



Figure 32. Exposure of the Ocala limestone (restricted) overlain at the top by the Suwannee limestone at locality C-108 in the Thomas pit in the SW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 36, T. 20 S., R. 18 E.

OLIGOCENE SERIES

INTRODUCTION

As generally recognized in the Gulf Coast (Cooke, Gardner and Woodring, 1943), the Oligocene series is divided into three parts. The lowest includes the Forest Hill sand and Red Bluff clay of Mississippi and Alabama and the *Lepidocyclina fragilis* zone of Florida, (MacNeil 1944, p. 1324). The middle portion is composed of the Marianna limestone and the Byram formation, which together form the Vicksburg group as restricted by MacNeil (1944). Both the Marianna limestone and Byram formation are present in Jackson County, Florida, but westward in Holmes and Washington counties, a uniform lithologic unit to which Vernon (1942, p. 56) applied the name Suwannee limestone, contains a fauna that varies from locality to locality, some containing mollusks and foraminifers that characterize the lower Chickasawhay marl of eastern Mississippi, some containing foraminifers of the marl member of the Byram formation, some containing bryozoa found in the Glendon limestone member of the Byram, and still others containing mollusks described from the type Suwannee limestone. The sediments were mapped as a unit, no satisfactory subdivisions could be made. The term Suwannee

limestone was correlated as the time equivalent of the Byram formation and the lower Chickasawhay marl.

The late Oligocene is recognized as the lower Chickasawhay in eastern Mississippi and western Alabama; the Suwannee limestone and the so-called Flint River formation are equivalents in Florida. However, Vernon (1942, pp. 130-133) showed that at least part of the Flint River formation is residuum of the Suwannee and older limestones that is incorporated in Pleistocene alluvium, and the name should probably be abandoned. The Suwannee limestone and a very thin bed of limestone which Cooke (1945, p. 85) placed in the Byram limestone, and which lies between the Ocala and Suwannee limestones along the Suwannee River in Suwannee, Lafayette and Madison counties, are the only formations of the Oligocene, known to occur in peninsular Florida.

The thin bed exposed along the Suwannee River that Cooke called Byram limestone was referred by Cooke and Mossom (1929, p. 72) to the Glendon limestone, considered to be of formational rank at the time. Cooke (1945, p. 86) listed five fossils from the bed that he thought were characteristic of the Byram limestone.

SUWANNEE LIMESTONE

Introduction and Definition: The Suwannee limestone was erected by Cooke and Mansfield (1936) for yellowish limestone exposed along the Suwannee River from Ellaville almost to White Springs. The formation was considered by some writers (Cooke, 1945, p. 86) as lower Miocene and earlier was placed in the Glendon formation. The exposure on the east bank of Suwannee River opposite Ellaville is considered typical of the formation and a section measured in 1913 and published by Cooke (1945, pp. 85-86) is reproduced as follows:

After Cooke, 1945

Feet

Wicomico (?) formation (Pleistocene):

5. Upper part concealed; lower part is argillaceous yellow sand containing small pebbles; the top is level with rail at bridge 16.5

Unconformity

Suwannee limestone (Oligocene):

4. Hard cream-colored to yellow limestone resembling bed 3 but very massive and without bedding planes; *Cassidulus gouldii* (Bouvé) very abundant 10.5
3. Hard, compact chalky-white to pink crystalline limestone; lower 2 feet appears to be brecciated; upper part is thin-bedded 4.0

Unconformity

Byram limestone (Oligocene):

2. Soft white marly limestone, indurated in places; contains a few bryozoans and many fragments of *Clypeaster rogersi* (Morton) 2.0
1. White or creamy yellow compact limestone loaded with molds of mollusks; honeycombed by solution; [contains *Lepidocyclus supra* (Conrad), *Clypeaster rogersi* (Morton), *Cassidulus alabamensis* Twitchell, *Olivella affluens* Casey, *Mitra conquisita* Conrad, typical of the Bryam formation]; extends to water level 5.5

This section correlates fairly well with locality C-64 at the Crystal River Rock Company quarry, in Citrus County, pages 165-167. Bed 13 of this locality is the same as bed 4 of Cooke's locality, and beds 7 to 12 probably correspond with beds 1 to 3 of Cooke's section. No unconformity in the Oligocene was seen in Citrus County and the writer was unable to find one at Ellaville during several visits to the section although there is a definite bedding plane along the contact of beds 2 and 3 of Cooke's section.

The identification of the basal beds at Ellaville as middle Oligocene was questioned by MacNeil (1944, p. 1317) who reported that the *Lepidocyclus* occurring in these beds, originally identified as *L. supra* by T. W. Vaughan, was later identified by Vaughan as *L. georgiana*, an Ocala fossil. In a footnote MacNeil (1944, p. 1317) stated:

"Work on this fauna since the preparation of this manuscript has shown that most of the mollusks in this bed are Mint Spring species. One species occurring abundantly in this bed, however, *Turritella martinensis*, has not been found in the Mint Spring itself, but it does occur in Mississippi in the upper few feet of fine clayey sand of the Forest Hill that characteristically carries a Mint Spring rather than a Red Bluff fauna. *Turritella martinensis* also occurs abundantly in a hard white basal ledge of the Oligocene in the large quarry about 6 miles southeast of Crystal River, Citrus County, Florida. *Turritella martinensis* was described from a now abandoned and poorly exposed quarry at Martin Station, Hernando County, Florida, from a horizon believed to be high in the Ocala limestone. It now seems probable that the *Turritella martinensis* zone is basal Oligocene, but whether the species ranges downward into the Ocala limestone has not been definitely determined. *Lepidocyclus georgiana* which almost everywhere in Florida is associated with *T. martinensis* may also be Oligocene. The *Turritella martinensis* zone is tentatively correlated with the Forest Hill sand, although it may prove to be a deep-water facies of the Marianna limestone. The possibility that it is Byram, as has been assumed in the past, is unlikely."

The greater percentage of the mollusks in beds 7 to 12 of locality C-64 and in the basal beds along the Suwannee River are undescribed

and no foraminifers, other than the *Lepidocyclina* sp., were present so that the position of the beds in the Oligocene series and their exact correlation with other sections cannot be determined. There is a slight difference in lithology between the lower and upper part of the section at locality C-64, but no evidence of an unconformity was seen. *Cassidulus gouldii*, listed in bed 13 of locality C-64, characterizes the type Suwannee limestone, and its presence with *Turritella martinensis*, *T. vicksburgensis* and some of the undescribed mollusks in bed 12 indicate that beds 7 through 13 are clearly related. Since the lower section of the interval assigned to the Suwannee limestone (beds 7 to 12) contains molds of mollusks found elsewhere in the Byram formation, the Forest Hill sand and the Suwannee limestone, there is a possibility that the section at Crystal River Rock Company quarry represents a time interval of the entire Oligocene epoch, and in this respect corresponds to the usage of the term, Suwannee limestone, in Holmes and Washington counties, Florida (Vernon, 1942). Since these basal beds, numbers 7 through 12, have been identified in Citrus County only at locality C-64 and possibly at C-108, pages 170-171, it was impossible to map these beds separately and they have been included with the Suwannee limestone.

As used in this report the Suwannee limestone includes all beds of Oligocene age in Citrus and Levy counties. The upper part of the formation is considered to be the equivalent of the lower Chickasawhay marl of eastern Mississippi, and the lower part possibly the equivalent of the Byram formation and Marianna limestone of western Florida.

Physiographic Expression and Outcrop Pattern: The Suwannee limestone is absent from Levy County and crops out in central Citrus County where it caps the high hills to form part of the Tertiary Highlands. In southeastern Citrus County the outcrop widens, see Plate 1, and the formation forms a rolling hilly topography.

General Lithology: As used in this report the base of the Suwannee limestone is a cream to tan, thin-bedded, pasty, sub-granular to lithographic, dense, hard limestone, with an occasional bed being made porous by numerous molds of mollusks. The upper portion of the formation, more typical of what is usually described as Suwannee limestone, is a cream-colored, granular, detrital, porous, thin-bedded limestone filled by abundant specimens of *Dictyoconus cookei*, *Coskinolina floridana* and the echinoid *Cassidulus gouldii*. The limestone generally contains a little sand that is often identified only after complete solution of the sample in acid. Thin seams and vertical pipes of greenish-gray, waxy clay are found in many outcrops. The seams fill spaces along bedding

planes and the clay in the pipes may be limestone altered by solution. The outcrop is marked in many places by residual boulders of tan to brown, silicified limestone and chert, in which molds of *Cassidulus gouldii* are commonly preserved.

Thickness: The thickness of the Suwannee limestone is considerably less than that penetrated in the subsurface in adjacent counties. The formation has been entirely removed from over Levy County and has been thinned by erosion in Citrus County. No well, from which rock samples were available, has penetrated the formation, but the geologic section D-D', figure 13, indicates a maximum thickness of 120 feet in the county. A minimum of 59 feet of the formation is exposed at locality C-102 and 22 feet at locality C-64.

Fauna and Age: The most prominent fossils in the Suwannee limestone are two echinoids, *Cassidulus gouldii* (Bouv  ) and *Clypeaster rogersi* (Morton). Mansfield (1937) has described the mollusks of the type Suwannee and listed 34 species of pelecypods, 32 species of gastropods, one species of scaphopod, and a species of echinoid. Of these, Mansfield (1937, p. 48) recorded that *Orthaulax pugnax hernandoensis* Mansfield, *Ampullina flintensis* Mansfield, *Chlamys flintensis* Mansfield, *C. brooksvillensis* Mansfield, *Chione* sp. aff. *C. bainbridgensis* Dall, *Kuphus incrassatus* (Gabb) and *Cassidulus gouldii* (Bouv  ) as characteristic of the formation.

