Southeastern Geological Society

9th Field Trip

LATE CENOZOIC STRATIGRAPHY AND SEDIMENTATION OF CENTRAL FLORIDA

Edited By
Harbans S. Puri

Tallahassee, Florida 1960
SOUTHEASTERN GEOLOGICAL SOCIETY

NINTH FIELD TRIP

Edited

By

H. S. Puri

Guidebook

LATE CENOZOIC STRATIGRAPHY AND SEDIMENTATION

OF CENTRAL FLORIDA

P. O. Box 641

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NOTES ON THE SURFICIAL GEOLOGY OF

CENTRAL PENINSULAR FLORIDA

Harbans S. Puri
and
Robert O. Vernon

Abstract

Physiographically, the area covered in this paper is the Central Highlands. These highlands consist of the Lake Wales Ridge, the Winter Haven Ridge, the Lakeland Ridge, the Brooksville Ridge and the Orlando Ridge. The highlands are characterized by relatively great relief and numerous solution hole lakes. Elevations in this area range from 40 feet to as much as 300 feet. Locally, the area embraces segments of undisturbed marine plain.

Limestones of the Williston formation (Jackson) are the oldest segments exposed in this area. The Crystal River formation overlies the Williston unconformably. Sediments of Oligocene and early Miocene age are represented by the Suwannee limestone. The Miocene rocks overly the Oligocene limestone unconformably and these sediments are represented by St. Marks formation of the Tampa Stage. The Alum Bluff Stage is represented by the unnamed coarse clastics, the Hawthorn formation and the Alachua formation. The Bone Valley formation overlies the Hawthorn and is represented by the phosphatic conglomerate, which is usually embedded in a sandy or plastic clay matrix and the overlying stratified phosphoritic beds. The beds of Pleistocene age overly the Miocene unconformably and are represented by the "Citronelle formation" in the northern part of the area. Unsorted, generally, uncemented quartz sand, with some seams of clay, represent the marine terrace deposits that overly the "Citronelle."

The central peninsular area of Florida is the principal source of phosphate in the State. The most abundant of the phosphate minerals is apatite. The greatest production of the phosphate is from the land-pebble phosphate deposits which occur in the sands and clays of the Hawthorn and Bone Valley formations. Kaolin occurs in the lower part of the unnamed coarse clastics and are mined commercially.
Florida's production of construction sand is mainly from the unnamed coarse clastics of the central peninsular area.

**Introduction**

The central peninsula was chosen for the site of the ninth field trip because of the growing interest in the nature of the stratigraphic relationship, paleoenvironment and the tectonic conditions that controlled the deposition of the Miocene and younger rocks in this area. These sediments are also of considerable economic importance as they contain the bulk of the State's mineral wealth in the form of phosphate, construction sand and kaolin.

**Geologic Setting**

Florida is a part of the eastern Gulf of Mexico sedimentary basin. This sedimentary basin is divided into two sedimentary provinces, the north Gulf Coast sedimentary province and the Florida Peninsula sedimentary province, separated by the Suwannee straits (Pressler 1947, p. 1851). The north Gulf Coast sedimentary province consists mainly of clastic sediments and includes the Apalachicola embayment and the southeast Georgia embayment. The Florida Peninsula sedimentary province is characterized by carbonate sediments and includes a South Florida embayment of the Gulf of Mexico basin, with its center of deposition passing through Sunniland Field, Collier County.

The principal structures of Florida are shown on figure 1. The dominant subsurface structure is the Peninsular arch which forms the axis
Figure 1. Index to principal geologic structures in Florida (after Puri and Vernon 1959)
Figure 2. Generalized geologic cross section through Florida (After Puri and Vernon 1959)
of peninsular Florida. The Peninsular arch trends south-southeast and extends from southeastern Georgia into central Florida and crests in the center of northern peninsular Florida around Union and Bradford counties (Applin 1951, p. 3). This structure was a topographic high during Cretaceous time and sediments of early Cretaceous age were deposited around it but did not completely cover it. Beds of Austin age (Upper Cretaceous) were deposited over the crest of this Paleozoic arch, where they overlie early Ordovician sandstone. Figure 2 is a geologic cross section through Florida which shows the pinching out of the Lower Cretaceous (both clastic and non-clastic marine facies) against the Peninsular arch.

The Ocala uplift, well developed along the western margin of the Florida Peninsula, passes westerly into a series of unnamed noses and basins that trend northeast-southwest and terminate in a broadly developed uplift known as the Chattahoochee arch. The Chattahoochee arch crests in Holmes, Jackson, and Washington counties and trends northeast-southwest.

The South Florida embayment of the Gulf of Mexico basin was proposed by Pressler (1947, p. 1856) to include Florida south of the Ocala uplift, Cuba, the Bahama Islands and the intervening submerged areas. Pressler (op. cit.) thought that the synclinal axis of this embayment plunged "toward the Gulf and trends northwestward between Cuba and the Bahamas, and Cuba and Florida along a general line through great Inagua Island to a point near the south end of Andros Island, thence across the Bahama Banks to the Florida Keys near the north end of Key Largo and across Dade and Monroe counties to the southwest coast of Florida." Information from wells drilled
since 1947 indicates that the axis of the South Florida embayment actually passes near the Sunniland and Forty-Mile Bend fields and trends almost east-west. Northward and updip, the thick sedimentary (principally carbonate) section thins and pinches out against the Peninsular arch.

The core of the Florida Peninsula is made up of pre-Cambrian crystalline rocks (encountered in three wells), pyroclastic rocks and rhyolitic lavas (encountered in eight wells), and sedimentary rocks of early Ordovician, middle Ordovician, late Silurian or early Devonian (?), and Devonian age (encountered in 37 wells). Diabase and basalt of Triassic (?) age (encountered in nine wells) occur either as sills or dikes in some wells and in others they are presumed to have been flows. Unnamed red beds of questionably Triassic age occur in two wells in the panhandle (Applin and Applin 1944, Applin 1951, Berdan and Bridge 1951, Bridge and Berdan 1952).

A cumulative section of 20,000 feet of marine sediments has been penetrated by the drill in Florida, ranging from Ordovician to Recent in age. The relationship of these sedimentary rocks to the pre-Cambrian crystalline rocks and Paleozoic or pre-Cambrian pyroclastic rocks is shown on figure 2. The nomenclature currently applied to these rocks appears in the stratigraphic nomenclature chart, figure 3.

**Physiographic Setting**

The topography of the area of this field trip is the Central Delta Plain and Tertiary Highlands (Vernon, 1951). This topographic sub-division extends down the central part of the peninsula from the Okefenokee Swamp to the southern part of Highlands County and is characterized by
Figure 3. Florida stratigraphic nomenclature chart (after Puri and Vernon 1959).
relatively great local relief and numerous solution basin lakes. Elevations in this area range from about 40 feet to as much as 300 feet. Locally, the area embraces segments of undисsected marine plains.

In order to minimize confusion that may result from the use of the term Tertiary Highlands and Delta Plain Highlands (since some of these are also dated as being Tertiary in age) White (1958) preferred to refer to each one of the highlands by a local name. These names were derived from cities located on the ridges. The following are the ridges recognized by White (op. cit.): the Lake Wales Ridge, the Winter Haven Ridge, the Lakeland Ridge, the Brooksville Ridge and the Orlando Ridge. The name Lake Wales Ridge should perhaps be abandoned, as the same feature was named earlier by Davis (1943) as the Highlands Ridge.

**Stratigraphy**

**Eocene Series**

**Ocala group:** The limestones of Jackson age in Florida are recognized as three mappable lithologic units. These are:

3. Crystal River formation
2. Williston formation
1. Inglis formation

**Inglis formation:** Vernon (1951, p. 115-116) proposed the name Inglis member of the Moodys Branch formation for 50 feet of the basal section of the "Ocala limestone" as exposed in the vicinity of Inglis, Levy County. Since Inglis differs both faunistically and lithologically from the overlying Williston and the underlying Avon Park limestone and has been recognized in the field and mapped, Puri (1953, p. 130) raised it to
formational rank.

Type Locality

The type locality of the Inglis formation is in the vicinity of Inglis, Levy County, where the limestone is exposed in several pits and quarries, and also along the Withlacoochee River. Vernon (1951, p. 123) gives the following section, about one-eighth mile below the Florida Power Corporation plant at Inglis, on the right bank of the Withlacoochee River in the SE$_4$NW$_4$

sec. 3, T. 17 S., R. 16 E.:

<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleistocene Series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pamlico formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Quartz sand.</td>
<td>Variable</td>
</tr>
<tr>
<td>Unconformity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Eocene Series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inglis formation (member of Vernon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Cream to tan, soft, porous, but casehardened and densely crystalline where weathered, massive, granular, miliolid, marine limestone. Contains numerous echinoids, particularly Eupatagus mooreanus, Periarchus lyelli floridanus, and associated foraminifers. Exposed to water level in the stream bank.</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Total thickness: 5.0

The channel was improved in 1942 and the contact of the limestone facies with the underlying dolomite facies of the Inglis member was penetrated. Boulders of the following lithologies can be seen along the banks of the river at this stop.
1. Gray, granular limestone as exposed along the river banks.

