 2 -- 0.3m (Cum Thickn. 0.9m)
Coarse calcareous quartz sand. Soft. Abundant fossils.

BED 1 -- 0.6m+ (Cum Thickn. 0.6m+)
Medium calcareous quartz sand. Soft. Burrowed.

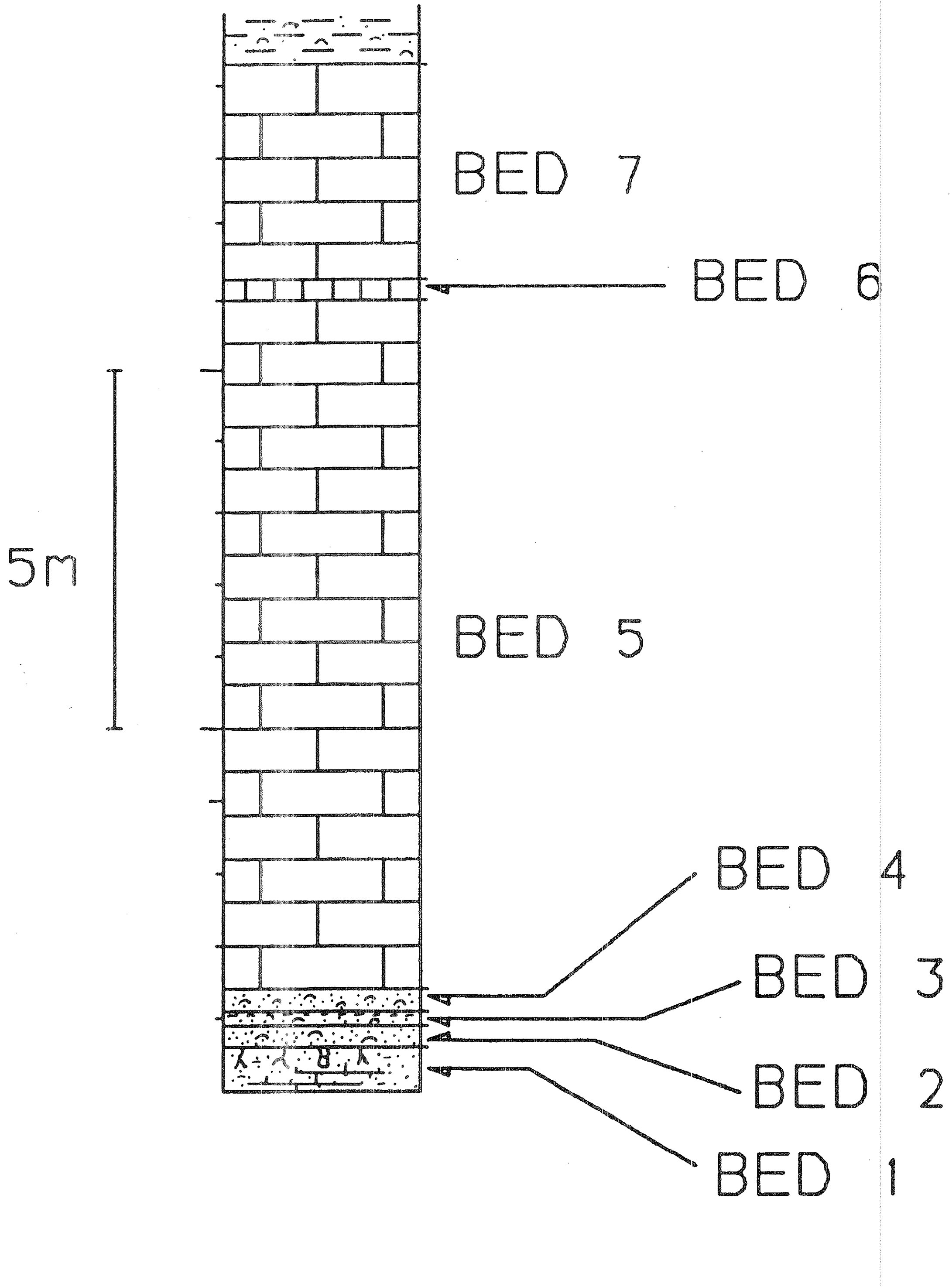

FIGURE 5-8 -- Measured section, Medusa Quarry. (From Manker and Carter, 1989). Based on data in Huddlestun and Hetrick, 1986.

RESUME FIELD TRIP -- Return to US 341. Turn left (south) on 341.

62.3	Junction GA 224. Turn right (north) on 224.
69.2	Perry City Limit. Continue on 224.
71.0	Junction US 41; "end" of 224. Continue straight ahead on 41.
71.3	Junction GA 127 at I-75. Cross I-75 and continue straight ahead on GA 127 W.
73.4	Junction GA 224. Fork left (west) onto 224.
76.4	Macon County Line. Continue on 224.
91.8	Stop at junction GA 26 inside Montezuma. Turn right (west) on 26/224.
92.7	Traffic light. GA 224 ends (for sure.) Continue straight on 26 through town.
94.1	Cross Flint River. Continue on 26.
97.0	Stop at junction GA 49. Turn left (south) on 49.
103.1	Entrance to left of Andersonville National Historical Site. Enter for **LUNCH AND SHORT VISIT**.

RESUME FIELD TRIP -- Proceed to park exit after stop.

104.0	Turn left (south) on GA 49.
104.6	Railroad crossing at Mulcoa entrance. Continue on 49.
111.3	Road to Souther Field to right. Continue on 49. Enter Americus.
114.5	Bear left at junction US 280 and cross westbound 280.
114.1	Junction US 280 E. Turn left (east) on 280.
114.7	Entrance to Jameson Inn. Turn right into Jameson Inn.

END ROAD LOG, DAY 2; END FIELD TRIP.

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