Of the foraminifers the upper part of the Suwannee limestone is characterized by *Dictyoconus cookei* (Moberg), *Coskinolina floridana* Cole and *Rotalia mexicana* Nuttall. These are not well-preserved in the outcrop area but in the subsurface, some samples are virtually a coquina of these foraminifers.

In addition to some of the fossils above, Mansfield (1939, p. 46) listed *Tubulostium* sp., *Pyrula* sp., *Cypraea* sp., *Ampullina*? sp., *Glycymeris*? sp., *Ostrea* sp., *Pecten brooksvillensis* Mansfield?, *Chione* sp. and *Lepidocyclina supera* (Conrad) in the Suwannee limestone of Citrus County. These fossils are present in beds 7 to 12 of locality C-64, in which the writer and MacNeil (1944) also have identified *Turritella martinensis* and *T. vicksburgensis*.

No foraminifers, other than a *Lepidocyclina* sp. presumed to be the same species that T. W. Vaughan (Mansfield, 1939) identified as *L. supera* were identified from the lower beds of the Suwannee limestone. Rare molds of the shape of *Dictyoconus* were observed but none could be definitely identified.

Stratigraphic Relations: The Suwannee limestone was observed to lie unconformably upon the Ocala limestone at two localities, C-64, page 166 and C-108, page 171, which are eleven miles apart and the unconformity is presumed to be widely spread. The upper contact is likewise unconformable, the Suwannee limestone being overlain by greenish-gray clays of the Hawthorn formation—middle Miocene, that fill valleys eroded in the Suwannee limestone. Where the Hawthorn formation is absent the Suwannee limestone is covered by sediments of the early Pleistocene or the Alachua formation, terrestrial Miocene.

Detailed Geologic Exposures: The Suwannee limestone is exposed in sections at localities C-64, C-80, C-101 and C-108, which were described in discussions of the Ocala limestone. Only at localities C-64 and C-108 are beds of the basal Suwannee limestone exposed, and these have been discussed in the descriptions of the sections and in the preliminary remarks on the Suwannee limestone. The upper beds of the Suwannee limestone are exposed in a number of road cuts, sinks and pits throughout the outcrop. The northernmost exposure is located at locality C-45 in a rock pit on John Newell's farm in the southeast quarter southeast quarter, Section 21, Township 18 South, Range 18 East where 8.1 feet of case-hardened, tough, soft, nodular to granular limestone with *Pecten* sp. cf. *P. brooksvillensis*, *Cassidulus gouldii*, *Dictyoconus cookei*, *Coskinolina floridana* are present.

Other exposures in the county are as follows:

- 1) Locality C-48: Road metal pit in the NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 24, T. 18 S., R. 18 E., on G. O. Barnes farm. The Tsala Apopka topographic sheet shows this hill to rise above 220 feet. Seventeen feet of cream, thin-bedded, very dense and hard, sub-lithographic limestone with *Cassidulus gouldii*, *Chione* sp. aff. *C. bainbridgensis* and thin partings of greenish-gray, waxy clay is exposed. A good concrete aggregate prospect.
- 2) Locality C-106: In a small sink, 200 yards southwest of J. D. Booth's home in the SW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 26, T. 20 S., R. 18 E. — 14 feet of case-hardened Suwannee limestone covered by 15 feet of soil containing silicified Suwannee limestone boulders. Similar silicified boulders are present on the Booth farm in the NW^c Sec. 25 of the same township and range.
- 3) Locality C-102: In the J. W. Conner and Sons road metal pit at the base of a high hill, upon which a fire tower is located; in the SW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 21, T. 20 S., R. 19 E.

Locality C-102

Feet

Oligocene series

Suwannee limestone

- 3) Cream, very porous, detrital, thin-bedded limestone with abundant mollusk molds, *Cassidulus gouldii*, *Dictyoconus*

cookei and *Coskinolina floridana*. Recrystallization has produced a cream, hard, dense, cryptocrystalline limestone with rare fossils molds and gives the rock an irregular bedding

2) Covered	12.0
1) Limestone of bed 3	22.0

Thickness of section

59.0

- 4) Locality C-2: Along a dirt road in a fire lane on U. S. Forest land in the W $\frac{1}{2}$ NE $\frac{1}{4}$ Sec. 9, T. 21 S., R. 19 E., at an elevation of 191.52 feet, 66 feet above the Hawthorn clays exposed in the Florida Portland Cement Company pit about 2 miles northeast — 27.3 feet of detrital Suwannee limestone with *Cassidulus gouldii*.
- 5) Locality C-13: On Alex Livingston's place in the SE $\frac{1}{4}$ Sec. 9, T. 21 S., R. 19 E. — numerous boulders of silicified limestone with many Suwannee mollusks replaced by silica. To the northeast on the land of B. I. Mayo, a crescent-shaped sink exposes 20 feet of hard, cream to tan, thin-bedded limestone containing numerous *Cassidulus gouldii* that appears to have been brecciated.
- 6) Locality C-25: A small sink north of paved road in the NE $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 35, T. 20 S., R. 19 E. — 8 feet of thin-bedded, detrital, mollusk mold-filled Suwannee limestone.
- 7) Locality C-109: Two pits, formerly operated by the Camp Concrete Rock Company, on J. A. Landrum's land in the NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 1, T. 21 S., R. 19 E. — 46 feet of cream-colored, thin-bedded limestone composed of soft, porous, detrital beds containing hard, crystalline nodules and interbedded, dense, hard, crystalline limestone. The beds appear to be slumped in some areas of the quarry and in places are massive. The limestone is extremely fossiliferous with molds of mollusks and *Cassidulus gouldii*.

Toward the south in Hernando County the Suwannee outcrop widens and most of the higher topography of that county is underlain by the formation with the Ocala limestone being found in the valleys.

MIOCENE SERIES

INTRODUCTION

Cooke (1945, p. 109) recognized a three-fold division of the Miocene; early, middle and upper, which were represented in peninsular Florida respectively by the Tampa formation, the Hawthorn formation and the Duplin marl. The term, Duplin marl, was introduced in Florida by Cooke (1945, p. 181) for beds of upper Miocene age, the *Cancellaria* and *Ecphora* zones, that were formerly the upper part of the Choctawhatchee formation. Cooke abandoned the use of the Choctawhatchee formation, placing the lower beds, the *Arca* and *Yoldia* zones in the Shoal River formation of middle Miocene age. This division has not been fully sub-

stantiated and the Duplin marl has not been traced from Florida to its type locality in North Carolina. The abandonment of a useful and established term such as the Choctawhatchee for the Duplin appears to be unwise until the beds are traced by means of wells or exposures and found to be equivalents.

The Miocene sediments in these counties were deposited in two separate depositional environments, a terrestrial and a marine facies. The area covered by the marine Miocene in Citrus County is small compared to the wide development of the terrestrial Miocene over the remainder of Citrus and most of Levy counties. The distribution and relationships of the two facies could be interpreted only after a study was made of most of the principal Miocene exposures in the State and of the Miocene sediments in approximately 1,350 wells, drilled in 35 counties of the Florida Peninsula extending from Jefferson County to Hillsborough County. The data of this study are summarized on figures 14 and 33 as structural, isopachous and distribution maps and geologic sections. Throughout these 35 counties the Tampa formation is definitely present in only Hernando, Hillsborough, Pasco, Pinellas and Polk counties and is questionably present in southern Citrus, Jefferson, Indian River, southern Lake and Osceola counties. The Tampa formation is covered by the Hawthorn formation except where the Tampa crops out in Hernando, Hillsborough, Pasco and Pinellas counties. This outcrop is contoured on figure 33 within the area where Hawthorn is shown to be absent. In these exposures the Tampa formation is a cream to white, sandy limestone containing a distinct molluscan fauna described by Mansfield (1937) and a distinct microfauna largely undescribed, but including numerous specimens of *Sorites* and *Archaias*.

Along the western edge of peninsular Florida there is a broad area within which no marine Miocene sediments occur, except in a limited area where the Tampa and Hawthorn formations occupy valleys and irregularities developed in the underlying Suwannee limestone. Within this area, located over the Ocala uplift as outlined on figure 33, a series of sands, phosphatic clays, and phosphate beds containing fragments of silicified wood and a vertebrate fauna of early, middle and late Miocene, Pliocene and Pleistocene ages crop out. These beds were named the Alachua formation and it seems clear that they were formed as a terrestrial facies over a period of time extending throughout the Miocene epoch and possibly into the Pleistocene epoch.

Surrounding the terrestrial facies to the north, east, south and possibly west (covered by Gulf waters) are a series of deltaic and marine sands,

clays and limestone of distinctive lithologic characteristics, which compose the Hawthorn formation. These sediments contain a high percentage of phosphorite and numerous remains of shallow-water, phosphorous-loving fishes and other vertebrates. The high percentage of sand in the Tampa and Hawthorn formations indicate that they were deposited in shallow water near an elevated land mass. The marine Hawthorn is a vari-colored, sandy, phosphoritic, finely crystalline, marly limestone and calcareous sandstone with seams and beds of greenish-gray, waxy, montmorillonitic clays. The base, as penetrated by wells, is commonly a limestone pebble conglomerate interpreted as the reworked residuum of Eocene and Suwannee limestones. The best example of this basal conglomerate is contained in the samples of Florida Geological Survey well W-136, Clay County, in which the Hawthorn formation lies upon the Ocala limestone (restricted). A large, gray, dense, lithographic, hard, limestone boulder was penetrated by the well at the base of the Hawthorn formation. The boulder has a weathered, case-hardened surface into which mollusk borers have penetrated. The insides of these borings also have been weathered and case-hardened but to a degree only a fraction of that on the surface of the boulder. The borings are filled with the phosphoritic, sandy limestone in which the boulder is incorporated. This basal conglomerate clearly indicates shallow-water, boulder-strewn, transgressing marine seas.