2. Cream colored, soft, granular, porous miliolid limestone with specimens of *Velates floridanus*, Lucinid sp. "A", buckshot miliolids and echinoids. In addition to these Dr. H. B. Stenzel identified "Cerithium" n. sp., *Xenophora* sp., *Turritella carinata* Lea?, *Crassatella? flexura* Conrad, *Trachycardium* or *Trigoniocardia* n. sp., and *Corbula* (*Caryocorbula*) *densata* Conrad or *C. alabamensis* *tecla* de Gregorio. Across the river in channel dredgings of similar rock, one *Aturia* sp. was found.

3. Mottled gray and brown, porous, finely crystalline, massive, sugary textured dolomite with rare molds of mollusks and *Periarchus lyelli* *floridanus*.

**Williston formation**: Vernon (op. cit., p. 141) proposed the name Williston member for about 30 feet of foraminiferal limestone overlying the Inglis and placed it in the Moodys Branch formation. Over 60 feet of the basal section at Newberry belongs to this formation. Vernon (1951, p. 122, 144) recorded that the Williston and Inglis thicken toward Polk, Baker and Volusia counties and this is confirmed by the presence of 25 feet of the Williston and 55 feet of Inglis sediments in water well W-381, Polk County. Furthermore, two faunizones (*Orioculinoïdes jacksonensis* faunizone and *Orioculinoïdes moodybranchensis* faunizone) can be recognized in the Williston. Because it was lithologically and faunistically distinct from the underlying Inglis formation, and because faunizones were recognizable in it, Puri (1953) raised the Williston to formational rank.

**Type Locality**

The Williston formation is typically exposed west of the town of Williston in Levy County. Vernon (1951, p. 145) gives the following
section on the southeast side of a limestone quarry in the SE_4^1NE_4^1 sec. 27, T. 12 S., R. 18 E. :

<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Eocene Series</td>
<td>Williston formation (member of Vernon)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Cream to tan, soft, detrital limestone containing numerous hard crystalline nodules, many Pecten sp., rare Amusium sp., Lepidocyclina ocalana, Operculinoides floridensis, Amphistegina pinarensis cosdeni and abundant Camerina vanderstoki</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>Cream colored, massive, somewhat nodular, pasty foraminiferal coquina limestone with numerous spongiform concretions. Foraminifers of Bed 4, Operculinoides floridensis, Nonion advenum, Rotalia cushmani and Eponides jacksonensis are very abundant</td>
<td>6.8</td>
</tr>
<tr>
<td>2</td>
<td>Cream colored, very hard ledge, porous, somewhat crystalline, very fossiliferous limestone containing numerous mollusks, molds, echinoid plates, abundant miliolids and other rare foraminifers</td>
<td>0.45</td>
</tr>
<tr>
<td>1</td>
<td>Cream colored, granular, detrital, soft, porous, miliolid limestone containing the fossils above. Somewhat more resistant to weathering and more massive than beds above</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Total thickness..............................................17.15

On the northwest side of the pit an additional 3.6 feet of Bed 4 is exposed in the face of the quarry and an additional two feet, 50 feet back of the rim. Limestones of the Williston formation are the oldest sediments exposed in the area of the field trip. The Williston section is almost 100 feet thick on the West coast in Hillsborough and Pinellas counties, but it progressively thins westward. It is entirely absent in W-381 and W-1411. Generally
speaking, the Williston thickens at the expense of the Inglis and in near
shore environment, deeper water facies of the Williston disappear and shallow
water facies (Inglis) occupies the entire Moodysbranch stratigraphic interval.
In some wells, like W-104, the Crystal River rests directly on the top of the
Avon Park (pl. 1).

**Crystal River formation:** The name Crystal River formation (Puri, 1953,
p. 130; Vernon and Puri, 1956, p. 35, 38) proposed for the 108 feet of lime-
stone exposed in the Crystal River Rock Company quarry, sec. 6, T. 19 S.,
R. 18 E., Citrus County, Florida, includes all calcareous deposits of upper
Eocene age, lying stratigraphically between the Williston formation and the
Oligocene limestones. It consists of a homogeneous microcoquina, almost
entirely made up of tests of Foraminifera. The basal portion may contain
a few beds, as much as 12 feet thick, of secondary dolomite. The Crystal
River formation is synonymous with "Ocala limestone (restricted)" of
Vernon (op. cit.). The entire Crystal River formation is nowhere exposed,
because its top is marked by an erosional unconformity, but a total of 310 feet
of sediments belonging to this formation are present in water well W-381,
Polk County.

The following faunizones are recognized in the formation:

- **Lepidocyclina (Nephrolepidina) chaperi** faunizone
- **Asterocyclina-Spirolaea vernoni** faunizone
- **Nummulites vanderstoki** Hemicythere faunizone
- **Lepidocyclina-Pseudophragmina** faunizone
- **Spiroloculina newberryensis** faunizone

A thickness of over 300 feet of the formation occurs in the subsurface
of Jackson County, Florida, where its upper portion has been designated
**Lepidocyclina fragilis** zone by MacNeil (1944).

**Type Locality**

Crystal River Rock Company quarry, NE$_{1}^{1}$ SW$_{4}^{1}$ sec. 6, T. 19 S., R. 18 E.,

Citrus County, Florida. (Section after Vernon, 1951, p. 166-167.)

<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oligocene Series</td>
<td><strong>Suwannee limestone</strong></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>A cream colored, porous, firmly cemented, detrital limestone composed of echinoid plates and spines, poorly preserved foraminifers and granular calcite. <em>Chlamys brooksvillensis</em>, <em>Chione</em> sp., <em>Clypeaster rogersi</em>, <em>Cassidulus gouldii</em>, <em>Kuphus incrassatus</em>, and numerous specimens of <em>Dictyoconus cookei</em>, <em>Coskinolina floridana</em> are present. The bed measured nine feet from the top of the highest pinnacle east of the quarry to the rim and an additional eight feet is exposed in the quarry face.</td>
<td>17.0</td>
</tr>
<tr>
<td>12</td>
<td>Cream to tan, hard, crystalline, nodular, very porous limestone with seams of the limestone of Bed 13 and containing many poorly preserved mollusk molds, including <em>Chione</em> sp. <em>cf. C. bainbridgensis</em>, <em>Turritella martinensis</em>, <em>T. vicksburgensis</em> and rare specimens of <em>Cassidulus gouldii</em> and <em>Lepidocyclina</em> sp.</td>
<td>1.6</td>
</tr>
<tr>
<td>11</td>
<td>White to light gray, dense, thin bedded, pasty to cryptocrystalline limestone containing rather numerous molds of <em>Turritella martinensis</em> and <em>T. vicksburgensis</em>. Weathered surfaces appear brecciated.</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>Layer of light gray to cream colored, weathered brown, cryptocrystalline, sublithographic, hard, dense, thin bedded limestone with an occasional seam of light green, waxy marl.</td>
<td>0.3</td>
</tr>
<tr>
<td>9</td>
<td>Light gray, dense, thin bedded, hard, lithographic limestone with rare molds of <em>Turritella</em>.</td>
<td>1.65</td>
</tr>
<tr>
<td>8</td>
<td>Brown to light gray, dense, hard, cryptocrystalline limestone with porous detrital limestone seams.</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Light greenish gray clay with fibrous, crystalline, light greenish gray calcite growths lying along a very irregular surface developed upon Bed 6. (.variable) 0.5

Unconformity
Crystal River formation  Elevation 124.65 feet

6 Cream colored, detrital, porous, firmly cemented limestone with seams of dense, crystalline limestone and numerous poorly preserved molds of mollusks and rare specimens of *Gypsina* sp. cf. *G. globula*. The upper few inches are very indurated and the top of the limestone is very irregular............. 1.9

5 Cream to white, massive, bedded, pasty, soft coquina composed of mollusks, Bryozoa, corals and large foraminifers in a pasty calcite matrix. Specimens of *Camerina vanderstoki* are common in the lower 25 feet, but decrease upward and are replaced by *Operculinoides ocalana*, *Turritella* sp., *Pecten* sp., corals, *Lepidocyclina ocalana*, *Gypsina globula*, *Eponides jacksonensis*, *Gaudryina jacksonensis* were identified................................. 43.25

4 Cream to white limestone of Bed 5, but containing irregular crystalline nodular concretions and *Ostrea podagrina*, *Amusium ocalanum*, *Pecten* sp., *Gypsina globula*, *Lepidocyclina ocalana*, *Reussella eocena Discocyclina flintensis*, *Nonion preadvenum*, *Cibicidites mississippiensis ocalanus*................................. 9.5

3 Cream colored, coquina limestone composed of foraminifers, Bryozoa, echinoid plates and spines, corals, *Pecten* sp. cf. *P."perplanus", Agassizia floridana*, *Oligopygus haldemani*, *Fibularia vaughani*, *Laganum floridanum*, *L. ocalanum*, *Peronella cubae*, *Schizaster ocalanus*, and some of the foraminifers above.................................................. 7.0

2 Cream colored, pasty, massive, coquina limestone with numerous irregular and spongiform concretions, and *Amusium ocalanum*, *Ostrea podagrina*, *Pecten* sp., *P."perplanus", Fibularia vaughani*, *Peronella cubae*, *Lagenia laevis* and foraminifers of Bed 4.............. 38.0

1 Cream colored, very pasty, porous, soft limestone containing *Lepidocyclina ocalana*, *Heterostegina*
ocalana, Operculinoides floridensis, Operculinoides sp., Gypsina globula, Cibicides mississippiensis, Rotalia cushmani and other poorly preserved foraminifers


Total thickness


The type area of the Ocala group is in the vicinity of Ocala, where the limestones of the Ocala group are represented by the Crystal River and Williston formations. At Kendrick (Stop 7, section on p. 124), five feet of Williston, 40 feet of Crystal River and 10 feet of ?Hawthorn sediments will be examined.

