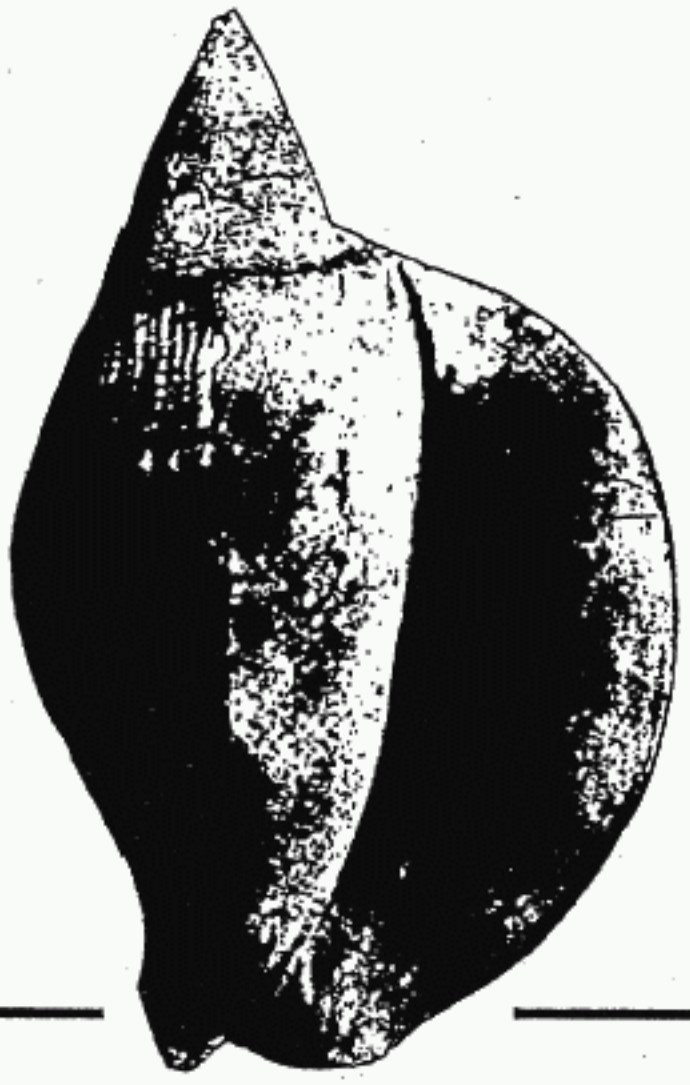

SECOND ANNUAL FIELD TRIP of the MIAMI GEOLOGICAL SOCIETY

February, 1968

LATE CENOZOIC STRATIGRAPHY OF SOUTHERN FLORIDA- A REAPPRAISAL

WITH ADDITIONAL NOTES ON
SUNOCO-FELDA & SUNNILAND OIL FIELDS

COMPILED BY

Ronald D. Perkins

WITH CONTRIBUTIONS FROM

Clarence V. Babcock
H. Kelly Brooks
Carlton V. Conklin
Jules R. DuBar
R. Michael Lloyd
Axel A. Olsson
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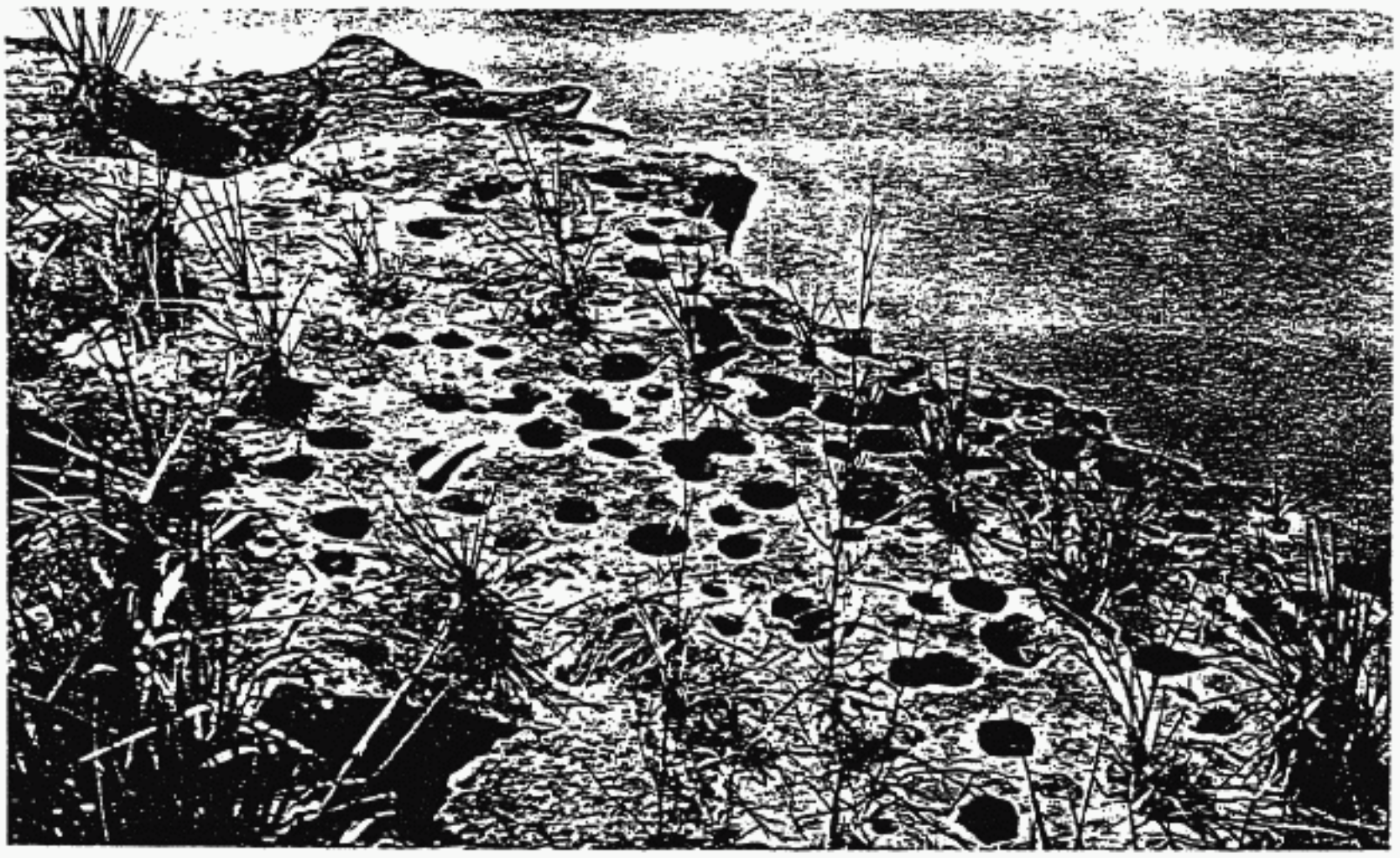

Solution-pitted surface of freshwater limestone at the type section of the Fort Thompson Formation on the Caloosahatchee River. Locality now destroyed by dredging operations.

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FIELD TRIP INTRODUCTION

by

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The first geological exploration of the Caloosahatchee River was conducted by Angelo Heilprin in 1886. Heilprin (1887, p. 28) believed these deposits to be the most remarkable yet discovered in the state and paleontologically perhaps the most significant deposits east of the Mississippi River. On the basis of ratio of extinct to extant molluscan species, Heilprin designated the lower beds the Floridan and assigned them a Pliocene age. These lower beds have subsequently been referred to as the Caloosahatchee Formation (Matson and Clapp, 1909, p. 123). The overlying Pleistocene deposits consisting of alternations of freshwater, brackish, and marine marls and limestones were subsequently grouped as the Fort Thompson Formation (Sellards, 1919, p. 71).

Heilprin's assignment of the Caloosahatchee Formation to the Pliocene was accepted by Dall (1887) and, in general, by most later workers. However, DuBar (1958, p. 95) seriously questioned the assignment of the Caloosahatchee to the Pliocene and, "on the basis of the vertebrate fauna and to a lesser degree on the molluscan fauna and stratigraphic relationships," assigned the Caloosahatchee to the Pleistocene. Olsson and Petit (1964, p. 513) reviewed the problem and concluded "the age assignment of the Caloosahatchee to the mid-Pleistocene ....is, therefore, wholly incompatible with existing information, and the true position of the Caloosahatchee in the upper Tertiary as held by all earlier workers remains more firmly established than ever."

A paper presently in progress by Druid Wilson (noted in Olsson and Petit, 1964, p. 513) focuses attention on a new stratigraphic unit (Unit A) between the Caloosahatchee and Fort Thompson Formations and separated from these units by sharp unconformable contacts. Unit A is considered to be the earliest Pleistocene in south Florida. Brooks (1967, personal communication; 1968, this publication) has recently suggested a reorganization of stratigraphic nomenclature for the Caloosahatchee River area in which the Caloosahatchee Formation has been subdivided into two members, the lowermost of which is assigned to the Pliocene, the uppermost to the Pleistocene.

With this historical background in mind, it seems appropriate that the Caloosahatchee age problem be reappraised at this time, incorporating some of the more recent work. We are pleased that Dr. H. Kelly Brooks, Dr. Axel A. Olsson, Dr. Jules R. DuBar, and Dr. Druid Wilson have agreed to participate as field trip leaders. It is the intent of this field excursion to bring these prominent workers together for a stimulating, free exchange of ideas and for a reevaluation of the field evidence bearing on the problem. With but one exception, all the articles contained within this guidebook have been especially prepared for this field conference and several interpretations are being presented for the first time.

The greatest portion of our trip will be devoted to exposures along the Caloosahatchee River between Ortona Lock and Fort Denaud. Recent widening of the river by the U. S. Army Corps of Engineers has produced numerous fresh exposures, while at the same time destroying older, more weathered localities. The type section of the Fort Thompson Formation has been completely destroyed by this most recent dredging operation (see photograph on title page).

On Saturday evening, Mr. Walter L. Erwin of the Sun Oil Company will address the group on the "Techniques, History, and Economics of Oil Exploration in Florida." This talk will provide an introduction to the second part of our trip which deals with the Sunoco-Felda and Sunniland oil fields of Hendry and Collier Counties. A brief article on these fields has been prepared by Clarence V. Babcock of the Florida Geological Survey.

The final portion of our trip will include stops along the recently completed Everglades Parkway (Alligator Alley) between Naples and Andytown. New exposures produced by dredging operations along the road will be examined and interpreted stratigraphically.

A detailed road log is included in the Appendix along with graphic sections for stops along the Caloosahatchee River.

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THE PLIO-PLEISTOCENE OF FLORIDA

With special reference to the strata outcropping on the Caloosahatchee River

by

H. K. Brooks

University of Florida

ABSTRACT

The strata outcropping on the Caloosahatchee River in Hendry and Glades County are reviewed and stratigraphic sections presented. One section from Charlotte County is included because of the occurrence of an early Irvingtonian (Kansan) vertebrate fossil assemblage. It is believed the most useful means of delimiting and tracing the six post-upper Miocene cycles of deposition is by use of the regressional fresh-water marls and the solution-pitted, case hardened limestones that occur at the top of each cycle. Laminated caliche crusts are common at these horizons in relationship to subaerial unconformities. The formations are revised. The two units of the Caloosahatchee Formation, containing many extinct species, are shown to be Plio-Pleistocene in age. The lower member, the Fort Denaud, is probably Late Pliocene age and corresponds to a 120-140 foot eustatic stand of sea level, the Okeefenokee Terrace. The Bee Branch Member is probably Aftonian and corresponds to the Wisconsin Terrace (90 feet) transgression. The Fort Thompson Formation is shown to consist of three marine transgressions. They probably correspond to fluctuations in sea level during the long Yarmouth interglacial stage with transgression (Penholoway-Talbot) 70-40 feet above present sea level. The Coffee Mill Hammock is re-established as a formation. It, and its equivalents, the Miami Oolite, the Key Largo Limestone and the Anastasia, were formed largely in relationship to the +25 foot stand of sea level, the Pamlico. It is possible that a Mid-Wisconsin sea level at +18 feet occurred, the Princess Anne. The older portion of the Lake Flirt Formation, consisting of three cycles of deposition, dates from this time.

INTRODUCTION

"This is without question the most remarkable fossiliferous deposit that has yet been discovered in the state, and from a purely paleontological standpoint, perhaps the most significant in the entire United States east of the Mississippi River. The fossils... crop out in almost countless numbers and attract attention, apart from their prodigious development by their great variety, large size and beautiful state of preservation."

Heilprin (1887, p. 28) wrote the above observations as the result of the first scientific exploration of the Caloosahatchee River. It is unfortunate that despite the monumental works of Dall (1890-1903) and others the true geochronological significance of these deposits has yet to be generally realized. In fact, such a state of confusion presently exists that the time-stratigraphic significance of the faunas is open to question and the stratigraphic and paleontological zones are not clearly defined and are frequently miscorrelated. Most significantly the true relationships of the strata to the climatic and glacial eustatic sea level events of the rest of the world have not been firmly established.

The zonations and interpretations that I am presenting in this paper have not been published elsewhere but are the result of eleven years of intermittent study. The basic interpretation has previously been presented orally to the Miami Geological Society (1966) and the annual meeting of the Gulf Coast Section of the S.E.P.M. (1967). Support for this study has been from the Florida State Museum, the Graduate School of the University of Florida, the Arundel Corporation of Baltimore, Maryland and the Great Lakes Dredge and Dock Company of Chicago, Illinois.

This field trip is being conducted to try to resolve differences of opinion on the stratigraphic and biostratigraphic interpretation of the deposits and to present data and ideas which have not been previously published. It is in this spirit that I have synthesized data from the literature and presented my observations and interpretations. It is hoped that as the result of examining the evidence in the field that the strata exposed on the Caloosahatchee River can be established as one of the most significant exposed sections for the Plio-Pleistocene in the world.

It would be an error to convey the impression that the geochronological events recorded in the strata are obvious. The maximum superimposed section that you will see is about eight feet thick. As a result of construction of a lock at Olga the water level has been raised one and one-half to two feet above the pre-1965 level. Thus the lower portion of the sections of earlier authors are below the present pool level. Within the thin exposed sections there are nine cycles of depositions of which the last three are in the Mid-Wisconsin to Recent deposits of the Lake Flirt Marl. There are six transgressional to regressional marine cycles separated by fresh-water sandy limestones (in places case hardened, capped by laminated caliche crusts and riddled with solution pipes) and unconformities. All of this within the sequence presently assigned to the Caloosahatchee and the Fort Thompson Formations.

The faunal assemblage in the Tamiami Formation of Late Miocene age is distinct. Even this distinct stratigraphic and faunal unit has been confused as being a Pliocene equivalent to the Caloosahatchee Formation (Parker and Cooke, 1944, p. 62-65). Olsson (Olsson and Petit, 1964, p. 511-520; Olsson, 1967, p. 5) has recently placed the "Pinecrest Beds" as a basal unit of the Caloosahatchee Formation even though he recognizes the Upper Miocene age of the rich fossil assemblage. A study of collections made from ditches along the Tamiami Trail near Pinecrest at Forty Mile Bend was Mansfield's (1939, p. 8) basis for proposing the "Tamiami limestone" as a basal Pliocene formation below the Caloosahatchee. Not only is there controversy as to whether the Caloosahatchee Formation should be extended to include the richly fossiliferous beds at the top of the upper Miocene sequence, but the discovery of the teeth of a Pleistocene horse, Equus sp. within deposits assigned to the Formation

has led DuBar (1958, 1962) and the Florida Geological Survey (Puri and Vernon, 1964, p. 231) to assign the total post-Miocene sequence to the Pleistocene. There is clearly something wrong! The composite Caloosahatchee fauna as it is now known consists of over 800 species of mollusks of which about one-half are extinct. Can such a "Pliocene assemblage" conforming to the classic definition of Lyell be so wrong? We have always had great faith in the information that is straight from the "horse's mouth"! To clarify these questions it will be necessary to review the stratigraphic units involved, their interrelationships, and faunas. It will also be necessary to review the concepts and definitions of the Pliocene and Pleistocene.

STRATIGRAPHY

The factual data presented herein will be based as much as possible on observations at the sites that will be visited. Emphasis will be placed primarily upon the lithology of the units, their transgressive or regressive nature, facies, unconformities, and the fossil assemblages. Large faunal lists have been presented elsewhere (Dall, 1903, p. 1605-1614; Mansfield, 1939, p. 11-31; Cole, 1931, p. 1-79; Olsson and Harbison, 1953, p. 13-26; Parker et al, 1955, p. 84-88; DuBar, 1958, p. 107-140; DuBar 1962, p. 14-38; Schroeder, 1954, p. 39-45; Olsson and Petit, 1964, p. 515-521). Foraminiferal assemblages by zone are being published herein by C. V. Conklin. It is especially important that the stratigraphic and paleontological sequence be established through careful study at each outcrop and then literally traced by "walking them out". I have spent many days in a boat physically tracing the zones along the nearly continuous exposures from west of the Fort Denaud Bridge to Ortona Lock. There are two interruptions in the continuous exposures. There is a high of the Upper Miocene extending one-half mile on either side of the LaBelle Bridge over which all of the Plio-Pleistocene section is absent except the upper "Chione sand". A low area is found between Fort Thompson and Ortona Lock where the marine section is exposed only below water.

The stratigraphic units which we will see will be discussed in ascending order from Upper Miocene to Recent.

Tamiami Formation

The Tamiami Formation, as redefined by Parker (1951, p. 823) includes all strata of Late Miocene age in southern Florida. Thus it consists of the Tamiami and Buckingham Formations of Mansfield (1939, p. 8-16) and the upper part of the Hawthorn Formation of Parker and Cooke (1944, p. 98-112). In his original description of these two units, Mansfield (1939, p. 8) believed the Buckingham Limestone was of Late Miocene age, whereas the Tamiami Limestone was believed to be Pliocene, but older than the Caloosahatchee Marl. The type locality for the Buckingham is in the old marl pits at the south edge of Buckingham, Lee County, Florida. The type of the Tamiami is the

exposures in the canals along the Tamiami Trail from Carnestown eastward to near Pinecrest (Forty Mile Bend) in Collier County, Florida.

Parker and Cooke (1944, p. 64) traced by means of cable tool cuttings rocks, which they thought were subsurface equivalents of the outcropping Tamiami, eastward directly under the Miami Oolite as far as Miami. They therefore believed that the Caloosahatchee and the Tamiami Formation interfingered and were time equivalents. Hoy and Schroeder (1952, p. 285) obtained better well samples and discovered six fresh-water limestones within the sequence below the Miami Ooolite. The earlier error was partially corrected when they assigned these strata, on the basis of the fresh water marls, to the Fort Thompson Formation.

A specimen of Ecphora quadricostata umbilicata (Wagner) was found by Schroeder (1954, p. 35) in the marly clay, silt, and fine sand facies (Buckingham Marl) just west of Fort Denaud in Banana Creek, a tributary of the Caloosahatchee River. During the last several years I have collected additional specimens, as have students from the University of Florida and others, from excavations in Lee and Charlotte Counties. Recently, several specimens were collected in a drainage ditch that crosses U.S. Highway 41 near the Sarasota-Charlotte County line. Another specimen has also been found at Pinecrest on the Tamiami Trail in Collier County (Olsson and Petit, 1964, p. 552).

The lithology of the Tamiami Formation is complex, consisting of a number of different facies. In Lee County near Buckingham the lithology is a cream to tan phosphatic calcilutite. There are varying proportions of fine sand, silt, and clay. Northwestward along the Gulf coastal areas to Tampa Bay, the Tamiami is generally a gray to greenish-gray, calcareous, phosphatic sand or sandy limestone. Oysters and barnacles are common fossils. Exposures in Collier County to the south reveal an off-white calcarenite, often with abundant quartz, in various stages of induration. Lithified rocks revealed in quarries in this formation are largely developed in coarser calcarenite and shell facies containing a richly diverse molluscan fauna. These lithified deposits have been altered by solution of aragonite and redeposition of calcite.

The exposures on the Caloosahatchee River just to the west of the Fort Denaud Bridge and on either side of the LaBelle Bridge are mostly gray to green, fine-grained sand, clayey sand, and clay. In a barrow pit west of LaBelle there is a lens of very coarse gravel composed of oblate spheroids of quartz. These pebbles also occur in the "Pinecrest Beds" of Olsson near Forty Mile Bend on the Tamiami Trail. The City of Immokalee owes its excellent water supply to this coarse clastic facies of the Tamiami Formation. The occurrence of these diagnostic pebbles in the Tamiami Formation is excellent support of Bishop's (1956) interpretation that the Citronelle Formation underlying the high hills of central Florida, especially the Lake Wales

Ridge, is Late Miocene in age.

The "Pinecrest Beds" of Olsson and Petit (1964, p. 516) are named from a locality near Forty Mile Bend on the Tamiami Trail near the Collier-Dade County line. Below a thin, sandy, slightly oolitic, hard limestone (Fort Thompson) "is a soft fine quartz sand ranging from 10 to 20 feet in thickness. Over a part of this region, this sand bed is barren of fossils aside from scattered worn fragments of Turritella and Macrocallista." (Olsson and Petit, 1964, p. 516).

The rich, diverse fauna assigned to this unit (Olsson, 1967) was largely collected from excavations near Brighton and Kissimmee north of Lake Okeechobee, Fisheating Creek, Pinecrest and Acline in Charlotte County. Tucker and Wilson (1932 and 1933) first described new specimens from a quarry at Acline and this problematical assemblage has become known as the "Acline fauna". Druid Wilson estimates that the assemblage consists of about 600 species. DuBar (1962, p. 39) believes the collection is stratigraphically mixed and represents a conglomeration of Late Miocene, Caloosahatchee, and Recent species. In this I agree, but from my observations I also recognize that it is possible for pockets of richly fossiliferous lenses and beds to occur within the Tamiami Formation. It is probably such beds that are yielding the "Pinecrest fauna".

I certainly cannot agree with Olsson that the "Pinecrest Beds" of Late Miocene age are a lower unit of the Caloosahatchee Formation. Every place where the base of the true Caloosahatchee Formation can be seen it rests unconformably on the Tamiami Formation, such as the exposures west of the Fort Denaud Bridge (Stop 5). That the stratigraphic sequence from the "Pinecrest Beds" of Late Miocene age to the Caloosahatchee Formation of Late Pliocene age (or Pleistocene) cannot be conformable is supported by several lines of evidence.

1) The lower Pliocene is not known to occur in Florida, 2) there are a number of sites at elevations at or near sea level where assemblages of Late-Middle Pliocene to Early-Late Pliocene age land vertebrates have been found (Webb and Tessman, 1967). Recently several vertebrate fossils of this age have been collected in the Kissimmee River area near Brighton and, 3) most significantly, the great river straths of peninsular Florida are all eroded into Upper Miocene or older strata. They are back filled with deposits of Late Pliocene or younger age (Brooks, 1966, p. 41). These eroded valleys contain the lagoonal and fluviatile deposits of the Bone Valley Formation of the Suwannee, New River, Santa Fe River, and the Peace and other rivers of the Bone Valley area of central Florida. The Nashua Marl of the St. Johns and the "Caloosahatchee deposits" of the Kissimmee occur in such eroded straths. The "St. Petersburg Fauna" also is associated with one of Florida's great estuaries as are the Caloosahatchee beds exposed in the creeks associated with Charlotte Harbor. It is even

true that the type Caloosahatchee occurs in a valley-like depression between the highlands to the north and the Immokalee high to the south.

The Upper Miocene stratigraphy of the Atlantic Coast and of the panhandle of Florida consists of two phases. A cool water fauna assemblage, "the Ecphora zone", occurs in deposits that underlie a deposit containing a fauna indicative of warm tropical affinities, "the Cancellaria zone". If it can be proven that these two phases of the Upper Miocene exist in south Florida, then a) the Buckingham Marl should be re-established as a member for the lower phosphatic marl, sand, and clay equivalent to the Ecphora zone at Jackson Bluff in Leon County, and b) the upper calcarenites, limestones, and clastics (including the fine to coarse marine clastics containing the "Pinecrest fauna" with its tropical affinities) should be recognized as an upper unit of the Tamiami Formation, the Pinecrest Member, equivalent of the Cancellaria faunizone. It is doubtful that valid lithological criteria will be established in these variable deposits to warrant both units being recognized as mappable formations.

Plio-Pleistocene Sequence

History

From his brief exploratory study of the richly fossiliferous beds containing extinct species exposed on the Caloosahatchee River, Heilprin (1887, p. 103-104) lists 89 species of which 41 are still members of the Recent fauna. This is 46% of the total assemblage. He thus correlated it to the Astian of the Italian Pliocene series and referred to it as the "Floridian Formation" (p. 32-68). The outcrops from which he collected were eastward of the limestone bluffs at Daniels (p. 28-33), the present site of the Fort Denaud Bridge, and extended as

> "highly fossiliferous deposits ..... practically without intermission to Fort Thompson, a distance along the river of some ten to twelve miles. I made a careful examination of the banks to ascertain if any dividing line or horizon, characterized by distinct assemblages of organic remains, existed, but failed to discover any such; the fossils appear to be packed almost indiscriminately, and in several instances when I thought that a certain localization of some species could be detected, the same forms would appear in other parts of the bank .... Only along the top line was there a true differentiation, the uppermost (marine) bed being densely charged with the valves of Venus cancellata, largely to the exclusion of the numerous forms that so eminently serve to define the bank in general. Nor did I succeed in obtaining any extinct species from this topmost stratum, although no true

> junction line between it and the stratum immediately underlying could be determined. There is no question in my mind that this upper Venus bed, the same as we found at other points of the river, is of Post-Pliocene age ..... For some distance below the Fort Thompson rapids the topmost of the marine deposits exposed on the river -- the Post-Pliocene Venus cancellata bed ..... is seen to be overlain by a heavy stratum of limestone, in which the remains of fresh-water organisms, Planorbis, Limnea, etc., are very numerously imbedded. This fresh-water limestone... can be traced to the rapids (and beyond), where it acquires its maximum development, with a thickness of two to two and a-half feet. It here rises from two to four feet above the surface of the water everywhere overlying the Venus cancellata bed, which in turn here and there exposed the older fossiliferous deposits...."

In Dall and Harris' classic paper on the correlation of the "Neocene" (1892, p. 145-146) the Chione cancellata bed and the "Planorbis rock" were included in the Pliocene. They use the name Caloosahatchee marl in an informal way (p. 145) as Dall (1887, p. 169) had done earlier. Dall's (1889-1903) great contribution was the description of 639 species of which 49% were extant. Dall's collections included specimens from the Caloosahatchee River and Shell Creek, Alligator Creek and Myakka River in the Charlotte Harbor area. The other taxonomic studies of importance on faunas believed to be contemporaneous in Florida are Olsson and Harbison's (1953) study of a rich fauna from St. Petersburg and Mansfield's (1918) study of the Nashua Marl fauna of the St. Johns River from south of Palatka to near DeLand.

Meaningful stratigraphic zonation of the strata exposed on the Caloosahatchee River dates to Sellards' (1919, p. 71-74) work in which he defined the Fort Thompson Formation of Pleistocene age as the "alternating fresh-brackish water and marine shell marls and limestones typically exposed at Fort Thompson" and the overlying unconsolidated shell bed consisting predominately of Chione cancellata as the Coffee Mill Hammock Marl. Their types were at Fort Thompson and at Coffee Mill Hammock near the present site of Ortona Lock. Unfortunately Cooke and Mossom (1929, p. 198-211) later suppressed the Coffee Mill Hammock to a member of the Fort Thompson Formation. They correlated the other known Pleistocene units on the east coast and in southern Florida (Anastasia Formation, Miami Oolite, and Key Largo Limestone) to the Fort Thompson Formation.

As Cooke was deeply involved with marine terraces and glacial eustatic fluctuations of sea level, Parker and Cooke (1944, p. 94-95) made note of the four marine transgressions they recognized

in the Plio-Pleistocene sequence and correlated the terraces then believed to be of Pleistocene age with the Fort Thompson units (including the "Coffee Mill Hammock member"). Their diagrammatic interpretation is reproduced without alteration as figure 1.

A published measured section that has not received appropriate notice was presented in the guide book of the eighth field trip of the Southeastern Geological Society (Schroeder, 1954, p. 28-29). It was a composite section between the lock and the railroad bridge at Ortona Lock. Six marine units separated by fresh-water limestone and unconformities were recognized in the Caloosahatchee-Fort Thompson sequence. The upper unit of the Caloosahatchee, the "Vermicularia bed", was incorrectly assigned to the Fort Thompson Formation. The multiplicity of units assigned to the Pleistocene was used to refute Parker and Cooke's eustatic correlation and to support Richards' (1945, p. 404) statement that he "is still not entirely convinced that the variations between fresh-water and marine limestone along the Caloosahatchee River could not have all taken place within a single interglacial stage...".

During the summer of 1953, DuBar made a startling discovery of Pleistocene horse teeth within an outcrop of the "Caloosahatchee Marl" along the Caloosahatchee River near Ayers Landing one and one-half mile upstream from the Fort Denaud Bridge. DuBar (1958) did an excellent job of zoning the individual exposures and interpreting the ecology of the faunas, but I believe he mis-correlated the units between outcrops (his diagrammatic correlation between the strata at Fort Thompson and Ortona Locks is herein reproduced without alteration as figure 2). Most significantly, he relegated the classic Caloosahatchee fauna with so many extinct species to the last interglacial stage of the Pleistocene, the Sangamon. The varying units DuBar assigned to the Fort Thompson were stated to be Wisconsin. Studies in the Charlotte Harbor area (1962) were used to support his earlier interpretation. His stratigraphic zonations were mostly referred to in relation to faunal zones. DuBar did name a secondarily hardened limestone and concretionary marl, the Bee Branch Member of the Caloosahatchee Formation. In the type area, this was the middle marine unit. He later (1958b, p. 136) proposed the name Fort Denaud member for the lower unit and the Ayers Landing Member for his upper unit.

Without taking into account the unconformities within the stratigraphic sequence, and the biostratigraphic significance of the molluscan fauna, especially the percentage of extinct species, he based his correlations only on the supposed late Pleistocene age of the vertebrate fauna.

Overlying the marine strata on the Caloosahatchee River and elsewhere in Florida are surface sands. In low places, river valleys, and especially in south Florida, lake basins such as Lake

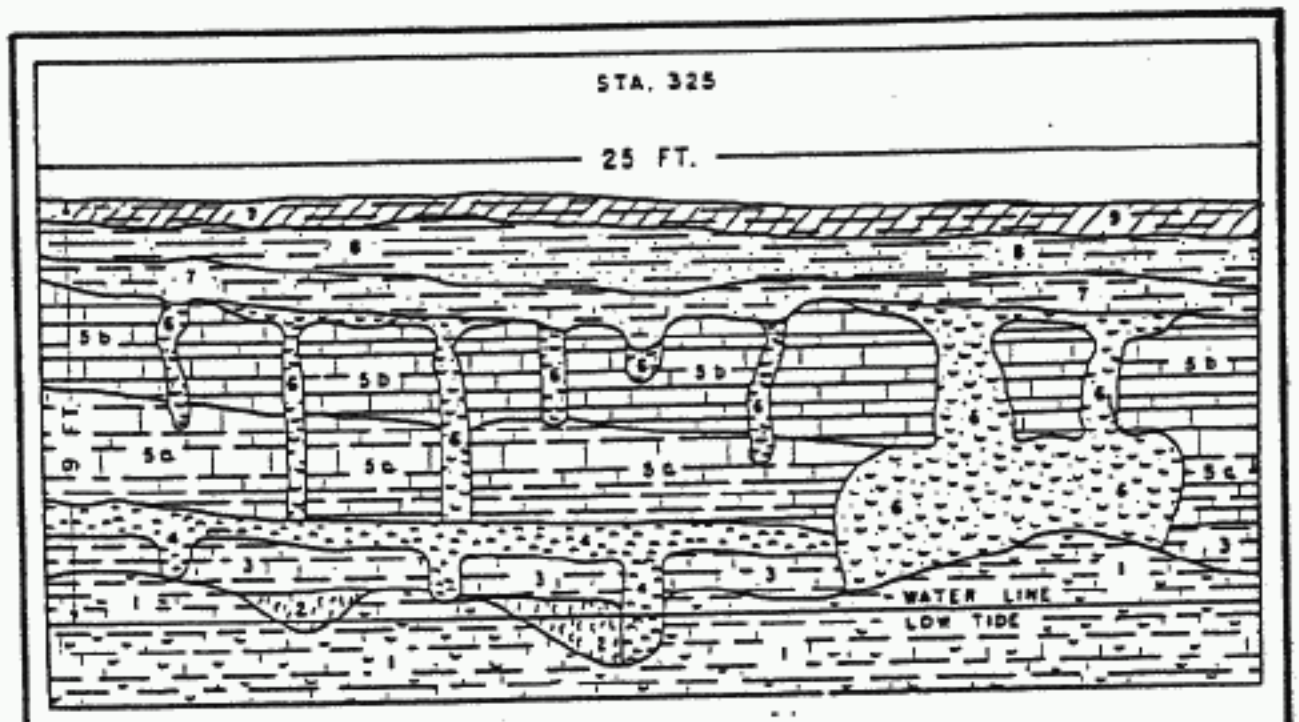


Fig. 1 Idealized geologic section at Fort Thompson presented by Parker and Cooke, 1944, fig. 4, p. 89.