In an area centered over the Osceola low, Plate 2, and counties to the east, the Hawthorn formation is a radiolarian-phosphate-rich marl and the base of the formation may contain up to 40 per cent phosphorite. There is a tremendous thickening of Miocene sediments in this area, largely occurring in the upper Miocene, to fill the depression of the Osceola low, see Plate 2 and figure 33. The base of the formation is a phosphoritic, sandy limestone containing rounded, gray, limestone pebbles.

The terrestrial facies, the Alachua formation, being younger in part than the Hawthorn and Tampa formations, lies above these formations in some wells. In others it appears to merge with the Hawthorn formation and to replace it in the stratigraphic section. Commonly the Alachua formation is thickest where the Hawthorn formation is thickest and occurs on top of structurally low as well as structurally high marine Miocene deposits.

As illustrated in figure 13, a series of marine deposits that contain an upper Miocene microfauna is present along the coastal margins of eastern Florida. These sediments range from consolidated, very porous,

cream to gray, sandy marl with seams of greenish-gray, blocky, waxy clay to a cream, very porous altered coquina of shells, the shells having been dissolved and only molds, encrusted with calcite, remaining in a matrix of sandy, marly limestone. The base of these upper Miocene beds is more sandy and phosphoritic and stringers of phosphorite and limestone pebbles are common.

THE MIOCENE PROBLEM

As interpreted by Cooke (1945) and many other students of Florida geology (Cathcart, 1950), the early and middle Miocene are exposed about a breached dome, the Ocala uplift, these sediments having covered all of Florida and having been subsequently domed and eroded. In the erosion of the Hawthorn formation, middle Miocene, the phosphorite contained in it was concentrated to form the hard rock phosphate deposits and other sediments of the Alachua formation which is referred to the Pliocene by these writers. Following the widespread deposition in Hawthorn time, the sea withdrew beyond the present shore line and in late Miocene time the sea again invaded the land, part of which may have remained above sea level as an island, (Cooke, 1945, p. 109.)

Insofar as the data developed during this study are concerned, there is evidence that the Miocene marine beds, represented elsewhere in the Florida Peninsula by the Tampa and Hawthorn formations, never extended across the Ocala uplift and completely covered it. No residuum of these formations occurs in this area, although there is a tremendous thickness of residuum of the Suwannee and Ocala limestones mixed with phosphatic clay, fine sand, silicified wood, and remains of vertebrate animals of early Miocene to Pleistocene ages. These sediments compose the Alachua formation and are clearly a terrestrial deposit. In other areas where the Tampa formation is weathered deeply, a thick residuum of silicified shells and corals is developed, and where the Hawthorn formation is deeply weathered large numbers of shark teeth, fish and ray plates, manatee bones and silicified corals, particularly *Siderastraea* sp., are abundant. None of these fossils are present in large numbers in Citrus and Levy counties although rare specimens are found. Manatee bones are present in the underlying Eocene beds and those in the Alachua formation of these counties may be reworked from these deposits. They could also be remains of manatee, indigenous to the Alachua formation.

In southern Citrus County a massive bedded deposit of montmorillonite clay occupies depressions in the Suwannee limestone, the top of the clay lying well below the top of the limestone on surrounding hills.

The clay contains no phosphorite and is a brackish-water or marine deposit of the Hawthorn formation.

The evidence developed in the field study of Citrus and Levy counties and of the subsurface geology suggests that the Alchua formation ranges in age from the lower Miocene to the Pleistocene, and appears to be for the most part the terrestrial equivalent of the entire marine Miocene of Florida. This evidence also suggests that the early and middle Miocene deposits wedge out against the Ocala uplift and that the outcrop area of the Alachua formation is the source of large quantities of phosphoric acids from which much of the phosphorite in the Hawthorn formation may have been derived. This is strongly indicated in the distribution of phosphate in the Hawthorn formation, since the beds around the Ocala uplift contain limited quantities of phosphorite, being clays and sandy limestones, and if these are typical of the deposits that are presumed to have covered the Ocala uplift, they could not have contributed the large quantities of phosphate rock that occur in the Alachua formation. Also, the presence of the Alachua formation over sediments of the Hawthorn formation in some well samples bears no relationship to the presence of phosphorite in each formation. In some wells phosphorite occurs in the Hawthorn formation in greater concentrations than in the overlying Alachua formation. In others the Alachua formation contains greater concentrations and in some wells the Alachua has phosphorite and overlies fuller's earth of the Hawthorn formation in which no phosphorite is present whatsoever.

It is suggested that the area across the Ocala uplift was high during the Miocene and the site of a peninsular or insular area upon which bird rookeries were prominent. These rookeries contributed large quantities of phosphoric acid to shallow marine waters in Hawthorn time, part of which was precipitated as phosphorite nodules and a portion supported a large fauna of phosphorous-using vertebrates, largely fishes. The limestone composing the land mass was rapidly reduced by phosphate fixation, a very erosive process, requiring four molecules of calcium carbonate for each molecule of calcium phosphate that is formed.²⁵ A highly irregular limestone surface underlying the Alachua formation and much siliceous residues of older limestones is formed, and a ready source of phosphorite during the Miocene is provided. Table 14 illustrates this interpretation of the Miocene rocks of the Florida Peninsula.

²⁵The formula of the reaction is as follows:

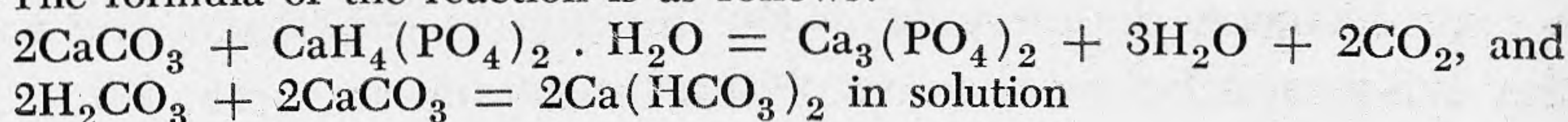
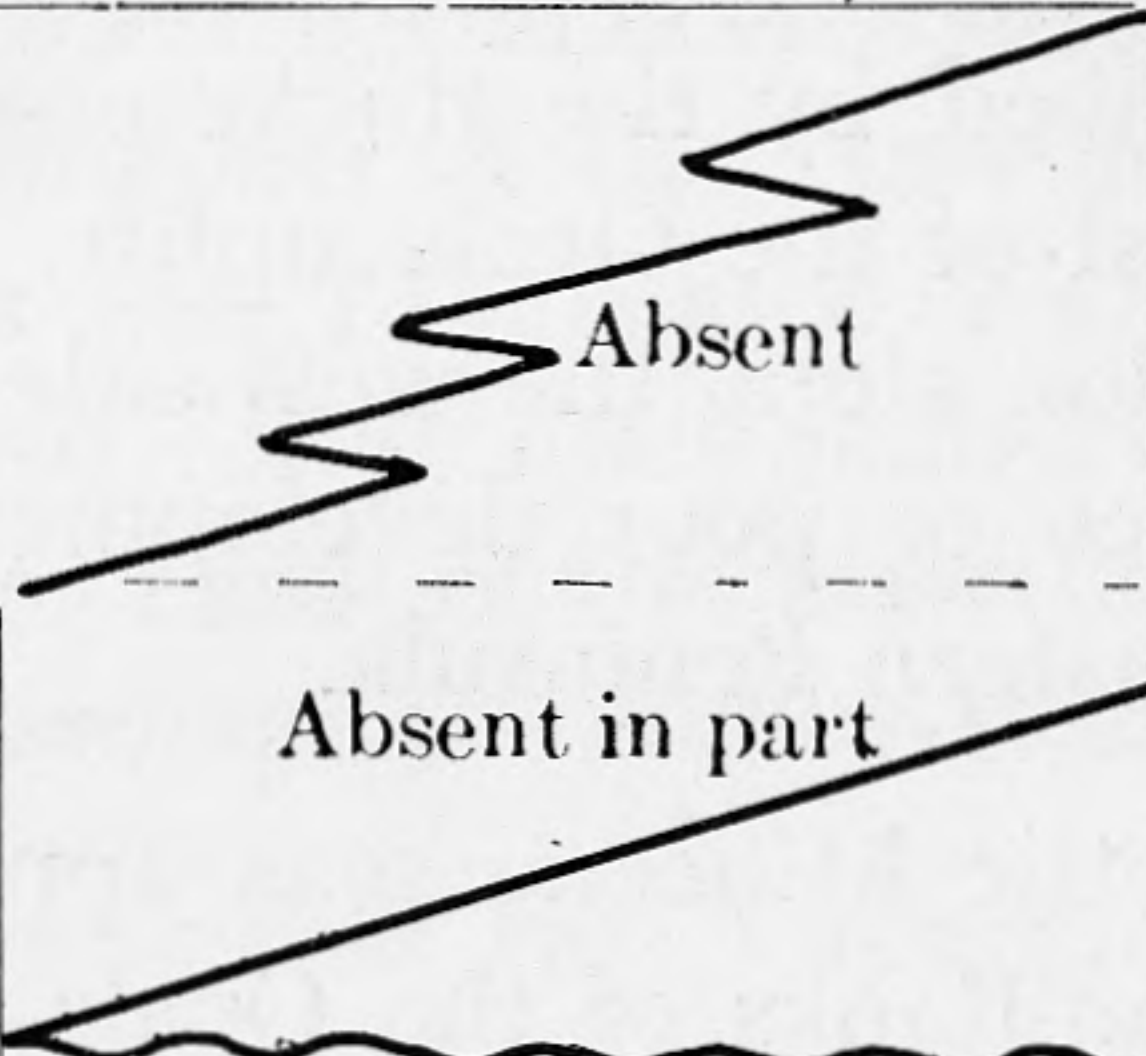


TABLE 14.