Crystal River formation has an abundant fauna. The microfauna is described in detail in the Florida Geological Survey Bulletin 38. Harris (1951) described the pelecypods from the "Ocala" (most of Harris' locations belong to the Crystal River formations). A forthcoming report by Mrs. K. Van Winkle Palmer will be a comprehensive report on the Mollusca contained in these beds.

Thickness: An exact estimate of the thickness of the Crystal River formation is rendered difficult because the rock is unevenly eroded at the top and its base is of transitional nature. A maximum of 310 feet of the formation is present in water well W-381, Polk County. Over 300 feet of the formation occurs in the subsurface in Jackson County.

Vernon (1951, p. 141) assigned 30 to 35 feet of sediments to the Williston formation. The Williston formation thickens at the expense of the Inglis formation in the Florida Panhandle, and may replace the Inglis locally.
The Inglis formation seems to have a more or less constant thickness of 50 to 55 feet in the vicinity of Inglis, Levy County, which is the type locality. In northeastern and eastern peninsular Florida (Columbia, Bradford, Duval and Volusia counties) the Inglis formation appears to thicken as much as 150 feet (Vernon, op. cit., p. 122).

**Distribution:** The limestones of the Ocala group outcrop in two extensive areas in Florida. The more extensive area is a regional feature, the Ocala uplift, which borders the Gulf of Mexico in the northwest part of peninsular Florida. The other area is the northern half of Washington and Jackson counties and the eastern portion of Holmes County, whence the limestones extend into southern Alabama and southwestern Georgia.

The Ocala group underlies the entire State of Florida except for small areas in northern Seminole County, Volusia County, southern Orange County, northern Osceola County, Lake County, Marion County, and in southern Levy County, where it is absent (Vernon, op. cit., pl. 2). Applin and Applin (1944) showed that their upper member of the "Ocala" which is the typical Crystal River formation, occurs in subsurface throughout Florida except on the east coast in parts of Seminole County. The wells in this area, on the east coast, penetrated the lower less fossiliferous member of the "Ocala" directly beneath a thin cover of Miocene or younger beds.

**Oligocene Series**

The Oligocene sediments in Florida are separated into four formations: Bucatunna clay, Marianna limestone, Byrann formation and Suwannee limestone.
In the area of the trip, Bucatunna clay, Marianna limestone and Byram formation are not recognized and the entire Oligocene section is represented by the Suwannee.

**Suwannee limestone:** The term Suwannee limestone was erected by Cooke and Mansfield (1936) for the exposures of hard, crystalline, yellowish limestone with *Cassidulus gouldi* (Bouvé) exposed on the Suwannee River between Ellaville and White Springs.

The Suwannee limestone in the peninsula is a cream, soft, very porous calcarenite composed of loosely cemented foraminifers, largely cones, in which large numbers of *Cassidulus gouldi* (Bouvé), other echinoids and rare mollusk shells are held. Thin beds of lithographic limestones and clay seams mark the base of the bed in the peninsula. The foraminifers and ostracodes are for the most part not studied and described from the Suwannee but a comprehensive description of mollusks is given in Bulletin 15 of the Florida Geological Survey, "Mollusks of the Tampa and Suwannee Limestones of Florida," by Wendell C. Mansfield.

One of the most interesting characteristics of these sediments in the peninsula is the occurrence of species of foraminifers and ostracodes in the Suwannee that are present in the Avon Park limestone of middle Eocene age with several hundred feet of upper Eocene sediments lying between them. A hand specimen of one formation cannot be identified and separated from one taken from the other formation, by lithology and frequently not by fauna. However, the echinoids and rare foraminifers of the Suwannee and Avon Park differ.
Excellent exposures of these sediments are present at Ellaville on the Suwannee River at Falmouth Springs, near Live Oak in Suwannee County and at the Crystal River Rock Company quarry near Crystal River in Citrus County, section on page 13.

Downdip facies of the Suwannee limestone thickens to several hundred feet in southern Florida. The upper portion of the Suwannee in the southern part of the State carries Miogypsina-Heterostegina fauna. This section is stratigraphically higher than the type Suwannee in Suwannee County and is correlated with the Tampa (pl. 1). This downdip facies of the Suwannee resulted from a continuous deposition during Oligocene and Tampa times.

The regional lithostratigraphy of the post-Eocene rocks is discussed by Goodell and Yon (see p. 75).

Miocene Series

The Miocene is divided into three time-rock units: Tampa Stage, Alum Bluff Stage and Choctawhatchee Stage. Litho and biostratigraphic stages are termed facies. Plate 1 shows the distribution of the Miocene and its relationship with older sediments.

Tampa Stage: The Tampa Stage includes all Miocene sediments lying between the Oligocene series and the Alum Bluff Stage. This definition includes such sediments exposed in the Florida Panhandle and their equivalents in the central and western Gulf states. The type area is near Tampa Bay, the famous Ballast Point locality which is now largely covered by buildings and improvements, and on Sixmile Creek at Orient,
Hillsborough County, Florida. The stage includes all sediments deposited between post-Vicksburg (Nodosaria blanpiedi zone of the Chickasawhay limestone) and pre-alum Bluff ages. In the Florida Panhandle, two lithofacies are recognized: a calcareous St. Marks facies downdip and a silty Chattahoochee facies updip.

The name Tampa was first used by Johnson (1888). Dall (1892) used the term Tampa limestone and also Tampa beds. Matson and Clapp (1909) used the name Tampa formation and also recognized that it was contemporaneous with the Chattahoochee formation. Cooke and Mossom (1929, p. 78-79) changed it to Tampa limestone because the formation is chiefly limestone and redefined it to include the Chattahoochee formation. Vernon (1942) revived the original term, Tampa formation, to include "all sediments lying above the Suwannee limestone and below the Alum Bluff group."

Lithologically, the Tampa consists of sand, silts, marls, subordinate limestone and fullers earth downdip. The limestones are restricted to the lower part only.

The fossils described from the Tampa are Mollusca (Dall, 1890, 1915; Mansfield, 1937). The Foraminifera and Ostracoda fauna of the Tampa is meager and is largely undescribed. Archaia floridanus is the most common species reported from the surface exposure.

**Alum Bluff Stage**: The Alum Bluff Stage embraces all sediments of the post-Tampa and pre-Choctawhatchee age, the "middle" Miocene of most authors, in the Florida Panhandle, the Florida Peninsula, and their equivalents in the central and western Gulf states. The type locality is the section exposed
below the *Ephora* facies of the Choctawhatchee Stage at Alum Bluff, Liberty County, Florida. In the Florida Panhandle, five lithofacies, Chipola, Oak Grove, Shoal River, Hawthorn and unnamed coarse clastics are recognized. In the Florida Peninsula the Hawthorn, unnamed coarse clastics and Alachua lithofacies are essentially Alum Bluff Stage, but these lithofacies may in part be Tampa Stage.

**Hawthorn facies:** The name Hawthorn formation was first used by Dall (1892, p. 107) after the community of Hawthorn, where Dall noticed phosphatic rock being quarried at old Simmon's farm and used as fertilizer. Although Dall (op. cit., p. 107) observed that at the time of his visit, the "beds have a considerable thickness," no lithologic section was given in his reports. At the time of the writer's visit at the old Simmon's farm in 1956, the small quarry had been filled with debris and only scattered boulders of phosphatic limestone were seen at the site. Since the first locality mentioned by Dall in his report was Devil's Mill Hopper, this locality and the section at Brooks Sink was designated as cotype localities for the Hawthorn (Puri and Vernon, 1959). These two sections are very thick and are representative of the Hawthorn formation as conceived by Dall.