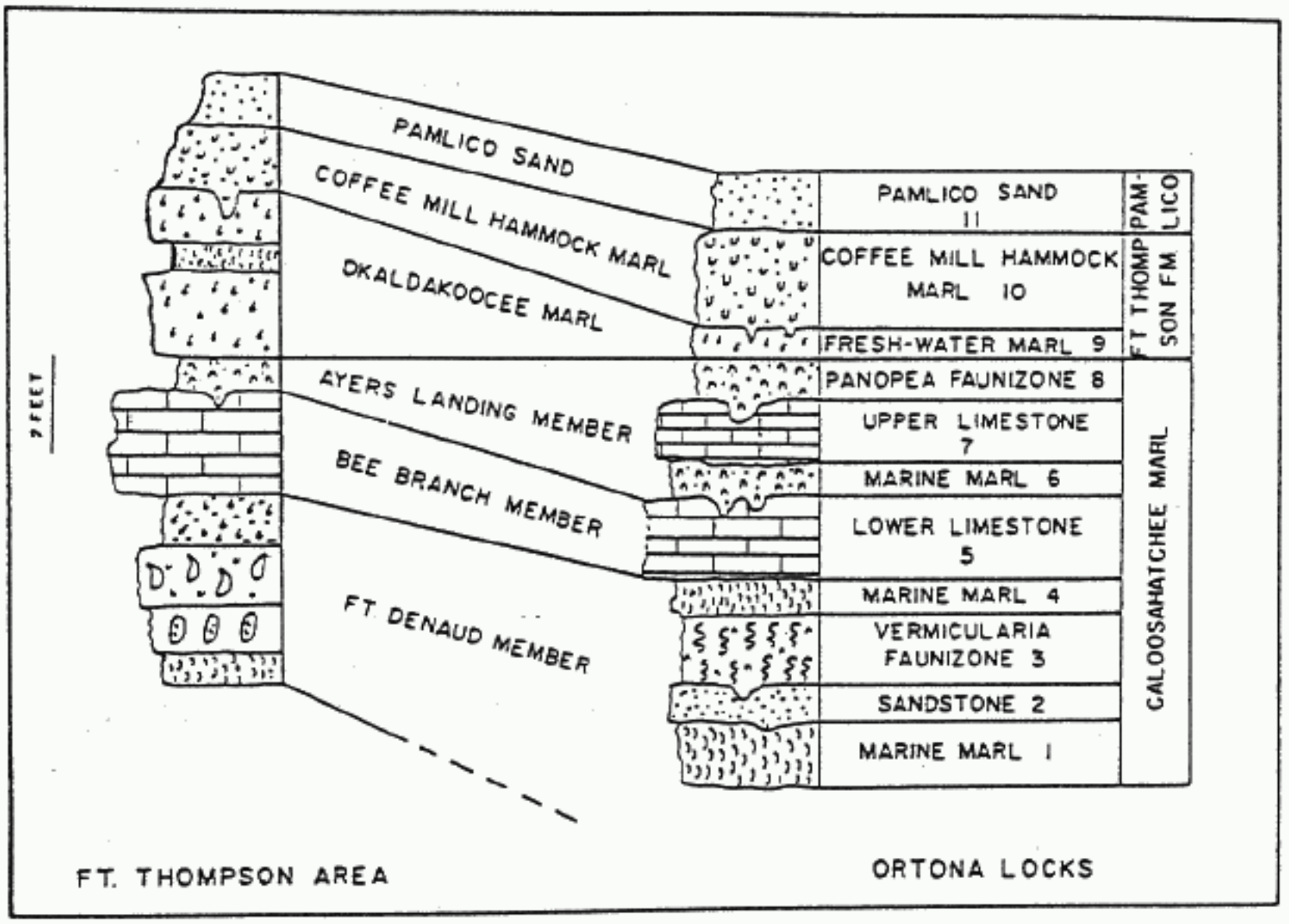


Fig. 2 Correlation between Fort Thompson and Ortona Lock as interpreted by DuBar (1958b).

Okeechobee, there are fresh-water marl sequences. These have been referred to as the Pamlico Sand and the Lake Flirt Marl.

The Pamlico Formation was proposed by Stephenson (1912, p. 286-290) for "fine sandy loams, sands and clays and to a limited extent gravels" near Pamlico Sound in eastern North Carolina. He correlated all such deposits underlying the plain that do not exceed 25 feet altitude from North Carolina northward to Maryland. Cooke (1931 and later) has associated the sand deposits with the origin of the 25-foot terrace throughout the Atlantic Coastal Plain and Florida. Richards (1936, 1938) has also assigned the fossiliferous estuarine and Chione cancellata beds of the Atlantic and Gulf Coasts to this formation. He (1936, p. 1643) makes note that fossils of the 100% extant marine assemblage are found up to an elevation of 25 feet above present sea level, "and never above". He correlates the beds as late Pleistocene, probably Sangamon.

Cooke (1945) disagrees with Richards' usage and would designate the Pamlico Formation as representing only the surficial nonfossiliferous sand associated with the 25-foot terrace. Formational names have also been assigned to the unfossiliferous clastics associated with the higher terraces.

It can readily be shown that the surficial sand of the coastal plain associated with the "marine terraces" are heterogenetic and heterochronic. In some places they represent beach, dune deposits, and regressional sand, but in many cases they are nothing more than soil profiles developed in the normal course of soil formation.

The Lake Flirt Marl was named by Sellards (1919, p. 73-74) for the deposit overlying the Coffee Mill Hammock shell bed. It "consists of a calcareous mud in which fresh-water shells, chiefly gastropods, are embedded" and has a thickness of three to four feet. It underlies the lake basin from Old Fort Thompson to Coffee Mill Hammock. It is of "fresh-water origin and quite recent in age." Cooke (1945, p. 312) and others have extended it to include the marl underlying the peat and muck in the Everglades and elsewhere. Cooke (1945, p. 312) states that "Deposition of the marl probably began during late-Wisconsin (post-Pamlico) emergence and may have continued locally into the Recent epoch." Previously Cooke and Mossom (1929, p. 211) were in agreement with Sellards that it was Recent.

Stratigraphy

DuBar (1958) has been the only person who has previously published detailed stratigraphic and paleontological sequences. His sections are remarkably accurate relative to lithology and fossil content. However I disagree with him on the following points: a) I do not include all nodular or altered rubbly sandy limestone in the

Bee Branch Member of the Caloosahatchee Formation, b) I do not agree with his correlation of zones between outcrops, and c) I feel he has not recognized subtle evidences of unconformities between similar lithologies.

Six marine zones can be distinguished within the Plio-Pleistocene sequence. Each marine unit is separated by an unconformity of considerable magnitude. There are regressive marls associated with each marine unit. Case hardened and solution-pitted limestone, often with caliche crusts, can be shown to occur associated with each unconformity. At many places the unconformities can only be detected by careful search for relics of these limestones and "crusts" or, less convincingly, through the presence of fresh-water shells into what appears to be otherwise a conformable marine sequence. DuBar recognized the presence of fresh-water limestones and unconformities in his sections of the Caloosahatchee. He discounted their significance in this and in the Fort Thompson Formation as being of minor time-stratigraphic significance.

The stratigraphic sections critical to interpretation of the post-Miocene strata on the Caloosahatchee River are presented together in diagrammatic form . They conform to the scheduled Stops 2 to 8, but will not be discussed in that order. For convenience of reference my formational assignments are given on the stratigraphic diagrams presented for each stop. There is space on each diagram for notes on difference of interpretation by others. In the following discussions we will refer to the units of the Caloosahatchee, Fort Thompson, and Coffee Mill Hammock Formations as Units one to six. The Lake Flirt will be referred to by name because there is no question of its boundaries. See Appendix for these graphic sections.

* * * *

Stop 4. The outcrop on the south bank of the Caloosahatchee Canal about two and one-half miles west of the bridge at LaBelle in the southwest Corner of Section 12, R. 28 E., T. 43 S., Hendry County, is near the center of the area from which the classic fossil collections were made and should be considered the type of the Caloosahatchee Formation. This is near Station 20 of Parker and Cooke (1944, p. 86), Stop 5 of Schroeder (1954, p. 44) and A 28 of DuBar (1958, p. 234-235).

As Parker and Cooke (1944, p. 86) observed, "This station is located in an area where wide variations in lithology are common. In some places nearly the entire Pliocene section consists of soft unconsolidated shell marl; in other places the top layer of ledge rock is entirely missing or is represented merely by scattered cobbles. The Caloosahatchee contains many coral heads at this station." Parker and Cooke's section was apparently measured on the adjacent property to the west where the upper "Chione sand" is best developed above a limestone ledge. DuBar's section appears to be at the same place as mine.

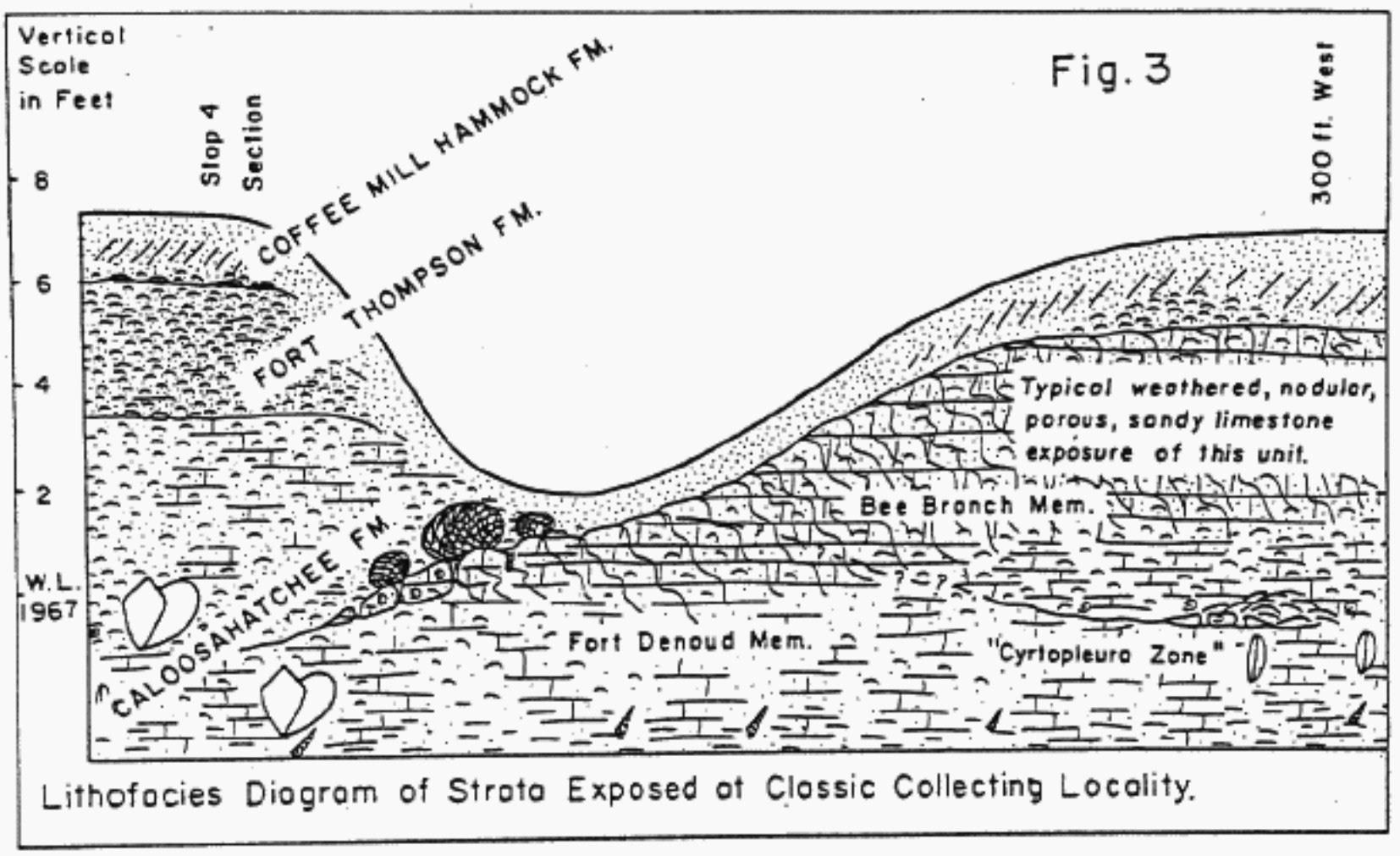
Figure 3 (also see stratigraphic section for Stop 4) portrays the complexity of the lithological relationship at this site. There are four fossiliferous marine units exposed here, the lowest and oldest of which is now largely under water (Unit 1). In ascending order the overlying units are designated 2, 3 (4? or 5?) and 6.

Unit 1 consists of three sub-zones. The lowest zone consists of one to one and one-half feet of sandy calcilutite with abundant Turritella and a meager variety of other species. It grades upward into one to one and one-half feet of calcarenite with a richly diverse "Caloosahatchee" molluscan fauna including Vassum horridum, Turritella perattenuta, Scaphella floridana, Strombus leidyi, Arca wagneriana and Cypraea problematica. Articulated shells of Cyrtopleura costata are found burrowing downward into these beds. Westward 300 to 400 feet beyond the limestone ledge, this "Cyrtopleura zone" can be examined again where other fossils are not so abundant. There are a few brackish-water indicators present, including Rangia nasuta. At this site there are discontinuous relics of hardened fresh-water limestone above the Cyrtopleura bed. By the oak tree this upper sub-unit is missing, but it can be seen just to the west of the tree where it forms the rocky substratum for a patch of corals developed within the next transgressive sequence. The unconformity above Unit 1 will be discussed after description of the overlying marine unit.

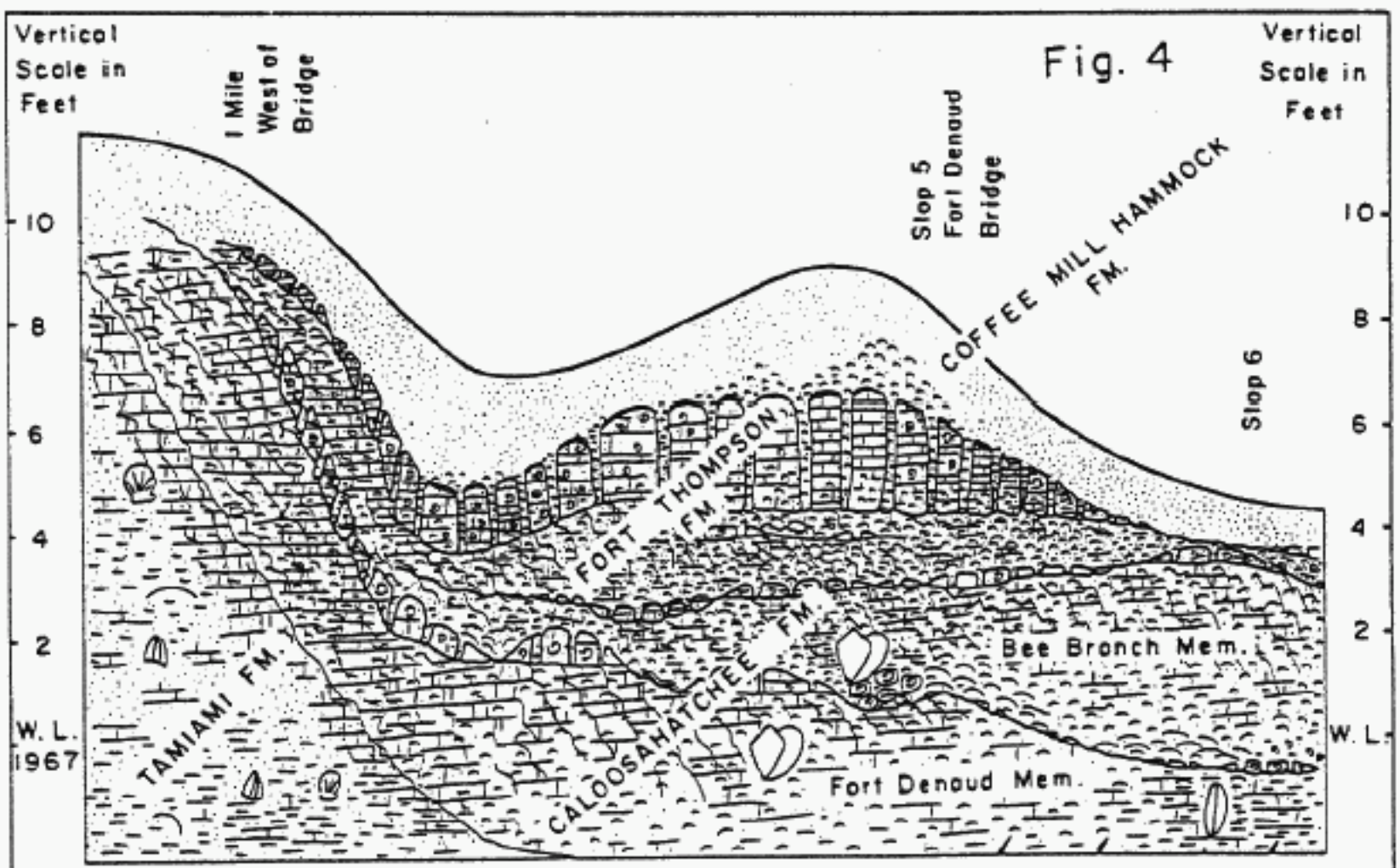
Unit 2 is a calcarenite which at this site contains an abundant and diverse Caloosahatchee marine molluscan fauna. A thin oyster and pecten bed occurs at its base westward of the limestone ledge. The ledge itself consists in part of the limestone at the top of Unit 1, but largely it is a sandy, hard, rubbly limestone that has resulted from the weathering of Unit 2. (This is the Bee Branch Member of DuBar).

East of the patch reef, the section exposed in the bank superficially appears to be a conformable sequence between Unit 1 and Unit 2. That there is an unconformity within the sequence is not only proven by the relic patches of fresh-water limestone, but also by the fresh-water snails that have been reworked into the basal portions of Unit 2.

Unit 3 (4?, 5?) appears to be superimposed conformably on the underlying unconsolidated marls. However, westward of the patch reef where the second unit is highly altered to Bee Branch type limestone, the richly fossiliferous "Chione cancellata beds" with relatively fresh shells are very conspicuous. At the measured section it is difficult to prove the occurrence of an unconformity between these "Chione cancellata beds" and the underlying unit. Diligent search will reveal that here and there a contact can be found with an occasional piece of relic fresh-water limestone or laminated caliche crust. DuBar failed to distinguish these two units, and thus grouped



Lithofacies Diagram of Strata Exposed at Classic Collecting Locality.



Lithofacies Diagram of Strata Exposed in Vicinity of Fort Denoud Bridge.

together the combined materials of my Units 2 and 3.

There are a few extinct species, e.g. Pyrazus (Pyrazisinus) scalatus (Heilprin), in Unit 3. For the most part, Chione cancellata comprises 20 to 50% of the specimens. This is obviously the "Venus cancellata bed" of Heilprin and Dall. It is in part the Ayers Landing Member of the Caloosahatchee Formation of DuBar. It does not contain nearly all of the extinct species attributed to it by DuBar. It is not a "Caloosahatchee assemblage" just as both Heilprin and Dall had previously recognized.

The six teeth of Equus that I have collected here and apparently the teeth that DuBar collected further westward near Ayers Landing, came from the base of Unit 3, or above the two beds containing the profusion of extinct species.

These teeth that have been cited as proof of a Late Pleistocene age of the Caloosahatchee Formation belong to the caballine horses. In discussing the relationship of the Irvingtonian occurrence of this group Savage (1951, p. 239) used the name Equus cf. caballas Linnaeus (the modern domestic horse) because of the problem inherent in the differentiation of species. Savage (p. 243) states that one "is completely overwhelmed by the multitude of presumably diagnostic species characteristics which have been used; he is even more confused to find that most of the proposed distinctions collapse into minor variations within a species when a large number of specimens are available from one locality." The type specimen of E. leidyi (p. 246) "and other teeth which Hay has referred to this species greatly resemble teeth which have been referred to E. complicatus Leidy, E. holmesi Hay (nomen vanum) and other proposed species. I regard E. leidyi as a nomen vanum." How can one be so sure of the Late Pleistocene age of Unit 3 when the caballine horses have a known biostratigraphic range of Kansan to Recent? I am deeply indebted to David Webb and Norm Tessman for the advice and the help given me with this problem.

Unit 3 consists of relatively fresh shells in a slightly calcareous sand matrix, but in places it is weathered at the top to a nodular conglomeration. In the section between the oak tree and the reef patch, there are relics of laminated crust at the top of this unit. These relics represent and testify to the occurrence of a sub-aerial unconformity.

Unit 6 consists of patches of shell in sand above the relic caliche crusts. The overlying sand is in part residual. The humate zone is typical of soils developed under poorly drained conditions.

It is estimated that Units 1 and 2 contain 30 to 40% extinct species, Unit 3 contains 5 to 10% extinct species and Unit 6 contains no extinct species. For convenience the marine fauna of the

lower two units will be referred to as a typical Caloosahatchee fauna.

* * * * *

Stop 5. The measured section occurs on the south side of the Caloosahatchee Canal under and on either side of the Fort Denaud Bridge, north center of Section 15, R. 28 E., T. 43 S., Hendry County. This must be the area of the limestone cliffs at "Daniels" referred to by Heilprin. The section presented by Parker and Cooke (1944, p. 58, station 385) and DuBar (1958, p. 277, A 39) were measured on the north bank and to the west of the old bridge. Similarity between their sections ends with recognition of the surface sand as the Pamlico Formation. DuBar correctly recognized the existence of pockets of Chione sand filling solution pipes in the underlying strata as Coffee Mill Hammock? (assigned to the Fort Thompson). However, he included 2.5 feet of weathered rubbly sand and shell above the deposits containing typical Caloosahatchee species in the Caloosahatchee Formation, whereas Cooke had assigned his comparable unit, containing only a few extinct species, to the Fort Thompson Formation.

This is an area of outcrop that requires careful study to interpret because of thickening and thinning of units and because much of the marl, sand, and shells has been altered to a nodular, sandy, porous limestone. The lower units slowly rise westward for about one mile. The upper units are progressively eliminated until the complete section below the surface sand is fine sand, clayey sand, and marl of the Tamiami Formation. This relation is diagrammatically shown in figure 4. Please refer also to the stratigraphic section presented for Stop 5.

Four marine zones can readily be distinguished. Herein they will be discussed as representing Unit 1, Unit 2, Unit 3 (4?, 5?) and Unit 6. In some places there is evidence for two cycles of deposition within Unit 3.

Unit 1, the lowest exposed bed at the bridge, is for the most part a fossiliferous calcarenite that has been altered to a solution riddled, medium to hard, limestone. In some places the calcarenite is relatively unconsolidated. In places, laminated caliche crusts and fresh-water limestone relics indicate the presence of an unconformity between this and the overlying unit which is very similar, even to containing the same "Caloosahatchee fauna".

Unit 2, the Bee Branch Member of the Caloosahatchee of DuBar, is distinguished here because of the development of oysters and pectens at many places near its base. In addition to seeing these "basal oyster biostromes" of DuBar, one can also find locally a conglomerate consisting of boulders of reworked fresh-water limestone in pockets above the basal unconformity. Where not altered, this unit contains an abundance of shells. It is capped nearly everywhere by remnants of fresh-water limestones in places with laminated crusts two to six inches thick.

Unit 3 is, for the most part, badly weathered to a nodular, rubbly porous sandy limestone. It apparently was originally a sand and shell bed in which Chione cancellata dominated. Here and there one can find relics of fresh-water limestone and laminated crusts within this unit. There is no question about the "cap rock" of this unit. It dominates the section and consists of a hard sandy limestone riddled with solution pipes. The lower portion contains a marine fauna whereas the upper portion contains only fresh-water snail shells. This gradation of marine to mixed fauna to fresh-water snails can be observed at many places and is not restricted to the regressive sequence of this unit. The percentage of extinct mollusks in this unit is difficult to estimate because of the poor preservation, but there are definitely two or three species. Because of the conspicuous "cap rock", solution pipes, and laminated crusts, there can be no question about the unconformity at the top of this composite stratum.

Unit 6 occurs as pockets and, just to the east of the bridge, as a continuous stratum up to one foot thick. This sand and shell deposit contains an extant assemblage in which Chione cancellata is dominant. The thick overlying sands two to three feet thick appear to be largely residual.

* * * * *

Stop 6. The exposure to be studied is about 2,000 feet east of the Fort Denaud Bridge on the south side of the canal. It is on the south bank in the NE 1/4 of Section 15, R. 28 E., T. 43 S., in Hendry County.

Besides being a typical exposure this section is of great significance because here one can clearly see the solution-pitted regressional fresh-water marl within the Caloosahatchee Formation below an intraformational unconformity and above the occurrence of the Cyrtopleura burrowing clams. There are also patches of a transgressive fresh-water marl above the unconformity. (Most of the fresh-water marls are regressive and grade downward into the underlying marine deposit through a mixed transitional zone which in places contains beds of oysters and pectens). See DuBar's section A 36 which is reproduced below.

Three cycles of deposition can be distinguished at the exposures occurring at Stop 6. To either side a fourth marine zone occurs as weathered "Chione cancellata" shells at the base of the surficial sand in solution pockets and as discontinuous beds. The units shown in the diagram for Stop 6 (with sub-units) are 1, 2, and 3.

Unit 1 at the bottom, and below the present water level, is a plastic marl with 30 to 40% very fine sand. It contains oysters and pectens mixed with a fresh-water snail fauna. It grades downward into a clayey marl with an abundance of Turritella. At the top this regressive sequence grades upward into a sandy limestone containing an

abundance of fresh-water snail shells. This cap rock is case hardened, discontinuous, and contains solution pipes in relationship to the unconformity.

Unit 2 consists of three intergrading and intermixed lithologies. At the bottom are patches of an unconsolidated marl, zero to six inches thick, with an abundance of fresh-water snail shells. In places the snails from this marl are intermixed with the calcarenite. The calcarenite contains considerable quartz sand. The marine fauna is abundant and diverse and represents a typical "Caloosahatchee assemblage". At the base of this marine zone are oysters, pectens, and Rangia shells. In places in this vicinity there are actually oyster biotherms. The calcarenite and shells are weathered to a porous, sandy, rubbly limestone in the upper two feet or so of this four foot thick unit. Capping the limestone is a discontinuous layer, zero to four inches thick, of a very sandy, hard rock containing fresh-water snails.

Unit 3 is a calcareous sand and shell deposit in which Chione cancellata shells are very common. At the top of this marine cycle are relics of a discontinuous, thin, hard, sandy limestone. The surficial sands are mucky and their origin is questionable. However, laterally one can find patches of Chione shells at the base of the sand sequence.

The diagram presented earlier as figure 4 displays the relationship between the zones distinguished here and in the higher canal banks at the Fort Denaud Bridge.

It is important that two sections measured by DuBar be presented at this time. They are as follows (1958, p. 236-237, A 36; and Puri and Vernon, 1964, p. 245-246, A35):

A 36: NW 1/4 SW 1/4 sec. 11, T. 45 S., R. 28 E., Hendry County, Florida, left bank of the Caloosahatchee River about 0.9 mile upstream from the bridge at Fort Denaud.

Bed	Description	Thickness (feet)
	Pamlico Formation	
10	Sand, quartz, fine to medium, fairly well rounded, unconsolidated; no fossils.....	0.8
9	Sand, quartz, carbonaceous, fine to medium, fairly well rounded, black; no fossils observed	1.5

Bed	Description	Thickness (feet)
	Unconformity	
	Fort Thompson Formation	
8	Shell marl (Coffee MillHammock marl?), sandy, only slightly indurated, brown with cream shells, occurs as a thin bed and in solution holes in bed below; Chione cancellata common	0.1 - 0.5
	Unconformity	
	Caloosahatchee Formation	
7	Marl, marine sandy, slightly concretionary, otherwise relatively unconsolidated, tan to buff, mottled orange; sparsely fossiliferous. Amusium mortoni characteristic	2.5
6	Limestone, fresh-water, sandy discontinuous, tan; very sparesely fossiliferous, Helisoma most common	0.1 - 0.5
5	Shell marl, marine, sandy, cream to white, weathers gray; very fossiliferous, typical Caloosahatchee species	1.5
4	Limestone (Bee Branch member), marine, marly, concretionary, gradational below and above solution features common; thin oyster bed at top, buff, mottled orange; fossiliferous throughout	1.5
3	Marl, brackish, loosely consolidated, cream to gray; many fresh-water and marine mollusks, Chione cancellata, Mulinia sapotilla, and Helisoma conanti characteristic	1.6
2	Oyster marl, sandy, hard, porous, tan to cream with gray and white shells; Crassostrea virginica and Chlamys solarioides common	0.5
1	Marl, marine, argillaceous, slightly concretionary, loosely consolidated, tan to cream; Cyrtopleura costata characteristic.	1.5

(A 35): SW 1/4 NW 1/4 sec. 11, T. 43 S., R. 28 E., Hendry County, Florida. Right bank of Caloosahatchee River near Ayers Landing.

Bed	Description	Thickness (feet)
	Pleistocene Series	
	Pamlico Formation(?)	
6	Sand, quartz, fine to medium, subangular to subrounded, well sorted, unconsolidated, light gray; no fossils observed	0.9
	Fort Thompson Formation(?)	
5	Sand, quartz, medium, subangular to subrounded, fairly well sorted, slightly consolidated, upper two feet mottled brown, lower 0.2 foot dark brown	2.2
	Unconformity	
	Caloosahatchee Marl Formation	
	Ayers Landing Marl Member	
4	Shell marl, sandy, unconsolidated, tan to gray, insoluble residue 58% by weight, mostly medium subangular to subrounded quartz sand; mollusks abundant including Retusa canaliculata, Anachia caloosahatcheensis, Mitra heilprini, Anomalocardia caloosana, Chione cancellata, Nuculana acuta, Chama heilprini, Spondylus rotundatus and numerous fresh-water gastropods	3.1
	Bee Branch Member	
3	Marl marine, hard, calcareous, buff to gray, insoluble residue 15% by weight, mostly fine quartz sand and silt; mollusks abundant including Chione cancellata, Chama willcoxi, Chlamya nodosus, Spondylus rotundatus, Lemintina decussata, and Liochlamys bulbosa	2.6

Bed	Description	Thickness (feet)
	Fort Denaud Member	
2	Marl, brackish, calcareous, sandy, mostly medium subangular quartz, buff to gray; mollusks abundant including both brackish-water and fresh-water species	1.0
1	Marl, argillaceous, especially near base, increasingly calcareous upward, white to light gray, insoluble residue 12% by weight, comprised mostly of fine quartz sand and silt, and clay; molluscan fossils abundant, including Crassostrea virginica near the top, and Cyrtopleura costata in the lower part .....(to water level).....	1.1

Puri and Vernon (1964, p. 246) quote a statement by DuBar (1958, p. 236) that "between this section and a distance of 50 yards upstream there occurs an excellent exposure of the upper Caloosahatchee shell bed (Ayers Landing Member) that contains in addition to a profusion of mollusks and many coral heads a good vertebrate fauna including teeth of Equus (Equus) cf. E. (E.) leidyi."