<i>Area over the crest of the Ocala uplift</i>		<i>Southwest flank of the Ocala uplift (south of Citrus County)</i>	<i>Northeast flank of the Ocala uplift (Duval County)</i>		
Miocene and possibly younger	Alachua formation (Terrestrial deposits)		Sediments con- taining upper Miocene microfauna	Upper	MIOCENE
			Hawthorn formation	Middle	
		Tampa formation	Absent	Lower	

PRE-MIOCENE SURFACE

The Miocene of peninsular Florida was deposited upon an eroded surface composed of Eocene and Oligocene limestones. Deep valleys and hills, sinks, lake basins and structural features had developed upon this surface and these irregularities were covered by sediments formed during the early and middle Miocene. A combination of the structural and isopachous data on figure 33 shows that the top of the Miocene sediments is a gentle slope but that the base of the Miocene sediments is most irregular, the sediments having thinned over high areas and thickened to fill depressions to bring the top of the Miocene to a fairly even grade. In Osceola, Brevard and Indian River counties where the Miocene is greatly thickened, over the Osceola low, a normal thickness of middle and possibly lower Miocene is present and the increased thickness is in the upper Miocene sediments.

GEOLOGIC HISTORY OF THE MIOCENE

The sediments of Miocene age were deposited upon the irregular limestone surface which appears to have been highest, in post-Oligocene-pre-Miocene time in an elongate area nearer the eastern coast line of Florida than at present, along the crest of the Ocala uplift, see figure 13. In a series of geologic sections crossing the State approximately at right angles to the axes of the Peninsula and the Ocala uplift, the Suwannee and Ocala limestones are found to be thin to absent along the east flanks of the Ocala uplift, indicating the region was high and being eroded during post-Oligocene time. The west flank is submerged by the Gulf and the stratigraphic section is not available for study.

Beginning about early Miocene time the Ocala uplift began to form along the western and northern Peninsula, the eastern and southern parts of the State were tilted downward, and marine encroachment began near the outer edges of the land mass. The encroachment was accompanied by continued doming of the Ocala uplift and tilting to the east and south. This is evidenced by the thickening of the Hawthorn sediments away from the crest of the Ocala uplift, by the presence of well-developed Tampa formation along the west side of the Florida Peninsula combined with its absence or poor development over the crest of the Ocala uplift and in the eastern Peninsula.

The encroachment of the Miocene seas apparently began in Tampa time and advanced up the flanks of the Ocala uplift, penetrating along valleys cut into the Eocene and Suwannee limestones, and wedging out against the flanks of the uplift. Since only the Tampa formation and scattered deposits of the Hawthorn formation are present in Citrus, Hernando, Pasco and part of Pinellas counties, see figure 33, it is presumed that the eastern portion of Florida stood as a land mass and that the seas were rolled back from over the western portion of peninsular Florida during early middle Miocene time by the continued movements forming the Ocala uplift. This confirms Mansfield's (1937, p. 44) contention that there was a period of uplift at the close of Tampa time.

During the time that early and middle Miocene seas were encroaching upon the State, the land mass created by the Ocala uplift probably stood as a broad plain or a series of undulating hills forming a large insular area or a narrow peninsula that extended south from Georgia along the western part of peninsular Florida.

The sediments composing the Hawthorn formation at Tallahassee, Florida, and eastward are fine-grained silts and sands interbedded with phosphatic-clayey sands, some of which are so thinly bedded as to appear laminated and some are cross-bedded. In distribution and lithology these beds resemble deltaic sediments and a large delta plain is believed to have been present over much of the area, probably abutting to the east against the peninsula or island developing along the Ocala uplift.

The Miocene delta plain and the reduced peninsula were inhabited by numerous plain-dwelling vertebrates, and the shallow marine waters were inhabited by a tremendous colony of phosphorous-loving fishes, the remains of which are prolific in the sediments of the Hawthorn formation. Sellards (1916, pp. 83-90) described a fauna found on the Griscom plantation about 15 miles north of Tallahassee, which included a horse, *Parahippus leonensis* Sellards; a dog, *Mesocyon? iamonensis* Sellards; a

camel, *Oxydactylus*? sp.; a deer-like animal, *Leptomeryx*? sp.; and indeterminate fragments of a fresh-water turtle, crocodile, shark, and eagle ray. The fossils are contained in phosphatic sands of the Hawthorn formation.

Colbert (1932) identified a rhinoceros, *Aphelops* sp., and a camel, *Oxydactylus* sp. from sediments of the Hawthorn formation exposed in a pit dug for a pump at the Tallahassee Water Works. Wood (1932) described and named two forest and plain-dwelling rodents from the sand just above the fuller's earth of the Hawthorn formation at Midway, Gadsden County; *Proheteromys floridanus* Wood and *P. magnus* Wood.

Along the Miocene peninsula two important localities of vertebrate remains were recorded by Simpson (1930, 1932). In a pit of the Franklin Phosphate Company near Newberry, Alachua County, specimens of a dog, three-toed horse, rhinoceros, deer, camel, and a large pig-like animal were identified by Simpson and the fauna was thought to be contemporaneous with that of the Griscom plantation and the Thomas farm. By far the best locality for collecting vertebrates in the eastern United States is located at the Raeford Thomas farm 8 miles north of Bell, Gilchrist County. Simpson (1932), White (1942) and Thomas Barbour have made extensive studies of the fauna and have identified 18 genera and 22 species of mammals and Wetmore (1943) described one bird, a gull, from the locality. White (1942, pp. 22-47) reported that the fauna ranged from the lower through the upper Miocene and believed the deposit was an alluvium developed in a stream which had arrived at grade during Hawthorn time. White (1942, pp. 44-45) explained the range of the fauna throughout the Miocene as accelerated development of animals trapped in the area, and was unable to offer a satisfactory explanation for the silting of the Miocene stream following a period of excavation.

The distribution of the Tampa and Hawthorn formations, figure 33, the development of the Ocala uplift in early Miocene time and the encroachment of Miocene seas upon the uplift provided a possible solution of some of the seeming ambiguity. The area upon which these animals lived was a land mass of large proportions and had been intensely eroded during post-Oligocene time. Continental deposits of the Alachua formation were extensively developed upon this land, and the deposits at the Thomas farm are believed to be Alachua in age. Beginning in early Miocene time the land mass was encroached upon by Miocene seas, and streams emptying into these seas alluviated their valleys to adjust to elevated sea levels. The western portion of peninsular Florida was a land

mass throughout all of the Miocene, being elevated along the Ocala uplift progressively throughout a period extending at least through the upper Miocene. The Hawthorn sea gradually covered the flanks of the Ocala uplift and younger beds overlap older beds in the Hawthorn formation. The ending of Hawthorn time marked the broadest development of the sea and upper Miocene seas retreated to cover limited areas along the present coast, see figure 13. The Miocene vertebrate animals of the Alachua formation have had a normal progressive evolution covering a period from early to late Miocene, during the time the Alachua formation was being developed and their remains are preserved in alluvium and sinks developed upon the land mass.

From the data on the distribution of Miocene sediments, developed during the study of Citrus and Levy counties, the following generalized observations can be made: 1) The Tertiary of Florida was high during post-Oligocene and pre-Miocene time in an area located east of the crest of the Ocala uplift. 2) There was a long period of erosion in Florida following the deposition of the Suwannee limestone. 3) The Miocene epoch was a time of great deposition, with expanding seas during the early and middle Miocene and decreasing seas in the upper Miocene. 4) The Miocene epoch was a period of crustal adjustment in Florida. 5) A large land mass, located in western peninsular Florida, was present throughout the Miocene epoch, and terrestrial sediments including Miocene vertebrates and birds and large quantities of phosphate, possibly derived from guano, were developed upon this land. 6) Terrestrial deposits of the Alachua formation and brackish-water or marine deposits of the Hawthorn formation are present in Citrus and Levy counties.

HAWTHORN FORMATION

Introduction and Definition: The beds of Citrus County to which the name, Hawthorn formation, is applied in this report were referred by Vernon (1943, p. 52) to the more comprehensive term Alum Bluff group. Because the clay composing these beds is lithologically similar to clay in the Hawthorn formation and because of the presence in it of *Ostrea normalis* Dall, a fossil characterizing the Hawthorn formation, the more specific name appears to be justified.

The type locality of the Hawthorn formation is at Hawthorne, Alachua County, and the name was proposed by Dall and Harris (1892, p. 107). As somewhat loosely used by most students today, the formation includes all phosphorite-bearing sands, sandstones, limestones and the fuller's earth clays of peninsular Florida and as thus used is the time

equivalent of all of the Miocene in parts of the State. As used in this report, the Hawthorn formation includes marine beds of Miocene age, younger than the Tampa formation, and older than marls and sands that contain a microfauna of the upper Miocene in peninsular Florida.

Physiography and Outcrop Pattern: The Hawthorn formation crops out only in the south-central portion of Citrus County, Plate 1, and occupies an irregular pattern in valleys cut in the Suwannee limestone, figure 14, D-D'. Post-Miocene erosion has removed much of the limestone that composed the valleys in which the clay was deposited. The clay now crops out on hills or slopes and erosional remnants of the Suwannee limestone rise above it. There is commonly a sharp contrast between the soils of the sand covered Suwannee limestone hills which are covered by scrub oak and a few pines, and the slopes and valleys that are underlain by the clays of the Hawthorn formation upon which hard wood and a lush vegetation, good soils, farms and groves have been developed.

General Lithology: The Hawthorn formation in Citrus County is a greenish-gray, massive to blocky clay that contains roughly 10 per cent quartz, and 90 per cent nearly pure montmorillonite,²⁶ the physical properties of which suggest that it may be bentonitic but no glass shards or other indication of volcanic ash could be detected. The clay contains minor thin beds, pellets, veins and irregular masses composed of 80 per cent opal, 10 per cent fine quartz sand grains and 10 per cent montmorillonite clay pellets. The clay is similar to clay that occurs elsewhere in the Hawthorn formation, some of which appears to have formed by direct replacement of limestone. ←

The clay in Citrus County rests upon a cream to tan, sandy, leached, marine limestone that contains unidentifiable mollusk molds and which resembles lithologically the limestone of the Tampa formation. In the absence of definite Tampa fossils and because the bed is thin and limited to two exposures the sandy limestone is included in the Hawthorn formation of this report.