The section at Devil's Mill Hopper will be seen at Stop 1 (section on p. 114). About 120 feet of section belongs to the Hawthorn. The lower dolomitic limestone bed rests directly on the eroded surface of the Crystal River formation and unconformable contact can be seen during dry periods when the sink is dry. The overlying section is composed of greenish gray phosphatic clays, sands, sandy limestones and dolomitic limestones.
About 145 feet of Hawthorn sediments are known to occur at Devil's Pit sink, Stop 5 (section on p. 120).

The Hawthorn beds unconformably underly the Bone Valley formation in Polk County. These sediments are composed mostly of greenish gray, phosphatic, kaolinitic clays. The Hawthorn sediments will be seen at Stop 11 (section on p. 128) and the Hawthorn-Bone Valley unconformity will be seen at Stop 13 (section on p. 130).

Unnamed Coarse Clastics: Coarse clastics are found in the peninsula in a narrow belt extending along a relatively straight line from western Clay County to the south-central part of Highlands County. These nonmarine sediments consist of poorly sorted quartz grains, ranging in size from fine sand to small pebbles, in a clay matrix. The clay is predominantly kaolin. The upper part of the material is usually red or orange in color while the lower part is generally white or light yellow-gray. Locally these deposits contain appreciable amounts of finely divided muscovite. Most of these coarse clastics are of Alum Bluff age but in places these beds are both younger and older than the Alum Bluff.

The clays in these deposits are the source of commercial kaolin and the coarse clastics are the chief source of most of Florida's construction sand.

Coarse clastic beds also occur in the panhandle. At Alum Bluff, over 19 feet of gray and white, variegated, crossbedded thinly laminated sands overlie the Chipola facies unconformably. The lower portion of these sediments contain numerous leaf impressions and two carbonized logs, one
of which was 3.25 feet long and 4 inches in diameter, were found set in extremely crossbedded coarse sand. Ninety-two feet of those sediments are present at Rock Bluff. In the Tallahassee area, mottled variegated clays and sands are present and these sediments have yielded a terrestrial vertebrate fauna of Alum Bluff age. These sediments are contemporaneous with the Chipola and Shoal River facies and are a part of the Hawthorn delta (Vernon, 1951, p. 184).

Cooke (1945) included the unnamed coarse clastics of the peninsula in the Citronelle formation. In Highlands County, Bishop (1956) placed these rocks in the nonmarine Hawthorn. Most of the Citronelle formation as mapped by Cooke in the Florida Peninsula belongs to these unnamed coarse clastics. Current studies by the writers and E. W. Bishop will not only establish their exact stratigraphic position, but will also provide a formational name for these beds.

Unnamed coarse clastics will be seen at Stops 8, 9 and 10.

Alachua Formation: The term "Alachua Clays" was introduced by Dall (Dall and Harris, 1892, p. 127) for largely terrestrial clays in Alachua County which carries a varied vertebrate fauna of middle Miocene to Pleistocene in age. The formation consists of heterogeneous lithologies and besides the vertebrate-bearing clays of Alachua and Gilchrist counties, deposits of sand, residuum of older limestones (Hawthorn, Suwannee and Ocala) in its lower portion. The upper portion of its formation is more uniform and it consists of a succession of blue-gray, blocky clays, overlain by a thin bed of phosphoritic limestone, which in turn is overlain by white to
cream colored phosphatic sand. In Gilchrist County, the formation overlies the Crystal River and Williston formations which exhibits a very irregular surface (karrenfeld). It is not uncommon to find in some quarries pinnacles of Crystal River and Williston formations that vary in height up to 25 feet. The clays and phosphatic sands of the Alachua formation overly such an irregular surface with the result that various beds in a given vertical section vary greatly in thickness over short distances. It appears most logical that clays and phosphatic sands of this formation were deposited in a well developed sinkhole cavernous-type of eroded limestone surface and that the lower portion of the section which carries a residuum of older limestone was developed in collapse-type topography.

**Bone Valley Formation:** The term Bone Valley gravel was used by Matson and Clapp (1909, p. 138) for phosphate beds west of Bartow, where these beds are mined commercially for phosphate. Cooke (1945, p. 203) discarded the term "gravel" because only a small part of these deposits were really gravel and used the term Bone Valley formation. Ever since Cooke's extended usage of the term Bone Valley formation, beds overlying the Hawthorn formation and underlying the Pleistocene terrace deposits have been included in this stratigraphic unit. Puri and Vernon (1959) restricted the use of this term to the basal Bone Valley conglomerate, which is usually embedded in a sandy or plastic clay matrix and the overlying stratified phosphoritic beds (generally greenish gray to dark brown, sandy clays). The section overlying the stratified phosphoritic beds does contain phosphate but these beds consist mostly of reworked rubble material. A report by
E. W. Bishop and H. Stewart on the Polk County geology will clarify some of the stratigraphic problems in the hard-rock phosphate area. 

Sediments assigned to the Bone Valley will be seen at Stop 13.

Pleistocene Series

"Citronelle Formation": The name 'Citronelle formation', after the town of that name in Alabama, was first used by Matson (1916) for variegated sands, clays and conglomerates. The type locality is in a railroad cut at Lambert Station, south of Citronelle; the type section and also sections on the west side of Perdido Bay and Foley, Alabama, were described by Matson and Berry (1916), who also described the fossil plants from these localities and assigned a Pliocene age for these sediments.

Matson (1916) extended the "Citronelle" into Florida for the first time and mapped it as far west as Crestview. Cooke (1945) extended the Citronelle'as far west as Quincy in the panhandle and as far south as Sebring in the peninsula. Vernon (1942, 1951) assigned an early Pleistocene age for these sediments, although he recognized the possibility that the beds may date back into the late Pliocene.

Stringfield and LaMoreaux (1957) described the section at Red Bluff on Perdido Bay, and noted that the flora from all three of Matson's localities is of Pliocene age and that "in addition to the fossil evidence which indicates a Pliocene age for the Citronelle, the writers have observed that the oldest marine terrace of Pleistocene age in Florida is underlain by the
Citronelle formation, indicating that the formation is older than the oldest Pleistocene terrace." Doering (1960) has presented conclusive evidence for a pre-glacial Pleistocene age for the "Citronelle formation" and has mapped it from the type area as such as far east as St. Mary's River and as far south as Gainesville in Florida. The beds assigned to "Citronelle" will be studied at Stops 2, 3, 4 and 5. Sixty-eight feet of sands are exposed at Stop 4 (section on p. 119) and 35 feet of "Citronelle" overlies the Hawthorn at Stop 5 (section on p. 120). In a paper by Brooks (see p. 32) the size frequency distribution of particles in the "Citronelle" are discussed.

Most of the sediments mapped by Cooke (1945) as "Citronelle" in the south central peninsula were recognized as a nonmarine facies of the Hawthorn by Bishop (1956) in Highlands County. These sediments are now included in the unnamed coarse clastics.

Marine Terrace Deposits: Florida is blanketed with a cover of unsorted, generally uncemented quartz sands that are occasionally set in a nitrogenous organic matrix and which contain seams of clay. Belts of this sand extend around the State, parallel to the present coastline. These belts occur in step-like terraces rising inland from the coast, the oldest sediment being the highest in elevation. Each coastwise belt extends up the major streams as deltas and flood plain alluvium.

Only those sediments lowest in elevation and youngest in age contain identifiable fossils of a marine environment. Nevertheless, because of beach ridges, abandoned wave-cut escarpments, the distribution and trend of the sediments and general lithology, these sediments are thought to
represent land marginal marine sediments deposited during cycles of eustatic adjustments in sea level, associated with maxima and minima developments of ice in the Pleistocene.

The coastwise belts and their contemporaneous upstream extensions are bound by erosional escarpments and as such they are terraces. The higher and older terraces are poorly defined. As many as nine terraces have been recorded by some students, but only four are separable up the streams. Five significant coastwise surfaces are present, the highest of which is a high-level alluvial deposit being present in the north panhandle and down the center of the peninsula.

These terraces and contemporaneous deposits are presented below with tentative age assignments:

Table 1.

<table>
<thead>
<tr>
<th>Tentative Age</th>
<th>Terrace and Shore Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late Wisconsin, Interglacial</td>
<td>Silver Bluff, 8 feet</td>
</tr>
<tr>
<td>Late Wisconsin, Glacial</td>
<td>Erosion</td>
</tr>
<tr>
<td>Peorian, Interglacial</td>
<td>Pamlico, 30 feet</td>
</tr>
<tr>
<td>Early Wisconsin, Glacial</td>
<td>Erosion</td>
</tr>
<tr>
<td>Sangamon, Interglacial</td>
<td>Wicomico, 100 feet</td>
</tr>
<tr>
<td>Illinoian, Glacial</td>
<td>Erosion</td>
</tr>
<tr>
<td>Yarmouth, Interglacial</td>
<td>Okefenokee, 150 feet</td>
</tr>
<tr>
<td>Kansan, Glacial</td>
<td>Erosion</td>
</tr>
<tr>
<td>Aftonian, Interglacial</td>
<td>Coharie, 220 feet</td>
</tr>
<tr>
<td>Nebraskan, Glacial</td>
<td>Erosion. High-level alluvium</td>
</tr>
</tbody>
</table>
More complete discussions of the history and mechanisms of deposition of the Pleistocene deposits are given by Vernon (1942; 1951, p. 17-43, 208-215) and MacNeil (1950). Cooke (1945) presented a different view.