They also recognize that "The entire upper section of the Caloosahatchee Formation which is called the Ayers Landing Marl member of DuBar (1958b) was included in the Fort Thompson Formation by the previous workers (Parker and Cooke, 1944; Parker, et al., 1955) and was considered to be Pleistocene in age."

It is here fixed that the major vertebrate fauna cited by DuBar (1958, p. 138) as occurring in the "Upper Shell Bed" and the "Undifferentiated Beds" are probably from the base of a bed equivalent to my Unit 3. It should further be noted that in section A 36 he miscorrelates the Bee Branch Member to the top of the lower regressive sequence (1, 2, 3, and 4 of his zones) and not to the second cycle (5 and 6 of his zones). He was apparently misled by the pectens and oysters which usually do occur in this area at the base of the second unit. At Fort Thompson we will see another occurrence at the base of my third unit; this is DuBar's Chlamys gibbus irradians zone.

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Stop 7. This stop is in the area of the type Fort Thompson Formation. Most of the previous sections have been measured on the south bank of the canal. The two sections presented herein are on the north bank about 140 yards east of a drainage ditch entering the Caloosahatchee Canal from the north and at a waterfall in the same ditch just north of the culvert. Both are about one and three-fourths miles east of the bridge at LaBelle, in Section 3, T. 43 S., R. 29 E., Hendry County, Florida.

There is a great variation in the strata both laterally and vertically as the individual lithosomes thicken and thin and rise and fall in elevation.

Five cycles of deposition separated by unconformities overlain by surficial marl and muck can be recognized in the present exposures. They are Units 2, 3, 4, 5 and 6 plus the Lake Flirt Marl.

Unit 1 is below water and has never been exposed even before the water level was raised in 1965.

Unit 2 is also now largely under water. In a few places it rises to near water level where its upper portion can be seen as a sandy, solution-pitted, fresh-water limestone just below the Chlamys gibbus irradian bed of the superimposed unit. In the drainage ditch at the waterfall the "cap rock" of this unit rises a foot or more above water. It can be seen to grade downward from a case hardened sandy limestone to a marly sand, both containing only fresh-water snails, to a fine sand in which the Helisoma shells are mixed with an occasional Mulinia. Below this is the typical Caloosahatchee lithology. There is no question but that Sellards (1919, p. 71) and all subsequent authors have been in error by including the upper freshwater marl and limestone of this Caloosahatchee unit as the basal unit of the Fort Thompson Formation.

Unit 3 consists of a gradational sequence from the Chlamys beds into calcareous sand and shell and then back through a mixed fauna to a thick fresh-water marl and limestone. The total thickness is as much as three feet, but in places it is less than one and one-half feet. The dominant portion of this unit is the regressive fresh-water marl and limestone which ranges from one and one-half to two feet in thickness throughout this area.

Unit 3 appears to be equivalent to the Ayers Landing Member of the "Caloosahatchee Formation" of DuBar in the westward exposures between LaBelle and Fort Denaud. Believing it to be a different unit here, DuBar (1958b, p. 145) has suggested that it be called the Okaloakoochee Marl Member of the Fort Thompson Formation. He did not separate this marl from the overlying unit which, at this site, is largely a fresh-water marl and limestone nearly identical to that of Unit 3. Parker and Cooke (1944, p. 89, 90) did recognize the presence of two units and designated the zones 5a and 5b (see figure 1).

Unit 4 is a hard to very hard sandy limestone upon which has developed a laminated caliche crust up to one inch thick. This unit is riddled with solution pipes that extend downward through this 0.6 to 1.0 foot thick limestone into the underlying unit. It is because of the crusts that have developed within the solution pipes and the sand and shells that have subsequently filled these solution pipes that it is difficult to prove here that this represents a distinct

cycle of deposition. About one-third mile eastward pockets of marine shells, not associated with solution pipes, occur between the marl and limestone of this unit and the underlying "cap rock of Unit 3. At Ortona Lock it can readily be shown that this is truly a second cycle of the Fort Thompson. Studies along the eastern shores of Lake Okeechobee in the canal excavated for construction of the levee prove the existence of marine elements in this, the second cycle of the type Fort Thompson Formation (not including the Coffee Mill Hammock unit).

Unit 5 has been completely overlooked by all previous investigators. This is not surprising inasmuch as it occurs only as pockets between the limestone of the typical Fort Thompson and the overlying unconsolidated sands and shells of the typical Coffee Mill Hammock.

There are very few places on the Caloosahatchee Canal where remnants of Unit 5 can be seen. Where we will examine it, it consists of four to twelve inches of a basal, transgressive, slightly calcareous sand with Helisoma shells overlain by zero to eight inches of sand containing a diverse extant fauna, including a few corals, in which Chione cancellata dominates. In places this appears to give way imperceptably to the overlying "Chione cancellata sand" of the typical Coffee Mill Hammock. Close study proves the existence of lenses and relics of a bed of sandy limestone zero to four inches thick.

Unit 6 is the typically fine sand in which Chione cancellata occurs almost to the exclusion of specimens of the other molluscan species. It is one and one-half to two feet thick and does not here display transgressive or regressive sub-zones at the bottom and top.

Unit 7 is separated from the underlying bed by a significant unconformity but here there is little or no evidence of subaerial exposure of the marine shell bed. The superimposed marl-to-muck sequence is the Lake Flirt Marl of Sellards (1919, p. 73-74). At the waterfall the Lake Flirt Marl generally rests directly upon the limestone of Unit 4, with none of Unit 5 and only a few patches of Unit 6 remaining. The stratigraphy of the Lake Flirt marl and the muck will be discussed in relationship to Stop 3.

* * * * *

Stop 2. The section is on the south side of the canal at a waterfall in a small drainage ditch 600 feet west of Ortona Lock, SE 1/4 of Section 27, R. 30 E., T. 42 S., Glades County. Because of recent widening of the channel, the excellent exposures that Schroeder (1954, p. 28) described have temporarily been obscured. It is noteworthy that the composite section of Schroeder included six Plio-Pleistocene marine units separated by fresh-water limestone or marl and by unconformities. These can all be seen in this area but we will concentrate our interest on the section at the waterfall and the four marine zones, Units 1, 2, 3 and 6, that can be seen here. This is

one of the few sites where the lower unit of the Caloosahatchee Formation in an unaltered condition can still be seen above water. (The other site is on the north side of the canal about one-half mile west of Stop 4, approximately three miles west of LaBelle in the south-central portion of Section 12, R. 28 E., T. 43 S., in Hendry County). Stop 8, north of the canal, will provide an opportunity to better examine the upper cycles of deposition.

Unit 1 can be seen in the pool below the waterfall. It is a calcarenite with some quartz sand. There is a rich, diverse molluscan fauna constituting up to 50% of the deposit. It is this shell bed that has attracted the attention of the collectors of Caloosahatchee fossils. Arca wagneriana, Anadara scalarina, Vasum horridum, Cypraea problematica, Strombus leidyi, and Scapella floridana plus many more the 639 species listed by Dall in the Caloosahatchee fauna can be collected here. There is a discontinuous, very sandy marl to limestone, zero to ten inches thick that caps this unit. Please note that the snail fauna in this "cap rock" also includes specimens of a terrestrial snail, Polygyra. There is an unconformity between this and the superimposed unit.

Unit 2 presents a unique occurrence of the "reef-forming" gastropod, Vermicularia recta, that grew upward from the substratum provided by the "cap rock" of Unit 1. The beds and patches of Vermicularia can be seen occurring in this stratum westward nearly to the railroad bridge. The same zone on the north bank of the canal lacks this interesting fossil. Most geologists have referred to this bed as the "Vermicularia zone". A shell hash, mostly consisting of small or broken shells, surrounds and covers the clumps of Vermicularia. It contains a richly diverse Caloosahatchee fauna. The upper marine portion of this unit is a less fossiliferous calcarenite which becomes lithified upward into a hard dense limestone six inches to eighteen inches thick that forms the rim of the waterfall. The total thickness of Unit 2 is about three feet thick.

Unit 3 rests unconformably upon the "cap rock" of Unit 2. It consists of one to two feet of calcareous sand in which 50 to 60% is shell. Most, if not all, of the molluscan species are extant. There is a very sharp lithological contrast at the unconformity between this and the overlying unit, but the regressional fresh-water limestone is missing.

Units 4 and 5 are missing.

Unit 6 consists of a sandy shell bed in which Chione cancellata dominates. It is covered by about one foot of dark mucky sand.

* * * * *

Stop 8. It is appropriate that this portion of the field trip ends at this locality where more the Plio-Pleistocene units can be seen above water at one time than that at any other site in Florida. Here DuBar (1958, p. 75) recognized five marine zones 1, 3 and 4, 6, 8 and 10. His diagrammatic section was reproduced above as figure 2.

The section presented for this stop was measured on the north bank of the Caloosahatchee Canal at the western entrance to the docking and launching basin at the Corps of Engineers Park, SE 1/4 of Section 27, T. 42 S., R. 30 E. From this site the units drop in elevation rapidly westward toward the railroad. Beyond the railroad bridge the banks are lower and the upper marine unit, the Coffee Mill Hammock, is extremely well developed. This the type section of the Coffee Mill Hammock Formation.

At this time only five marine cycles of deposition can be demonstrated with the lowest under water on this side of the canal. The units are 1, 2, 3, 4 and 6.

Unit 1 is a richly fossiliferous calcarenite; the same that can be seen at the waterfall across the canal at Stop 2. Just beneath the water one can collect specimens of a very sandy limestone, four to six inches thick, containing abundant specimens of the terrestrial snail, Polygyra (this same bed occurs four to five feet below the water level at the type Fort Thompson site in the same stratigraphic position). Fred Thompson of the Florida State Museum in Gainesville has studied specimens from this bed. Polygyra is known to have evolved rapidly and the fossils are excellent for correlation. Thompson believes the terrestrial fauna in this unit is probably Pliocene in age.

Unit 2 is the Vermicularia zone, but on this side of the canal this sessile colonial gastropod is uncommon. There is a basal portion, six to eight inches thick of arenaceous calcarenite in which the molluscan shells of the "Caloosahatchee fauna" are common. This unconsolidated to semi-consolidated deposit grades upward into a hard to very hard sandy limestone about 18 inches thick. Patches of oysters occur within the upper portion of this unit. There are a few solution pipes as well as case hardening which indicates an unconformity.

Unit 3 is largely a sand and shell bed that has been altered to a hard to very hard sandy limestone. Here and there at the basal portion there are patches of sand and shell that are relatively unconsolidated. A few fresh-water snails occur in the matrix at the top of the limestone. The total thickness is 18 to 24 inches. Solution pipes penetrating downward through this unit are common in relationship to the unconformity between this and the next superimposed marine bed. There is a thick, laminated caliche crust developed on the upper surface of the limestone.

Unit 4 at the measured section has a total thickness of 16 to 18 inches. Eastward in the park near the power line it is reduced to patches with maximum thicknesses of four to six inches. The main body of this cycle is a sand and shell bed in which Chione shells dominate but in which there is a diverse fauna including some

Turritella. There is a discontinuous, hard to very hard, sandy limestone four to six inches thick capping this unit. The case hardening of the limestone, solution pipes, and the discontinuous nature of the "cap rock" are evidences of an unconformity.

Unit 5 cannot readily be demonstrated at the present time.

Unit 6 occurs only as patches at the site of the measured section. These Chione cancellata sands thicken westward. Beyond the railroad bridge this bed is at its maximum development with a thickness of as much as four feet. Chione cancellata shells occur in great profusion. Other species are identical to those that now live in the very shallow water of the Gulf near Fort Myers.

The surficial marly to mucky sand is herein assigned to the Lake Flirt Marl.

* * * * *

Stop 3. Between Fort Thompson and Ortona Lock a shallow topographic basin exists which contained Lake Flirt before construction of the Caloosahatchee Canal. This is the type locality of the Lake Flirt Marl. At this stop we are at the maximum development of the marl and muck of the Lake Flirt which was named by Sellards (1919, p. 73-74). We shall see three cycles of deposition plus a Recent muck exposed in the south bank of the Caloosahatchee Canal, three and three-fourths to four miles west of Ortona Lock in the west central portion of Section 30, T. 42 S., R. 30 E., Glades County.

With reference to the stratigraphic section, please note that there are three distinct marl beds separated by mucks. Eastward from this site, the lower marl was eliminated by an unconformity produced through the downward scouring of channels into underlying regressive marine sand. Westward from this site the marls have been destroyed by the combined action of ground water and the associated acid mucky sand. A C^{14} date on organic material from above the lower marl had a date of $20,900 \, {}^{+1400}_{-1600}$ years. It is likely that the two upper marls date from 17,000 to 18,000 years and 11,000 to 12,500 as do similar marls in northern Florida. Additional samples from this site on the Caloosahatchee River are presently being dated. The upper muck is Recent in age; that is it is less than 7000 years old. It is not practical to separate this upper muck from the Lake Flirt sequence. Westward from the measured section the complete Lake Flirt Formation, as it will hereafter be referred, is a composite muck sequence that cannot be separated for mapping purposes.

* * * * *

Gomphothere Site. It is unfortunate that we cannot visit the "Gomphothere Site" because it was here that unequivocal evidence was obtained that the "Caloosahatchee fauna" is not Late Pleistocene in age. At this site David Webb and students of the University of Florida have collected an excellent assemblage of early Irvingtonian

(Kansan) vertebrate fossils. They were found south of Bridge 18 on the Jones Loop Road three miles southeast of Punta Gorda on the south prong of Alligator Creek, Section 26, R. 33 E., T. 41 S., Charlotte County. My measured section is presented in figure 5.

The vertebrate fossils occur in the sand just above the two beds containing a Caloosahatchee fauna. Webb will publish the results of his study. For the present he has provided the following partial faunal list:

Cuvieronius sp. (gomphothere)
Mammuthus haroldcooki (primitive mammoth)
Equus cf. scotti (horse)
Odocoileus sp. (deer)
Terropene carolina putnami (turtle)

This is one of the last known occurrences of gomphotheres. Cuvieronius was the last of this typically Pliocene proboscidean family to become extinct. The primitive nature of M. haroldcooki sets it apart from the later Pleistocene mammoths (Webb, 1966, oral communication).

The true Caloosahatchee beds have a total thickness at this locality of only five feet. A hole dug downward three feet below the then existing water level reached the upper surface of calcareous sands containing an upper Miocene assemblage of oysters, pectens, barnacles and echinoids.

The fauna in the overlying beds, but below the bone bed, is not highly diverse, but such diagnostic species as Arca wagneriana, Arca scalarina, Anadara rustica, Strombus leidyi and Cypreae problematica were collected. The assemblage in the two marine beds differs only in that there is a basal oyster biostrome in the lower Plio-Pleistocene unit and more abundant Chione shells in the upper unit. Near the top of the section there is a sand bed 16 to 18 inches thick that contains a very badly weathered assemblage of shells, mostly Chione cancellata. In many places in this area the upper Chione sand which contains no extinct species rests directly upon my second Plio-Pleistocene unit. Near Punta Gorda it can be seen resting directly upon the Tamiami Formation.

DuBar (1962, p. 7-19) has interpreted the three marine shell beds occurring in the Charlotte Harbor area as being conformable, despite the occurrence of the "cap rocks" on both of the lower shell beds (in which he also recognized the occurrence of the Caloosahatchee fauna). With the two lower units he included the upper shell bed, containing no extinct species, as the Caloosahatchee Formation. The overlying sand was assigned to the Fort Thompson. All the post-Upper Miocene sequence was relegated to the Late Pleistocene, the Sangamon or later.

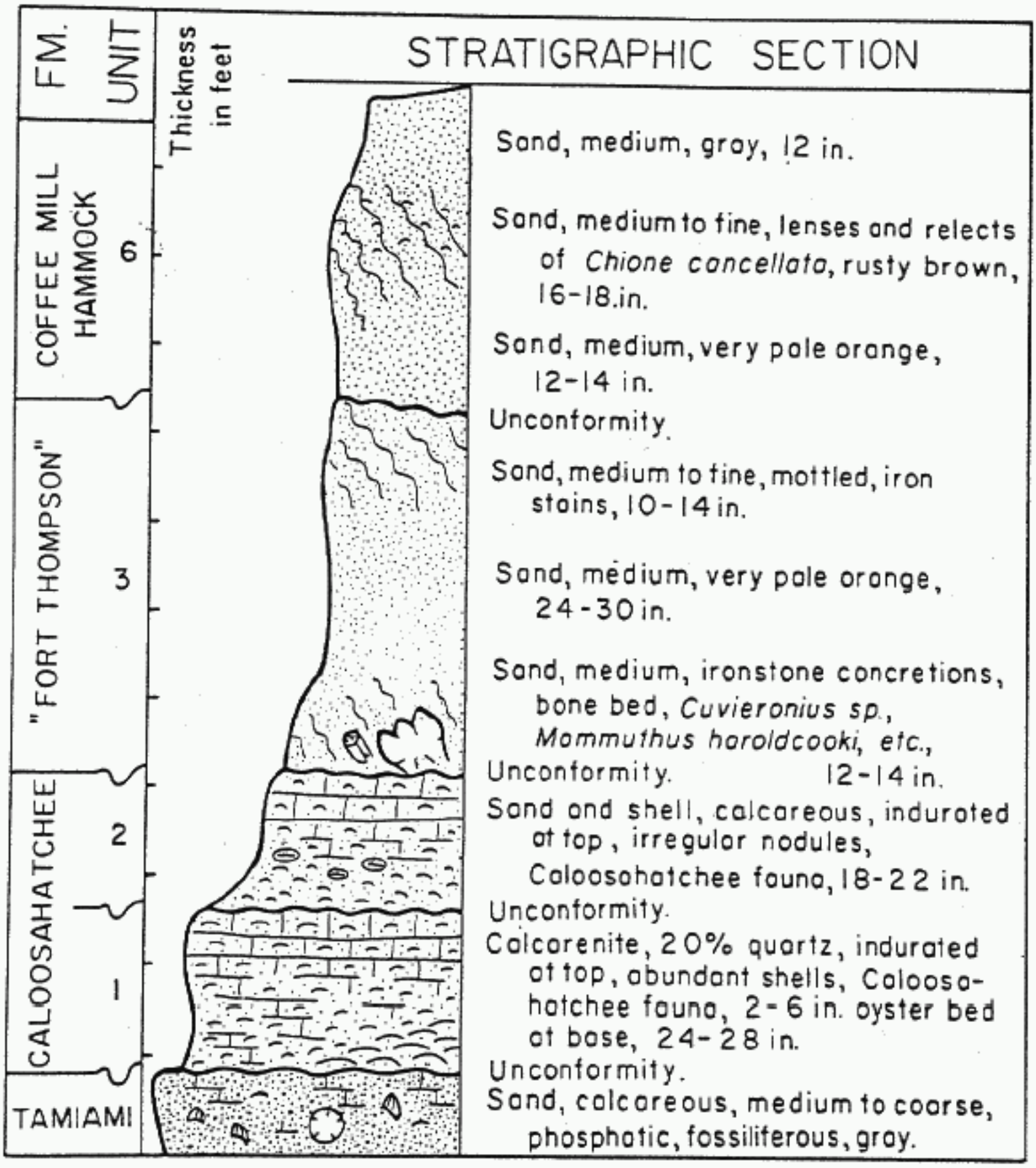


Fig. 5 Strata exposed at the gomphothere site, south prong of Alligator Creek, Section 26, R.23E., T.41S., Charlotte Co., Fla. Stratigraphic section by H.K. Brooks.

The evidence provided by the occurrence of the early Irvingtonian vertebrate fossils prove that the true Caloosahatchee fauna is pre-Kansan in age. It could be either Pliocene or Aftonian Pleistocene. The warm, tropical nature of the fauna with affinities with the molluscan marine fauna of the West Indies is probably not equivalent to the first Pleistocene glacial stage, the Nebraskan.

Formational nomenclature

The post-Upper Miocene stratigraphic sequence on the Caloosahatchee River consists of deposits representing marine transgressions separated by unconformities. There are trends within the sequence from calcarenite matrix with minor quartz sand to a quartz sand matrix. The lower two beds, Units 1 and 2, contain a diverse faunal assemblage with tropical affinities. Many of the species are indicative of off-shore conditions with water depths of 100 feet or more. There are 30 to 50% extinct species in the assemblage. The next three beds, Units 3, 4 and 5, at their maximum marine development, are calcareous sands in which Chione cancellata is the most conspicuous element of the fauna. The assemblage is diverse and there are a few extinct species, possibly 10%. They include Pyragus (Pyragisimus) scalatus (Heilprin) and Turritella subannulata Heilprin. Transgressive and regressive fresh-water deposits are found in the lower and upper parts of these marine units at many localities. The last marine unit discussed is a shallow water sand containing an abundance of shells in which Chione cancellata dominates. All the molluscan elements of this fauna are extant. Representatives of all the species now live in very shallow water in the Gulf of Mexico.

Dall (Harris and Dall, 1892, p. 144-145) hedged when he assigned the fauna of Units 3 and 4 (thus 5) to the Pliocene, sic "The upper siliceous Planorbis rock was by the author, as well as Prof.Heilprin, supposed to be Quarternary until the fossils were studied .....", but he then fails to list the occurrence of a single extinct species.

All authors subsequent to Sellards' (1919) establishment of the Fort Thompson and Coffee Mill Hammock Formations, assigned the two marine beds then recognized (Units 3 and 6) to the Pleistocene. DuBar also conforms to this assignment, but he assigns Unit 3 to both the Caloosahatchee Formation (as the Ayers Landing Member) and to the Fort Thompson Formation (the Chlamys gibbus irradians bed as the Okaloakoochee Member). At this time, I too would like to delay publishing a faunal list of all the extinct species occurring in these three units. The most significant of all species relative to correlation are the species of vertebrate fossils that have been cited above in the discussion of stratigraphic sections. The occurrence of Equus sp. at the base of Unit 3 on the Caloosahatchee

River proves only that it is Kansan or younger. Cuvieronius sp. and Mammuthus haroldcooki occur at the same stratigraphic position in Charlotte County. The true Caloosahatchee fauna in Units 1 and 2 must be pre-Kansan and the modified marine fauna occurring in Units 3, 4, and 5 must be post-Kansan and probably Yarmouth. It has now been proven by several Th^{230}/U^{238} and U^{234}/U^{238} dates that the deposits associated with the 25-foot terrace, the Pamlico, are Sangamon (Broecker and Thurber, 1965; Osmond, Carpenter, and Windom, 1965). Unit 6 is the only marine unit of Late Pleistocene age we will see on this trip. It is the Coffee Mill Hammock Formation as it was originally proposed. It is equivalent to the other formations of Florida associated with the 25-foot stand of sea level. They are the Miami Oolite, the Key Largo Limestone and the Anastasia Formation; their equivalent on the Caloosahatchee River is not the Fort Thompson Formation as herein restricted. Cooke (1945, p. 259) also correlated only the Coffee Mill Hammock to these Late Pleistocene formations of eastern Florida.

As I will use the formational names in the following discussion, the Caloosahatchee will consist only of two marine beds and their associated fresh-water marls and "cap rocks". Unit 1 will be referred to as the Fort Denaud Member and Unit 2 will be referred to as the Bee Branch Member.

The Fort Thompson will not include the fresh-water marl and/or the "cap rock" of the second marine cycle of deposition. Its base will be the unconformity above Unit 2. The Fort Thompson will include three cycles (but not the Coffee Mill Hammock) of which only the lowest, Unit 3 is usually developed. Fresh-water marls, "cap rocks", and laminated crusts reach their maximum development in these units, especially Unit 4. The upper member of the Fort Thompson Formation, Unit 5, has often been confused with the Coffee Mill Hammock. It also possesses a "cap rock", but of minor proportions. Until such time as these members are extended to other areas, it is sufficient to refer to them by number, or as the lower, middle, and upper members of the Fort Thompson Formation.

The Coffee Mill Hammock should be re-established as a formation for only Unit 6. These Chione cancellata sands are faunally and lithologically distinctive and, as Richards (1936, p. 1643) observed, never occur above 25 feet above present sea level.

The Lake Flirt Marl will herein be referred to as the Lake Flirt Formation because it contains more mucky sand than it does marl. For the present time it is convenient to refer to the three sandy marl beds, where they can be distinguished, as the Lower, Middle and Upper Marl Members. It is not practical to differentiate the Recent muck deposits in the type area.

As redefined, it is believed that the four post-Miocene formations occurring in Hendry and Glades County become meaningful and can be mapped without difficulty.

GEOCHRONOLOGY

It has been established in the discussion above that the three members of the Fort Thompson Formation are post-Kansan, probably Yarmouth, that the Coffee Mill Hammock Formation is genetically related to the Pamlico Terrace, probably Sangamon, and that the Lake Flirt Formation is Late Wisconsin age. However, the oldest marl of the Lake Flirt Formation occurs below a muck on which a C^{14} date of about 21,000 years was obtained. This lower bed is therefore older than the "classical Wisconsin". If the two upper marls do correlate with a similar sequence in north Florida, then the middle marl beds probably correlate with a Tazewell-Cary Interstad (18,000 - 17,000 years B.P.) and the upper marl bed to the Two Creeks Interstad (12,500 - 11,000 years B.P.).

At the present time considerable evidence has accumulated for a marine unit equivalent or slightly older than the lower marl of the Lake Flirt Formation. For example, there is a pure bed of Rangia cuneata, two to three feet thick, underlying Lake Okeechobee. Carbon 14 dates on this and other deposits associated with the Princess Anne Terrace (Wentworth, 1930, p. 18) are now being rechecked. There is still some uncertainty about a Mid-Wisconsin eustatic high of sea level 30,000 to 37,000 years ago as this is near the limit of the present analytical methods used in C^{14} dating. There may have been a late Sangamon stage of sea level that produced the marine deposits genetically related to the Princess Anne Terrace.

The perplexing problem is the age of the two marine units of the Caloosahatchee Formation. Are they Pliocene (as most believe them to be) as indicated by the percentage of extinct species (Dall, 1903, p. 1604, lists 639 species of which 51% are extinct whereas Olsson and Harbison, 1953, p. 10, lists 505 species of which 66% are extinct), or did the warm water marine mollusks of the rich Caloosahatchee fauna persist in eastern North America until exterminated by Kansan glaciation? Before establishing a firm correlation, the history of the origin and usage of the time-stratigraphic units must be reviewed in relation to the climatic events and to known faunal changes.

Lyell in 1833 (p. 52-54) established the major time stratigraphic divisions of the "Tertiary" which we now use in a considerably modified form. Lyell's divisions were based upon the percentage of extinct species listed in the tables of fossils prepared by M. Deshays. The Recent contained nearly 100% extant species, the Newer Pliocene contained more than 70% extant species and the Older Pliocene contained 40 to 70% extant species. To avoid confusion, Lyell later (1839) proposed the name Pleistocene as a substitute for the Newer Pliocene and restricted Pliocene to the older Pliocene. In 1840, Agassiz

presented convincing evidence that the earth had recently been subjected to continental glaciation. In studying the origin of the marine fauna of the British Iles, Forbes in 1846 used the Pleistocene for the "Glacial epoch". Twenty-seven years later, Lyell (1873) adopted Forbes' definition and reassigned the "Newer Pliocene" (the type Pleistocene) back to the Pliocene. No wonder there is confusion as to the Plio-Pleistocene boundary!

The fact that multiple glaciation occurred during the glacial epoch is now firmly established, but the magnitude and complexities of the four glacial stages and the three interglacial stages are still not completely understood or adequately considered. The first continental glaciation, the Nebraskan (Guntz), was of minor magnitude. It was the Kansan (Mindel) that was the first major climatic event in a generally cooling trend that began in the Miocene. Zeuner (1959, p. 285) concluded "The faunal break between Sicilian (the original type Pleistocene of Lyell) and the Tyrrhenian faunas (later Pleistocene terraces) is, therefore, of especial interest and highly significant ..... the terrestrial faunas of temperate Europe show a similar break, which coincides with the first intense glaciation, i.e., the Antepenultimate one (= Kansan). Land faunas of the Antepenultimate Interglacial contain Pliocene survivals and are, from a climatic point of view, somewhat inconsistent, whilst post ApGI faunas are essentially Pleistocene and climatically more sharply defined. Exactly the same applies to the marine molluscan faunas of the Mediterranean, and one is tempted to ascribe the change from Sicilian to Tyrrhenian fauna to the same cause, namely the great climatic break caused by the Antepenultimate Glaciation." Within the deposit of the Mediterranean area there are three events recorded in beds containing the Sicilian fauna; the Lower Calabrian which contains a cold water fauna, the Upper Calabrian (Emilian) which contains a fauna indicative of a mild climate and the Sicilian which contains a cold water fauna. Bos, Equus and Elephas occur in the Villafranchian, a terrestrial equivalent of the Calabrian. Because of the occurrence of these Pleistocene vertebrates, evidence of cold climate, and because this included the type of Lyell's original Pleistocene, the 18th International Geological Congress (Moore, 1949) has designated the boundary between the Calabrian and the underlying Upper Pliocene beds of Astian age as the base of the Pleistocene. The cold water elements in the Calabrian deposits now high above sea level are, no doubt, due to great tectonic uplift in the area. They do not record high interglacial eustatic stands, but rather low glacial eustatic stands of sea level.

It has long been established that the significant faunal extinction in the vertebrate faunas of North America did not occur at the Plio-Pleistocene boundary. It occurred at the onset of Kansan glaciation (Hibbard, et al, 1965, p. 509). Akers (1965, p. 742) has shown that the Discoasteridae and certain planktonic Foraminifera,

the biozone of which was previously believed not to extend beyond the Plio-Pleistocene boundary, are found in strata that are probably Aftonian in the Gulf of Mexico.

In light of the above facts, it is not improbable that a portion of the Caloosahatchee Formation (restricted) is Aftonian, first interglacial Pleistocene. Evidence for the probable age assignment of each of the two units is provided by a bathymetric analysis of the depth of water indicated by the foraminiferal faunas present and by information from other areas in Florida relative to the ages of the eustatic stands of sea level which produced the marine terraces.