Thickness: The thickest exposures of the Hawthorn formation in Citrus County are penetrated by two pits, one formerly and one currently operated by the Florida Portland Cement Company. Locality C-96 exposes 30.8 feet of clay and up to 3 feet of sandy limestone and locality C-98 exposes 25.0 feet of clay and 3 feet of sandy limestone. The formation was not penetrated by any well from which samples were available and the exact thickness is unknown. No wells in the area located be-

²⁶Description of clay and opal after Dr. C. S. Ross, U. S. Geological Survey, Washington, D. C., letter dated, October 29, 1948.

tween Citrus County and Tampa, Florida, penetrated the Hawthorn formation although some wells penetrated limestone assigned to the Tampa formation. The Hawthorn appears to be absent except for the local occurrence in Citrus County over the crest of the Ocala uplift as shown in figure 33, and is probably thin along the flanks of the Ocala uplift, upon which it apparently wedged out.

Fauna and Age: The fauna of the Miocene beds in Citrus County is limited to the known occurrence of rare specimens of *Ostrea normalis* Dall²⁷ in montmorillonite clays and unidentifiable, poorly preserved molds in the sandy limestone that occurs at the base of the clay. On the basis of the oyster and the lithology, the beds in Citrus County are believed to be middle Miocene in age and are mapped on Plate 1 as the Hawthorn formation. The sandy limestone may possibly be early Miocene in age and a facies of the Tampa formation, but are included in the Hawthorn formation in the absence of identifiable fossils.

Stratigraphic Relations: The Hawthorn formation lies in erosional valleys, unconformably upon the Suwannee limestone. It appears to interfinger and to be overlain by terrestrial deposits of the Alachua formation of Miocene(?) age but critical exposures are lacking to definitely determine the contact of these beds. Where the Alachua formation is lacking, Recent and Pleistocene sediments unconformably cover the formation.

Detailed Geologic Exposures: The Hawthorn formation is exposed only in road cuts and in pits dug for the clay that composes the formation. Only four good exposures were found, and these are described as follows:

- 1) Locality C-96: The Florida Portland Cement Company formerly operated a clay pit on George Rooks' land in the southwest quarter, northwest quarter, Section 25, Township 20 South, Range 19 East, where light greenish-gray, sandy, montmorillonite clay, 30.8 feet thick is exposed. The clay contains seams of hard, silicified clay and veins and irregular masses of opaline silica. At the base, as at the present pit of the Florida Portland Cement Company, there are 2 to 3 feet of mottled cream to white, dense, brittle, sandy limestone, leached at the top where weathered and containing irregular flattened lumps and partings of the clay that lies above it.
- 2) Locality C-98: The pit currently operated by the Florida Portland Cement Company is located on C. M. Jones' land in the southwest quarter, northwest quarter, Section 2, Township 21 South, Range 19 East, and exposes 25.0 feet of light greenish-gray, massive to blocky, sandy, montmorillonite clay that contains white, hard beds, boulders and nodules of opaline silica and rare specimens of *Ostrea normalis*. The upper 3 feet of

²⁷Identified by F. Stearns MacNeil in the field, May 4, 1950.

clay is weathered and forms a brown to black clay soil. In the faces of the quarry that have been cut into the slope of the hill, thin-bedded to massive, tan to cream, mottled, phosphatic-clayey sand of the Alachua formation lies upon, and in some areas appears to interfinger with, the clay of the Hawthorn formation. The base of the pit exposes 3 feet of light, greenish-gray to cream, dense, hard and tough, very sandy, pasty limestone containing rare molds of poorly preserved, and unidentifiable mollusks. This limestone resembles the limestone of some facies of the Tampa formation, but until more fossils can be obtained and an age definitely determined, the bed is placed tentatively in the Hawthorn formation. The rare specimens of oysters present in the sediments possibly indicate a brackish-water environment of deposition.

- 3) Some further evidence that the sediments of the Alachua formation interfinger with the clay of the Hawthorn formation is present in a phosphate pit located in the southeast quarter, northwest quarter, Section 28, Township 20 South, Range 20 East. Here, a 10-foot exposure of hard, tough, indurated, phosphatic-clayey, fine, quartz sand overlies a 1- to 2-foot phosphate ore bed of the Alachua formation, in which seams and nodules of greenish-gray clay similar to that in the Hawthorn formation are present.
- 4) Eight feet of the greenish-gray clay, very weathered at the top, is exposed in a cut on the road between Florida City and Chassahowitzka (State Road 480) in the center of southeast quarter, Section 34, Township 20 South, Range 19 East.

ALACHUA FORMATION

Introduction and Definition: The term "Alachua clays" was published by Dall (Dall and Harris, 1892, p. 127) for deposits of vertebrate-bone-bearing clay in Alachua County, Florida, the deposits being preserved in numerous depressions. Cooke (1945, p. 199) has summarized the history of the use of the term Alachua formation, and it is not repeated. As used by Cooke, the formation includes the clays of Alachua County and deposits of sand, clay and residuum of older limestones in which quantities of phosphate rock are found or are closely associated. Cooke (1945, p. 200) believed the bulk of the sediments of the Alachua formation were the compacted residues of the Hawthorn and older formations that accumulated in situ.

The phosphate rock of the area was believed by him to have occurred as grains in the Hawthorn formation and to have been dissolved by downward percolating rain water and reprecipitated as calcium phosphate by reaction with the underlying limestone bedrock. This theory of the origin of commercial phosphate is discredited by the fact that no such reaction is occurring in Florida today where the Hawthorn formation lies upon older limestones. Well samples show a distinct lithologic break at the contact of Miocene and older beds. A basal conglomerate,

incorporated in phosphoritic marine sediments, lies directly upon unaltered Oligocene and Eocene limestones, and no phosphatic reaction zone is present.

The Alachua formation as used in this report includes terrestrial deposits of diverse lithologic characteristics, but composed largely of clays, fine sands and a basal rubble of phosphate rock, silicified wood, clay beds, and silicified Suwannee and Ocala limestone residuum. The sediments rests upon a bedrock of limestone ranging in age from middle Eocene to Oligocene except in southern Citrus County, where they interfinger with, and, in part, lie upon the Hawthorn formation. The formation is overlain unconformably by fine to medium quartz sand containing no phosphorite and believed to be early Pleistocene in age. An undetermined phosphate clay mineral forms the matrix for much of the fine sand and the phosphate rubble and the Alachua formation is characterized by the presence of this mineral, and by fairly numerous specimens of vertebrate remains contained in sinks and depressions. These vertebrates range in age from lower Miocene into Pleistocene, and the sediments of the formation may have accumulated not only throughout the Miocene epoch but also during the period extending into the Pleistocene. Almost no stratigraphic relationships were determined during the identification of the vertebrate fossils and the presence of Pliocene and Pleistocene fossils may represent contamination, by the entrapment of these animals during epochs following the Miocene.

Physiography and Outcrop Pattern: The Alachua formation occupies irregularities in the underlying limestone bedrock and covers the bedrock to considerable depths. These irregularities appear to be solution pits, sinks and valleys and the deposits are grouped along northwest-southeast trends that parallel the crest of the Ocala uplift and the fracturing that is associated with the uplift. Depressions developed along the fracturing probably served as depositional basins and the confining limestone walls have been subsequently reduced by phosphatic, humic and carbonic acids.

The formation underlies the Coharie-Okefenokee Sand Ridge and remnants are present in irregularities of the limestone of the Tsala Apopka Lake area and the Williston Limestone Plain. A small area of possibly reworked sediments of the Alachua formation is present along the northeast edge of the Chiefland Limestone Plain in alluvium of the Wicomico formation, see figures 2 and 37.

General Lithology: The Alachua formation is terrestrial, in part possibly lacustrine and fluvial, and is a mixture of interbedded irregular de-

posits of clay, sand and sandy clay of the most diverse characteristics. There is at first sight no consistent lithologies or succession of beds, but studied regionally, a certain consistent stratigraphy is apparent. The base of almost every section exposed in the abandoned phosphate pits in Citrus and Levy counties is a rubble of phosphate rock, silicified limestone residuum and silicified wood contained in a matrix of cream to gray, phosphatic clay and greenish-gray, waxy clays. Overlying this material, which is the ore bed, there is a variable thickness of very fine quartz sand held in a matrix of cream to white, phosphate-clay. The whole section is overlain by sands of the Pleistocene formations.

Although exceedingly variable in its lithologies the upper portion of the Alachua formation is characteristically a faintly stratified, cross-bedded, poorly indurated, gray, fine sand, contained in an unidentified phosphate-clay mineral matrix. These sands have the peculiar characteristics of standing in vertical walls much like loess, and they are so poorly coherent that they can be crumpled between the fingers yet on weathered surfaces will absorb repeated hammer blows without fracturing but with considerable compaction. Interbedded with and commonly underlying these sands are occasional pebbles of water worn flint, erratic boulders of limestone, silicified limestone and flint, clay lenses, pebbles and boulders of phosphate rock conglomerate, phosphatic clay, colloidal phosphate, and an occasional concentration of vertebrate fossils. These gray sands have a wide distribution and characteristically weather pink or purple although occasionally yellow and brown colors predominate. Where the phosphate rubble does not occur this gray sand generally replaces it and in the pits the ore bed commonly is worked into a barren face composed of this sand.

The clay lenses are montmorillonite clay in light pastel shades of blue and green and have a waxy-like constituency. They occasionally contain some pebbles of phosphate and silicified clay although the phosphate content in the matrix is generally only a minor constituent. This clay is blocky and is generally very irregular in its occurrence, although quite commonly a clay bed separates the phosphate bed from the underlying limestone.