**Economic Geology**

**Phosphate**

Phosphate is a general term applied to natural deposits valued chiefly for their phosphorus content. The most abundant of the phosphate minerals is apatite, which is primarily calcium-fluoro-phosphate \( \text{Ca}_5(\text{PO}_4)_3\text{F} \). The structure and diadochic substitutions in the apatite group are discussed in a paper by Bishop (see p. 64). In another paper on the geochemistry of phosphorus, also by Bishop (see p. 38), phosphorus in phosphorite deposits is discussed in detail.

The phosphates of Florida are divided into several types of which land pebble and hard rock are the most important. The greatest production is from the land pebble deposits which occur in the sands and clays of the Hawthorn and Bone Valley formations in the area east of Tampa in Polk and Hillsborough counties. A paper by Reves (see p. 50) gives the X-ray analysis of land pebble phosphate samples, and the environment in which the phosphate was deposited.

Florida has for 67 consecutive years been the leading state in the production of phosphate. The 1959 production was over 10 million tons, valued at $70 million.
Kaolin

Kaolin occurs in the lower part of the unnamed coarse clastics of the central peninsular area and is mined in Putnam County by Edgar Plastic Kaolin Company and the United Clay Mines Corporation. Florida's kaolins have physical properties that are intermediate between ball clays and more typical kaolins.

The material being mined in Putnam County consists of a mixture of kaolin and quartz sand with the kaolin content averaging about 18 to 20 percent. It is now known that this deposit, which was formerly thought to be limited to small areas in Putnam and Lake counties, is very extensive and underlies a large part of the central peninsular area.

The characteristics of the kaolinitic sediments in peninsular Florida are discussed in a paper by Pirkle (see p. 36), who believes that kaolinitic sediments are deposited in an alluvial environment as sedimentary clay.

Construction Sand

Florida's production of construction sand is principally from the unnamed coarse clastics of the central peninsular area. The principle producers are located in Polk County at Davenport and at Lake Wales. The sand produced is used principally for building and paving; small tonnages are used for blasing, engine, filter, molding and glass sands. Total production of sand in Florida is about 5.5 million tons, valued at about $4.4 million.
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Vernon, Robert O.


White, William A.
SIZE FREQUENCY DISTRIBUTION OF PARTICLES IN SEDIMENTS OF THE "CITRONELLE FORMATION"

H. K. Brooks

Abstract

The results of mechanical analysis of the kaolinitic sands and pebbly sands are presented as histograms to show the textural variability of the different lithologic components of the "Citronelle formation" exposed at the Diamond Interlachen Sand Company pit, sec. 16, T. 10 S., R. 24 E., Putnam County, Florida.

Discussion

Representative mechanical analyses of samples of the kaolinitic sands and pebbly sands collected from the section of "Citronelle formation" exposed at Stop 4 of this field trip are presented herein to supplement field observations. The materials analyzed from the pit of the Diamond Interlachen Sand Company are representative of the coarse kaolinitic clastic deposits underlying the central axis of peninsular Florida. These deposits have been considered to be fluvial sands and gravels of the Citronelle formation and thought to be of Pliocene age (Cooke, 1945). Recently, Puri and Vernon (1959, p. 177) included these sediments in high-level alluvial and deltaic deposits and observed that "sediments called 'Citronelle' by Cooke are believed to be more closely associated with the Pleistocene than with the Pliocene." The more recent contribution to our knowledge of the "Citronelle" is by Doering (1960), who considered the
Citronelle sediments occurring in Alabama, Mississippi and west Florida, to be of pre-glacial Pleistocene age. There is presently a lack of unanimity in the interpretation of the origin of the coarse clastic sediments of peninsular Florida.

The analyses presented in plates I and II are of samples collected as spot samples from the north wall of the pit from different beds and lenses described in the measured section (p. 119). These samples were chosen to represent the range of textural variability of the different lithologic materials present.

In the laboratory, the samples were processed and analyzed by the standard methods of sieve analysis. For consistency of results, all samples were wet-sieved with a 230 U. S. T. M. mesh sieve with openings of 0.062 mm. Wet-sieving was necessary to remove the clay matrix which was present in amounts up to 19 percent of the samples. Class intervals chosen for the finer sands and kaolinitic sands are based upon the $\sqrt{2}$, whereas sieves for the coarser material correspond to the class limits of the Wentworth grade scale. The results of the analyses are presented in the form of histograms.

Gratitude is expressed to E. C. Pirkle and Roland Keller for assistance with field and laboratory work respectively.
Explanation of Histograms

Plate I

Figure
1. A horizon of soil profile; light tan, medium sand; 66 feet from bottom of section or two feet from the top.

2. B horizon of soil profile; medium to coarse iron stained sand with clay matrix; 55 feet from bottom of section or 13 feet from the top.

3. Lower thin heavy mineral concentrate bed; "salt and pepper" colored, medium sand containing 17.5% heavy minerals; 44 feet from bottom of section or 24 feet from the top.

4. White kaolinitic, fine sand; 22 feet from bottom of section or 46 feet from the top. Most of the material in the class interval less than 0.062 mm. was kaolinite.

5. White kaolinitic, fine sand; six feet above base of section. Most of the material in the class interval less than 0.062 mm. was kaolinite.

6. White kaolinitic, coarse pebbly sand; 33 feet from base of section or 35 feet from the top. Most of the material in the class interval less than 0.062 mm. was kaolinite.

Plate II

1. Iron stained sandy gravel lens near the base of the B horizon of the soil profile about 200 feet eastward from the measured section on the north wall of the pit.

2. Pebbly sand exposed about 200 feet eastward from the measured section on the north wall of the pit about half way down the slope.

3. White kaolinitic, pebbly sand exposed about 200 feet eastward from the measured section. This sample was taken from immediately beneath the above sample. Most of the material in the class interval less than 0.062 mm. was kaolinite.

4. White kaolinitic pebbly, medium to coarse sand; 30.5 feet above base in the measured section. Most of the material in the class interval less than 0.062 mm. was kaolinite.
Coarse pebbly sand; 11.5 feet above base in measured section.

White, kaolinitic, coarse sand; 5 feet above base of measured section. Most of the material in the class interval less than 0.062 mm. was kaolinite.

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Puri, H. S., and Vernon, R. O.
CHARACTERISTICS OF KAOLINITIC SEDIMENTS IN PENINSULAR FLORIDA AND IMMEDIATE ORIGIN OF THE KAOLIN

E. C. Pirkle

Abstract

Thick sections of kaolinitic sediments occur in the Lake Wales Ridge area of peninsular Florida. These materials, usually referred to as the Citronelle formation in the published literature, consist largely of quartz sand and gravel with a binder of kaolinite. In exposures the sediments often can be divided, from the surface downward, into three zones: (1) loose surface sands, (2) red and yellow clayey sands, and (3) white clayey sands. In much of western Putnam County, the present mining area, the loose surface sands have resulted from weathering and erosion of the kaolinitic sediments. The color of the reddish zone is due to oxidation above the water table of iron compounds. Throughout large areas the kaolin-bearing sands rest unconformably on the middle Miocene Hawthorn formation. On the eastern side of the Lake Wales Ridge, the kaolinitic sediments in some localities overlie shell marls of late Miocene or younger age.

Present data indicate that kaolinitic clay usually is more abundant in the lower part of the formation. This portion of the formation is close to the surface in parts of Clay, Putnam, Marion, Lake and Polk counties.

1Published by permission of Economic Geology, where this paper is scheduled to be published in full.
In areas where the Lake Wales Ridge is highest, for example in Polk County, the lower part of the formation can be found outcropping or close to the surface on the sides of the ridge and in low areas of the ridge crest. The kaolinite is believed to have been deposited as sedimentary clay in an alluvial environment rather than having been derived from the weathering in situ of feldspar sand or some clay mineral.
THE GEOCHEMISTRY OF PHOSPHORUS

E. W. Bishop

Abstract

Phosphorus is one of the most abundant and important minor elements in the Earth's crust. The principal phosphorus mineral is fluorapatite.

As a rule, the amount of phosphorus in igneous rocks is controlled by the acidity of the rocks. Basalts are relatively high, intermediate rocks medium, and very acidic rocks low in contained phosphorus. An exception to the rule is the abundance of phosphorus in acid and intermediate pegmatites.

Phosphorus is of prime importance in the biosphere as it is an essential constituent of all living matter. Plants obtain soluble phosphorus from the soil, where it has been liberated from rocks by weathering. Animals obtain phosphorus from plant products. Bacteria and fungi have exceptionally high content (22,000 to 25,000 ppm) of phosphorus and are important agents in the circulation of phosphorus in soils.