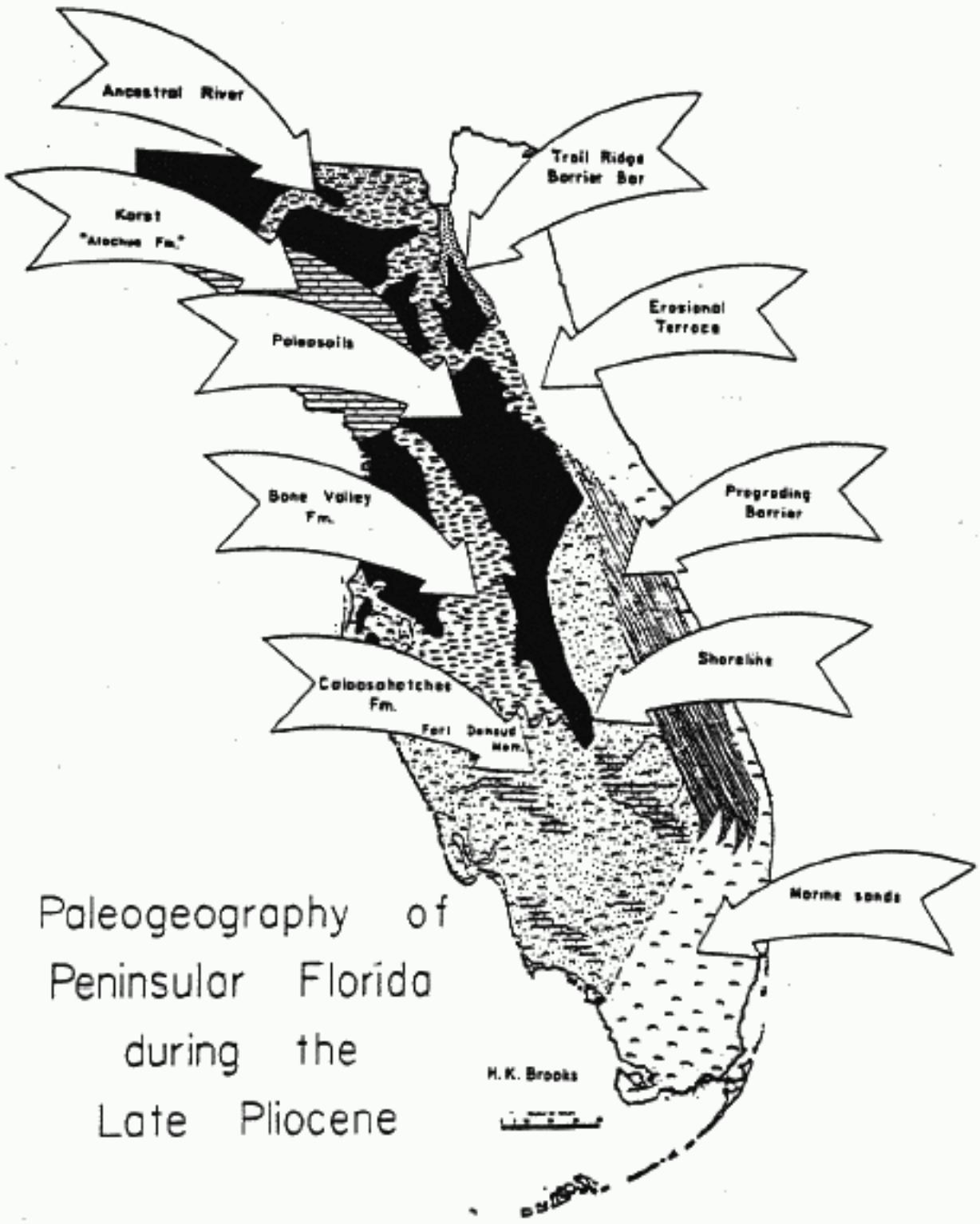
C. V. Conklin (this publication) reports that the lower bed (Unit 1) at its maximum transgression has a benthonic foraminiferal assemblage equivalent to a depth of water about 120 to 140 feet deep. The upper bed, Unit 2, has a maximum transgression depth of about 90 to 100 feet. The Okeefenokee deposits in the eroded straths of the Suwannee and Peace Rivers, contain estuarine to fluviatile deposits bearing a Late Pliocene vertebrate fauna (Brooks, 1967, p.19-20; Webb, 1967, p. 11-15). Though there are sporadic occurrences of slightly earlier Pliocene terrestrial fossils indicative of a prior lower stand of sea during the Pliocene interval of erosion, the high fluviatile and estuarine deposits of the Bone Valley Formation appear to be graded to a base level at about 140 feet. This is the best evidence that I can offer at this time that the Fort Denaud Member of the Caloosahatchee Formation is Late Pliocene age.

A marine terrace, the Wicomico, exists at an elevation of about +90 to 100 feet. At Hail, in western Alachua County, there is a spring throat deposit filled with marl containing fresh-water snails. Within this deposit are a few Chione cancellata shells. It is believed that this deposit is Pleistocene. Sea level would have had to have been 90 to 100 feet above its present level for the marine species to have encroached into the area of the ancient spring. The bathymetric data provided by Conklin from his study of the foraminifers in the Bee Branch Member of the Caloosahatchee Formation, now near sea level, suggest contemporanity with the Wicomico eustatic stand of sea level, Aftonian in age. It has been established earlier that the Coffee Mill Hammock, and its equivalents were formed at a Sangamon stand of sea level at about 25 feet above present sea level.

If the above correlations are correct, the three members of the Fort Thompson can only be equivalent to the Yarmouth interglacial stage and to the intermediate terraces, the Penholoway (70 feet) and Talbot (40 feet). Conklin's research is in support of this correlation, at least for the lower member (Unit 3).

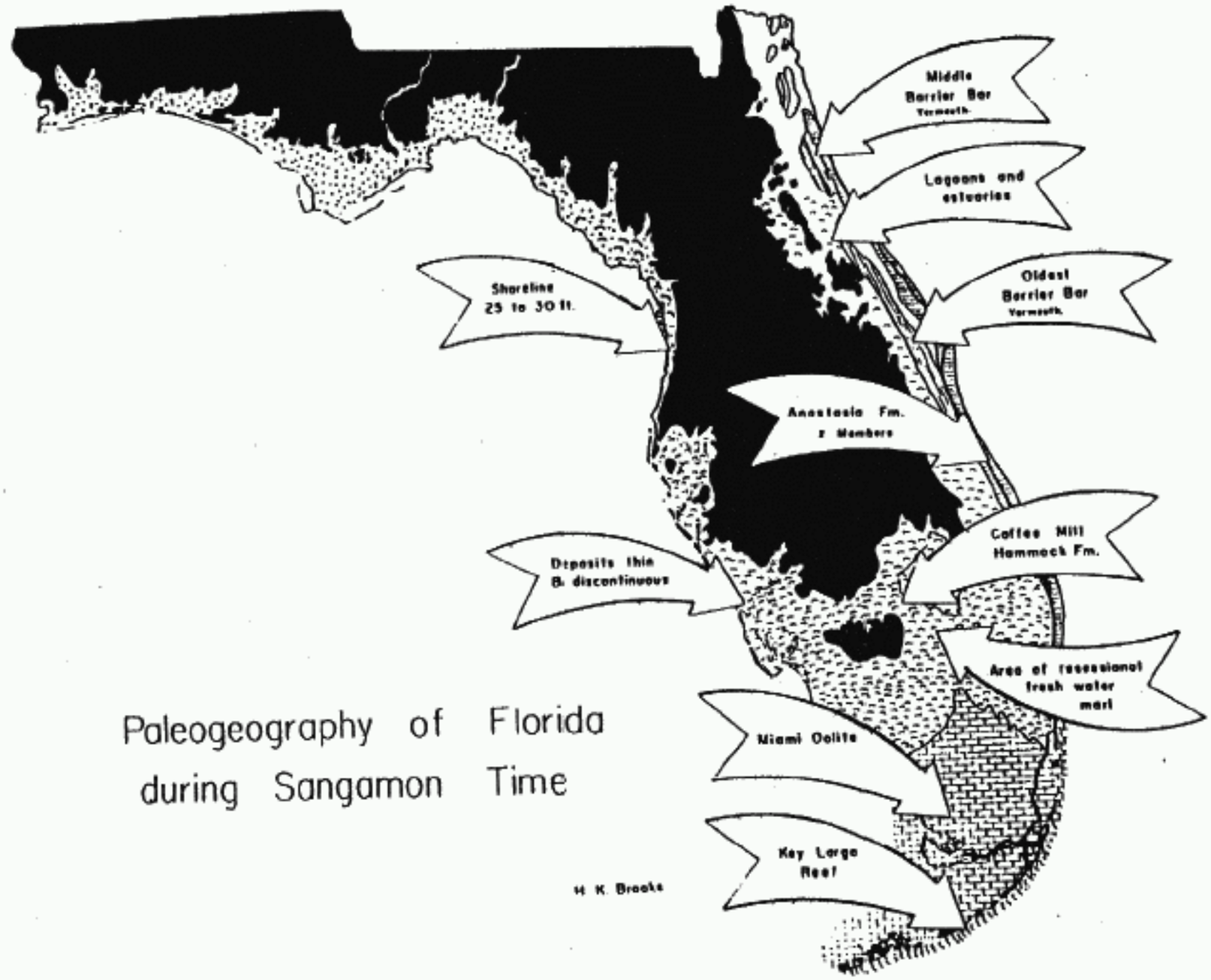
That this correlation of three cycles within one interglacial is not improbable is provided by evidence from Europe. Zeuner

Fig. 6



Paleogeography of Peninsular Florida during the Late Pliocene

Fig. 7



Paleogeography of Florida
during Sangamon Time

(1959, p. 79) has referred to the equivalents of the Yarmouth as the "Great Interglacial, which was of long duration and during which considerable erosion took place, (and it) possibly includes one or two minor glacial phases."

My interpretation of the Plio-Pleistocene stratigraphy can best be portrayed graphically by two paleogeographic maps, one for the late Pliocene, figure 6, and one for the Sangamon, figure 7.

I believe that the stratigraphic record in Florida of the Pliocene-Pleistocene events is probably unexcelled any place else in the world, but much remains to be done.

In summary, it is believed that the best correlation that can be made at this time is as follows. The Caloosahatchee Formation, restricted, is Plio-Pleistocene in age. The Fort Denaud member is Late Pliocene age and corresponds to the Okeefenokee eustatic stand of sea level at 120 - 140 feet. The Bee Branch Member is Aftonian Pleistocene and correlates with the 90 to 100 feet marine terrace, the Wicomico. The three members of the Fort Thompson all are Yarmouthian and corresponding to the intermediate terraces, Penholoway and Talbot, at 70 - 40 feet and their equivalent barrier bars in eastern peninsular Florida. The Sangamon is represented in Florida by evidence produced by the Pamlico stand of sea level at about 25 feet elevation. Deposits associated with this terrace are the Coffee Mill Hammock, Miami Oolite, Anastasia Formation and the Key Largo Limestone. A Mid-Wisconsin event is suggested which is equivalent to an 18-foot stand of sea level, the Princess Anne. The Lake Flirt Formation is Mid-Wisconsin to Recent in age.

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AN INTERPRETATION OF THE ENVIRONMENTS OF DEPOSITION OF THE CALOOSAHATCHEE, FORT THOMPSON, AND COFFEE MILL HAMMOCK FORMATIONS BASED ON THE BENTHONIC FORAMINIFERAL FAUNAL ASSEMBLAGES[1]

By

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[1] Thesis, University of Florida, 1967

INTRODUCTION

The recognition by DuBar (1958) that the strata exposed on the Caloosahatchee River consist of a succession of distinct lithotopes, and the subsequent zonation of lithosomes into mappable units by H. K. Brooks, have served as the stratigraphic basis for this study.

The type exposures of the Caloosahatchee, Fort Thompson, and Coffee Mill Hammock Formations are found along the Caloosahatchee River between Fort Denaud and Ortona Locks. It is within this area that the present study was made. Where possible, the units are subdivided into Zones A, B, and C which represent transgressive, open marine, and regressive cycles of sedimentation, respectively. For example, Unit 2 (Bee Branch Member) as developed on the south bank of the Caloosahatchee River at Fort Denaud Bridge (stop 5) is subdivided in Zones 2A, 2B, and 2C, whereas only an open marine sequence was recognized in Unit 3 ("Ayers Landing Member" of DuBar) at the time the samples were collected.

Until recently, paleoenvironmental studies have relied almost exclusively upon a descriptive taxonomic approach with emphasis upon the direct comparison of modern species with their fossil homeomorphs and isomorphs. In the last few years two new concepts have been developed which may be utilized by geologists in the reconstruction of paleoenvironments.

Bandy (1960) and Bandy and Arnal (1960) have shown that there is a striking correlation between environment and the composition, structure, and form of foraminifers. Bandy (1960) believes the principal reason for this correlation is convergent evolutionary trends which may in turn be correlated with changes in bathymetry and temperature. The significance of these convergent evolutionary trends is that shelf species of polar regions have related forms in the shelf areas of the tropics and, conversely, bathyal species in polar regions do not become shelf species in the tropics.

Walton (1964) has investigated the characteristics of foraminiferal faunas that are exclusive of specific or generic identifications. The basic ecological principle involved in Walton's study is that the variability of the environment is reflected in animal populations, regardless of their species composition. The faunal characteristics which Walton refers to are faunal variability and faunal dominance.

Faunal variability, defined in terms of the number of species or organisms that occurs in any given environment, is inversely proportional to the variability of the environment. Environmental variability is related to the depth of water and hence to the distance offshore. The number of benthonic species of foraminifers increases from generally less than 10 in the marginal marine environment, nearshore, to over 80 near the edge of the continental shelf (Walton, 1964).

Faunal dominance may be defined as the percentage occurrence of the most dominant species increases. Walton (1964, p. 216) stated that "faunal dominance varies from greater than 90% in the coastal marshes to less than 10% in the deeper waters off the edge of the continental shelf."

Geologists thus have at their disposal three methods which may be utilized in the reconstruction of paleoenvironments: a) direct comparison of modern species with their fossil homeomorphs and isomorphs, b) correlation between environment and structure, and c) nonspecific faunal characteristics, i.e. faunal variability and faunal dominance.

In the following discussion, the faunal associations within each zone as delineated by Brooks will be discussed in terms of the most dominant species within that zone and defined in terms of the next two or more most common species. Paleoecological evaluations will be based upon the concepts discussed above.

ZONE 1B (FORT DENAUD MEMBER)

Zone 1B represents the open marine sequence of the first marine zone exposed along the Caloosahatchee River. In Zone 1B, forty-six species and subspecies of Foraminiferida were identified, representing twenty-five genera and nineteen families (Conklin, 1967).

Quinqueloculina lamarckiana comprises approximately 38% of the foraminiferal population within this zone. Phleger (1960) considered Q. lamarckiana to be transitional between an open gulf and beach fauna. Along the southeastern coast of the United States, the highest frequences of Q. lamarckiana are found in scattered small patches at depths between 15 and 26 meters (Wilcoxon, 1964). Bandy (1956) reported Q. lamarckiana in low frequencies from the intermediate and bay mouth channels of Tampa Bay. In the vicinity of the Bahama Banks, Q. lamarckiana is restricted to or is more common in exposed localities along the open-ocean edge of the Banks (Illing, 1952). Many of the specimens within Zone 1B show considerable wear and abrasion and, in part, may represent a reworked fauna from Zone 1A.

Rotalia beccarii variants are equally well represented in Zone 1B, comprising approximately 27% of the foraminiferal population. As with Q. lamarckiana, R. beccarii variants are considered to be a transitional fauna between the marginal and open marine faunas (Walton, 1964). R. beccarii variants dominate the foraminiferal fauna over the innermost portions of the open continental shelf in the Gulf Coastal regions. The seaward edge of the Rotalia dominant zone closely follows the 10 fathom contour in this area (Walton, 1964). R. beccarii variants appear able to tolerate a wide range of environmental extremes, at least for periods of short duration. Bradshaw (1957) successfully cultured a population of R. beccarii tepida in the laboratory over a period of two years. During this period, experiments were conducted to determine the effects

of salinity and temperature upon the rate of growth and reproductive activity. Normal growth and reproduction resulted with salinities between 20 ppt. and 40 ppt. and temperatures between approximately 20°C and 30°C.

Elphidium gunteri constitutes less than 4% of the foraminiferal fauna in Zone 1B. E. gunteri is common over a large portion of the Gulf of Mexico, occurring in greatest abundance in less than five fathoms (Walton, 1964). E. gunteri may occur in both the open marine and lagoonal assemblages and is occasionally present in the marsh-estuary fauna.

The occurrence of Pyrgo subsphaeric is very significant. This species is very characteristic of the outer shelf fauna from depths between 60 and 180 meters.

The presence of such a typically West Indian fauna containing Amphistegina gibbosa, Planorbulina mediterranensis, Sigmomorphina undulosa, Cymbaloporetta squammosa, and Discorbis floridana indicates tropical conditions during the time represented by the deposition of these strata.

As has been stated before, there is an inverse relationship between faunal variability and faunal dominance. The relationship between these two nonspecific faunal characteristics indicates that Zone 1B represents a period of maximum transgression (See figure 1). With regard to faunal variability, Walton (1964, p. 217) states that "46% of all faunas with 41 to 50 species occurs between 10 and 20 fathoms (7% less than 10 fathoms; 29%, 20 to 50 fathoms; 18% greater than 50 fathoms)." Forty-six species and subspecies are represented in Zone 1B. The majority of these forms are characteristic of the outer portions of the transitional zone between marginal marine conditions and open marine conditions.

ZONE 1C (FORT DENAUD MEMBER)

Zone 1C represents the regressive cycle of sedimentation within the first marine zone exposed along the Caloosahatchee River. This zone comforably overlies Zone 1B and is easily recognized by the presence of the large pholadid clam, Cyrtopleura costata. Zone 1C grades upward into a series of oyster beds consisting almost entirely of large shells of Crassostrea virginica and Ostrea sculpturata. Remnants of a fresh-water marl which includes small fresh-water snails overlie the oyster beds. Thirty-four species and subspecies of Foraminiferida representing nineteen genera and fifteen families were identified in Zone 1C (Conklin, 1967).

Rotalia beccarii variants compose more than 45% of the foraminiferal fauna within this zone. As has been previously mentioned, members of the genus, Rotalia, can tolerate a wide range of environmental extremes. Their domination of the fauna indicates an approach to marginal marine conditions.

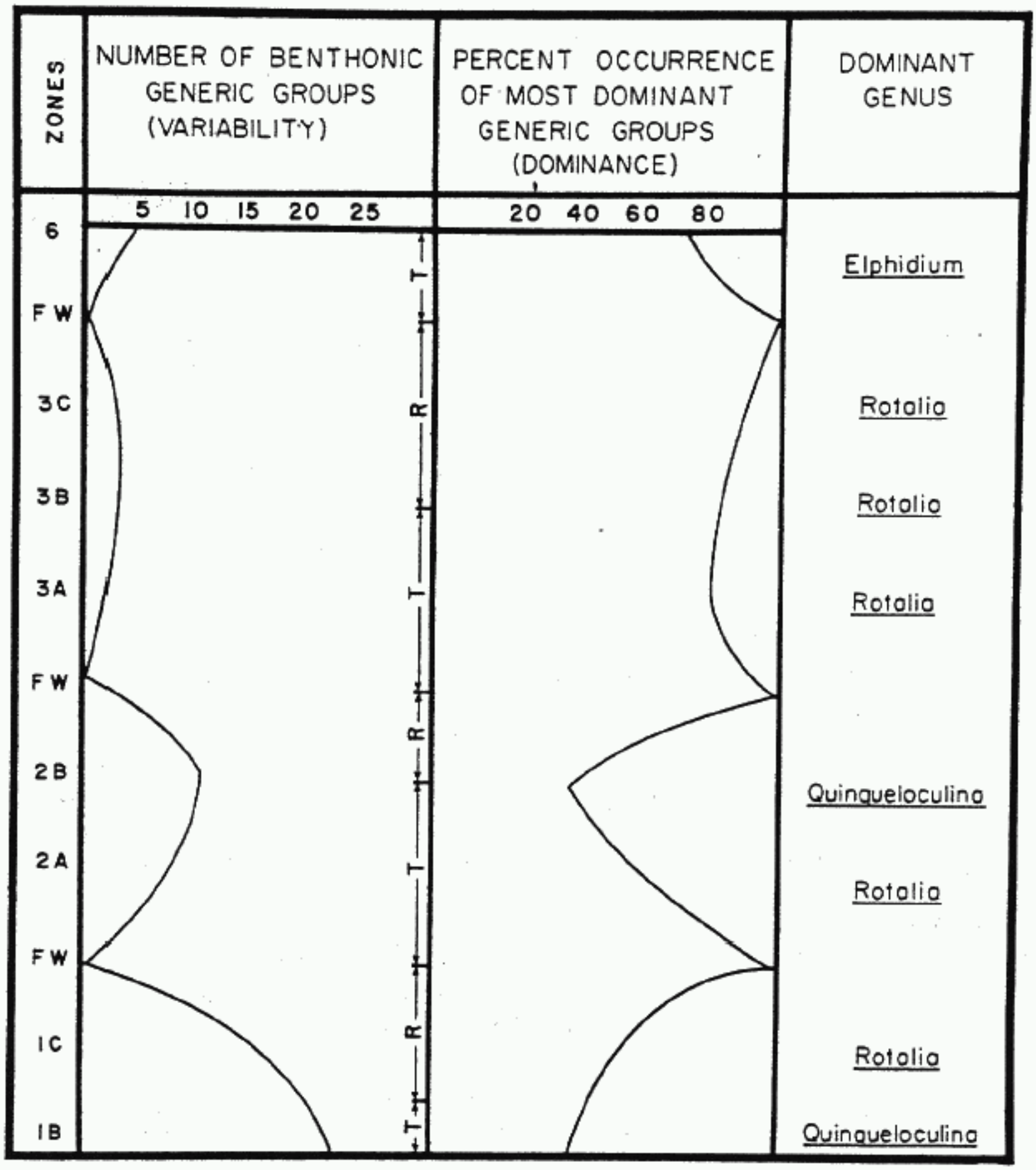

Fig. 1. Variability - Dominance Log

R- regression, T- transgression, F W- fresh water

The Miliolidae are well represented in this zone by the species Quinqueloculina lamarckiana, which comprises approximately 25% of the population. It is interesting to note the relationship between Q. lamarckiana and R. beccarii variants in Zones 1B and 1C. In Zone 1B, Q. lamarckiana occurs in higher frequencies than do R. beccarii variants. In Zone 1C, the inverse of this is true, indicating an approach to marginal marine conditions. Specimens of Triloculina fichteliana, although only present in low frequencies, are significant. Hedberg (1934, p. 475) stated that "Quinqueloculina fusca ..... is commonly a brackish to fresh water species. It may live in water of less than one-thirtieth the salinity of normal sea water and evidently prefers brackish water to marine environment." T. fichteliana has been reported by Cushman (1922) from the shallow brackish waters at Runaway Bay on the north coast of Jamaica.

Elphidium gunteri comprises approximately 9% of the foraminiferal fauna. E. gunteri occurs in greatest abundance in water shallower than 5 fathoms (Walton, 1964).

As in Zone 1B, the presence of a typical West Indian fauna, i.e., Planorbulina mediterranensis, Amphistegina gibbosa, Cornuspira planorbis, Vertebralina cassis, and various species of Discorbis, indicates tropical conditions during the deposition of these strata.

Walton (1964, p. 217) stated that "60% of all faunas with 21 to 40 species occurs between 10 and 20 fathoms (25%, less than 10 fathoms; 15%, 20 to 50 fathoms)." Thirty-four species and subspecies are represented in Zone 1C.

The faunal association and faunal variability indicate that Zone 1C represents a period of regression culminating in the deposition of a fresh-water marl. The water depth, at a maximum, was probably no greater than 20 fathoms.

ZONE 2A (BEE BRANCH MEMBER)

Zone 2A unconformably overlies Zone 1C. Locally large coral heads, Siderastrea dalli, occur along the base of the zone. Twenty-five species and subspecies of Foraminiferida representing thirteen genera and ten families were identified in this zone (Conklin, 1967).

Rotalia beccarii variants comprise 62% of the foraminiferal fauna within Zone 2A. According to Walton (1964, p. 217), "100% of all faunas whose dominant species constitutes over 35% of the entire fauna occurs shallower than 10 fathoms (20% occurs between 10 and 20 fathoms)." Presently along the Florida Gulf Coast, the Rotalia dominant zone lies between the 5 and 10 fathom depth contour. This zone is bounded faunally on the shoreward side by the Ammobaculites and the Elphidium dominant zones and on the seaward side by the Nonionella dominant zone in non-calcareous areas (Walton, 1964). In calcareous areas, various species of Miliolidae compose the dominant zone seaward of the Rotalia zone.

The high frequency of occurrence of Elphidium gunteri (29%), and the correspondingly low frequency of occurrence of Quinqueloculina lamarckiana (7%), indicate that the water was shallower than 10 fathoms.

With regard to the faunal variability within this zone, Walton (1964, p. 217) states that "80% of all faunas with 21 to 30 species occurs in water shallower than 10 fathoms (20% occurs between 10 and 20 fathoms)."

ZONE 2B (BEE BRANCH MEMBER)

Zone 2B conformably overlies Zone 2A and represents the open marine cycle of sedimentation within the second marine zone. Twenty-eight species and subspecies of Foraminiferida representing twelve genera and nine families were present in the fauna (Conklin, 1967).

As in the open marine sequence in Zone 1B, the Miliolidae, represented principally by the species Quinqueloculina lamarckiana, dominate the foraminiferal fauna. Rotalia beccarii variants and Elphidium gunteri each constitute approximately 29% of the population. The high frequencies of Q. lamarckiana, R. beccarii variants, and Elphidium gunteri, each diagnostic of a faunal depth zone, are very significant. During the time represented by the deposition of the strata in Zone 2B, the depth of the water varied between the shoreward side of the Rotalia dominant zone, the Elphidium zone (1-5 fathoms), and the seaward side of the Rotalia dominant zone, the Miliolidae zone (10 fathoms).

The faunal variability within Zone 2B indicates that the water was shallower than 20 fathoms. Walton (1964, p. 217) states that "100% of all faunas with less than 30 species occurs in water shallower than 20 fathoms."

A tropical depositional environment is indicated by the presence of a warm-water fauna, i.e., Pyrulina albatrossi, Amphistegina gibbosa, Textularia floridana, and various species of Discorbis.

ZONE 3(4?, 5?) (FORT THOMPSON FORMATION)

The foraminiferal population within the Fort Thompson Formation dictates that it be treated ecologically as one unit without the customary subdivision into a transgressive, open marine, and regressive cycle of sedimentation. Eight species and subspecies of Foraminiferida representing three genera and two families were identified within this zone (Conklin, 1967).

Rotalia beccarii variants comprise approximately 84% of the total foraminiferal fauna. The almost complete domination of the fauna by the genus Rotalia indicates that the Fort Thompson Formation was

deposited in a near-shore environment. Along the Florida Gulf Coast the Rotalia dominant zone lies between the 5 and 10 fathom depth contour.

The genus Elphidium represented by E. fimbriatulum, E. incertum, E. sagrum, and E. poeyanum comprises approximately 15% of the fauna. Bandy (1956) reported E. poeyanum as one of the most dominant species of benthonic Foraminiferida in the 8 to 40 foot faunal zone.

Walton (1964, p. 217) states that "100% of all faunas with less than 20 species occurs in water shallower than 10 fathoms" and "100% of all faunas whose dominant species constitutes over 35% of the entire fauna occurs shallower than 10 fathoms."

ZONE 6 (COFFEE MILL HAMMOCK FORMATION)

Zone 6 is equivalent to the Coffee Mill Hammock marl of Sellards (Sellards, 1919). Twelve species and subspecies of Foraminiferida representing five genera and five families were present in the fauna (Conklin, 1967).

The genus Elphidium represented by the species E. fimbriatulum, E. incertum, E. gunteri, E. poeyanum, and E. sagrum comprises approximately 60% of the foraminiferal fauna. Rotalia beccarii variants comprise approximately 20% of the fauna. Based upon their study of the bay fauna of southwest Texas, Phleger and Parker (1953, p. 17) stated that "Elphidium gunteri and Rotalia beccarii variants A and B may be open Gulf species which have invaded the bay environments, and may be at high frequencies in river and marsh facies as well." Walton (1964, p. 159) remarks that "although species of Elphidium are common over a large portion of the northeastern Gulf of Mexico, the zone of greatest abundance is usually shallower than 5 fathoms." The Elphidium dominant zone is bounded faunally on the seaward side by the Rotalia dominant zone.

DuBar (1958, p. 127) concluded from a study of the mollusk assemblages that "the type Coffee Mill Hammock marl was formed in the shallow protected waters of a high-salinity bay or in an inlet leading to a bay."

Both the faunal variability and the faunal dominance indicate a depth of water considerably less than 10 fathoms during the time represented by the Coffee Mill Hammock Formation.

SUMMARY AND CONCLUSIONS

Oscillatory eustatic changes in sea level are recorded in the Plio-Pleistocene strata exposed along the Caloosahatchee River by a succession of foraminiferal faunal assemblages, each diagnostic of a distinct depositional environment.

STRATIGRAPHIC UNIT		UNIT	MAXIMUM DEPTH IN FATHOMS	TEMPERATURE	SALINITY	ENVIRONMENT OF DEPOSITION
COFFEE MILL HAMMOCK FORMATION		6	Less than 5	Tropical to sub-tropical	Variable	Marginal marine
		unconformity				
FORT THOMPSON FORMATION		3	5-10	Tropical to sub-tropical	Normal marine	Shallow open marine
		unconformity				
CALOOSAHATCHEE FM.	BEE BRANCH MEMBER	2B	10-15	Tropical	Normal marine	Open marine
		2A	5-10	Tropical		Shallow open marine
		unconformity				
	FORT DENAUD MEMBER	1C	10-15	Tropical	Normal marine	Open marine
		1B	15-20	Tropical		

Figure 2. Environmental Evaluation Caloosahatchee, Fort Thompson, and Coffee Mill Hammock Formations

The maximum transgression occurred during the time represented by marine Zone 1B (Fort Denaud Member). A regressive phase of sedimentation followed, culminating in the deposition of a fresh-water marl. A return to open marine conditions is indicated in Zone 2B (Bee Branch Member), where a foraminiferal assemblage quite similar to Zone 1B is present. In both Zones 1B and 2B the family Miliolidae, represented by the species Quinqueloculina lamarckiana, dominates the fauna. The dominant species within Zone 3 (Fort Thompson Formation) is Rotalia beccarii variants indicating that the maximum depth of water was considerably less than that attained within Zones 1B and 2B. Zone 6 (Coffee Mill Hammock Formation) represents the last marine sequence exposed along the Caloosahatchee River in the study area. It unconformably overlies the marine zones within the Fort Thompson Formation. The species, Elphidium gunteri, dominates the fauna within this zone, indicating that the water was very shallow during the time represented by the deposition of this strata.

Many attempts have been made to establish the relationship between the principal interglacial stages of the Pleistocene and the Caloosahatchee and Fort Thompson Formations (Dall and Harris, 1892: Cooke, et al., 1943; DuBar, 1958).

Alt and Brooks (1965) have shown that high eustatic sea level stands date back to late Miocene and Pliocene time. Brooks (1966) revised this earlier paper and assigned the following ages and elevations to the eustatic sea level stands.

25 foot stand	3rd interglacial (Sangamon)
60± foot stand.....	2nd interglacial (Yarmouth)
90 foot stand	1st interglacial (Aftonian)
120 foot stand	Pliocene

On this basis, the Fort Denaud Member of the Caloosahatchee Formation can be correlated with the Pliocene stand of sea level and the Bee Branch Member, Fort Thompson Formation ("Ayers Landing Member") and Coffee Mill Hammock Formation can be correlated with the Aftonian, Yarmouthian, and Sangamonian interglacial stages, respectively.

The depositional environments of the four marine units as interpreted from the benthonic foraminiferal assemblages are summarized in figure 2.

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STRATIGRAPHY AND PALEONTOLOGY OF THE LATE NEOGENE STRATA OF THE CALOOSAHATCHEE RIVER AREA OF SOUTHERN FLORIDA[1]

by

JULES R. DuBAR

[1]Excerpt from Florida Geological Survey Bulletin No. 40, 1958, p. 136-146.

A G E R E L A T I O N S H I P S

AGE OF THE CALOOSAHATACHEE MARL

General Discussion

The Caloosahatchee marl generally has been considered to be Pliocene in age since it was first studied by Heilprin in 1886. This age assignment has been based primarily on the nature of the molluscan faunal assemblage and secondarily on the assumption that the formation is unconformably overlain by beds of early Pleistocene age.

Vernon (1952, p. 59-60) correlated an upper Caloosahatchee freshwater bed, exposed at Fort Thompson, with the Nebraskan glacial stage. He tentatively placed the lower marine beds at Fort Thompson in the lower Pleistocene. Recent studies by the writer support Vernon's suggestion and necessitate rejection of the traditional Pliocene age classification of the Caloosahatchee marl. The most compelling evidence of Pleistocene ages of the Caloosahatchee beds is derived from the vertebrate fauna, but the invertebrate fauna, and paleogeographic and facies relationships also tend to support this classification.

Evidence of the Invertebrate Fauna

The molluscan fauna of the Caloosahatchee marl is distinctive, containing many species not known from any other deposits. Dall (1903, p. 1604-1605) recognized 639 species of mollusks as occurring in the formation, of which 314 (49 per cent) are also Recent. The St. Petersburg, Florida area has yielded 505 Caloosahatchee species (Olsson and Harbison, 1953, p. 10), of which 33.8 per cent are Recent. From the type locality of the Caloosahatchee the writer has identified 341 species, of which 39.5 per cent occur in the Recent fauna. Thus, on the basis of percentage of the extinct molluscan species alone, the Caloosahatchee marl seems to have been correctly assigned to the Pliocene. Actually, the differences between many Caloosahatchee species and their present day descendants are slight and it is doubtful if the differences are of more than subspecific value. Some species thought to be extinct probably survive, having migrated to more southern latitudes where they have not yet been observed. In addition, none of the molluscan species is elsewhere restricted to deposits of undoubted Pliocene age.