In the Section 12 Mine, operated by the Kibler-Camp Phosphate Enterprise, south of Dunnellon, Florida, a well-developed layer of peat and sapropel separates the limestone from the phosphate bed on the east side of the quarry.

Silicified limestone and flint boulders occur in many of the abandoned phosphate pits of Citrus and Levy counties and occur in all degrees of

consolidation from a very porous and friable silicified coquina of foraminifers to dense, crystalline, completely silicified, flint boulders. The silicified limestone is yellow to brown and the flint may be yellow, white and even light blue. These boulders are a nuisance in mining phosphate as they are intimately mixed in the ore and must be eliminated, often a selective job of hand picking. They are very irregular in size and are of many shapes; some are oval, others flat and they vary in size from pebbles to boulders weighing many tons. Silicified fossils or molds of fossils are common in these and the degree of preservation is exceptionally good in some. An occasional boulder of limestone is also recovered from the ore and these presumably were dislodged from the bedrock underlying the phosphate ore in mining operations.

The phosphate rock occurring in the Alachua formation is really a minor constituent of the deposit, although its economic value has made the Alachua formation well known. The phosphate occurs as boulders, pebbles, laminated-phosphate (plate-rock), replacements of limestone and as clastics ranging in grain size from pebbles to colloidal clay.

In the plate-rock deposits, formerly mined near Anthony, Standard, Sparr and Juliette in Marion County, there is limited evidence of an original stratification, (Sellards, 1910, p. 28). This stratification has been greatly altered by subsidence into irregularities of the limestone and by fracture of the plate-rock. A large amount of fine clastic phosphate and very few boulders occur in these pits in relation to the deposits in other pits, and flint and silicified limestone residues are likewise rare to absent.

Thickness: The maximum thickness of the Alachua formation is unknown, but the bed is very irregular in occurrence and variable in thickness. It has been deposited on a very irregular solution surface developed upon a limestone bedrock. The maximum exposure of the formation in the two counties was measured July 16, 1946, at locality C-4, page 203, in Citrus County, and found to be 66 feet. The bed may be thicker or thinner underlying other portions of the Coharie-Okefenokee Sand Ridge but evidence is lacking, no wells or pits having been dug in this area.

Fauna and Age: The Alachua is almost destitute of fossils except for occasional concentrations of indigenous vertebrate remains and invertebrate fossils contained in erratic limestone and flint boulders eroded from older formations. Silicified specimens of *Lepidocyclina ocalana*, *Pecten* sp. cf. *P. "perplanus"*, numerous camerinids of the Ocala lime-

stone and *Cassidulus gouldii* of the Suwannee limestone are quite common.

Some of the concentrations of vertebrate fossils, possibly preserved in sediments that fill sinks and valleys, are especially rich in both numbers and species and the Alachua formation was first recognized because of these fossils, which range in age from lower Miocene to Pleistocene and are good guide markers. Some of the better known localities of Miocene vertebrates, predominately plain dwellers, have been discussed on pages 184 and 185. Remains of plain-dwelling vertebrates of Pliocene and Pleistocene ages also are common in deposits of the Alachua formation and include one or more species of rhinoceros, mastodon, hipparion, camel, tapir, deer, crocodile or alligator and horse. Sellards (1916, p. 94) lists the species described from the Alachua formation and in the same paper describes four new species and gives a bibliography of the principal papers on these fossils. Unfortunately much of the work on the fossils was paleontological and not stratigraphic and fossil lists are not based on associations and segregations within any exposure or series of exposures.

The larger number of described species, other than those from the Raeford Thomas locality in Gilchrist County, come from the J. M. Mixson farm northeast of Williston, Levy County, in Section 29, Township 12 South, Range 19 East. The solution pipes that penetrate the Eocene limestone in the vicinity of Williston are filled with red to yellow, sandy clay, containing phosphorite and specimens of these vertebrates. From the Mixson's farm, Simpson (1930, p. 176) lists *Hipparion ingenum* (Leidy), *H. plicatile* (Leidy), *H. minor* Sellards, *Teleoceras proterus* (Leidy), *Aphelops longipes* (Leidy), *?Megatylopus major* (Leidy), *?Procamulus minor* (Leidy), *?P. minimus* (Leidy), *Serridentinus floridanus* Leidy, which he believed to be of Pliocene age. Species of Pleistocene vertebrates have also been found at this locality and these indicate a mixture of the fauna by slumping in solution pits or the upper few inches may be Pleistocene in age.

In Citrus County, at the abandoned Dunnellon Phosphate Company No. 5 Mine, near Hernando, Simpson (1930, p. 176) lists *Serridentinus floridanus*, *Hipparion* sp., and an indeterminate species of camel, which he thought indicated an age relationship of the phosphate beds to the Mixson locality. Rare remains of shark teeth and fish bones were noted in Citrus and Levy counties, but these fossils are more abundant in the phosphate pits of Alachua and Marion counties. The deposits in the latter pits are slumped and exposures of the ore beds are covered. The

pits are located further down on the flanks of the Ocala uplift than those in Citrus and Levy counties and the Hawthorn may have been developed thinly over portions of the area and subsequently eroded. In fact, at the maximum advance of Hawthorn seas, low places and valleys across the Ocala uplift may have been submerged.

Bones of vertebrates are found in almost every exposure in abandoned phosphate pits and solution pipes in the area. In spite of the mixing of the faunas of several ages in solution holes, additional close stratigraphic work, not attempted in this general study because of time restrictions, will probably find that these bones of various ages are stratified within individual localities, and will help in the determination of the geologic history of the area.

Stratigraphic Relationships: The Alachua formation in Citrus and Levy counties lies unconformably upon a solution surface dissolved in the Avon Park limestone, the Moodys Branch formation, the Ocala limestone and the Suwannee limestone. The whole of the limestone surface is dissected into pinnacles, pipes and solution depressions, see figure 34. A similar feature on guano islands has been called a Karrenfeld (Hutchinson, 1950). The phosphate ore of the formation occupies the depressions and crusts the pinnacles of the Karrenfeld, see figure 35. The sandy, phosphate-clay fills some of the depressions and covers the limestone pinnacles, extending as a phosphorite barren deposit connecting

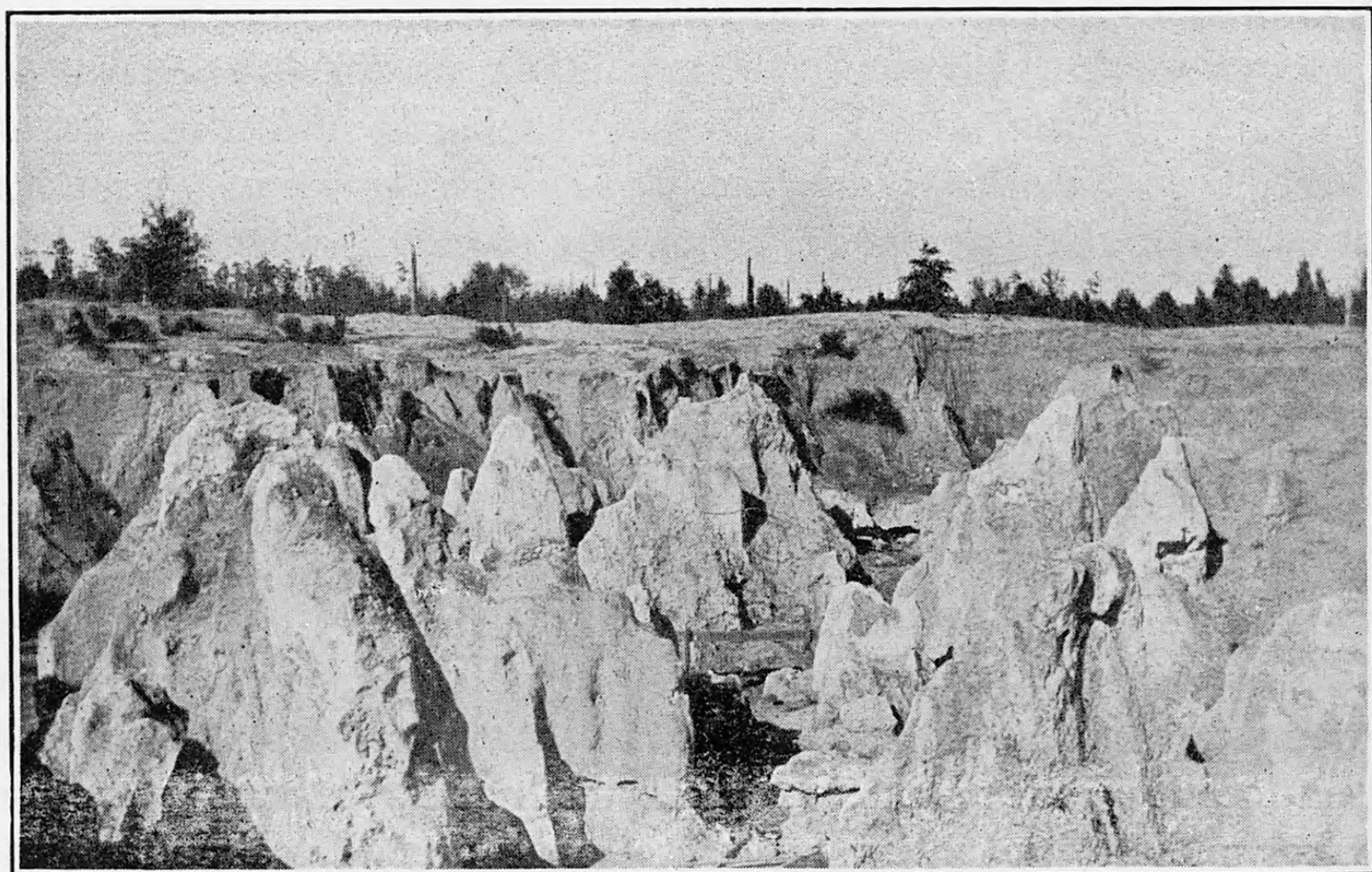


Figure 34. Photograph after Sellards (1910), a very irregular surface of limestone, called a Karrenfeld, developed beneath the Alachua formation.

phosphate ore beds. The formation is believed to be in part contemporaneous with the Hawthorn formation and in part of younger age. It was formed on uplands and as a rule overlies the Hawthorn formation, but in some wells occupies the stratigraphic position of the Hawthorn. The quartz sands of the early Pleistocene formations unconformably overlie the Alachua formation, except where they have been removed by erosion.