The phosphorus content of sea water varies with depth from zero at the surface to more than 80 ppm at about 10,000 feet. Deep ocean water, which is believed to be saturated with phosphorus, forms great reservoirs of this element.

Fresh water is thought to be generally low in phosphorus content.

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1 This paper was prepared for partial fulfillment of graduate studies in Geochemistry under Dr. H.G. Goodell, Florida State University.
Exceptions to this are probably waters of low pH.

The phosphorus content of sediments deposited under open ocean conditions is usually low and generally ranges from about 150 ppm to about 1,300 ppm.

Sedimentary phosphorite deposits are thought to represent special conditions of marine deposition. The solubility of phosphorus and calcium is strongly controlled by the pH of the surroundings. The solubility curves for phosphate and calcium carbonate are similar and parallel, with the solubility of phosphate being much less than that of calcium carbonate. Under special conditions of reduced pH, such as could prevail in restricted basins, phosphate rather than calcium carbonate could be the principal sediment. Phosphate deposits may also result from the accumulation of remains and excrement of animals and birds.

**General Statement**

Phosphorus is one of the most abundant and important minor constituents in the Earth's crust. Green (1953) lists the following data concerning this element: Phosphorus (P) has an atomic weight of 30.975 and an atomic number of 15. Weight of one atom is \(51.43 \times 10^{-24}\) grams. Atomic radii of phosphorus ions are: \(P^3^+ 0.93\) Å, \(P^+ 0.44\) Å, \(P^{5+} 0.35\) Å, with corresponding volumes of 3.37 cubic Å, 0.36 cubic Å and 0.18 cubic Å. The ionization potential in electron volts are: \(P^3^+ 30.04\), and \(P^{5+} 64.74\). The electrostatic valences are: \(P^+ 1.75\), \(P^{5+} 1.25\). In fourfold coordination phosphorus has radius ratios with oxygen of 0.31 for \(P^3^+\) and 0.25 for \(P^{5+}\).
The standard heat of formation is 75.18 kg-cal/mole. The standard free energy of formation is 66.71 kg-cal/mole. The logarithm of equilibrium constant of formation (25°C) is -48.897 log kf. The entropy at 25°C $S^\circ$ (gas) is 38.98 cal/ degrees-mole and at 25°C $S^\circ$ (solid) it is 10.6 cal/degree-mole. Phosphorus occurs as a siderophile, lithophile and biophile element. The abundance figures for phosphorus, in grams per metric ton are as follows: igneous rocks 1,180, sandstone 350, shale 740, limestone 1,100, sulphide meteorites 3,100, iron meteorites 2,200, silicate meteorites 1,580±130, seawater, as organic phosphorus 0-.016, as phosphate .001-.10, and cosmos 397. Unlike many other minor constituents, phosphorus is always mineral-forming and always occurs as the phosphate ion ($PO_4^3-$). The principal phosphorus minerals with the percentage of the element contained are: apatites 17.9-18.5%, monazite 11.3-13.1%, amblygonite 20-21.4%, autunite 6.8% and turquois 14.9%. The bulk of the phosphorus of the lithosphere occurs in minerals of the apatite group, especially fluorapatite. Structure of fluorapatite is discussed in a separate paper (see p. 64).

**Phosphorus in Igneous Rocks and Meteorites**

The average phosphorus content in igneous rocks has been estimated to be 1,180 grams per metric ton, or parts per million, Green (1953); 760 ppm Voght (1931); and 1,200 ppm Conway (1945). The following table from Goldschmidt (1953) presents statistical data on the occurrence of phosphorus in various kinds of igneous rocks. The following quantities are calculated: the arithmetic mean (M), the coefficient of dispersion (cd), the median (Me), the mode (Mo), and the atomic ratio P:100 Si, derived from the mean.
<table>
<thead>
<tr>
<th>ROCKS</th>
<th>N*</th>
<th>M</th>
<th>cd</th>
<th>Me</th>
<th>Mo</th>
<th>P:100 Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basalt</td>
<td>342</td>
<td>2,440</td>
<td>57</td>
<td>2,000</td>
<td>1,300</td>
<td>0.96</td>
</tr>
<tr>
<td>Andesite</td>
<td>220</td>
<td>1,230</td>
<td>71</td>
<td>1,130</td>
<td>650</td>
<td>0.40</td>
</tr>
<tr>
<td>Rhyolite (liparite)</td>
<td>83</td>
<td>550</td>
<td>105</td>
<td>580</td>
<td>220</td>
<td>0.09</td>
</tr>
<tr>
<td>Gabbro (norite)</td>
<td>171</td>
<td>1,700</td>
<td>95</td>
<td>1,140</td>
<td>440</td>
<td>0.64</td>
</tr>
<tr>
<td>Diorite</td>
<td>200</td>
<td>1,440</td>
<td>85</td>
<td>1,140</td>
<td>650</td>
<td>0.49</td>
</tr>
<tr>
<td>Syenite</td>
<td>194</td>
<td>1,330</td>
<td>81</td>
<td>1,150</td>
<td>650</td>
<td>0.43</td>
</tr>
<tr>
<td>Granite</td>
<td>340</td>
<td>870</td>
<td>79</td>
<td>800</td>
<td>650</td>
<td>0.24</td>
</tr>
</tbody>
</table>

*N= number of analyses calculated

The arithmetic mean as seen from the above table, indicates a gradual increase of phosphorus with decreasing acidity of igneous rocks.

The medians in the above table do not show a gradual increase of phosphorus with decreasing acidity. Though the basalts still show the larger amounts and the granites and rhyolites show the smaller amounts, the intermediate rocks show a great deal of uniformity.

The modes in the table indicate the basalts as carrying most of the lithosphere's igneous phosphorus, with rhyolite carrying the least. In this method of presentation the granites along with the intermediates show uniform amounts.

According to Goldschmidt (1954): the ratio P:100 Si, which gradually decreases with increasing acidity, is probably due to the increase of silicon rather than a decrease of phosphorus.

An analysis of the data in the table presents only one conclusion:
that basalts are high, intermediate rocks medium and relatively uniform and very acidic rocks low in phosphorus. An exception to this is the abundance of phosphorus minerals in acid and intermediate pegmatites, but this is a specific and relatively minor occurrence of the element.

The most abundant phosphorus minerals in igneous rocks are the apatites. The most common apatite is fluorapatite but many other members of the group also occur. The phosphorus minerals of acid and intermediate pegmatites, though quantitatively very small in relation to igneous rocks as a whole, are of geochemical interest. Here the apatites dominate. In addition to fluorapatite other members of the apatite occur fairly frequently. Some of the most common are hydroxyapatite, chlor-fluor-apatite and fluor-oxy-apatite. The phosphorus-rare earth minerals, monazite and xenotime, also occur mainly in pegmatites.

The percent of phosphorus is much higher in meteorites than in the lithosphere. The sulphide meteorites contain about twice the phosphorus of silicate meteorites. According to Rankama and Sahama (1949) phosphorus does not present chalcophile features even though it is abundant in meteoric sulphides.

**Phosphorus in the Biosphere**

Phosphorus, in both organic and inorganic combinations, is an essential constituent of the bones, brain, blood and tissue of animals. Also, all plants contain phosphorus and the phosphate content of soil is one of the factors that limits their growth.
According to Forbes and Keith (1914) the phosphorus in both animal and vegetable matter is in a highly oxidized state and probably exists in the form of organic and inorganic compounds of orthophosphoric acid. They conclude that there is probably no significant change in the state of oxidation during metabolism.

The prominence of phosphoric acid in bone, muscle, brain and liver is very marked, according to Forbes and Keith (1914), being approximately 50 percent of the ash of these parts.

Gilbert and Pasternak (1905) sum up the total $P_2O_5$ content of the human body as being 30 to 40 grams at birth and about 1,600 grams at middle age. Of this amount 1,400 grams are contained in the bones, 130 grams in the muscles, 12 grams in the brain, 10 grams in the liver, 6 grams in the lungs and about 4 grams in the blood.

Phosphorus is also used in animals in: the digestion and utilization of sugars; in helping to maintain the body fluids in a neutral or slightly alkaline state; in protein catabolism, and in the transfer of energy within the body. According to Forbes and Keith (1914) the use of phosphorus in protein catabolism make it inevitable that the solid and liquid excreta of animals contain appreciable quantities of phosphorus.

Plants vary widely in their phosphorus content. Goldschmidt (1954) lists analyses of various plants and parts of plants which show phosphorus ranging from as low as 47 ppm of dry matter in the wood of pine to as high as 22,000 to 25,000 ppm in bacteria and fungi. Goldschmidt calls attention to the high content of phosphorus in bacteria and fungi and emphasizes the
importance of these plants in the circulation of phosphorus in soils.