Foraminifera are relatively abundant in the Caloosahatchee marl but studies by Cole (1931) and Cushman and Ponton (1932) fail to demonstrate important differences between late Miocene, Caloosahatchee, late Pleistocene and Recent assemblages. A more recent study of the foraminifers has led Puri to assign at least the upper Caloosahatchee beds to the Pleistocene.

Wells considered several species of corals in the upper Caloosahatchee beds to be of late Pliocene age or younger. Two of the identified coral species are restricted to the Caloosahatchee marl and on this basis are judged by Wells to be Pliocene in age. Two species of corals are restricted to the Pleistocene and the Recent, one species ranges from Caloosahatchee

time to Recent, and one species ranged from Miocene to Recent. If the two species restricted to the Caloosahatchee marl are omitted from consideration, then it seems that the coral fauna represents a Pleistocene rather than Pliocene age.

No attempt was made to analyze in detail the echinoid fauna; however, the largest and most conspicuous species in the Bee Branch member is Clypeaster rosaceus which also occurs in the Recent fauna.

The invertebrate fauna alone does not seem to offer a solution to the problem of the age of the Caloosahatchee marl. Most species, however, are known to occur in late Pleistocene or Recent deposits and those restricted to the Caloosahatchee formation offer conclusive evidence neither for nor against a Pleistocene age.

Evidence of the Vertebrate Fauna

The vertebrate assemblage collected by the writer from the Caloosahatchee marl presents convincing evidence of the Pleistocene age of the formation. There is no doubt that the bones were in place and most of them were covered by several feet of marl and limestone, bearing many of the most typical Caloosahatchee molluscan species. Most of the fossil vertebrates were collected from the upper shell bed but a few were found in the Bee Branch member and Cyrtopleura costata faunizone. The vertebrate species collected by the writer from the Caloosahatchee marl of the type region are listed below:

Cyrtopleura costata Faunizone

Testudo sellardsi

Bee Branch Member

Cetacean remains
Equus (Equus) cf. E. (E.) leidyi

Upper Shell Bed

Trachemys sculpta
Testudo sellardsi
?Machrochelys temminki
Alligator mississippiensis
Crocodilian remains
Tanupolama sp.
Equus (Equus) cf.E. (E.) leidyi

Undifferentiated Beds

?Holmesina septentrionalis
Odocoileus sp.

None of the Caloosahatchee vertebrate species are known to be restricted elsewhere to Pliocene deposits and, in fact, most are known only from

the Pleistocene. According to Savage and Winters, ". . . one of the species of turtles is still living in Florida, and the other two are found only in Pleistocene and early Recent deposits. The equid teeth are indistinguishable from those of the so-called Equus leidyi, the medium-sized, late Pleistocene and early Recent Florida horse. The Chlamytheriinae seem to be restricted to the Pleistocene of North America. The evidence is strongly in favor of a post-Blancan age for at least the upper part of the Caloosahatchee formation, and it possibly dates from one of the inter-glacial stages when the sea level stood some 15 to 20 feet higher than at the present."

Winters has found no record of either Equus (Equus) or a chlamytherid from the Blancan faunas. The earliest record of Equus (Equus) known to him is from late Kansan deposits of the Nebraska-Kansas area and there is no known pre-Sangamonian record of the chlamytherid from North America. The giant armadillo ?Holmesina septentrionalis, has been recorded from 18 to 20 localities in Texas, Florida, Oklahoma, and Mexico, and all but three, which occur in reworked stream deposits, present strong evidence of being Sangamonian or later in age.

The cetacean remains of the Bee Branch member were examind by Dr. Reminton Kellogg, who says, "Of all the known occurrences of comparable elements, the axis resembles most closely the Diestien-Lower Pliocene Plesiocetus dubius of the Antwerp basin, Belgium..... The Mysticeti or whalebone whales of the Pleistocene so far as known are not strongly differentiated from those of the Recent period. This axis was not ankylosed to the atlas and differs in other respects from the Recent species of whalebone whales. On this evidence alone I would not be inclined to suggest a Pliocene age. Pliocene genera may have survivied in the early Pleistocene period. As yet this assumption has not been confirmed by recognizable fossel remains.

The Caloosahatchee fish and reptile fossils are considered by Auffenberg definitely to represent a Pleistocene age.

The vertebrate species, accordingly, present strong evidence of a post-Kansan age for the Caloosahatchee beds and the presence of the giant armadillo ?Holmesina septentrionalis points to a Sangamonian or later age.

Relationship to Pleistocene Marine Shorelines

The Caloosahatchee marl contains a semitropical or tropical molluscan fauna which probably lived during a warm interglacial stage. If, as the vertebrate fauna suggests, the formation is no older than Kansan, then it must be asigned either to the Yarmouthian or Sangamonian interglacial stage. The inland limits of known Caloosahatchee deposits, as shown by Cooke's geologic map of Florida (1945), correspond closely to the Wicomico and Okefenokee shorelines as distinguished by MacNeil (1949) but appear to coincide most closely with the Wicomico at an elevation approximately 100 feet above present sea level. The Wicomico terrace is regarded as Sangamonian in age (MacNeil, 1949, p.99; Cooke, 1945, p. 17; Vernon, 1951, p. 21-27), and the Okefenokee is classified as Yarmouthian by MacNeil (1949, p. 99), although possibly it is older. Winters believes that the Okefenokee shoreline is Aftonian. This is based on the occurrence near Brewster, Florida, of Blancan vertebrates just below the 150-foot contour.

Paleoecological studies indicate that the Bee Branch member was deposited in an offshore continental shelf environment where the water depth probably exceeded 15 fathoms. The upper shell bed was probably deposited closer to shore in shallower water. If the water depth of the Caloosahatchee sea was approximately 90 to 100 feet where the Bee Branch limestone was being deposited, the corresponding shoreline should have closely approximated the level and outline of the Wicomico shoreline. As shown by MacNeil's map (1949), the distance is approximately 30 miles from the Caloosahatchee type area to the nearest Wicomico shore. All of the overlying and underlying Caloosahatchee beds appear to have been deposited in shallower water than strata of the Bee Branch member, and therefore traces of earlier Caloosahatchee shorelines have been destroyed or buried. The Penholoway shoreline probably was formed during the recession of the Caloosahatchee sea.

Correlation With Other Units

Several Florida formations have been considered to be facies of the Caloosahatchee marl, representing varied deposits of Pliocene age. Among these is the Tamiami formation now regarded as late Miocene in age and known to be unconformably overlain by the Caloosahatchee marl. Other so-called facies or correlatives include the Bone Valley, Charlton, Croatan, Waccamaw, and Citronelle formations. The Bone Valley formation was considered by Cooke (1945, p. 18) to represent an estuarine facies of the Caloosahatchee, although the formations are not known to inter-finger. The vertebrate fossils of the Bone Valley beds include a mixture of Pliocene and Miocene species, none of which is known from the Caloosahatchee marl. With little doubt the Bone Valley beds are considerably older than the Caloosahatchee formation and they possibly represent an estuarine facies of the Tamiami formation (Miocene).

Cooke (1945, p. 227-229) and Cole (1944, p. 23) seem correctly to have correlated the Charlton formation of northeastern Florida with the Caloosahatchee marl, although the Charlton could represent a slightly younger deposit, judging from its molluscan assemblage. Cooke considers the Charlton to be an estuarine facies of the Caloosahatchee marl.

The red sands of central Florida have been assigned, in the past, to the Citronelle (Cooke and Mossom, 1929) and Cooke (1945, p. 231) considered these beds to be a Pliocene, near-shore facies of the Caloosahatchee marl. No interfingering of the two formations has ever been observed.

Recent work by Bishop (1956) shows that the so-called Citronelle red sands of central Florida are actually the upper part of the Hawthorn formation (middle Miocene). This observation is confirmed by the fact that Tamiami beds (upper Miocene) overlap the red sands in the southern part of Highlands County.

The Waccamaw and Croatan formations of North Carolina and South Carolina are correlated by Cooke, Gardner, and Woodring (1943) with the Caloosahatchee marl of Florida. The mollsucan assemblages of the Caloosahatchee marl in Putnam and Volusia counties appear intermediate between that of the type Caloosahatchee and the Waccamaw deposits. Faunal differences between the Caloosahatchee marl and the Waccamaw and Croatan beds can be explained at least partly by differences in latitude and corresponding temperature differences. If the Waccamaw and Croatan formations are indeed correlatives of the Caloosahatchee, they too will have to be reclassified as Pleistocene deposits.

Conclusions

On the basis of faunal, paleogeographic, and paleoecological evidence, the Caloosahatchee marl seems to be Kansan or younger in age. The presence in the upper Caloosahatchee beds of Equus (Equus) cf. E. (E.) leidyi and ?Holmesina septentrionalis suggests that the formation may be Sangamonian or younger. This suggestion is substantiated by the fact that the known distribution of the Caloosahatchee marl and paleoecological evidence indicates that the formation should be correlated with the Wicomico (Sangamonian) shoreline.

AGE OF THE FORT THOMPSON FORMATION

Evidence of the Fauna

Almost all species of the Fort Thompson formation are represented in the Recent fauna. The marine molluscan fauna indicates at least as warm a climate as that of today and, therefore, the formation probably was deposited during an interglacial stage.

The vertebrate fauna of the Fort Thompson formation is sparse, but according to Winters seems to be indistinguishable from the early Recent faunas of Vero Beach, Melbourne, and Seminole Field in Florida. A list of the vertebrate species collected from the Fort Thompson formation is given on page 135. The fossils point strongly to a late Pleistocene age of the Fort Thompson formation and suggest that the deposits were formed during a late Pleistocene interglacial stage.

Relationship to the Glacial and Interglacial Stages

The alternating fresh-water and marine beds of the Fort Thompson formation were correlated by Parker and Cooke (1944, p. 89, 94-96) and by Cooke (1945, p. 250-252) with interglacial and glacial stages of the Pleistocene. Parker and Cooke recognized two fresh-water beds and three marine beds in the Fort Thompson formation at the type locality. The lower fresh-water unit was classified by them as Kansan and the upper as Illinoian. The lowest marine stratum was placed in the Aftonian glacial stage, the middle marine unit in the Yarmouthian, and the upper (Coffee Mill Hammock marl) in the Sangamonian.

If it is conceded that the Caloosahatchee marl is Yarmouthian or younger then Parker and Cooke's classification of the Fort Thompson beds must be modified. In addition, the marine marl thought by Parker and Cooke to represent the base of the Fort Thompson at the type locality is considered by the writer to be an erosional remnant of the upper Caloosahatchee shell bed. Thus the lowest Fort Thompson bed in the type section is a fresh-water marl.

The Fort Thompson beds exposed in the vicinity of the type locality are thin and discontinuous. The Chlamys bed (middle marine unit of Parker and Cooke) occurs as thin tongues that locally divide the fresh-water marl into upper and lower units. Where the Chlamys bed is absent, the upper and lower fresh-water units coalesce to form a single bed, which unconformably overlies the Caloosahatchee marl and is overlain in turn by the Coffee Mill Hammock marl.

The entire Fort Thompson formation was deposited during a single interglacial stage and the alternation of fresh-water and marine beds represents minor fluctuations of sea level under near-shore conditions.

The maximum depth of water in which marine shell marls of the Fort Thompson formation were deposited could not have been more than five fathoms. In addition, the beds appear to have been deposited in an inlet or bay environment near to shore. Therefore, if one of the Pleistocene marine shorelines of southern Florida corresponds to these deposits, it must be one which now stands less than 50 feet above sea level. The Pamlico shoreline, of course, is well developed at about 25 feet above sea level, is located within a few miles of the Caloosahatchee River areas, and otherwise corresponds rather closely with the known distribution of the Fort Thompson beds. Richards (1936, p. 1644; 1938, p. 1284-1287) correlates the Fort Thompson formation with the Pamlico of North Carolina, but apparently does not give consideration to the quartz sands which overlie the Fort Thompson beds and which are regarded by most workers as Pamlico. No marine Pleistocene deposits in Florida are recognized by Richards higher than 25 feet above sea level and he places all Pleistocene deposits located below this elevation in the Pamlico formation (1938, p. 1284). These "Pamlico beds" are considered by Richards to have been deposited during the last major interglacial stage.

Conclusions

The Fort Thompson formation is late Pleistocene in age. If the Caloosahatchee is Sangamonian, then the Fort Thompson beds were deposited during a Wisconsin glacial recession when the sea stood approximately 25 feet higher than at present. The alternation of fresh-water and marine beds represents minor fluctuations in the sea level during a single interglacial stage.

AGE OF THE PAMLICO FORMATION

The Pamlico sands of southern Florida are undoubtedly of late Pleistocene age. Winters believes that the Pamlico overlies and intertongues with Fort Thompson beds, although evidence of such intertonguing of these formations was not observed by the writer. At almost all localities along the Caloosahatchee where the Fort Thompson formation is present it is overlain by quartz sands of the Pamlico formation.

No marine fossils were observed in the Pamlico sands, although the formation does contain scattered terrestrial vertebrate remains in the Caloosahatchee River area. All traces of invertebrate shells possibly have been leached by ground-water solution. Inasmuch as the Pamlico sands form a thin blanket over much of southern Florida, it is difficult to imagine a marine environment in which the deposit could have formed. The sands are unconsolidated and are noncalcareous, similar to some littoral sands forming today along the Florida coast and may have formed during recession of the Fort Thompson sea.

S U M M A R Y

1. A stratigraphical and paleoecological study of Neogene strata of southwestern Florida is given. The report is primarily concerned with out-

crops and subsurface auger hole samples along the Caloosahatchee River between Ortona Locks and Ft. Denaud. Some data are derived from other areas such as Shell and Alligator creeks in Charlotte County.

2. The formations studied in greatest detail are the Caloosahatchee marl and Fort Thompson formation. The Tamiami, Pamlico, and Lake Flirt marls are considered to a lesser extent.

3. Approximately 2,000 pounds of sediments were collected and examined. Insoluble residue analyses were made of more than 60 samples. Sixty-five samples of marl, one cubic foot or less in volume, collectively yielded more than 200,000 specimens of mollusks and numerous specimens of other organisms including corals, echinoids, barnacles, ostracods, foraminifers, and vertebrates. The following number of invertebrate species have been identified: 163 pelecypods, 272 gastropods, two echinoids, and six corals. No attempt was made to study the microfauna.

4. The Caloosahatchee marl is classified as late Pleistocene in age. Analysis of vertebrates and paleoecological data suggests that the formation may have been deposited during the Sangamonian interglacial period and that the accumulation of Caloosahatchee sediments probably should be correlated, at least in part, with making of the Wicomico shoreline (approximately 100 feet above sea level).

5. The Fort Thompson formation is classified as Wisconsinan in age, and it is suggested that the formation may have been deposited during a temporary recession of the Wisconsinan glaciers. Paleogeographical and paleoecological studies strongly indicate that deposition of the formation should be correlated at least in part with the making of the Pamlico shoreline (approximately 25 feet above sea level). The Pamlico sands may represent, in part, littoral deposits from the receding Fort Thompson sea.

6. In southern Florida the Caloosahatchee marl rests unconformably on the heavily dissected surface of the Tamiami formation and is unconformably overlain by the Fort Thompson formation. Between Ortona Locks and Lake Hicpochee the formation reaches a maximum thickness in excess of 60 feet.

7. The Caloosahatchee marl of the type area is subdivided into several members including, from the base upward, the Cyrtopleura costata faunizone, oyster biostrome, brackish-water marl, Bee Branch limestone, and the upper shell bed. At Ortona Locks several additional members are recognized including a lower sandstone, Vermicularia faunizone, upper marine limestone, and a Panope faunizone. Laterally, the most persistent and easily traced member is the Bee Branch limestone which represents deposition in a relatively deep-water, offshore, continental shelf environment. The other members appear to have been deposited in shallow water either on the continental shelf or in a bay environment.

8. At its type locality the Fort Thompson formation is comprised of three fresh-water and two marine members. The uppermost marine member is the Coffee Mill Hammock marl which probably was deposited in a bay or inlet. The lower marine marl occurs as a thin tongue which separates the fresh-water marl into lower and upper units. The entire sequence represents deposition along a

fluctuating shoreline. Elsewhere along the river one or more of the above mentioned members are absent. Subsurface studies show that in the Caloosahatchee River area the maximum thickness of the formation is probably not more than 35 feet and generally is much less.

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A PALEOECOLOGICAL INTERPRETATION OF THE CALOOSAHATCHEE FORMATION USING STABLE ISOTOPE METHODS[1]

by

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Oxygen isotope measurements were made on four pelecypod species collected from the classic Caloosahatchee Formation outcrops along the Caloosahatchee River. The four species were Anomalocardia caloosana, Chione cancellata, Mulinia sapotilla, and Varicorbula caloosae. Comparison to nearest living relatives suggests the following habitats for these subtropical species:

A. caloosana - restricted marine, probably hypersaline
C. cancellata - restricted marine, wide salinity tolerance
M. sapotilla - restricted, probably brackish water
V. caloosae - open shelf

The oxygen isotope values are summarized in the table below:

	No.	O^{18} Range	O^{18} Mean
Anomalocardia caloosana	10	0.0 to 2.3	1.1
Chione cancellata	19	-0.8 to 1.0	0.2
Mulinia sapotilla	16	-1.0 to 3.8	1.1
Varicorbula caloosae	4	-2.0 to 0.1	-1.0
Heliosoma sp.	5	-1.3 to 2.0	0.1

The factors controlling the oxygen isotope composition of pelecypod shells are temperature and the oxygen isotope composition of the water. The O^{18} values for A. caloosana, C. cancellata, and M. sapotilla are too high and show too great a range to be explained by temperature fluctuations and suggest the presence of water isotopically enriched by evaporation. This fits well with the ecology of A. caloosana and C. cancellata which thrive at high salinities. The fact that M. sapotilla, a brackish species, also shows evidence of enriched water suggests periodic influx of re-evaporated fresh water from coastal swamps in response to a seasonal rainfall pattern. This is supported by the positive values of a few specimens of Helisoma sp., a fresh water snail, apparently transported into the marine deposits. A similar ecological regimen exists at the present time along the northern shore of Florida Bay.

This evidence suggests that the Tamiami high west of the outcrop area at times existed as a shallow submarine barrier and at other times as a low-lying land mass during Caloosahatchee deposition. The presence of Varicorbula caloosae with "normal" oxygen isotope composition further suggests that at times the sea stood sufficiently deep that the Tamiami high had little effect on the ecology of the area.

[1]A more extensive paper on this subject has been submitted for publication in the Journal of Paleontology

A REVIEW OF LATE CENOZOIC STRATIGRAPHY OF SOUTHERN FLORIDA

by

AXEL A. OLSSON

INTRODUCTION

The purpose of this field trip is to acquaint local geologists and visitors with some general features of the geology and stratigraphy of south Florida and the basic observations on which it rests, and to bring everyone together for a general discussion of the many problems involved.

Florida, like most of the coastal plain of which it is a part, is low and flat with a high water table. Permanent exposures are few and found only along a few stream courses. Such exposures are not always reliable since they have been affected by many surface conditions, such as bank slumping during high water, case hardening so as to resemble limestones, or solution channeling and sinkhole development which introduces into parallel beds extraneous material from above, often in such a manner as to be hardly recognizable. It is likely that some of these surface alterations will be seen and examined on this trip. Therefore, many of the older and even more recent views based on surface exposures, and especially the collecting of loose fossils from spoil banks, have led to certain deductions which have not stood up after more thorough study. In late years, numerous canal excavations, such as the one along the northwest bank of Lake Okeechobee excavated during the construction of high storm levees, permitted direct observations of exposures in the canal walls to a depth of 20 to 30 feet as the working end of the canal diggings was pumped dry for easier excavation. Other excavation projects were similarly dewatered and permitted direct entrance into the pit for close examination of undisturbed strata and the collecting of fossils in place. These fresh exposures were necessarily temporary. Some were open for close inspection and collecting for several months along a course of many miles; others for much shorter periods. It is upon these transient exposures that the section as now understood and on which I published a preliminary review in 1964 is based. These excellent exposures demonstrate how important it is for us all to be continually on the alert for similar opportunities which may open up from time to time. Fortunately, we have in our area a group of highly qualified, interested amateur fossil collectors who are in the field at every opportunity and who have thus far allowed nothing of importance to be missed. No doubt other wonderful opportunities for critical observations will occur in the future, and which, I hope, will be studied in detail.

These observations on fresh exposures have shown that the Tertiary and Quaternary succession of south Florida is not exceptional or any different from that of the rest of the coastal plain, and is especially similar to that of North and South Carolina. The formations are of the same character and age; the only marked difference being the greater richness of the fossil faunas due to the inclusion of a larger element of tropical forms. It is this character of combining both northern and southern elements in its paleontology that gives to the Tertiary succession in south Florida its greatest interest and also its greatest importance in terms of regional geology and stratigraphy. Some of us are deeply interested in the fossils and devote most of our time in identification and determining their affinities and relationship with other known forms. The fossils, however, are only a by-product of the geology, a tool of research, just as a hammer to break open rock or hand lens to inspect mineral grains in a hand specimen. It is on this theme, the importance of the geology itself, that this review has been mainly written. Those of you who attended our Society's annual

dinner in December, will remember that it was this aspect of the subject which I stressed in my talk.

The stratigraphy of rock formations in south Florida is relatively simple as compared with the great complexities seen in most Tertiary sequences in South America where the same age rocks attain great thicknesses. They are often consolidated into hard rock, such as quartzites, and, as in Costa Rica, are involved in mountain building structural deformation. The main difficulty which has prevented an understanding of Florida stratigraphy is the general lack of critical exposures. Many formations lie almost wholly in the subsurface below a high watertable. The most widespread of all our fossiliferous formations, and in its totality the richest in faunal makeup, is still unknown from any surface outcrop in south Florida, although in many places it lies less than 15 feet below the surface. Surface formations, with the exception of parts of the Tamiami exposed in the Everglades and in part of western Florida, as well as exposures along the Caloosahatchee and a few other streams, represent only the highest beds in the series. With the exception of certain features of Unit A, these exposed formations are also the ones of least interest and importance in the geologic framework of south Florida.

REGIONAL STRUCTURE

Normal and undisturbed, the fossiliferous formations lie horizontal or with a dip so low that it cannot be seen or measured by ordinary means. Where some dip or inclination occurs, it can be attributed to depositional irregularities or, if along formational contacts, to a wavy erosional surface of unconformity (as locally seen along the base of Unit A). A larger regional structure is however evident. A general alignment of formational distribution suggests a N15°W or S15°E strike with a low northeasterly dip. Hence, the oldest and lowest formations are in the western part and younger and thicker formations in the eastern section. This situation is also illustrated in the different outlines of the east and west Florida coasts. Some east-west faulting has been suggested, as well as local warping, with the intervening hollows filled with thickened sediments. In addition, there are many inlying and outlying areas which suggest overlap relations which cannot be properly understood on the basis of existing data and the lack of continuous outcrops.

STRATIGRAPHY

The chart accompanying this review (Fig. 1) shows in graphic form the fossiliferous units found in the shallow subsurface of south Florida. Before discussing this section, a few remarks are necessary.

Except for surface deposits of peat and some other Pleistocene deposits which do not concern us, the underlying beds are mainly Tertiary in age. Those of Upper Miocene age are the most important and have the widest regional distribution. The realization of the overriding importance of the Miocene in south Florida is a relatively new development which was not even suspected a decade ago. Helen Tucker and Druid Wilson (1932, 1933) were the first to suggest a Late Miocene age for the Acline fossils. Mansfield (1931) suggested a similar age for some shells from Pinecrest. Mansfield, however, erred in giving a younger age to the Tamiami, a mistake which I also made in the book on St. Petersburg mollusks (1953); an error

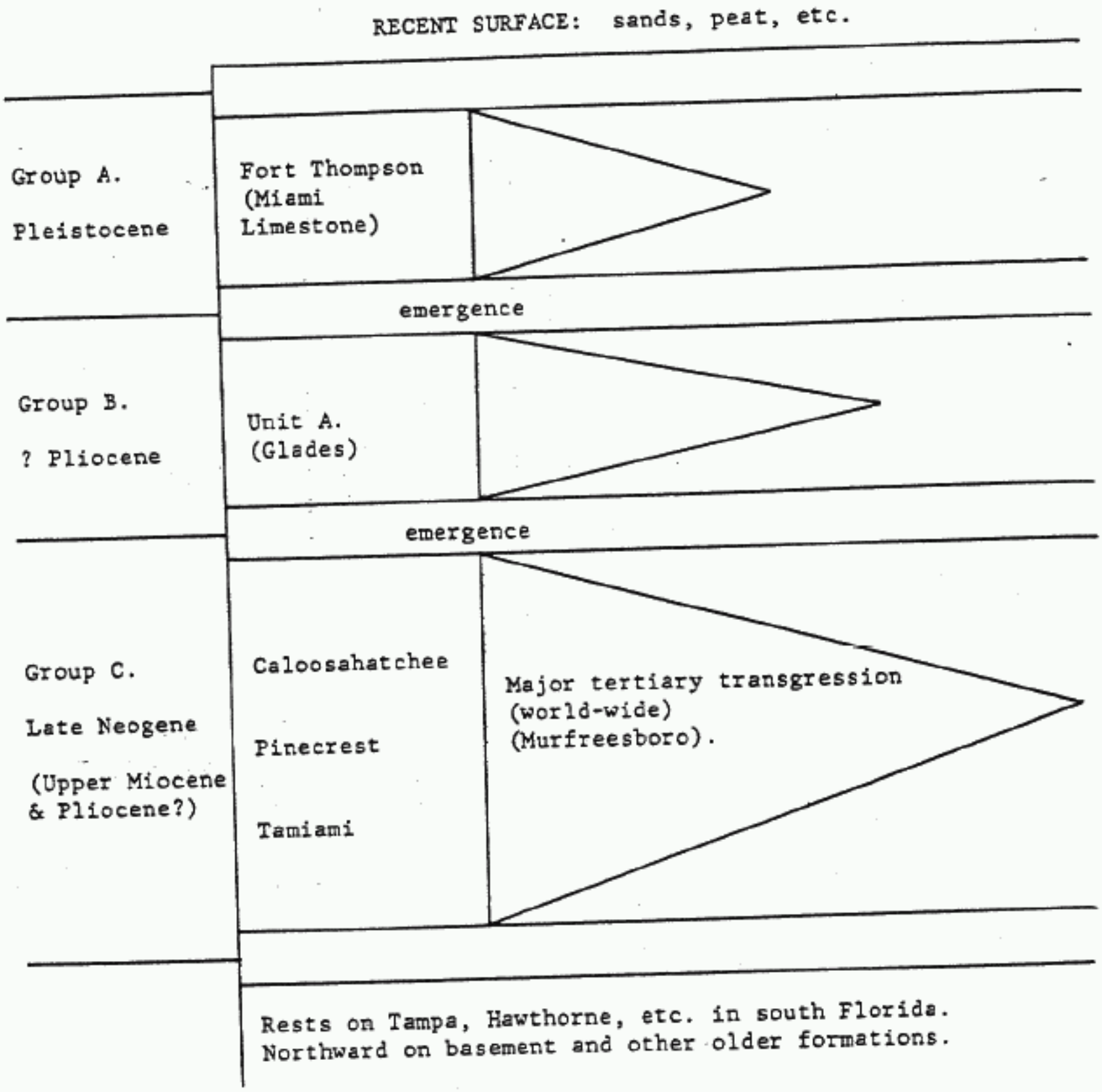


Figure 1. Stratigraphic units in the shallow subsurface of south Florida. The general magnitude of each transgression indicated by symbol > .

due to my complete lack of knowledge of the geology of the Tamiami area. In the meantime, Druid Wilson (as well as a few local collectors, such as Hughes) had begun to recognize Miocene shells along the main canal embankments and was able to distinguish them by their state of preservation, as well as specific identity with common Chesapeake forms from the north. During the St. Petersburg investigations, some poor Miocene outcrops were recognized on Snell Island, and a rich Miocene assemblage of fossil shells had been dredged up from Tampa Bay and used as fill opposite the Hotel Vinoy. In the Miami district, Howard Klein of the U. S. Geological Survey brought me a fine collection of Chesapeake Miocene shells from a well at the cement plant on Krome Avenue. They are now on deposit at the U. S. National Museum. Shortly thereafter followed the big diggings along the northwest shore of Lake Okeechobee which, for the most part, were in Miocene beds with a conspicuous Chesapeake faunal character. Later came the operations at Pinecrest with its abundant and characteristic organic remains. These occurrences brought the Miocene into sharp focus. All other observations made since have served to confirm the importance of the Late Miocene in all parts of south Florida. The significance of this discovery, to which so many contributed, cannot be underestimated; not only from its regional conception, but its direct bearing on the interpretation of the rest of the Tertiary section, particularly as it affects the age and relationship of the Caloosahatchee marls. In a sense, with our closer understanding of the evolutionary development of the main components of the Caloosahatchee mollusks, along with the recognition of Unit A, the Caloosahatchee Formation has shrunk notably from its predominant position in the stratigraphy of Florida which it once held.

In Figure 1 are the names adopted for the fossiliferous formations in which we are mainly interested. It is practically the same chart which I published in 1964 in preparation for the Geological Society of America convention of that year in Miami Beach. Since these units are mappable in a general way, and display individual lithological and faunal characteristics, they can be considered as formations. Over large and small areas, they may show considerable facies variation. Thus, in the Pinecrest, we have the typical facies at Pinecrest itself; at Acline that of Acline; Brighton and Kissimmee, each its own. Since in most cases we cannot actually get down into a water-filled canal, we do not know whether the different fossils found in dredged material come from a single bed or a series of alternating ones.

These formations are relatively thin and composed, in most instances, of fine-grained sand reworked from older sediments. They are all of shallow-water origin, deposited in waters of 50 feet or less. In some cases, as in the Pinecrest, the rocks may even be beach deposits as indicated by the local abundance of flattened, wafer-shaped quartz pebbles. Consideration of water depth during deposition must be taken into account in any correlation of strand-line terraces with marine formations in south Florida. This is especially true of terraces at high elevations, unless tectonic disturbance of considerable magnitude can be demonstrated.

For the sake of discussion, I have referred our Tertiary and Quaternary formations to three main groups, termed A, B, and C from the top down (Fig. 1). Group A includes the Pleistocene Fort Thompson and its probable equivalent, the Miami Limestone of Hoffmeister. Group B consists of Unit A, not yet officially named. Group C represents the large, main

group of Tertiary formations which includes the Tamiami, Pinecrest, and the Caloosahatchee Formations. Each group represents a single, depositional cycle of a transgressive sea over the land, following a period of uplift when erosion took place. Each transgression was the result of a higher stand of sea level of world-wide dimensions, and each transgression brought in a new faunal development.

Between each of the marine groups, Figure 1 shows a blank space representing a pause in sedimentation and a lost record of time. In the rock succession, these gaps denote unconformities between group formations, generally indicated by an indurated surface or pavement at the top of the underlying formation, and often by a basal conglomerate or rubble zone in the lower portion of the overlying marine beds. The two upper unconformities, between Groups A and B, and between B and C, have been seen at several places. The lines of separation between the formations in Group C are arbitrary, based on changes in lithology and fauna and have no great time significance.

Group A

This group includes the Fort Thompson Formation of the Caloosahatchee River area and the Miami Limestone to the south. Actual tracing of the Miami Limestone northward into the Fort Thompson beds has not yet been accomplished, but in my opinion they are probably equivalent and represent merely facies variations within contemporaneous deposits. On the Caloosahatchee River at La Belle, the Fort Thompson consists of an alternating series of marine and fresh-water layers of a total thickness of about 5 feet. Cooke believed this thin stratigraphic section included the entire record of Pleistocene time. He interpreted the fresh-water layers as indicating low stands of sea level correlated with glacial advances, and the marine layers of interglacial origin during high stands of sea level. I believe this explanation is altogether too simple and finds no added support in the geology. Moreover, according to Daly's theory of sea level changes during the height of glaciation, the land area stood at least 200 feet higher than now. These alternations between fresh and marine conditions are due only to shifting changes in salinity along the inner margin of the lagoonal area, possibly due to storm conditions. The situation is well illustrated by many similar changes from fresh water to marine which have affected Lake Worth during the last 30 to 50 years due to hurricane action. The molluscan fauna of the Fort Thompson is sparse in number of species and is similar to that of Biscayne Bay. All the recorded species are Recent. Chione cancellata is the most common species as it is in the Recent fauna in lagoonal waters throughout the tropical or subtropical areas of the western Atlantic.