Origin of the Phosphate: Various theories of the origin of hard-rock phosphate have been advanced, and the principal ones were summarized by Sellards (1913, pp. 45-56). These theories can be grouped into three divisions; phosphatized large foraminifers, mineralized guanos, and phosphorite concentrated from older sediments by solution. Sellards (1913, p. 58) believed the phosphate was formed *in situ* by the solution in ground water of phosphorite from older sediments, largely the Hawthorn formation, and the precipitation of phosphate lower in the section. Later students have agreed with Sellards, but the evidence presented in this report, namely that the Hawthorn formation was never deposited over portions of the area in which the hard-rock phosphate is present, casts serious doubt on the theory.

In considering the origin of hard-rock phosphate in Florida, certain geologic relationships must be understood. The Miocene epoch appears to have been a period of prolonged phosphate formation, phosphate rock being present in the Miocene sediments throughout all of the southeastern Atlantic states. Florida appears to have been a critical area in this deposition of phosphate in that the Miocene of the State consists of alternating marine beds of limestone, clay and sandstone containing phosphorite as well as more or less irregular occurring beds of terrestrial origin containing great concentrations of phosphate rock.

During post-Oligocene and pre-Miocene time a long period of erosion in Florida occurred and the Oligocene and upper Eocene beds were removed in many places. During this period of erosion, the Florida Peninsula was a land area of greater proportions than it is at present, and an active area of structural relief was formed over the western portion of this land mass, beginning in the early Miocene epoch and possibly extending into the Pleistocene epoch. The Miocene seas drowned all of the eastern and southern portions of the Peninsula and lapped up on the high land areas of the western portion of the Florida Peninsula. These shallow marine Miocene seas abounded in fish of types that used considerable phosphorus in their skeletal structure; sharks being most abundant. An abundant source of phosphate is thereby indicated.

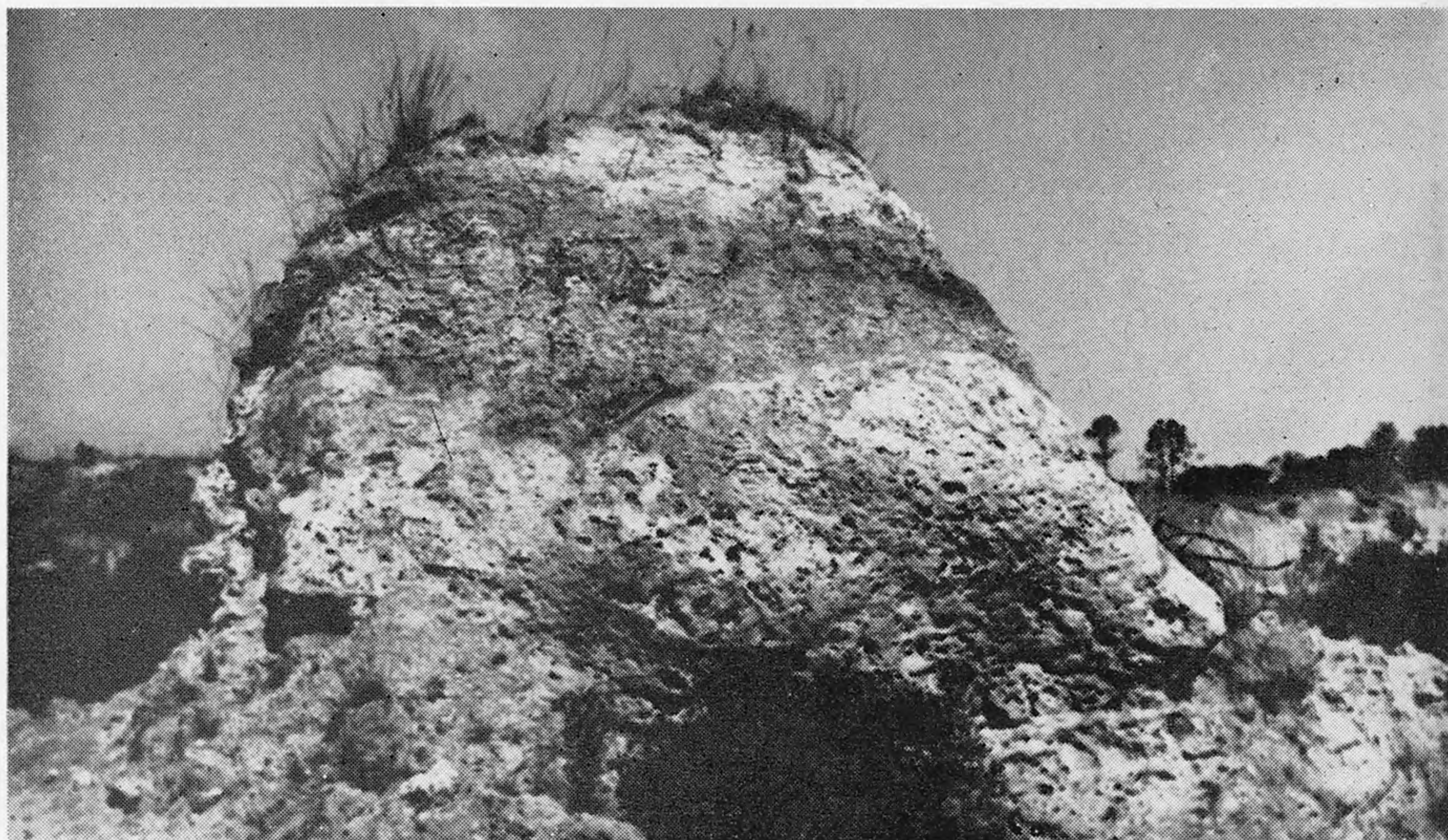


Figure 35. Pinnacle of limestone uncovered at locality C-4, Section 12 Mine of Kibler-Camp Phosphate Enterprise, Citrus County. Note the pitting and etching of the limestone by phosphatic acid solution and the crust of phosphate formed upon the pinnacle.

The Miocene seas appear to have gradually covered the Peninsula of Florida so that these deposits are thickest south and east of the Ocala uplift. Irregularities on the erosional surface of limestone were filled and the thickest sections of the Miocene are preserved in erosional and structural irregularities, figures 13 and 33.

The thesis that the Hawthorn formation once was present across the crest of the Ocala uplift is clearly inconsistent with the facts as developed in the previous discussions of the Miocene. Furthermore, if an explanation of the presence of the phosphate in the Hawthorn formation is approached by working deductively, there must have been an abundant source of phosphate to support the large schools of fish, amphibians and other marine vertebrates, the remains of which make up a sizable percentage of the middle Miocene and parts of the upper Miocene. The abundance of these animals contributed much phosphate to the deposits of the Miocene, but they could have existed only in the presence of large concentrations of phosphate in solution in the water in which they thrived.

Hutchinson (1950) has indicated that marine deposits of phosphate are always intimately associated with a rich supply of phosphorus from the land and if as postulated by Sellards (1913) and Cooke (1945) the phosphate in the Alachua formation was derived from the erosion of

the Hawthorn and the concentration of the phosphorite contained in it, a source for the Hawthorn phosphate is still undetermined. Isopach and structural maps of the Miocene, figure 33, do not provide space for such a source except over the Ocala uplift, but if located there the area was a land mass and the phosphate of the Alachua and Hawthorn formations are contemporaneous in part, and the absence of the Hawthorn formation over the crest of the uplift, figure 33, can be explained.

The Alachua formation appears to have been deposited over a structurally active area and to have spilled off of this land mass into adjacent shallow-water Miocene seas. The phosphate rock appears to have formed *in situ*, the phosphoric acid reacting with the limestone bedrock to form calcium phosphate. In some pits the phosphate has so replaced the limestone as to give it a brecciated appearance. The irregular growth of phosphate is clearly evident where the phosphate has been mined, the pits exposing pock-marked limestone pinnacles, roughly cylindrical holes, and irregular trenches. Continued solution of the limestone by phosphoric and natural acids released the phosphate as boulders and pebbles that collected in depressions formed by the solution. Some of the pebble phosphate, colloids and clay fractions were reworked along stream channels and deposited as plate-rock and clastics in fans and deltas in depressions, lakes and swamps of the land mass.

The presence of a land mass surrounded by shallow marine waters abundantly filled with marine life suggests a ready source of phosphoric acid; large rookeries of birds as first suggested by Dr. Albert R. Ledoux (Sellards, 1913, p. 45). The phosphoric acid, whatever its source, upon contact with carbonate rocks precipitates as calcium phosphate and liberates carbon-dioxide which in turn combines with water to form carbonic acid and in turn dissolves the limestone. In this manner the chemical action creates a solution depression which serves to localize further concentrations of acid and creates a rugged limestone Karrenfeld.

In suggesting guano islands as a source area it is not the intent to resolve the origin of all the phosphate in Florida nor to intimate that the erosion of the Hawthorn formation did not produce considerable quantities of phosphate. It is suggested that limestone islands existed with bird rookeries on them during the Miocene and younger epochs, and the similarity of the Florida hard-rock phosphate deposits and Miocene sediments to the modern deposits of guano-phosphate formed upon limestone islands is clearly illustrated.