Phosphorus in plants is partly stored in tubers, leaves, needles, flowers, seeds, fruit, etc., which serve as food for animals.

**Phosphorus in the Hydrosphere**

The phosphorus content of sea water is relatively low. According to Goldschmidt (1954) it varies both seasonally, with temperature and depth of the water. Biological processes taking place in the surface water apparently account for the seasonal variation. Sea life utilizes maximum amounts of phosphorus during periods of high metabolic activity which is controlled by intensity of sunlight. Consequently the content of phosphorus reaches a maximum in early spring (in the northern hemisphere) and is practically depleted in autumn.

Atkins' (1925) studies on the variation of phosphorus in sea water at different levels showed a gradual increase of phosphorus with increasing depth and decreasing temperature. He interpreted this as being due to the increased solubility of the phosphate ion in water increasingly richer in carbon dioxide. His measurements showed that the $P_2O_5$ content increased gradually from zero from the upper 50 meters to 88 ppm at a depth of 3,000 meters. The temperature variation was from 21°C at the surface to 3°C at 3,000 meters.

Atkins concluded from his study that the ocean deeps are great reservoirs of phosphate, containing 50-80 ppm $P_2O_5$. Goldschmidt (1954) believes that it is probable that such sea water is saturated with phosphorus
and that much, if not all, of the phosphorus presently carried to the sea is being deposited in marine sediments.

Clarke (1924) lists analyses of lake and river water which show that the content of phosphorus is usually low in fresh water, commonly less than 5-10 ppm of \( P_2O_5 \). Clarke's data seems to be much too scanty to be conclusive on the matter of the phosphate content in fresh water. It is known that the solubility of some phosphorus minerals, especially calcium phosphate, is strongly controlled by the pH of the water - increasing with increasing acidity. It is probable that water of low pH following through an area rich in calcium phosphate would carry much more than 10 ppm of \( P_2O_5 \).

**Phosphorus in the Sequence of Sediments**

Green (1953) lists the average content of phosphorus in sedimentary rocks as follows: sandstone 350 ppm, shale 740 ppm, and limestone 1,100 ppm. Clarke (1924) presents somewhat different values, namely: sandstone 342 ppm, shale 730 ppm, limestone 171 ppm, and red clay 1,280 ppm.

According to Goldschmidt (1954) phosphorus always occurs in its quinquevalent oxidation state and because of this its precipitation is independent of the oxidation potential of the environment. However, the solubility of both calcium phosphate and calcium carbonate are strongly controlled by the pH of the surroundings. The solubility curves for phosphate and calcium carbonate in relation to pH are similar and parallel, with the solubility of calcium carbonate being much greater than that of the phosphate. According to Krumbein and Garrels (1952) calcareous sediments
formed under open marine conditions have a low content, 150-200 ppm, of phosphorus because of the differences in solubility of phosphate and carbonate.

**Phosphorus in Phosphorite Deposits**

According to Dietz, Emery and Shepard (1942), phosphorite nodules of organic and inorganic origin are fairly common on the ocean floor. Phosphorite nodules are often found in deep-sea sediments, and some shallow water sediments are thought by the above authors to have been precipitated from colloidal suspension.

Enormous phosphorite deposits are known to exist in many geologic formations from very early Paleozoic to Recent and are geographically distributed throughout the world. Fluorapatite, or a mineral very similar to fluorapatite, is the principal constituent of phosphorites.

According to Krumbein and Garrels (1952) phosphorite deposits can be formed only when conditions permit a continuous removal of calcium as phosphate and when the activity product of the carbonate is not exceeded. They suggest that these conditions can be met in restricted basins with relatively low pH (7.0-7.5).

When upwelling currents, saturated with phosphate, ascend to a higher level with increasing pH and temperature and decreasing CO₂ pressure, a deposition of phosphorite may occur in restricted basins. Without the restricting basins the principal deposition will be calcium carbonate deposits similar to the ones being formed today on the Bahama
Almost all investigators believe that the source of the phosphate in phosphorite deposits is the sea. However, there is a strong possibility that the Florida phosphorites obtained at least a part of their phosphate from a river or rivers that built a large delta into the peninsula. The Florida deposits are almost in the center of the Floridan Plateau and far away from deep ocean water and steep continental slopes. The phosphorite was apparently deposited in shallow restricted bays formed by deltaic distributaries. The phosphorite is associated with an impoverished marine invertebrate fauna indicating abnormal marine conditions.

Remains and excrement of animals and birds sometimes give rise to phosphate deposits. The guano deposits of tropical islands consist mostly of the excrement of sea birds. Leaching and bacterial action removes the more soluble constituents of these deposits leaving them enriched in calcium phosphate. Often the underlying rock is phosphatized by percolating solutions from guano deposits.

The Phosphorus Cycle

The primary source of phosphorus is the phosphorus minerals in igneous rocks, especially apatite. During the process of weathering phosphorus is liberated as soluble and insoluble salts. Part of the insoluble material remains in the residuum and, if refusion occurs, gives rise to secondary igneous rocks. Thus a minor cycle of phosphorus is completed.

Most of the soluble and much of the insoluble phosphorus is carried to the sea, directly or indirectly. A part of the soluble phosphorus enters
the plant-animal cycle through the soil and eventually reaches the sea. The phosphorus carried to the sea remains partly in solution, forming a great reservoir of this element, and is partly deposited in different marine sediments. The marine sediments can reenter the cycle in two ways: 1) by being exposed to igneous activity and giving rise to secondary igneous rocks; and 2) by being elevated to the zone of weathering.

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AN X-RAY STUDY OF TWO FLORIDA LAND PEBBLE PHOSPHATE SAMPLES

W. D. Reves

Abstract

A series of 37 X-ray photographs were made of the clay minerals occurring in the closed chambers of two phosphate pebbles from the Florida phosphate field. As has been reported by previous workers, attapulgite was present. The presence of this clay mineral in the closed chambers tends to confirm the belief that attapulgite was present during the time of lithification of the parent rock of the Bone Valley formation and also that a magnesium environment persisted from the time of deposition of the parent rock until the development of the Bone Valley. It appears from this cursory selective study that attapulgite is changing to montmorillonite in the intermediate horizon of the Bone Valley formation and that montmorillonite is altered to kaolinite in its upper beds.

Introduction

Two different large phosphate pebbles were collected from a point near the base of the Bone Valley formation in a strip mine in central Polk County, Florida, in 1952, and were X-rayed at the University of North Carolina in 1954. One specimen, referred to as specimen H, in the discussion, represents typical minable low grade phosphate rock. The other specimen, referred to as specimen L, is a typical specimen since it is a chert pebble.

1Florida Geological Survey, Tallahassee.
showing an outer zone of phosphate replacement.

Though attapulgite has been reported in previous reports, it is hoped that the progressive selection of clay particles from sealed vugs or other chambers would lead to a better understanding of deposition and diagenesis.

Rock Sample Description, Sampling, and Preparation

Specimen H

Description: Specimen H has a BPL (Bone Phosphate of Lime) content of 68 percent. The pebble was 6 cm. in length, 4.5 cm. in width and 2.5 cm. in thickness. The color was moderate yellowish brown with white clay scattered in lenses, streaks and vugs throughout its entirety. The letter "H" was chosen to designate a pebble having a higher $P_2O_5$ content.

Sampling: Specimen H was progressively sampled from its exterior to a point very near its center (table 1).

Sample H-1 represents the outermost sample taken from the specimen. It is crushed phosphate rock taken from a point 2 mm. from the surface of the pebble.

Sample H-2 is white clay lifted from a closed vug whose dimensions were 3 mm. in length, 2 mm. in width and 2 mm. in thickness. The lens was located at a point 3 mm. from the surface of the pebble.

Sample H-3 is white clay lifted from a closed vug whose dimensions were 3 mm. in length, 3 mm. in width and 1.5 mm. in thickness. The vug was located at a point 8 mm. from the surface of the pebble.
Sample H-4 is a brown clay cast of a coiled gastropod. The dimensions of the clay cast were 1.5 mm. across the base, 1.5 mm. parallel to the axis of coiling. The clay cast was located at a point 12 mm. from the surface of the pebble which placed the sample very near to the center of specimen H.

**Preparation:** An insoluble residue was prepared from sample H-1 using dilute HCl. The sample was washed with distilled water to remove excess acid, split to clay size by centrifugation (Reves, 1959, p. 77) and dried at 32°C. in a constant temperature oven. The remaining samples (H-2, H-3, H-4) were dried at 32°C. at constant temperature and were then crushed and sieved on a 0.37 mm. screen.

**Specimen L**

**Description:** The BPL (Bone Phosphate of Lime) of specimen L is unknown, but it nevertheless has a much lower BPL percentage than specimen H.

Specimen L was 10 cm. in length, 7.5 cm. in width, and 5.5 cm. in thickness. The color of the pebble was greenish-black on the surface and moderate to yellowish brown from a point just beneath the surface to a point 3 mm. to 5 mm. inward into the pebble. Beyond this point, the color abruptly changed to a medium dark gray and thereafter proceeding inward it became progressively lighter in color until a light gray color was reached at the center.