In many places, the basal part of the Fort Thompson is a rubble zone with reworked fossils, and it was from such a mixture that DuBar (1958) obtained his horse tooth. It is well to note that remains of land mammals are exceedingly rare in a purely marine formation and all reports of such occurrences must be regarded with suspicion until fully confirmed by acceptable geologic evidence.

Group B

This is a distinct stratigraphic unit, formerly included in the Caloosahatchee as its uppermost member. It is Unit F of DuBar's classification who also included it in the Caloosahatchee Formation. The general

term "Unit A" was temporarily given to it in my 1964 paper in anticipation that it would be more fully defined and officially named by Druid Wilson shortly afterwards. The absence of an acceptable name for this unit for so long a time has been awkward, especially in discussing its fossils and in describing new species. = GLADES FORMATION

Unit A as a distinct stratigraphic unit was first differentiated by Druid Wilson about 1960 and shortly thereafter by Thomas Hughes (now deceased), a local fossil collector from Fort Pierce. Its differentiation from the Caloosahatchee by these two men represented a notable achievement in south Florida geology and it has helped immeasurably in clarifying many obscure problems which up to that time had evaded solution.

Unit A can be seen in surface exposures at La Belle and Ortona Locks, as well as in several rock pits. At La Belle and several other places, its base is marked by a zone of oysters (Ostrea virginica labellensis) along an undulating surface contact with the Caloosahatchee marls below. At other places, such as at Ortona Locks and in several rock pits, its base is marked by a reefal bed of worm shells (Vermicularia recta) in erect, colonial form. In many other known places, Unit A lies on the Pinecrest and, perhaps in some instances, upon the Tamiami. It was exposed at several places in the area north of Lake Okeechobee during construction of the storm levee previously mentioned. The Unit A molluscan fauna is very rich, with an estimated fauna of 600 species showing a high percentage (70 to 80 percent) of Recent species. The fauna is tropical or at least represents warmer water than that of present-day Florida.

The age of Unit A is uncertain and may be subject to different interpretation. Druid Wilson, it seems, considers the formation as earliest Pleistocene and probably pre-glacial. I am inclined to regard it as Late Pliocene, mainly because of its geological setting which is so similar to that of the Coralline Crag of England, as well as percentage of extinct species in its fauna. The Coralline Crag of eastern England remains one of Lyell's type examples of the Pliocene, in addition to the thicker Pliocene deposits found in north Italy. In England, the Coralline Crag deposits were laid down by an independent marine transgression and rest directly on the Cretaceous Chalk. Its beds remain now only in the form of small remnantlike hills surrounded and overlapped by the younger Crag deposits of Pleistocene age.

Group C

This is the largest group, the most interesting, and on which major attention has been focused. The group is Tertiary, and its lower formations, the Tamiami and the Pinecrest, are Late Miocene. These formations are correlated, both as to their geologic setting and on the basis of fossils, with the Duplin and Yorktown of the Carolinas and Virginia. The upper formation, the Caloosahatchee, as presently restricted, is so nearly related to the Pinecrest that no separation is possible except on purely paleontological grounds. The contact that has been observed between the Pinecrest and the Caloosahatchee is extremely indistinct. The Caloosahatchee Formation has the smallest areal distribution, as is to be expected in a regressive sea, and apparently is absent south of Broward County and in many other places its occurrence is patchy. All three formations have a single faunal development along evolutionary lines

which can be traced through several lineages until the end of Caloosahatchee time when they suddenly became extinct. Thus, there is a close age relationship between all three formations. In discussing the three formational units we will begin with the Tamiami, the oldest and also the one in which the marine transgression originated.

The Tamiami

The name "Tamiami" was proposed by Mansfield in 1939 for Tertiary deposits encountered in roadside ditches and rock pits near the junction of Route 41 (Tamiami Trail) and Route 29 in Collier County. The formation directly underlies a considerable part of the western Everglades and extends northward to the Caloosahatchee River, southward to Florida Bay, and westward to the coast at Fort Myers and Punta Gorda. It is quarried in numerous rock pits for fill and ballast, the rock usually first crushed and screened for the purpose intended. It is recognized as an ideal rock for road foundation, for when properly applied, spread and rolled, it hardens through its own recementation.

The Tamiami is made up mainly of calcareous marls with layers of hard, porous or crystallized limestone and beds of fine quartz sand. Fossils are plentiful, but most are in the form of internal molds or as cavities in the rock. All shells originally composed of aragonite have been leached away by circulating ground waters. Fossils of calcitic nature, such as oysters, pectons, echinoids and barnacles are well preserved except they may be encrusted with cemented matrix which is difficult to remove. A small sand dollar (Encope) is generally very common and is restricted to the formation. The Tamiami is Upper Miocene in age and correlates directly with the Choctawatchee of north Florida and with the Yorktown of Virginia.

The base of the Tamiami in south Florida has not as yet been recognized at any outcrop. It may be assumed that the formation rests unconformably on a variety of older beds as does its equivalent horizon elsewhere throughout the Atlantic coastal plain. In the region of its typical occurrence, the Tamiami displays the facies characteristic of a shallow-water, platform deposit as would be expected from its central position along the main axis of the Florida peninsular uplift. In its downdip position, the Tamiami is believed to grade into shelly sands like those of the Pinecrest, and in the zone below circulating ground waters, its contained fossils should be well preserved. The fossil horizon encountered in the well from the cement plant on Krome Avenue came from the Tamiami in a downdip position.

The paleontology of the Tamiami remains incompletely known as only the echinoids and some of the pectens and oysters have been systematically studied. The determination of the other fossils, mainly molds or impressions is difficult, but sufficient information is available to indicate that the Tamiami fauna is closely allied to that of the Choctawatchee of north Florida and to that of the Yorktown of Virginia. Eventually Tamiami localities may open up where the fossils are in good condition permitting a more accurate determination. Ecphora is known from the Tamiami at numerous places and during some dredging operations, such as at Olga, the shell was quite common. Unusually large specimens of Ecphora have been seen firmly embedded in hard Tamiami limestone at

many places. The shell of Ecphora is frequently encountered on the beach at Fort Myers Beach, along with shark teeth and other fossils.

The thickness of the Tamiami is not known, but may be estimated to be about 100 feet. Several pits in the Everglades are said to be 75 feet deep and dug entirely in the Tamiami formation.

It is well to note that for a long time much uncertainly prevailed as to the stratigraphic position of the Tamiami as well as its age. Mansfield in 1931 considered the formation as Pliocene. Parker in 1942 considered the Tamiami to overlie the Caloosahatchee and on this basis that it was younger than the Caloosahatchee. Olsson in 1953 followed Mansfield and Parker, and without personal knowledge of the geology in the Tamiami area, referred to it as a facies of the Caloosahatchee. Actually, as we now know, it lies below the Caloosahatchee and its age is definitely Late Miocene, correlating perfectly with the Ecphora zone of the Choctawatchee of north Florida and the Yorktown of Virginia.

The Pinecrest beds or formation

The name "Pinecrest beds" was proposed by me in 1964 for strata composed largely of fine-grained, white sand encountered directly below a bed of Miami Limestone of Pleistocene age in the general region of 40 Mile Bend on the Tamiami Trail and extending west for a short distance beyond the Dade-Collier County line. The name is taken for a settlement on the old Everglades road about one mile west of the Dade County line. A small collection of fossils obtained from a roadside ditch in this area was described by Mansfield in 1931 and referred to the late Miocene. The Acline mollusks described by Tucker and Wilson from a pit in the Punta Gorda district belong to the same unit and represent a different faunal and facies development.

During the canal dredging in the 40 Mile Bend area, the Miami Limestone at the surface was so hard and compact that it had to be bored through and blasted before the underlying deeper beds could be excavated. In the first stretch of the canal east of the bend, only barren white sand lies below the Miami Limestone. A short distance westward, beyond the curve in the road, highly fossiliferous beds occur over a wide area, containing a completely pure, undiluted fauna. For nearly a year, this locality offered unexcelled collecting to a great many fossil enthusiasts. As yet, these large collections are scattered in many hands and have not been fully worked up. Further westward, where the canal system runs almost due north, much of the Pinecrest is barren or carries only a depauperate fauna. The general character of Pinecrest deposits in this area is of very shallow-water, nearshore, and possibly even beach sediments locally.

The largest known area of the Pinecrest beds in the shallow subsurface is in Glades, Highland, and Hendry Counties north and northwest of Lake Okeechobee, which was available for observation during levee construction in 1962 and 1963. In this area the fauna is extremely varied with many interesting species such as Malea and Trochita not found elsewhere. Of still more recent date, wonderful collecting opportunities have been available in the Kissimmee area during the deepening and straightening of the river channel. Large collections have been made, mainly by workers from the West Palm Beach area.

The most interesting, as well as the most remarkable feature of the Pinecrest fauna is its mixed character; mixed in the sense of combining northern elements in its makeup (as Mulinia congesta) and distinctly boreal to subboreal forms (as Astarte, Cyclocardia, and the mud-snails, Llyanassa etc.) with warm water and tropical types (as the many species of Conus, Cypraea, Terebra, and a host of others). In all its known occurrences, the Pinecrest fauna shows a certain uniformity of character, easily recognizable, but at the same time showing many variations which are essentially local. Thus the Acline assemblage has many species not known outside of the Acline locality, some of which show Mexican affinities. Other places show relationships with Jamaica and with Santo Domingo. In its total, the Pinecrest is the largest Tertiary assemblage known in Florida and its number is on the increase with the discovery of each new locality. At the present time, it can be roughly estimated at about 1200 species, approximately three times that of the living Florida fauna in the same depth range. Not only are many species still undescribed, but many show obvious relationships with forms from Jamaica, Santo Domingo, and with the living species in the Panamic-Pacific region.

The Caloosahatchee marls

The Caloosahatchee marls represent the highest beds of Group C. The general characteristics of the Caloosahatchee have been described by so many authors that minor attention need be given to it here. As already noted, the separation of Unit A from the Caloosahatchee, formerly regarded as its upper member (Unit F of DuBar) and marked off from it by an erosional, unconformable surface, has greatly reduced the importance of the Caloosahatchee in Tertiary stratigraphy of south Florida and has also significantly reduced its percentage ratio with the Recent.

In areal distribution, the unit is also the most restricted with its principal development lying along a troughlike belt extending from North St. Petersburg in Pinellas County southeasterly across Manatee, Sarasota, and Hendry Counties to about the northwest corner of Dade County. Its most extensive exposures are found along the Caloosahatchee River at and near La Belle, where it is exposed at several places in the river bank and in rock pits. In most places, the Caloosahatchee is a friable shell marl, yellowish or cream-colored on surface exposures, but gray or blue within.

PALEONTOLOGY

Some mention has been made of the fossils of south Florida, but a longer account is beyond the scope of this review. The fossils illustrated on the two accompanying plates have been chosen to show a few common forms of special significance as guide fossils or those which show evolutionary trends. All are extinct species and most belong to extinct genera also. As previously mentioned, the main extinction point in our Florida Tertiary section is at the top of Group C or the Caloosahatchee marls; only a few minor forms continued into Group B. Thus, in Group B or Unit A, we have the first marine fauna closely allied to that of the Florida Recent or of the general western Atlantic.

The Tamiami with its abundance of echinoids, pectens, and marine oysters is a shallow-water, platform facies. Downdip it appears to change

into a more sandy facies similar to the Pinecrest with molluscan species more similar to those of the Chesapeake region of Virginia. Inasmuch as it lies below the zone of active water circulation of surface origin, its fossils are not leached.

Plate 1 shows a mixture of forms from the Pinecrest, Caloosahatchee and Unit A, with the exception of Ecphora whose position is not fully established (it could be from a Middle Miocene horizon). We have two other species of Ecphora in our section (Group C), the common Yorktown type in the Tamiami, and another in the Pinecrest. The Pinecrest species has since been found in Georgia.

Plate 2 also shows a mixture of forms from the Tamiami, Pinecrest, Caloosahatchee, and Unit A. Plate 2, figure 5 shows the inside of a valve of Spondylus bostrychites Guppy illustrated to show the selective effects of leaching. The inner layer of the shell composed of aragonite has been dissolved away leaving the performations and burrows of various marine organisms (mollusks, worms, sponges) filled with calcitic matrix, intact, plastered to the outer layer which in Spondylus is calcitic.

Only a rough estimate of the size of the Tertiary and Quaternary mollusks of south Florida is as yet possible. The following is a tentative, conservative estimate:

1. Group A. (Fort Thompson or Pleistocene). About 200 species of which all are Recent.
2. Group B. (~~Unit A~~ GLADES). Between 500 and 600 species of which about 80 percent are Recent.
3. Group C. (Tamiami, Pinecrest, and Caloosahatchee). Total between 1200 to 1500 with a percentage ratio of 40 or less of Recent or near Recent forms. The total is expected to go much higher.

Certain significant trends are evident among several groups and families.

Conidae: Total about 20 species, many undescribed.

~~Unit A~~ GLADES. - about 5 species, all Recent.
Caloosahatchee - about 5 species, 2 Recent.
Pinecrest - about 18 species, 2 Recent.
Tamiami - unknown.

Turritellidae:

~~Unit A~~ GLADES. - 1 species, also Recent.
Caloosahatchee - about 5 species, only 1 Recent.
Pinecrest - about 7 species, 1 Recent.

The two general terms, cold-water and warm-water have been used in the past in discussing the affinity of the Florida Miocene mollusks. There has been some objection to these terms from some, so a word of

Explanation of Plate 1

Figure 1 — Ecphora quadricostata (Say) 2/3rd size. Murdock (Miss Hunter). Middle Miocene probably. An index fossil for the Chesapeake Miocene.

Figures 2 & 3 — Vasum (Hystrivasum) 1/1 size. An endemic Florida group with about 4 species.
Fig. 2. V. locklini Olsson and Harbison. Pinecrest.
Fig. 3. V. horridum Heilprin. Caloosahatchee.

Figure 4 — Cancellaria propevenusta Mansfield 1/1 size. Index fossil for the Pinecrest; also in north Florida and Duplin of North Carolina. Pinecrest.

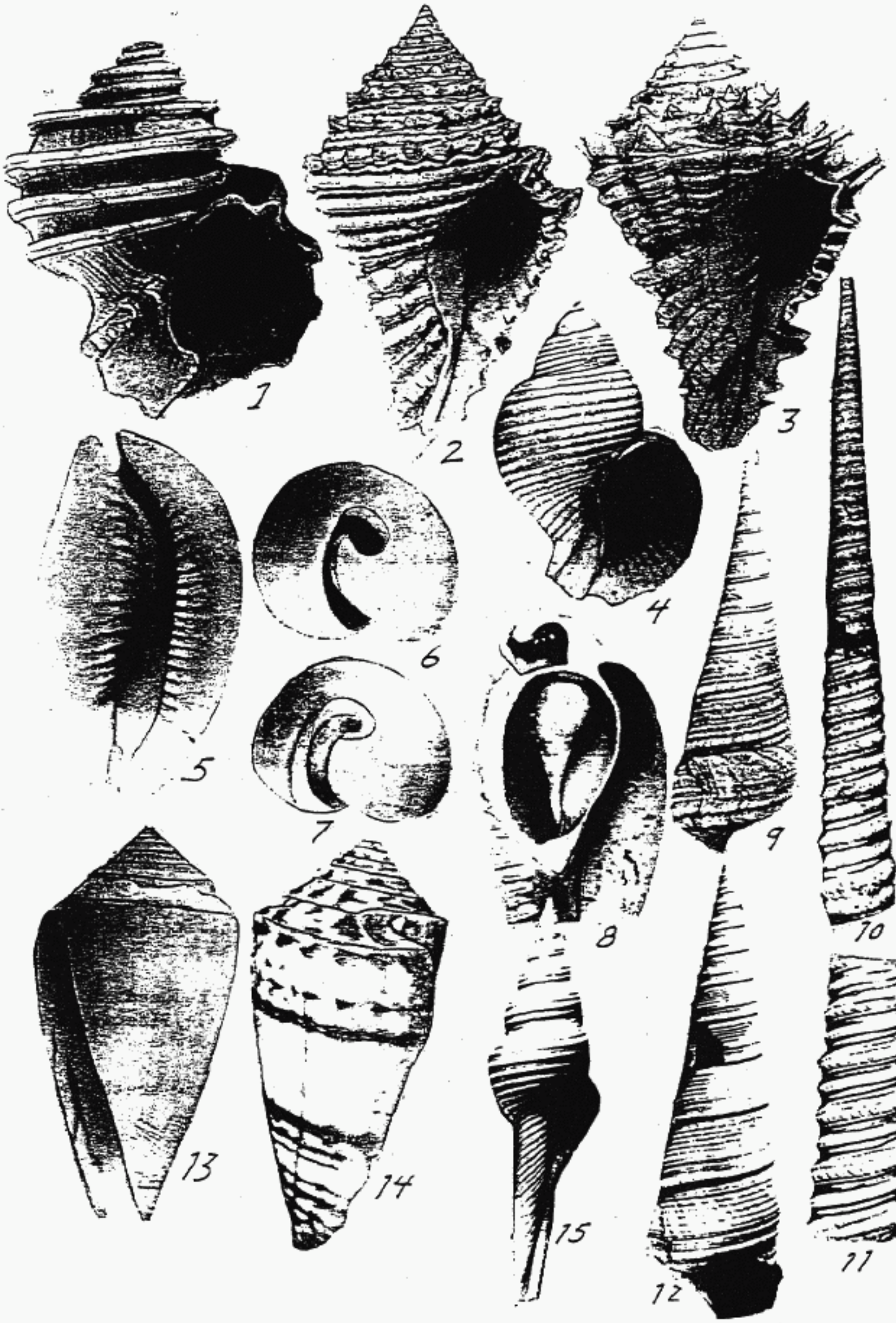
Figures 5 - 8 — Siphocypreaea lineages. An endemic Eastern American genus beginning in the Chipola and became extinct at the end of Group C. Not in Unit A.
Fig. 5. S. carolinensis floridana Mansfield. About 2/3 size with simple apical sulcus. Pinecrest.
Fig. 6. S. problematica Heilprin. 1/1 size with fully developed spiral sulcus. Caloosahatchee.
Fig. 7,8. S. transitoria Olsson and Petit. With transitional sulcus. Fig. 8 longitudinal section to show development of notch and Bulla stage whorls in the interior. Pinecrest. Brighton.

Figures 9- 12 — Turritellas.
Fig. 9. T. evergladeensis Mansfield. Pinecrest. Slightly enlarged, notice scupture and inflated body whorl.
Fig. 10, 11. T. perattenuata Heilprin. About 1/1 size. Caloosahatchee.
Fig. 12. T. pontoni Mansfield. About 1/1 size.
T. pontoni and evergladeensis are common Pinecrest species at all known stations.

Figures 13-14 — Conus (Contraconus)
The left-handed cone, the only group of left-handed cones in the world and restricted to Group C or its equivalent beds in the Carolinas.
Fig. 13. Conus advesarius tryoni Heilprin. About 2/3 size. Caloosahatchee.
Fig. 14. Conus adversarius Conrad. A specimen showing fluorescent pattern. Pinecrest.

Figure 15 — Fusinus watermani Maxwell Smith. 1/1 size.
Index fossil for Unit A. (Group B). Belle Glade.

Plate 1



Explanation of Plate 2

This plate shows a selection of fossils from the Tamiami, Pinecrest, Caloosahatchee, and Unit A. of special significance.

Figure 1. Pecten (Nodipecten) collierensis Mansfield. About 1/1. Tamiami.

Figure 2. Pecten (Pecten) hemicyclicus Ravenel. About 1/1. Tamiami.

Figure 3. Encope tamiamiensis Mansfield. About 1/1. Basal or ventral side. Tamiami.

Figure 4. Ostrea (Pycnodonta) haitensis (Sowerby). About 1/1. (O. monroensis Mansfield).
Often very large and thick. Both valves are plicated, and the shell texture is partly cellular. A Miocene species ranging through the Caribbean to South America. Tamiami.

Figure 5. Spondylus bostrychites Guppy. About 1/1.
Inside of a large valve showing casts of boring in the inner layer (aragonitic) leached away. A common Miocene species through the Caribbean to South America. Tamiami.

Figure 6. Chione ulocyma leonensis Mansfield. 1/1.
Pinecrest. Alligator Alley. Also in north Florida.

Figure 7. Anadara aequalitas Tucker and Wilson. 1/1.
Index fossil for Unit A. Belle Glade.

Figure 8. Anadara crassicosta Heilprin. 1/1.
Index fossil for Caloosahatchee. Caloosahatchee.

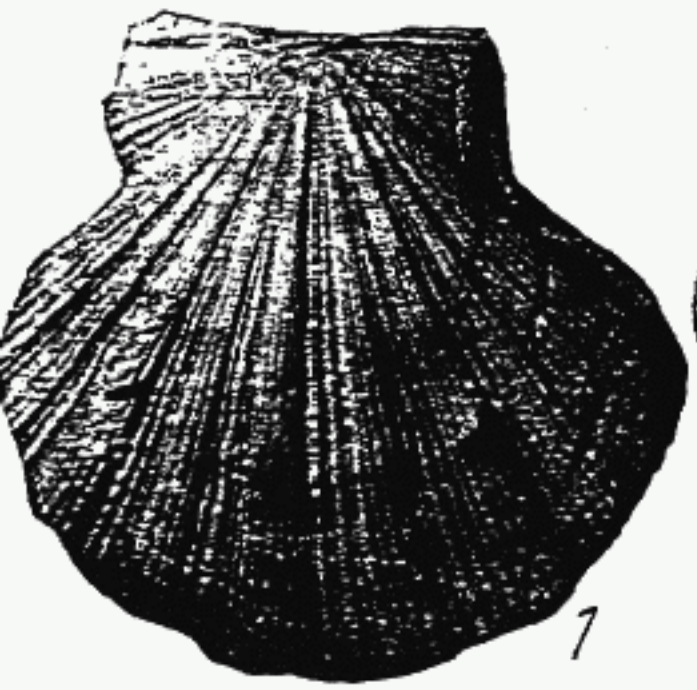
Figure 9. Anadara cf. tuberculosa (Sowerby) slightly reduced.
This fossil is related or identical with A. tuberculosa, a mangrove-mud species along the Pacific coast of Mexico, Central America to Peru, the principal food clam in that region. Its discovery in Unit A was quite unexpected, as the last lingering occurrence of a purely Pacific element in the fauna. Slough's ditch.

Figure 10. Pecten eboreus darlingtonensis Dall, slightly reduced.
Encrusted with a Miocene coral and worm-shells. Pinecrest. Fish Eating Creek.

Figures 11, 12. Astartes. Northern or Chesapeake elements in the south Florida Miocene.
Fig. 11. A. floridana Dall. Also north Florida. St. Petersburg. Downdip Tamiami.
Fig. 12. A. symmetrica Conrad. Pinecrest, Kissimmee.

Figure 13. Mulinia congesta Conrad.
A Chesapeake guide fossil for the Upper Miocene. Virginia to Florida, often very common. Pinecrest. Alligator Alley.

Plate 2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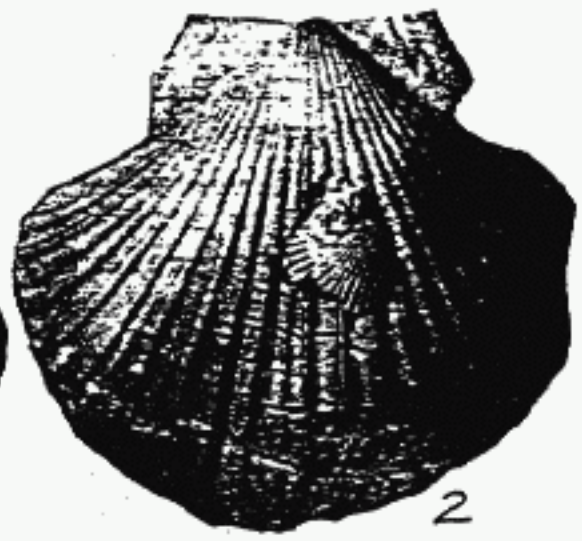
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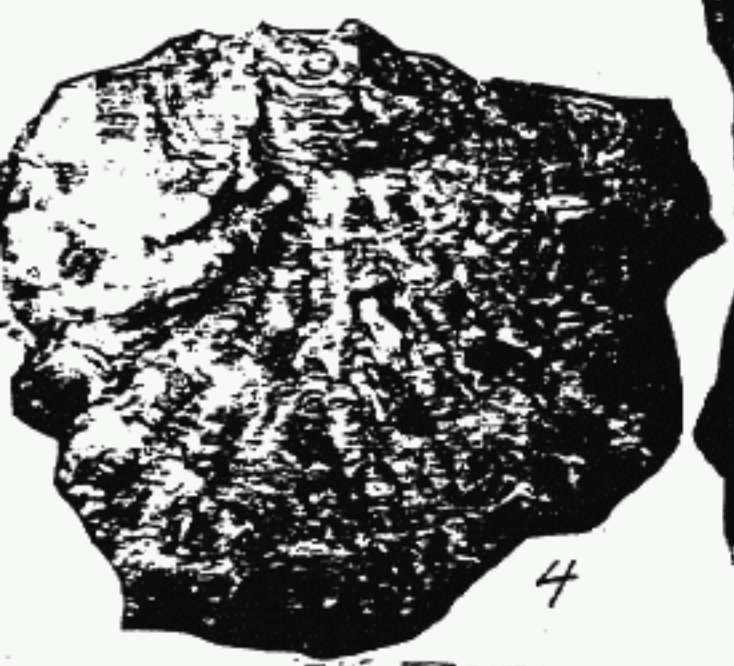
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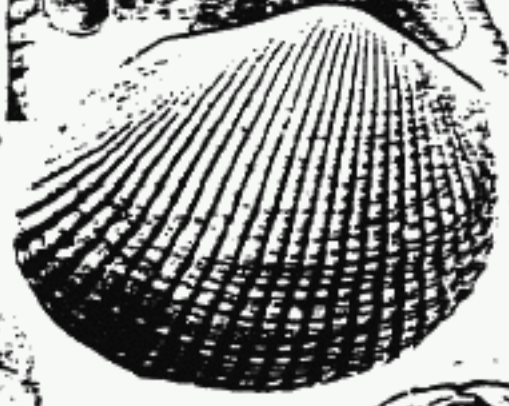
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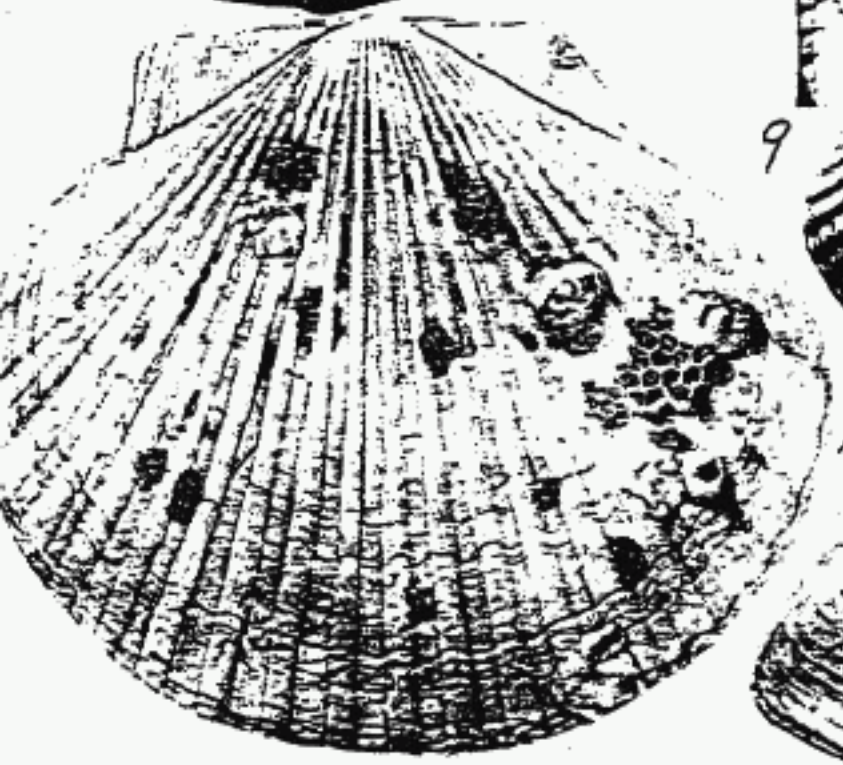
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explanation is needed. Cold-water refers to the presence of Chesapeake Miocene species from Maryland and Virginia. They are northern forms, and some of the genera such as Astarte, Cyclocardia, etc. are principally boreal in their distributional pattern today. A few are found only south of Cape Cod; but none along the Florida coast, even in deep water. Warm-water refers to tropical and subtropical forms, such as Conus, Cypraea, Terebra, and a host of others. The Caloosahatchee marl fauna is tropical and so is Unit A. The Fort Thompson fauna is subtropical and, hence, an indication that it is an interglacial formation. The fresh-water snails such as Heliosoma and Physa species interbedded with the marine in the Fort Thompson are subtropical and represent the same species as living in Florida today. They are, therefore, not glacial or allied to the species of the same genera north of Florida.

SUMMARY

Florida geology is based on Tertiary stratigraphy and paleontology, in which the molluscan fossils are the most important; and the makeup of the formations and succession in its general features are similar to those found along the length of the coastal plain from New Jersey southward. Because of the geographic location of south Florida, its Tertiary faunas includes both northern and southern elements; hence, it occupies a strategic position in intercontinental correlation through its northern elements with Europe (Germany, etc.) and by its tropical elements with South America. Florida therefore offers unlimited opportunities in Tertiary research such as stratigraphy, sedimentation, and faunal studies of the greatest importance, which in a sense outweighs all other aspects of geological investigations possible in this area.

The drawbacks to an easy unraveling of Florida geology is due to the almost total lack of good surface exposures; those found principally along a few stream courses are not wholly reliable due to surface disturbances and are of minor thickness and discontinuous outcrop. The determination of the succession of the Tertiary horizons has come largely through understanding of the fossils and by direct observations on beds in fresh exposures in artificial excavations. Fossils obtained from levee embankments by inexperienced geologists are generally useless, or from rubble beds, and much of the confusion which has prevailed here in late years has come from this source.

In figure 1, I have shown the general succession of the fossiliferous formations in this area and the names of these units as now in use. These fossiliferous horizons or formations may be arranged in three groups, A, B, and C; each group represents a single, complete, depositional cycle of sedimentation produced by a transgressive sea across the land surface following a period of emergence. Each group is separated from the underlying and overlying ones by sharp unconformities and along each unconformity there is often a basal rubble containing reworked fossils from the underlying formation together with boulders, phosphatic pebbles and teeth and bones of land vertebrates. Nearly all remains of land vertebrates in south Florida are found in such rubble beds, and in most instances are reworked.

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NOTES ON GEOLOGY OF THE CALOOSAHATCHEE RIVER AREA, FLORIDA

by

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INTRODUCTION

Over 100 core holes were drilled in this area by the U. S. Army Corps of Engineers during the last ten years. Samples from these cores were made available to us by the Corps of Engineers, through the courtesy of Mr. C. F. Dreves. Joseph E. Banks assisted in the examination of the cores and Mrs. Muriel Hunter helped with the identification of some of the mollusks.

The detailed study of the Caloosahatchee River area was undertaken by the Division of Geology because of the complexity of the outcrop area where facies changes are common, and older rocks are cut by channel deposits of younger age. A paleoecologic and paleogeographic approach is necessary to delineate the finer features of the stratigraphy of this classic outcrop area and to understand the geologic history. Consequently, the Division of Geology sponsored a study of the Caloosahatchee River outcrop area by DuBar (1958 a,b), and a few years later, of the Shell Creek exposures in Charlotte Harbor area (DuBar, 1962). The following preliminary notes are based on the study of a much larger, long-range regional project on the stratigraphy and paleoecology of southern Florida. Inasmuch as the stratigraphy of the exposed section of the Caloosahatchee River is under present study, and has been discussed elsewhere in the Guidebook, the following notes are confined to the Late Miocene section between Ft. Myers and Moore Haven.