Hutchinson (1950, p. 373) has described the relationship of rookeries to the life of adjacent seas, and indicated that on any coast line along

which ocean currents well up from deeper and cooler waters a high concentration of nutrients and a large colony of marine life can be expected near shore. Where bird colonies are situated on islands and coasts much of the nutrients from the sea are temporarily deposited on the island as guano. Hutchinson (1950, p. 373) stated:

“Wherever any of this material is washed back by rain or wave action into the sea, there will be locally and momentarily a much greater concentration of nutrients where the guano solution returns to the ocean than at any other place. The result of a very large bird colony on a section of coast line or on an island, whenever climatic conditions and the form of the substrate of the colony permit guano to be returned to the ocean, will be to steepen the nutrient gradient. Nutrient elements that without the birds would tend to remain in the bodies of fish in the peripheral part of the trophophoric field of the colony, and on the death of the fish would presumably be distributed widely through the general circulation of the ocean are concentrated by the birds on and around the islands. The result will be increased littoral productivity and probably increased littoral fish production. If the latter occurs the birds will not have to move so far out to sea for their food, and a steady state condition will be set up.”

It is thus demonstrated that large colonies of birds increase the phosphate found on land as guano, and increase the amount in solution in adjacent sea waters which tend to support a thriving population of phosphorous-using organisms, the hard parts of which upon death contribute to marine phosphate deposits. Precipitates of phosphate also may be formed in waters adjacent to these land areas. The Hawthorn formation in Brevard County, for instance, contains abundant radiolarians(?) the cases of which are filled with phosphate. It is suggested that upon the land mass and in the shallow marine seas of the Miocene epoch such a marine life-bird-guano cycle was established, that it continued until one phase of the cycle was interrupted possibly in late Miocene time, and that at least a portion of the phosphate contained in the Hawthorn and Alachua formations was formed in this manner.

Hutchinson (1950, pp. 360-380) reported that for guano to be formed it would require that the organism forming it be large, that it feed over a wide area, that it return to a relatively restricted site for rest and reproduction, that the bedrock be of such shape, exposure and composition that it will retain the deposit and that the rainfall be sufficient to cause solution but insufficient to result in complete removal by washing. All of these requirements could have been provided during the epoch extending from the Miocene to the Pleistocene. The large guano-producing birds are pelicans, boobies and cormorant which appear prone to deposit the greater amount of their droppings in colonized land areas. These birds are common in Florida now and there is no reason to

suspect their absence in the geologic past, even though the paleontologic evidence includes only one species from the Miocene (Wetmore, 1942). Of several sources of guano, Hutchinson (1950) showed that sea birds can most generally meet the geophysical limits of guano accumulation, namely, the coexistence of a highly productive feeding area and a dry area to provide the necessary solid substratum for reproduction. Such conditions would have been provided by the very fertile seas of the Hawthorn and the rather barren limestone peninsula and islands extending through these seas. The exceedingly well-developed marine life could have supported large colonies of birds, and the islands and peninsula could have served as roosts for the birds.

Little is known of the climate of Florida during the Miocene epoch but Hutchinson (1950, p. 364) limits large guano deposits to areas with rainfall less than 39.4 inches per year. Florida generally is considered to have a heavy rainfall, yet the average rainfall over the past 100 years at Key West, Florida, a narrow insular area, was only 38.6 inches per year.

Where rainfall is adequate to dissolve the guano the more soluble constituents, urates, nitrates and oxalates are removed and enrichment of the more stable constituents result. On limestone islands the phosphoric acids penetrate the limestone along crevices and form a crust of calcium phosphate. At the same time and subsequently the limestone beneath and around the phosphate is attacked by ground-water acids and by carbonic acid, developed in the reaction above, and the phosphate is released and left in a residue of clay and debris. Repeated cycles of the chemical reaction creates a Karrenfeld and a rubble of phosphate rock lying in the depressions.

That modern guano does attack limestone is recorded by Hutchinson (1950, p. 90 and p. 208) in Peru and the South Pacific islands. According to Power and Owen (Hutchinson, 1950, pp. 214-217) Ocean Island, Latitude $00^{\circ} 53' S$ Longitude $169^{\circ} 35' E$, an elliptical island 2780 X 2200 meters contains a minimum of 22 million tons of phosphate. The phosphate occurs as boulders, pebbles, smaller nodules and peruvulent materials of phosphate with pisolitic and öolitic phosphate bodies embedded in a matrix of sand and phosphatic clay. Many of the larger phosphatic fragments appear to be phosphatized limestone. The ore is contained in a dolomitized coralline limestone, the surface of which is dissected by many dolomite pinnacles, and the ore occupies the depressions between pinnacles. The pinnacles are in places phosphatized in part and finely laminated masses occur as coatings on the phosphatized limestone and as linings in cavities. This description of the occurrence

of guano-phosphate is so similar to that of the hard-rock phosphate that it can be used without change in the description of the later deposits. The guano-phosphates analyze, according to Jorbt, Hill, Marshall and Reynolds (Hutchinson 1950, p. 217), a mean of 3.08 per cent fluorine, almost the same as Florida phosphate, and a mean of 40.51 per cent P_2O_5 . Similar relationships of phosphate to bedrock and of high fluorine content are recorded by Hutchinson (1950) on Nauru Islands; Islands of western Pacific; Christmas Island; Astove Island; Cosmoledo Island; Aldabra Island; Navassa in the Caribbean; and Curaçao in the Caribbean.

A white clayey phosphate reported by Hutchinson (1950, p. 230) to occur under swamps in basin areas on Angaur suggests a possible origin for a similar clay-phosphate in the Alachua formation; in large swamps and dry basins. The fluoride content in the Angaur clay is high, as it is in Florida, and the presence of clay-phosphate, colloidal-phosphate, and platy-phosphate in the deposits of Florida suggests that movement of sols and gels played an important part in the formation of phosphate, possibly by ground water and by electrolytic precipitation.

One possible objection to the guano theory is the insufficient evidence that such large quantities of phosphate as occur in the hard-rock phosphate deposits could result from guano deposition. Nevertheless, Nauru Island, only 7 square miles in area, is reported by Hutchinson (1950, p. 379) to have an estimated original reserve of 87,500,000 tons of high grade phosphate, requiring approximately 490,000 years to form, based on the bird colony relationship to feeding area under existing equatorial Pacific conditions, but under existing Peruvian conditions the deposit could have been formed in approximately 4,000 years. The Miocene insular area or peninsula was many times larger in area and the combined deposits from only ten such islands as Nauru would exceed the known and probable reserves of hard-rock phosphate as estimated by Mansfield (1942, p. 48).

Mineralogy of the Phosphate Deposits: Phosphorous-bearing minerals occur in Florida as prominent percentages of the Hawthorn formation, the Alachua formation, the Bone Valley formation of Pliocene age and younger sediments. The phosphate in the sediments occurs as fluorapatites, some of which is so finely divided that it has the consistency of clay. It was thought that complete chemical analyses of phosphate minerals from the various deposits would provide some data on possible origin and Dr. John C. Rabbitt, Chief of the Trace Element Section, U. S. Geological Survey, Washington, D. C., kindly made complete

analyses of five samples which are reproduced in Table 15. Samples 1 and 2 are phosphorite from the Hawthorn formation taken from a number of well samples, sample 1 being shiny black limey grains and sample 2 being tan to brown, vitreous grains. Sample 3 is clay-phosphate from the upper part of the Alachua formation as exposed in the bed of the Withlacoochee River in the southeast quarter, Section 7, Township 17 South, Range 19 East. Sample 4 is land-pebble phosphate rock from the International Minerals and Chemical Company pit near Mulberry, Florida, and Sample 5 is hard-rock phosphate from the Section 12 Mine of Kibler-Camp Phosphate Enterprise, in northeast Citrus County.

In the analyses silica varies between 6.15 and 16.20 per cent, and it occurs as quartz sand grains embedded in the phosphate minerals. Each of the samples fall within the range of fluorapatites, as fine-grained, isotopic, hydrous and colloidal apatite to which the general term collophane has been applied. Frondel (1943) published an excellent summary of the minerals composing phosphate rock and found that they consist in bulk of the members of the apatite series. His studies were of the insular phosphates but are applicable to the Florida phosphates.

The clay-phosphate that is present in the Bone Valley formation, Polk County, has been tentatively identified as pseudowavellite $\text{CaAl}_3(\text{PO}_4)_2(\text{OH})_5 \cdot \text{H}_2\text{O}$,²⁸ but the percent of aluminum in the Citrus County sample is much too low for this mineral, sample 3, Table 15, and the clay is more probably a colloidal fluorapatite. The similarity of the analyses of the five samples in Table 15 possibly indicates a close relationship in their environment of deposition, but additional studies must be made before these relationships can be determined.

The uniformity and high percentage of the fluorine content in the phosphate of Florida as evidenced in the analyses of Table 15 are interesting since the ratio of P_2O_5 to fluorine in fresh Peruvian guano is approximately 0.005 (Hutchinson, 1950, p. 86) as compared to 0.11 in the above analyses. Organic and sedimentary calcium phosphate, when exposed to water containing very minute amounts of fluorine, absorb the element and remove it from the water, much the same as fluorine is removed from drinking water by living bone. Hutchinson (1950, p. 471) listed a fluorine content of 2.97 to 3.42 per cent in phosphate deposits derived from guano on Ocean Island, Nauru, and Makatea. The fluorine in these deposits is believed to have been added from ocean water by both spray and submergence, and by ground water.

²⁸Personal communication: Z. S. Altschuler, Trace Elements Laboratory, U. S. Geological Survey, Naval Gun Factory, Washington, D. C. Formula after the American Mineralogist, Vol. 28, No. 1, p. 64, January, 1943.