The Caloosahatchee Valley is a broad physiographic feature bounded by the Caloosahatchee Incline on the north and the Immokalee Rise on the south. This is an area of low relief where elevations seldom exceed 25 feet. Surface sands of the Pamlico formation are exposed throughout the area.

Geologic section from Ft. Myers to Moore Haven. Sediments of Upper Miocene age are the oldest beds encountered in the core holes in this area. These sediments consist of pale orange yellow to pale brown limestones, calcareous clay, sand with phosphorite, olive greey clay with phosphorite, sandy clay with phosphorite, and light green, blue-gray and olive-green clays (Figure 1).

Locally, between La Belle and Ft. Myers these sediments can be divided into two units, an upper calcareous unit and a lower clastic unit. The upper unit is divisable into two parts which consists of a limestone (2-10' thick) underlain by a barren calcareous clay (Alva clay) up to 35 feet thick. The lower clastic unit, consisting of several beds (LaBelle clay), is mainly composed of light green and blue-green clay underlain by olive-green clay. In some cores, both the upper and the lower parts of the LaBelle clay contain phosphoritic quartz sand (See W-6736).

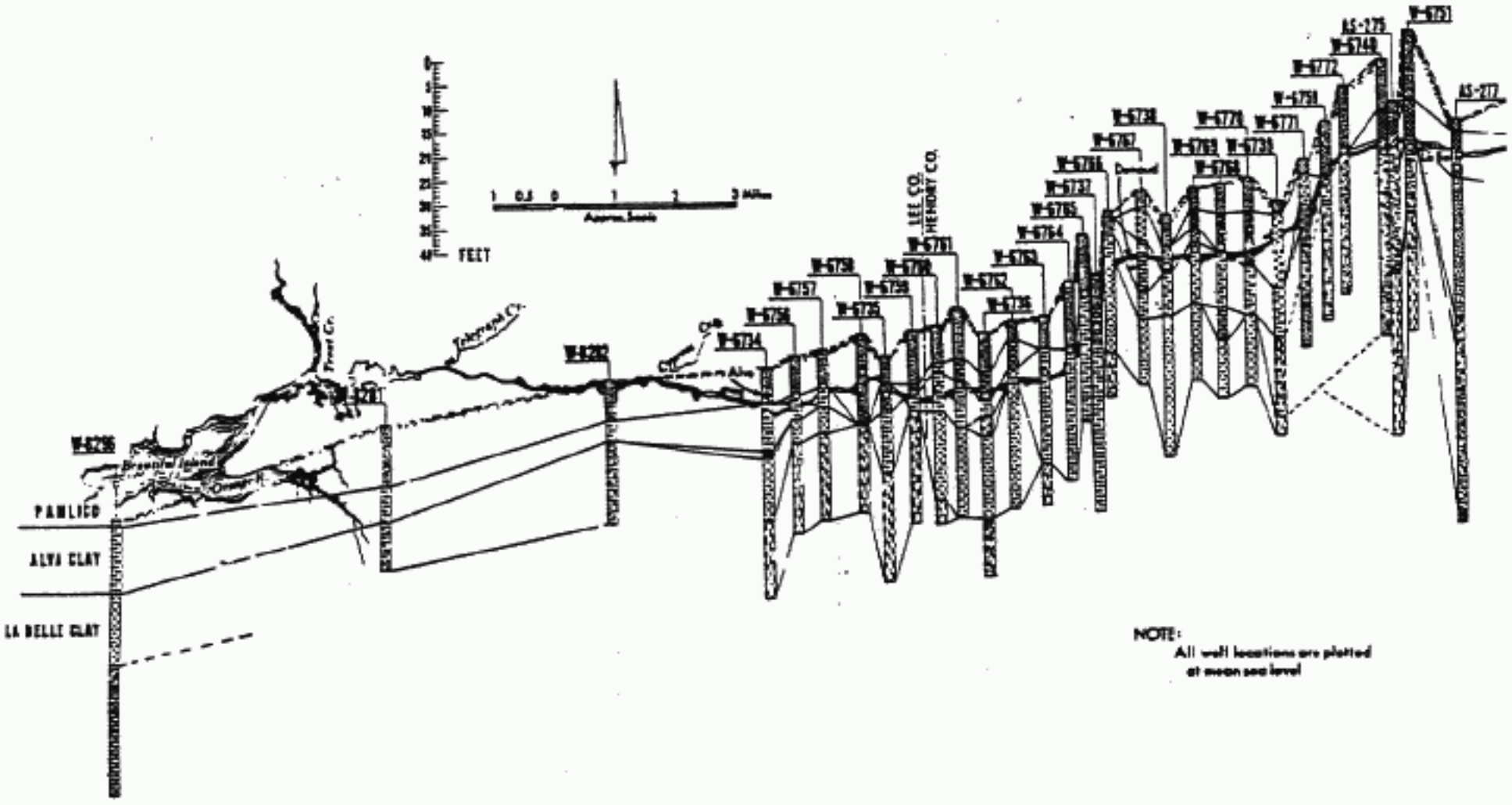
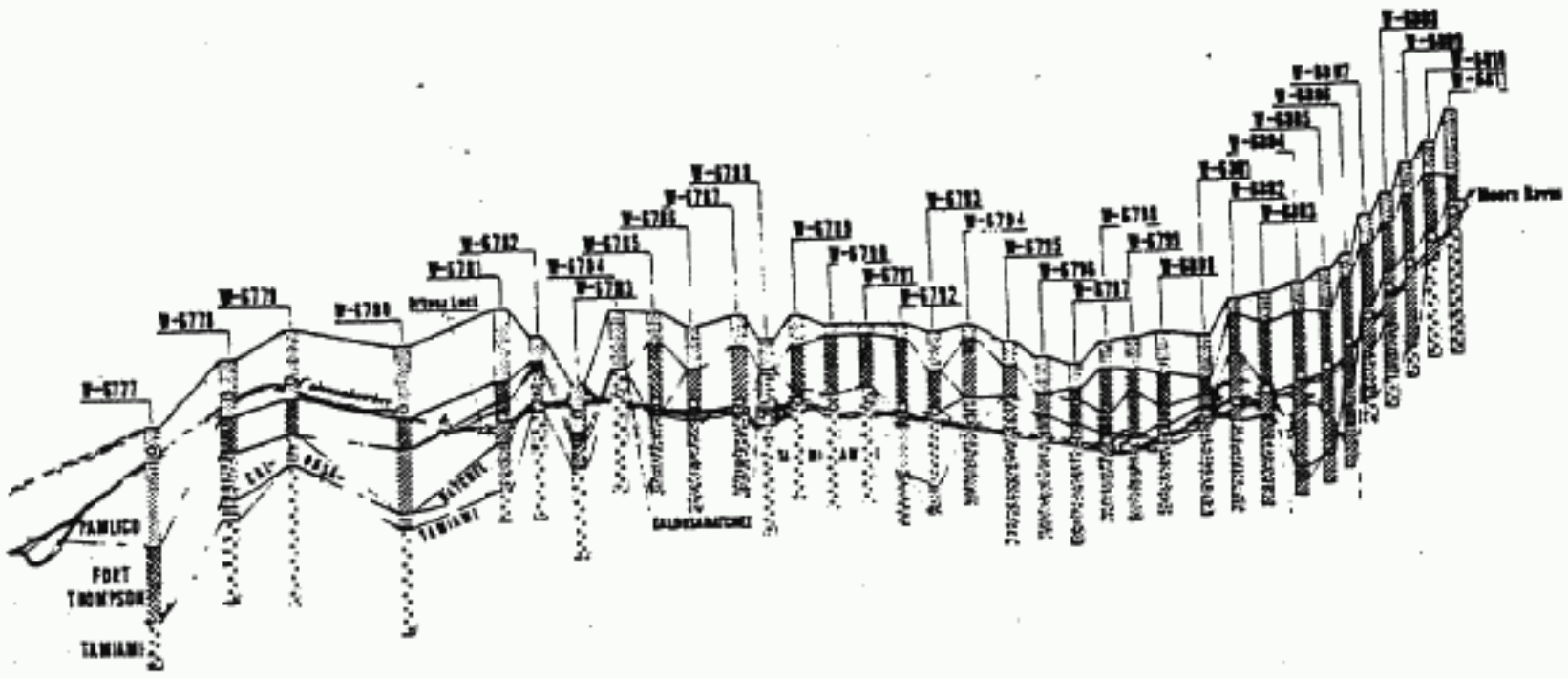


Figure 1. Geologic cross-section along the Caloosahatchee River



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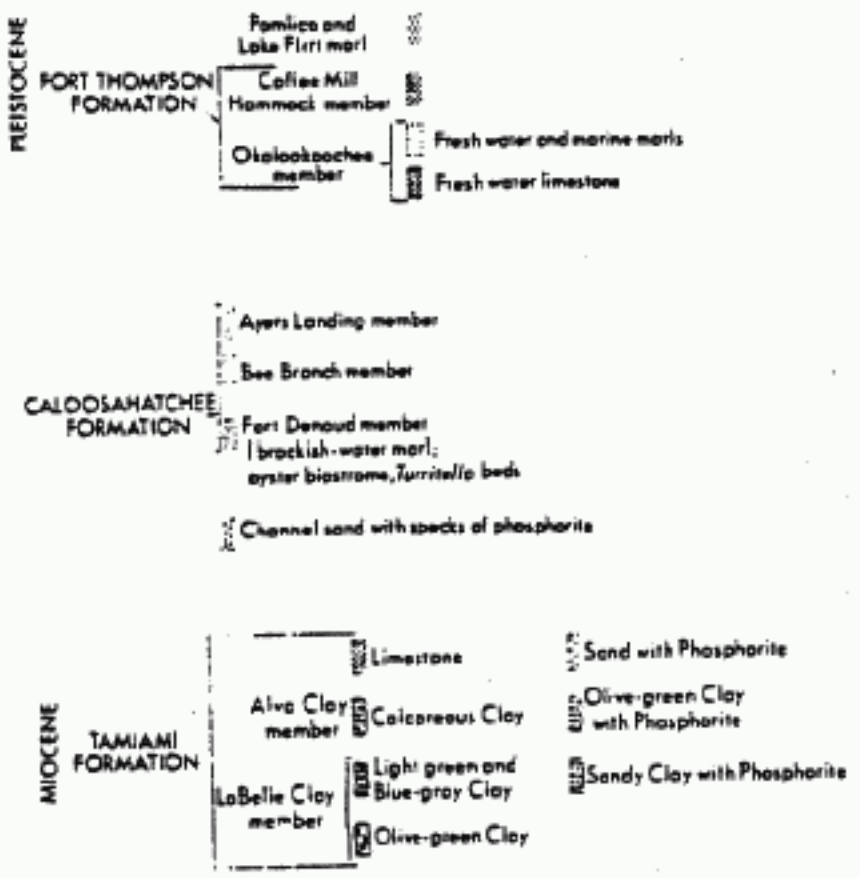

from Fort Myers to Moore Haven.

The Alva clay is thickest in the Banana Branch and Ft. Simmons Branch area; it thins to the east and west. It is entirely absent in core hole W-5758 where Pamlico sand directly overlies the olive-green clays of the LaBelle clay member. Thinning and absence of the Alva clay may be attributed to the presence of channels cut in the older sediments.

The late Miocene section farther east between LaBelle (W-6777) and Ortona Lock consists of sands with pebble phosphorite; the upper calcareous unit of the Miocene and most all of the Caloosahatchee section is missing. Locally, in a channel, shell beds of the Coffee Mill Hammock member overlie the clastic unit. In an area extending 2 miles east of Ortona Lock (W-6785, W-6786, and W-6787), Caloosahatchee sediments are present to total depth of the core holes. Under Lake Hicpochee (W-6804 and W-6805) a deep channel occurs, containing a thick section of fresh-water limestones and marls of the Ft. Thompson Formation. A blanket (?) of sand of late Miocene (?) age with specks of phosphorite, occurs in W-6807 to W-6811 near Moore Haven. Miocene beds in these wells may have marked the development of another channel system older than the ones containing Caloosahatchee or Ft. Thompson sediments.

Age of the Caloosahatchee Formation. The controversy over the age of Caloosahatchee sediments arises from the fact that a Pliocene age (ten million years) was assigned to its molluscan fauna by pioneer geologists who used the percentage of still living species as an index. Later work based on the age of an extinct horse (Equus cf. E. leidyi) placed a much younger Sangamon interglacial Pleistocene (approximately 130,000 years) age on the uppermost shell bed of the Caloosahatchee Formation (DuBar, 1958).

The controversy has arisen again; thorium/uranium age dating (Broecker and Thurber, 1965) of corals from the Key Largo Limestone (which is stratigraphically higher than the Caloosahatchee) indicates an age of approximately 95,000 years. The top of the Key Largo and the exposed part of the Miami Oolite (on which the City of Miami is built) was recently dated as approximately 130,000 years (Osmond, Carpenter, and Windon, 1965). Consequently, the age of all Caloosahatchee beds must be older than 130,000 years.

To be certain of these age relationships, an absolute age-dating method must be devised. Such a method is provided by thorium/uranium age determinations of carefully collected fossils from the sediments in question. Shells from the upper part of the Bee Branch Member, just under the uppermost shell bed (Bed 3A, of Section A28 of DuBar, 1958b) have yielded an apparent Th^{234}/U^{238} age of over 400,000 years (analysis by Dr. J. K. Osmond). The U. S. Geological Survey (1965) obtained part of a skull (identified by Whitmore as Equus, probably a mid-Pleistocene species) from the Caloosahatchee Formation in the type area near La Belle. This find indicates that the approximate age of 400,000 years, as determined by the thorium/uranium age method, is not too high. We are presently dating other well known horizons in the Caloosahatchee Formation with the hope that these analyses will resolve the problem.

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SUNOCO-FELDA AND SUNNILAND OIL FIELDS OF HENDRY AND COLLIER COUNTIES, FLORIDA

by

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SUNOCO-FELDA OIL FIELD

The Sunoco-Felda oil field, which is the newer of Florida's two currently producing fields, and which was discovered by the Sun Oil Company on October 9, 1964, is located in Hendry and Collier counties of southern Florida. The structural configuration of the field is shown in figure 1; the character on representative induction-electrical logs of the marker contoured is depicted in figure 2, a cross section. At the present time (December 31, 1967) this field contains 26 producing wells drilled on 160-acre spacing, and it appears that nine dry holes have mostly defined the limits of the field. It is possible that additional fields are present along a northwest-southeast trend of which the Sunoco-Felda field is a part.

The Sunoco-Felda field produces on pump from the miliolitic limestone of the Roberts zone, which is reached at a depth of about 11,460 feet, and which occurs 60 feet below the top of the Sunniland Limestone of Lower Cretaceous (Trinity) age. A large percentage of salt water is yielded by upgradient producing field wells to the north, where the porosity of the Roberts zone is reported by the operator to be poor. Woodson R. Oglesby (1967, p. 278) has suggested that a hydrodynamic barrier may have contributed to the oil accumulation in the Sunoco-Felda field.

The yield of the central wells in the field ranges from 230 to 300 BOPD. During the month of August, 1967, production was 80,995 barrels of oil, with an estimated 101,090 barrels of salt water. Cumulative production from the field since its discovery through August 31, 1967, is 2,386,407 barrels of oil, the gravity of which is about 24.5 degrees API.

SUNNILAND OIL FIELD

The Sunniland oil field (figure 3), discovered by the Humble Oil and Refining Company in 1943, is located about 18 miles south of the Sunoco-Felda field. During the month of August, 1967, this field produced 49,196 barrels of oil per day. This increases the average daily yield of the field in 1961 by 62 percent, and reflects the opening to production, beginning in 1962, of new and better zones in a total of nine wells. These new zones are not more than about 50 feet deeper than those from which production previously was obtained. Cumulative production from the field through August 31, 1967, is 10,337,671 barrels of oil, the gravity of which ranges from 19 to 26 degrees. At this time, it is thought that 30 million barrels of oil probably is a reasonable figure for the initially recoverable reserves of the field. The short-

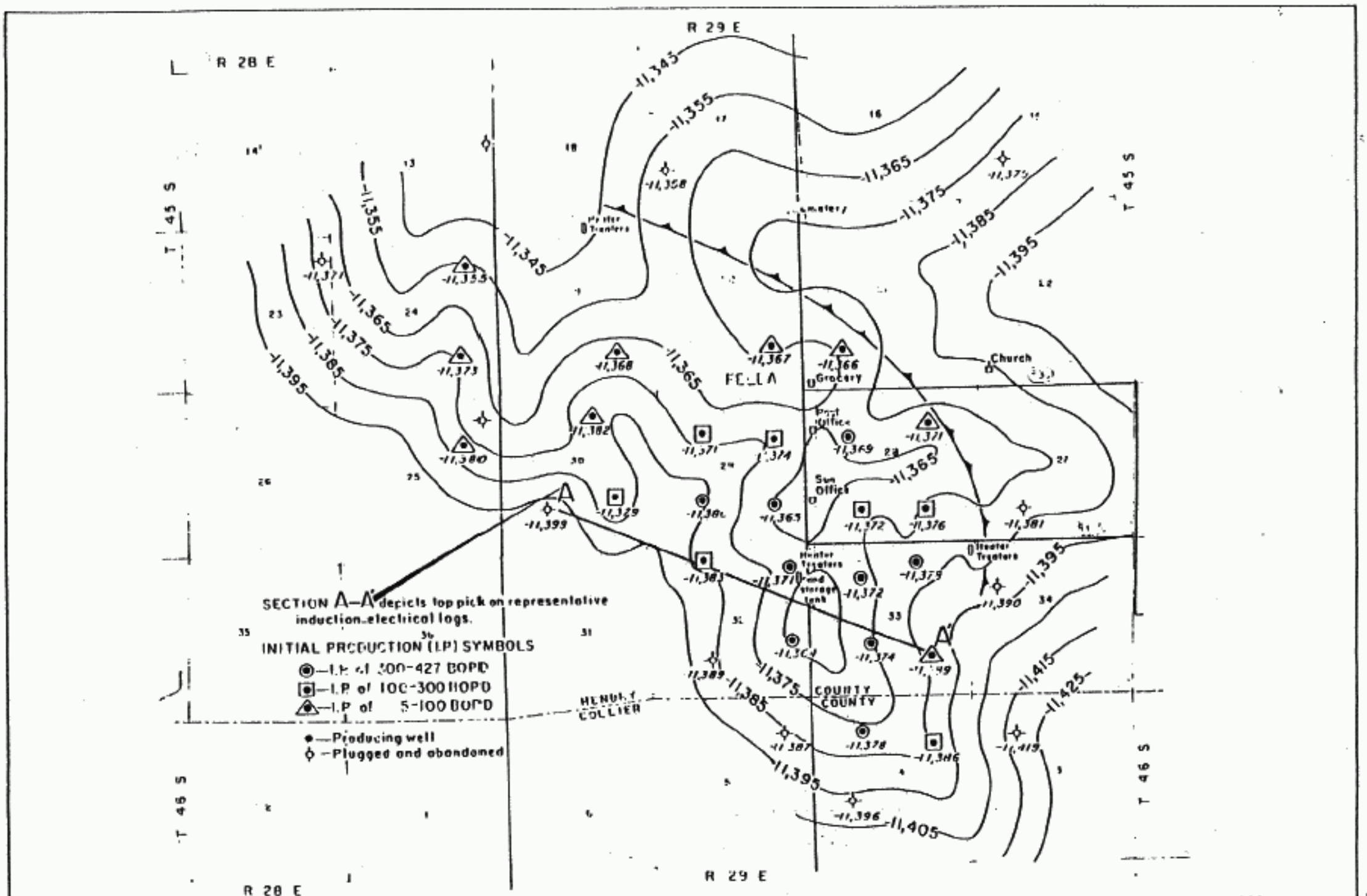
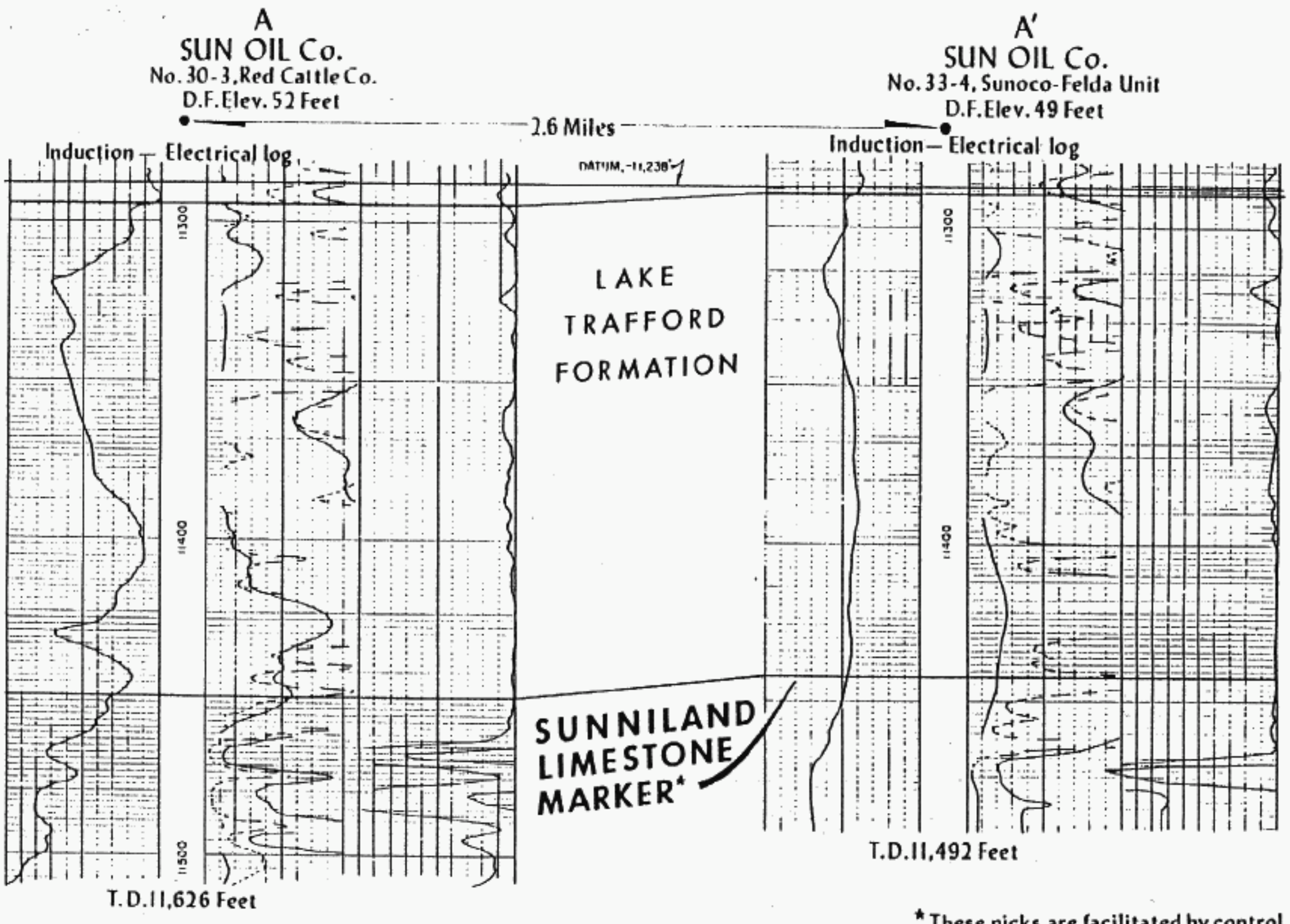


Figure 1. Structure map on top of the Sunniland Limestone, Sunoco-Felda Field, Hendry and Collier counties, Florida.



NOTE: Location of this section shown on Figure 1

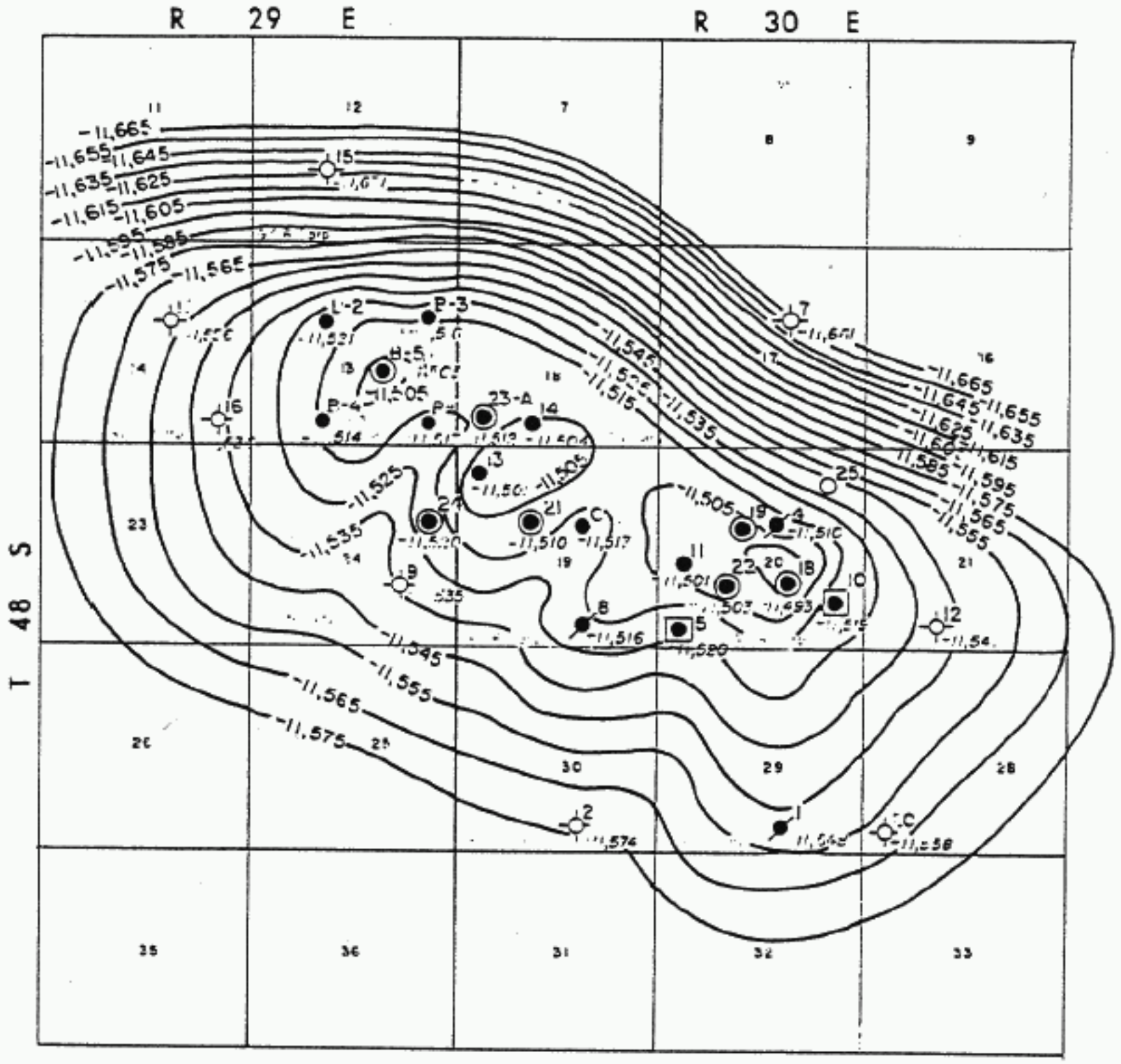
Figure 2. Section A-A', depicting character of Sunniland Limestone marker, Sunoco-Felda field, Hendry and Collier counties, Florida.

lived Forty Mile Bend field is the only additional discovery of a field similar to the Sunniland field.

Production in the Sunniland field is obtained from calcareous rock containing mostly disoriented macrofossils (rudistids) which is reached at a depth of about 11,500 feet. The trap is a gentle anticline associated with a biostromal reef. Productive zones begin at the top of the Sunniland Limestone and extend to a depth of about 75 feet lower in the section; the lowermost of these zones is correlative with the productive Roberts zone of the Sunoco-Felda field. Production ranges from 552 to 31 BOPD associated with 9 percent and 88 percent salt water, respectively.

REFERENCE

Woodson R. Oglesby, 1967, A gravity profile of the south Florida shelf, in Trans. Gulf Coast Association of Geological Societies (J. R. Sandidge, ed.), v. 17, p. 278-286.



EXPLANATION

- Producing well
- New producing well (Completed 1962-1965, incl.)
- Old producing well, deepened (Re-completed, 1963)
- Drilling well
- Abandoned producer
- Plugged and abandoned (initially)

-11,558 Datum below sea level

20 Well number

Contour interval 10 feet

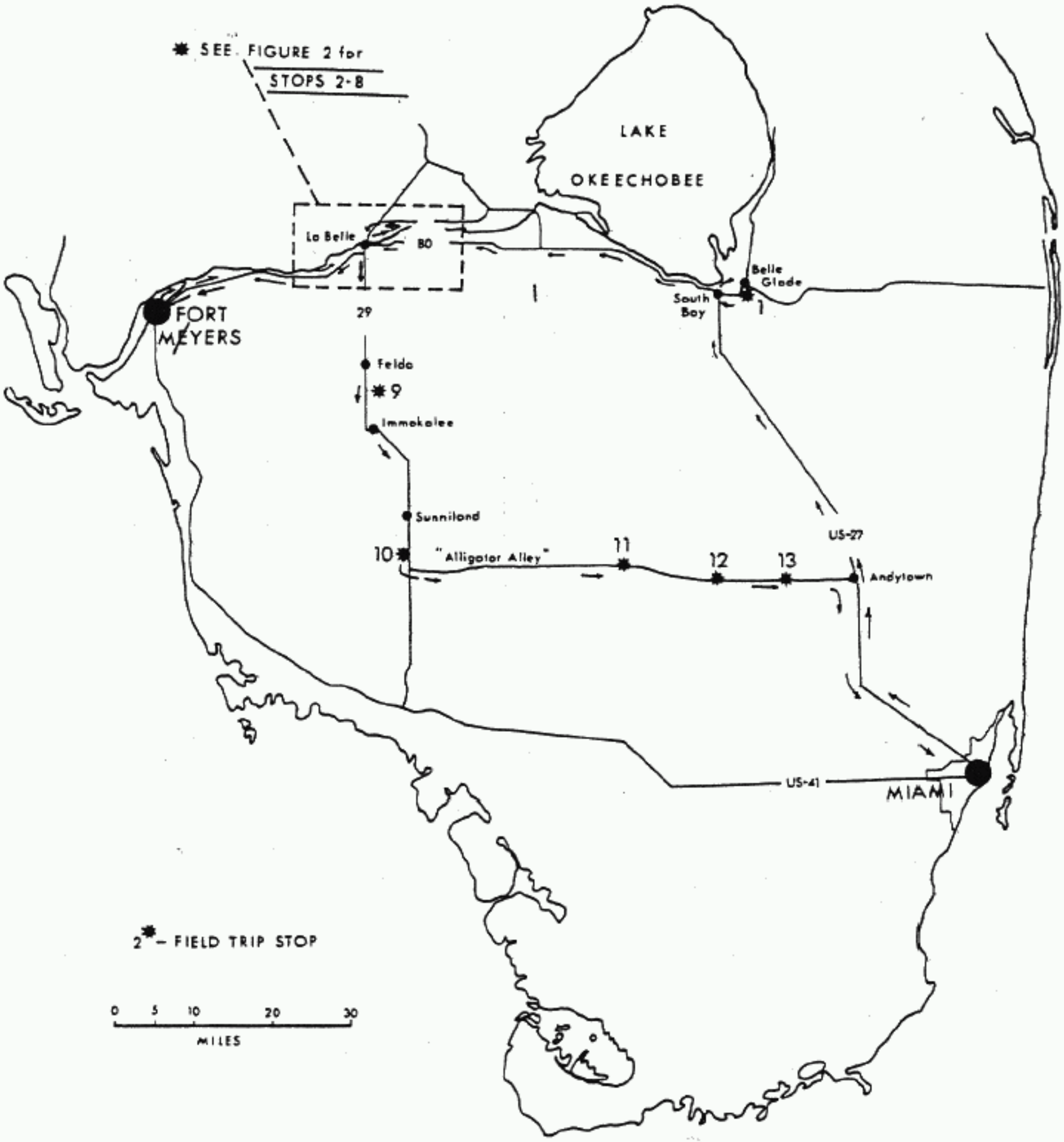
Figure 3. Structure map on top of the Sunniland Limestone, Sunniland field, Collier County, Florida.

APPENDIX

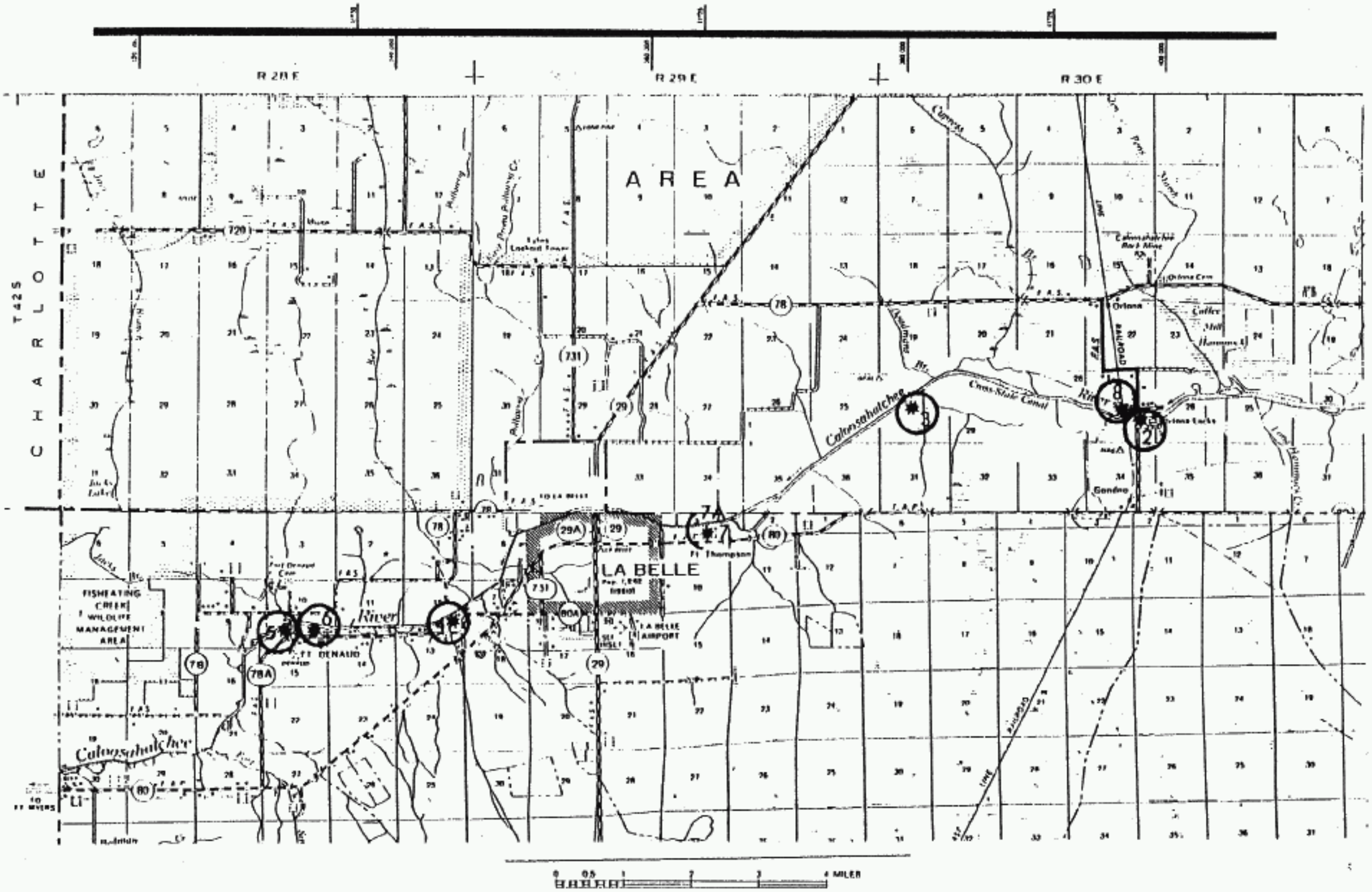
INDEX MAPS OF FIELD TRIP STOPS

ROAD LOG

GRAPHIC SECTIONS OF STOPS 2 THROUGH 8



Index map showing field trip route and locations of stops.



Detailed index map of field trip stops between Ortona Lock and Fort Denaud.

ROAD LOG

Mileage Interval	
0 mi.	Miami; proceed to Andytown via U. S. 27.
32 mi.	Andytown.
41 mi.	South Bay, intersection of U. S. 27 and State Road 80. Proceed east on State Road 80.
2.5 mi.	Entrance to Belle Glade Rock Company Quarry.
	STOP 1. Belle Glade Quarry, NE 1/4, Sec. 7, T.44S, R.37E. This stop will permit excellent fossil collecting from spoil piles on the edge of the pit. Much of the collecting in south Florida is done from such spoil piles, making precise stratigraphic paleontology very difficult, and, in many cases, impossible. Much of the fossil material found here is believed to come from Unit A.
	Return to South Bay via State Road 80. Turn north on U. S. 27.
16 mi.	Clewiston; proceed westward on U. S. 27.
10 mi.	U. S. 27 curves northward; proceed westward on Florida 80.
15.5 mi.	Goodno, "McGill's Market" at northwest corner of intersection. Turn northward on slightly improved road and proceed to Ortona Lock.
	STOPS 2 through 8 prepared by H. K. Brooks. See accompanying graphic sections.
1.4 mi.	STOP 2. Park out of way of construction company involved in widening of Caloosahatchee Canal. We will later return to the north bank. Please do not cross railroad bridge. The measured section is at the waterfall in the drainage ditch 600 feet west of the lock. The same zones as well as the Fort Thompson can be seen in the canal bank westward toward the railroad bridge.
LUNCH	Return to bus. Proceed westward on construction road paralleling south bank of the canal.
0.2 mi.	Railroad, proceed westward.
0.1 mi.	Coffee Mill Hammock can be seen in north bank at its type exposure.
1.1 mi.	Culvert.
1.8 mi.	Culvert. Note the development of the Lake Flirt Marl exposed in the north bank.

Mileage
Interval

0.5 mi.

Culvert.

0.3 mi.

STOP 3. This is the area of maximum development of the Lake Flirt Marl. The three marl units separated by mucks can be studied in exposures on the canal bank.

Return to bus and proceed westward noting that the marl units slowly disappear in a muck sequence.

1.8 mi.

Culvert. Marine units of Coffee Mill Hammock and Fort Thompson Formations can be seen rising westward on north bank of the canal. We are approaching the type area of the Fort Thompson.

1.5 mi.

Culvert.

0.3 mi.

Optional stop. This is the Fort Thompson type locality. The classic exposures have been destroyed in widening the canal. As yet the banks have not weathered and eroded sufficiently to facilitate study. Stop 7, to be visited tomorrow, is directly across the canal to the north. The exposed strata are essentially the same on both sides of the canal.

0.3 mi.

Turn left toward the south and proceed on trail through pasture.

0.3 mi.

Intersection with Florida 80, turn right and proceed westward.

0.6 mi.

La Belle. White house to right (north) is home of owner of Fort Thompson site. If you wish to return, permission and key to gate lock can be obtained from Mr. W. B. Barron.

1.0 mi.

Downtown La Belle. Intersection with Florida 29. Proceed westward on Florida 80.

0.7 mi.

Road curves toward the southwest.

1.3 mi.

Intersection, S-80A to left (east). Turn right, west, on Ft. Denaud Road.

0.5 mi.

At curve in road proceed straight into lane. Bear right by bougainvillea bush and park near little white house.

0.05 mi.

STOP 4. Type locality of the Caloosahatchee Formation. Please keep in mind that geologists need to remain on good terms with the owner of this and the adjacent property. Do not make a collection here except from materials that have washed out of the bank. The section we will study is just west of the live oak tree on the bank of the Caloosahatchee canal.

Return to bus. We will now return to Florida 80 and proceed west to Ft. Myers for the night.

30 mi.

Fort Myers.

Mileage Interval

Bus will leave the Holiday Inn at 8:00 A.M. and proceed eastward on Florida 80.

17.4 mi. Alva intersection, proceed eastward.

5.5 mi. Turn left (north) onto Fla. S-78A.

2.0 mi. Road curves to right (east).

0.5 mi. Road curves to left (north).

0.2 mi. Denaud; intersection, proceed northward to bridge.

0.15 mi. STOP 5. Park in area to right near attendant's shack south of bridge. The section presented is a composite of the exposures east of the bridge, under the bridge, and west of the bridge. A ladder leads down to waterlevel under the bridge. Boats will be available to assist in examination of the strata.

Return to bus; turn around and proceed southward on S-78A.

0.15 mi. Intersection at Denaud; turn left (east) onto Ft. Denaud Road.

0.3 mi. Turn left (north) onto dirt lane.

0.2 mi. STOP 6. Park near canal. The measured section is a few hundred feet to the east on the south bank of the canal near a pile of rotten lumber.

Return to bus; turn around, and return to Ft. Denaud Road.

0.2 mi. Turn left and proceed east on Ft. Denaud Road.

1.0 mi. To your left is an abandoned meander of the original Caloosahatchee River as it was before construction of the canal. It was a "river" such as this that Heilprin explored in 1886.

0.5 mi. Abandoned meander.

0.8 mi. Road curves to left (northward).

0.3 mi. Road curves to right. To your left is the site of our last stop yesterday (Stop 4).

0.5 mi. Intersection, turn left (northeastward) onto Fla. 80.

2.0 mi. Downtown La Belle. Turn left (northward) onto Fla. 78 and 29.

0.5 mi. Bridge over Caloosahatchee Canal.

0.2 mi. Fla. 78 to left. Proceed north on Fla. 29.

0.9 mi.

Mileage Interval

2.6 mi.

Turn right (eastward) on Fla. 78.

6.3 mi.

Ortona; turn right (southward) onto access road to Ortona Lock.

1.0 mi.

Road curves to the left. At bend proceed on southward through gate and through pasture.

0.6 mi.

Turn right onto road paralleling canal. Note the facies and units of the Lake Flirt marl as we proceed westward.

0.5 mi.

Culvert.

0.8 mi.

Culvert.

0.5 mi.

Culvert.

0.6 mi.

Culvert.

1.5 mi.

Culvert.

1.6 mi.

STOP 7. Park before road descends to next drainage ditch and culvert. Two sections are given for this locality which is opposite the classic Fort Thompson site. The strata can be studied from about 1000 feet eastward on the bank of the canal to the drainage ditch to the west. An excellent exposure of the Fort Thompson Formation is found in the drainage ditch just north of the culvert.

Return to bus; turn around, and return to the Ortona Lock access road.

6.1 mi.

Turn right (eastward) onto paved road.

0.3 mi.

Railroad crossing.

0.3 mi.

Road curves to right (southward).

0.5 mi.

STOP 8. Enter picnic area and park.

LUNCH

The section measured is on the north bank of the canal just west of the entrance to launching facility. You should walk about 1000 yards further to the west across the railroad tracks to see the type exposure of the Coffee Mill Hammock Formation.

Return to bus and retrace direct course to La Belle.

12.6 mi.

Intersection of Fla. 80 in La Belle, turn right (west).

0.05 mi.

Turn left, south on Fla. 29.

Mileage Interval

15 mi.

Felda. This is the area of the Felda Field of Sun Oil Co.

STOP 9. (optional) If a drilling rig is in operation in the Sunoco-Felda or the Sunniland oil field at the time of our trip, a stop is planned.

10 mi.

Immokalee. This is a center of winter truck crops.

12 mi.

Sunniland. Note the oil wells of Humble Oil and Refining Company, the Sunniland Field, and the large rock quarries developed in the Tamiami Limestone (upper Miocene).

In the banks of the canal along the east side of the road can be seen horizontal beds of the Tamiami at water level and a few feet above.

STOPS 10 through 13 prepared by Axel A. Olsson, Fred W. Meyer, and Donald R. Moore. Mileages are approximations.

5 mi.

STOP 10. Abandoned pit on west side of road where several large blocks of Tamiami can be examined with well preserved fossils. Many fossils are composed of original calcite, such as oysters, pectens, and sea urchins; others are preserved as impressions which show delicate shell sculpture in such detail that they can be readily identified. It should be noted that many of these fossils will be the same as those we shall see in the Pinecrest; others are species restricted to the Tamiami. Notice in particular Carditamera tamiamiensis which we can compare with specimens at Stop 11. One of the blocks in this rock pit contains a new species of Semele, as yet undescribed.

1 mi.

Intersection with Everglades Parkway ("Alligator Alley").

0 mi.

Proceed east on "Alligator Alley." This is a new toll road between Fort Lauderdale and Naples which crosses the central part of the Everglades and has only recently been opened for traffic. During construction, it afforded unexcelled collecting of Pinecrest fossils before the sites were leveled and planted with grass. We will follow the road eastward to its junction with Route 27 at Andytown, a distance of about 57 miles. Three stops will be made along this road; one in the Pinecrest and two in the Fort Thompson. "Alligator Alley" crosses the low-lying country of the Everglades (approximately 13 to 14 feet above sea level) which is partly under water during wet years. Topographically higher areas are vegetated by stands of Pines and Cabbage Palms. Along the north side of the road is a shallow canal which furnished the fill for the road embankment. The first 10 miles or so of this road are apparently underlain by Tamiami, but the spoil banks along this stretch are thickly overgrown with vegetation and haye

Mileage Interval

not been examined. Beyond this point, for a distance of 20 miles, a change of formations becomes evident, with white sand from the Pinecrest making up most of the spoil along the side of the canal.

29 mi.

STOP 11. Seminole Indian Reservation, canal bridge. The canal runs north-south with high banks of spoil material on the sides. This locality is approximately one mile west of the Broward-Collier County line. Here we shall collect fossils from the Pinecrest from the spoil banks. It should be noted that throughout the length of the road there is no evidence of any Caloosahatchee or Unit A. The Pleistocene Fort Thompson Formation rests directly on the Pinecrest.

Good fossil collecting is obtained here of a typical Pinecrest assemblage with pelecypods predominating. The most interesting as well as dominant species are Chione ulocyma and Mercenaria tridacnoides, both typical Miocene species. Note should be taken that many of the bivalves are found with closed, double valves showing that they represent an in situ fauna and that none of the other fossils show evidence of being transported. The two common Turritella, T. evergladeensis and pontoni, are found here as they are everywhere in the Pinecrest. They are particularly abundant at Pinecrest on the Tamiami Trail west of Miami. In the bank of the canal, the upper surface of the Fort Thompson limestone with deep potholes can be seen at water level indicating that the Pinecrest sands lie directly below.

Those of the party who are fossil collectors will have time to secure many of the typical forms. The large Carditamera tamiamiensis are the same as those found in the Tamiami Limestone at Stop 10. The large oyster is Ostrea (Pycnodonta) haitensis Sowerby, a common Miocene species found throughout the Caribbean and in northern South America.

Proceed east along "Alligator Alley." For the last 25 miles to the exit at Andytown the road crosses the Fort Thompson Formation, which yields the large blocks of limestone seen along the sides of the road.

STOPS 12 and 13. Two short stops will be made to examine blocks of Fort Thompson which consist of massive limestone and fine-grained quartz sand. Limestone blocks predominate at some places to the exclusion of the sand. The limestone occurs as two facies; marine and fresh-water, the latter recognized by a dark gray to nearly black color, a fetid odor when broken, and the presence of fresh-water, pulmonate snails. The marine limestones have a yellowish or brownish color and contain marine fossils such as Chione, Arca, and various lucinids. In some blocks, the texture varies from laminated to breccia-like and contains shard-like fragments of black, fresh-water

Mileage
Interval

limestone. Search should be made for pieces containing oolites as well as bryozoans. The upper surfaces of some of the blocks show deep, circular pot-holes, as we have seen overlying the Pinecrest at Stop 11. In the sandy facies, Recent shells can be seen, the commonest being Chione cancellata, and a rounded, spherical, smooth-surface lucinid (Loripinus chrysostoma). The sand also contains bonelike sand aggregates, as well as various tubes which are the cemented burrows of marine invertebrates such as the mud-shrimp (Squilla). The fresh-water snails are mainly Planorbids of the genus Helisoma. Right and left-handed coiled forms are present: H. connati and distoni (dextral), and H. scalaris (sinistral with an elevated spire). These snails are restricted to south Florida and denote climatic conditions like those of today.

57 mi.

Andytown; proceed south on U. S. 27 to Miami. End of trip.

NOTES

FM. UNIT | Thickness in feet

COFFEE HAMMOCK — 6

FORT THOMPSON — 3

CALOOSAHATCHEE
Bee Branch — 2
Fort Denaud — 1

W.L. 1967

STRATIGRAPHIC SECTION

STOP 2

Waterfall where drainage ditch joins Caloosahatchee Canal, south side, 600 ft. W. of Ortona Lock, Sec. 27, R. 30E., T. 42S., Glades Co., Fla.

Sand, mucky, fine, dusky yellowish-brown, 12 in.

Sand & shell, Chione cancellata dominant, grayish-brown, 8-16 in.

Unconformity

Marl, 20-30% fine quartz sand, slightly consolidated, marine shells discontinuous in lower foot, 12-14 in.

Unconformity, solution pipes common.

Limestone, hard, consolidated, silicious calcarenite and shell, 6-18 in.

Calcarenite and shell, some quartz, diverse Caloosahatchee fauna, semi-consolidated at top, 12-18 in.

Shell hash in calcarenite matrix, large clumps of Vermicularia recta, pale grayish-orange, 12-14 in.

Unconformity

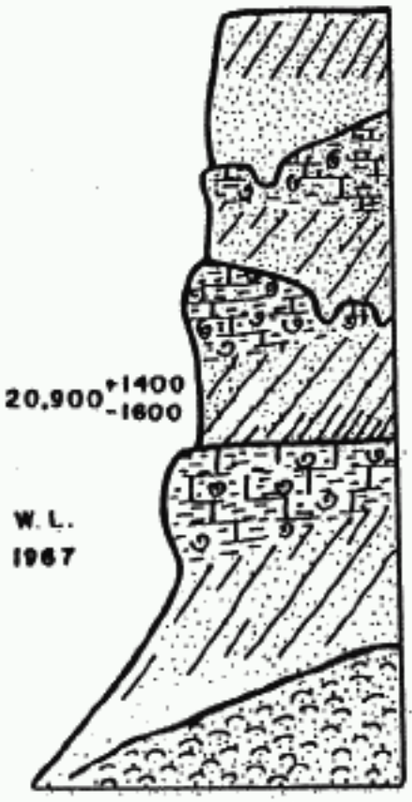
Marl, semiconsolidated, pale yellow-brown, 0-8 in. Calcarenite and shell, grayish orange, 60-70% shell, 24 in.

Section by H. K. Brooks

NOTES	FM.		Thickness in feet	STRATIGRAPHIC SECTION

STOP 3

South bank Caloosahatchee Canal, 4 mi. W. of Ortona Lock, Sec. 30, R.30E., T.42S., Glades Co., Fla.



Sand, mucky, brownish-black, 7 in.
Sand, fine, no fossils, 6-8 in.
Marl, very sandy, abundant f.w. snails, light olive gray, 2-8 in.
Sand, mucky, olive gray to brownish-black, 8-12 in.

Marl, minor sand, plastic, abundant f.w. snails, 0-8 in.
Muck, sandy, plastic, brownish-black, 8-12 in.
Marl, clayey, minor sand, plastic, yellowish-gray, abundant f.w. snails, 6-10 in.
Sand, mucky, 12-24 in.

Unconformity
Sand and Shell.

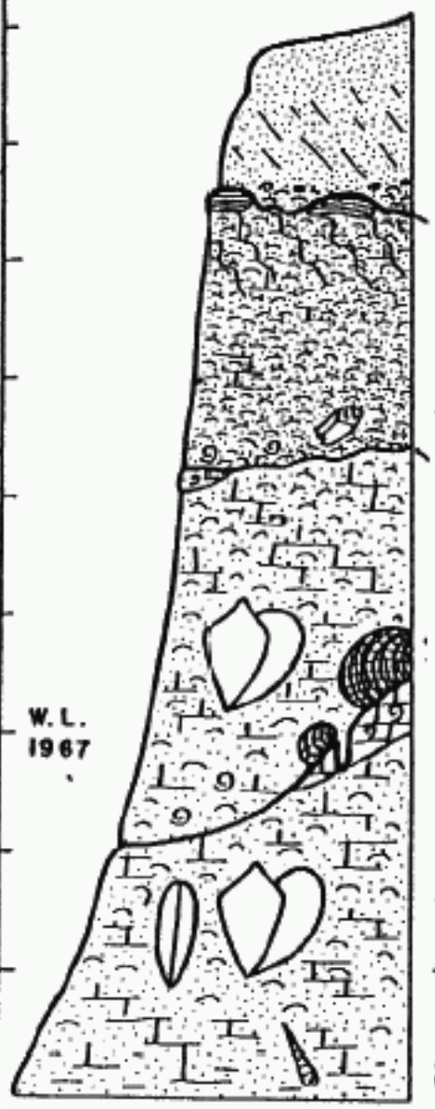
Section by H.K. Brooks

NOTES

STRATIGRAPHIC SECTION

STOP 4

South bank of Caloosahatchee Canal, 2.5 mi. W. LaBelle, Sec. 12, R. 28 E., T. 43 S., Hendry Co., Fla.



Sand, fine, gray to very pale orange, 4-6 in.
Sand, fine, humates, dark brown 12-14 in.
Relics, Chione cancellata, 0-2 in.
Unconformity
Relics, laminated crust, 0-2 in.
Sand and shell, Chione cancellata abundant, few extinct species. Equus sp. teeth at base, 24-30 in.
Unconformity, relic f.w. ls. Calcarenite, 20-40% quartz, Caloosahatchee fauna, coral heads at base, soft to semiconsolidated, 24-36 in.
Unconformity
"Cap rock", consolidated f.w. marl, hard, 0-8 in.
Calcarenite, 20-30% quartz, shells abundant, Turritella in lower clay marl, Caloosahatchee fauna, Cyrtopleura costata, 2+ feet.

Section by H. K. Brooks

NOTES

FM.	UNIT	Thickness in feet
COFFEE MILL HAMMOCK	6	
FORT THOMPSON	3	
CALOOSAHATCHEE Fort Denaud Bee Branch	2	
	1	W.L. 1967

STRATIGRAPHIC SECTION

STOP 5 Fort Denaud Bridge, south bank of Caloosahatchee Canal, Sec. 15, R. 28 E., T. 43 S., Hendry Co., Fla.

Sand, medium to fine, very pale orange. 6-12 in.

Sand, medium, grayish orange, 12-24 in.

Sand and shell, Chione cancellata predominant, occurs in solution pipes and as discontinuous bed, 0-14 in.

Unconformity

Limestone, marine shells in lower portion, f.w. snails in upper portion, hard, dense, solution pipes, laminated crust, 12-18 in.

Limestone, cobbly, porous, sandy, 18-24 in.

Unconformity

Consolidated f.w. marl, 0-6 in.

Calcarenite with abundant mollusk shells, some quartz sand, pectens at base, cobbles of f.w. limestone, 18-30 in.

Unconformity

Consolidated f.w. marl, 0-9 in.

Limestone, consolidated, fossiliferous calcarenite, some quartz, soft to hard, solution riddled.

Section by H. K. Brooks

NOTES

FM. UNIT

Thickness in feet

SURFICIAL SAND

FORT THOMPSON

CALOOSAHATCHEE

Bee Branch

2

W.L. 1967

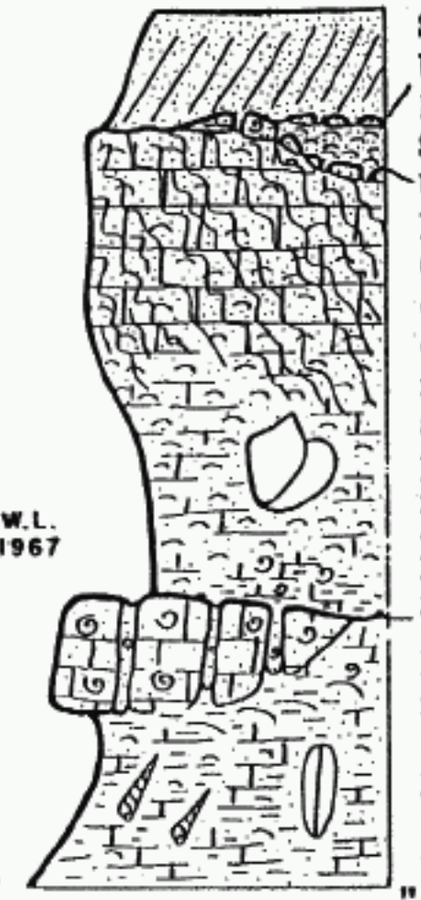
Fort Denaud

1

STRATIGRAPHIC SECTION

STOP 6

Two thousand feet east of Fort Denaud Bridge, south bank of Caloosahatchee Canal, Sec. 15, R. 28 E., T. 43 S., Hendry Co., Fla.



Sand, mucky, blackish-brown, 12 in.
Unconformity
Limestone, sandy, hard, 0-2 in.
Sand and shell, 0-6 in.
Unconformity
Limestone, sandy, f.w. snails, 0-4 in.
Calcarenite and shell, considerable quartz sand, shells common to abundant, Caloosahatchee fauna, oyster, Rangia and f.w. snail shells mixed into lower portion, patches of transgressive f.w. marl at base. Upper portion weathered to a nodular porous limestone, 40-48 in.
Unconformity
Limestone, sandy, abundant f.w. snail shells, hard, solution pipes, 0-12 in.
Marl, plastic, 20-30% fine quartz sand, oysters, etc. mixed with f.w. snails below "cap rock", "Cyrtopleura costata zone", 2+ feet.

Section by H. K. Brooks

NOTES

FM.	UNIT	Thickness in feet
LAKE FLIRT		
COFFEE MILL HAMMOCK	6	
FORT THOMPSON	5	
	4	
	3	

STRATIGRAPHIC SECTION

STOP 7 North bank of Caloosahatchee Canal, 140 yds. E. of culvert, 1.7 mi. E. of bridge at LaBelle, Sec. 3, T. 43 S. R. 29 E., Hendry Co., Fla.

Sand, fine, muck, very dark gray, 14 in.

Marl, unconsolidated, very sandy, pale yellowish-brown, 18 in.

Unconformity

Sand and shell, fine quartz, slightly calcareous, Chione cancellata extremely abundant, other mollusks uncommon, 18-24 in.

Unconformity

Limestone, sandy, 0-3 in.
Sand and shell, calcareous, 0-8 in.
Sand, calcareous, f.w. snails, 4-13 in.

Unconformity

Limestone, sandy, f.w. snails, laminated crust, 9-18 in.

Unconformity

Limestone, sandy, f.w. snails, solution pipes penetrating through superimposed unit, 18 in.
"Chlamys gibbus irradians zone" marine, brackish and f.w. shells, in calc. sandy matrix.

Section by H.K. Brooks

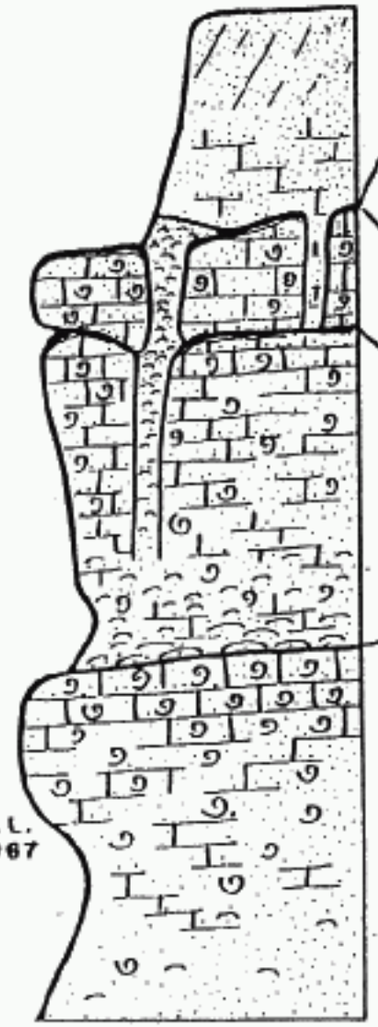
NOTES

STRATIGRAPHIC SECTION

STOP 7A

Waterfall in slough north of culvert, N. side Caloosahatchee Canal across from Fort Thompson, 1.7 mi. E. of bridge at LaBelle, Sec. 3, T. 43 S., R. 29 E., Hendry Co., Fla.

FM.	UNIT	Thickness in feet
LAKE FLIRT		
COFFEE MILL HAMMOCK		6
		4
FORT THOMPSON		3
CALOOSAHATCHEE		2



Sand, mucky, black, 12-14 in.
Marl, very sandy, abundant Helisoma, 12 in.
Unconformity
Sand and Shell, in patches.
Unconformity
Limestone, very hard, sandy, f.w. snails, laminated crusts, 6-12 in.
Unconformity
Limestone, sandy, soft at bottom becoming very hard at top, caliche crust, solution pipes, abundant Helisoma, 24 inches.
Sand and shell, calcareous, pectens at base, 6-8 in.
Unconformity
Marl, sandy, semiconsolidated, becoming a med. hard limestone in upper few inches, 12-14 in.
Sand, fine, slightly calcareous, Helisoma and an occasional Mulinia, greenish-gray, 2 feet.

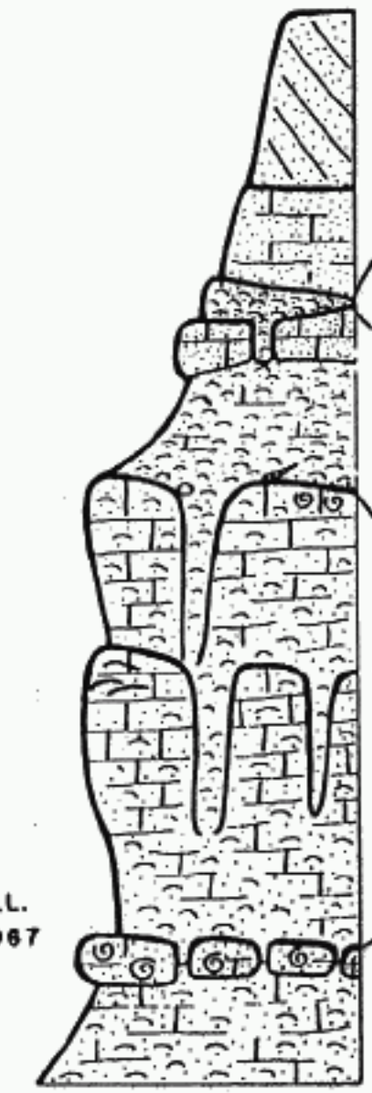
Section by H. K. Brooks

NOTES

STRATIGRAPHIC SECTION

STOP 8

Point on north side of Caloosahatchee Canal at entrance to docking and launching facility at Corps of Engineering Park, Ortona Lock, Sec. 27, R. 30 E., T. 42 S., Glades Co., Fla.



Sand, mucky, dusky brown, 18 in.

Marl, sandy, yellowish-gray 12-14 in.

Unconformity

Sand and shell, 4 ft. thick west of RR bridge.

Unconformity

Limestone, sandy, hard, 4-6 in.

Sand and shell, diverse fauna, 12-16 in.

Unconformity, solution pipes.

Limestone, sandy, few f.w. snails, very hard, 18 in.

Sand and shell, calcareous, 0-6 in.

Unconformity

Limestone, sandy, patches of oysters at top, med. to hard, 18 in.

Calcarenite, sandy, Caloosahatchee fauna, 8-12 in.

Unconformity

Limestone, very sandy, hard, dark yellowish-brown, 4-6 in.

Calcarenite, fossiliferous.

Section by H. K. Brooks