Other than the outer 5 mm. of the pebble, specimen L has the simple physical characteristics of chert. Occasional closed vugs occur from a
point near the surface of the pebble to a point near its center.

The letter "L" was chosen to designate a pebble having a lower $P_2O_5$ content. Though this specimen was collected stratigraphically lower in the Bone Valley section than was specimen H, this does not necessarily mean that it is an older rock since the genesis of each was the underlying sediments. **Sampling:** Specimen L was progressively sampled from its exterior to a point very near its center (table 1).

**Sample L-1** represents the outermost sample taken from the specimen. It is from the outer phosphatic portion of the specimen and was sampled at random from a point 2 mm. from the surface of the pebble.

**Sample L-2** is white unconsolidated clay taken from a sealed vug which commenced 3 mm. from the surface of the pebble and terminated near the center of the specimen. The vug was roughly cylindrical in shape and was 32 mm. in length and 5 mm. in diameter. This cavity was about one-third full of loose clay.

**Sample L-3** is white clay lifted from a closed lens whose dimensions were 6 mm. in length, 4 mm. in width and 1.5 mm. in thickness. The lens was located 3 mm. from the surface and extended to a point 5 mm. from the surface of the specimen.

**Sample L-4** represents that light gray portion of the specimen which occurs near the center of the specimen and has the simple physical characteristics of chert.
Preparation

The samples from specimen L were prepared in the same manner as specimen H with the exception that samples L-2 and L-3 were dried at 32°C. at constant temperature and were then crushed and sieved on a .037 mm. screen. Sample L-4 was ground in a steel mortar and sieved on a 0.37 mm. screen.

Table 1. The Size and Location of Clay Samples in Specimens H and L

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Sample</th>
<th>Sample dimensions</th>
<th>Distance from surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen H</td>
<td>Sample</td>
<td>Length</td>
<td>Width</td>
</tr>
<tr>
<td>Length 6 cm.</td>
<td>H-1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Width 4.5 cm.</td>
<td>H-2</td>
<td>3 mm.</td>
<td>2 mm.</td>
</tr>
<tr>
<td>Thickness 2.5 cm.</td>
<td>H-3</td>
<td>3 mm.</td>
<td>3 mm.</td>
</tr>
<tr>
<td></td>
<td>H-4</td>
<td>1.5 mm. base and 1.5 mm. parallel to coiling axis</td>
<td>12 mm.</td>
</tr>
<tr>
<td>Specimen L</td>
<td>Sample</td>
<td>Length</td>
<td>Width</td>
</tr>
<tr>
<td>Length 10 cm.</td>
<td>L-1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Width 4.5 cm.</td>
<td>L-2</td>
<td>32 mm.</td>
<td>5 mm.</td>
</tr>
<tr>
<td>Thickness 2.5 cm.</td>
<td>L-3</td>
<td>6 mm.</td>
<td>4 mm.</td>
</tr>
<tr>
<td></td>
<td>L-4</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Results of X-Ray Diffraction

Specimen H

Sample H-1: This outer area of the pebble showed no identifiable clay mineral present in either untreated sample, insoluble residue sample, or glycerol solvated sample (table 2).

Sample H-2 shows the clay mineral montmorillonite present. This sample expanded on glycerol solvation from 14.02 Å to 18.45 Å.

Sample H-3 shows the clay mineral montmorillonite present. This sample expanded on glycerol solvation from 14.48 Å to 18.80 Å.

Sample H-4 shows what is probably the clay mineral attapulgite. A band is present centered at 10.46 Å. A second sample showed a band at 10.52 Å. No change on glycerol solvation.

Table 2. Results of X-Ray Diffraction of Specimen H

<table>
<thead>
<tr>
<th>Sample</th>
<th>Univ. of N. C. Catalog No.</th>
<th>&quot;d&quot; spacing (Å)</th>
<th>Identification</th>
<th>Relative Intensity</th>
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</thead>
<tbody>
<tr>
<td>H-1</td>
<td>C-586</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>C-589</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-848</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-2</td>
<td>C-638</td>
<td>14.02</td>
<td>Montmorillonite</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C-637</td>
<td>18.45</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>H-3</td>
<td>C-587</td>
<td>14.48</td>
<td>Montmorillonite</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>C-588</td>
<td>18.80</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>H-4</td>
<td>C-647</td>
<td>Band 10.46</td>
<td>Attapulgite</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C-849</td>
<td>Band 10.52</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C850</td>
<td>Band 10.46</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Sample</td>
<td>Univ. of N. C. Catalog No.</td>
<td>&quot;d&quot; spacing Å</td>
<td>Identification</td>
<td>Relative Intensity</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------</td>
<td>---------------</td>
<td>---------------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>L-1</td>
<td>C-636</td>
<td>10.52</td>
<td>Attapulgite</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>C-633</td>
<td>10.52-14.48</td>
<td>Attapulgite-Montmorillonite</td>
<td></td>
</tr>
<tr>
<td>L-2</td>
<td>C-629</td>
<td>10.52</td>
<td>Attapulgite</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C-645</td>
<td>10.40</td>
<td>Attapulgite</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>C-846</td>
<td>10.40</td>
<td>Attapulgite</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>C-852</td>
<td>10.52</td>
<td>Attapulgite</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>C-863</td>
<td>10.40</td>
<td>Attapulgite</td>
<td>6</td>
</tr>
<tr>
<td>L-3</td>
<td>C-630</td>
<td>10.52</td>
<td>Attapulgite</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>C-632</td>
<td>10.52</td>
<td>Attapulgite</td>
<td></td>
</tr>
<tr>
<td>L-4</td>
<td>C-631</td>
<td>10.52</td>
<td>Attapulgite</td>
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</tr>
<tr>
<td></td>
<td>C-635</td>
<td>10.52</td>
<td>Attapulgite</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C-858</td>
<td>10.52</td>
<td>Attapulgite</td>
<td>2</td>
</tr>
</tbody>
</table>

Specimen L

Sample L-1: This outer area of the pebble shows only faintly identifiable attapulgite and questionable montmorillonite. X-ray photographs of glycerol solvated samples, insoluble residues and oriented aggregates failed to alter the above identification (table 3).

Sample L-2 shows the clay mineral attapulgite as present. This determination was unaltered by glycerol solvation or ammonium salt treatment.

Sample L-3 shows the clay mineral attapulgite as present.

Sample L-4 shows faint lines of the clay mineral attapulgite. The 10.53 Å spacing was reduced to a halo after heating to 700° C. for three hours. Three additional untreated samples showed 001 lines present at 10.9 Å.
Environmental Factors

General

In the past, little emphasis has been placed on the chemical alteration of the surficial area of outcropping limestone formations.

In a current study by the author on the Eocene to Miocene limestones that outcrop in the Florida Panhandle, it was observed that the upper few feet of these rocks contain an appreciable increase in magnesium carbonate. These magnesium carbonate percentages reach 9.4 percent in some instances and locally exceed this figure. This characteristic is the result of enrichment by solution of the more soluble calcium carbonate and/or the result of the availability of magnesium in the surficial environment. This latter magnesium environment could be accounted for by the Pleistocene encroachment of the sea. The occurrence of magnesium limestone may also be expected at depth on a buried erosional surface, where conditions as above prevailed prior to burial. Magnesium limestone at depth may also be the result of percolation of magnesium rich solution into zones of fracture. These solutions may also be diverted, during the downward percolation, by subsurface lithologic boundaries. This could also explain the occurrence of magnesium limestone adjacent to formational unconformities. Thus, these magnesium limestone zones may have been developed before or after burial.

It appears that there is a definite relationship between the occurrence of a magnesium environment and the occurrence of the clay mineral attapulgite. This relationship is discussed in the following occurrences of this magnesium-bearing clay mineral.
Carr (1959, p. 32) in his study of the Tertiary in west central peninsular Florida reports attapulgite as occurring in the upper portion of the Tampa, as well as in the upper portion of the Hawthorn formation. In this region the Tampa generally contains up to five percent magnesium oxide (Carr, 1959, p. 31) but locally, areally and vertically, further magnesium enrichment occurs. Carr also states that attapulgite is commonly found associated with dolomite in the upper part of the Hawthorn formation where the Hawthorn is overlain by the younger land pebble phosphate deposits.

Attapulgite is also present in the Miocene of some Florida Panhandle sediments. Griffin (written communication, 1959) found attapulgite in Bed 5 of the Tampa Stage-Chattahoochee facies in the Jim Woodruff Dam section (Puri and Vernon, 1956, p. 57). This bed is a slightly arenaceous clay where the principle carbonate is dolomite.

The "fullers earth" (attapulgite) deposits in the Gadsden County area of panhandle Florida occur in the Hawthorn formation which is typified by beds of "fullers earth" magnesium limestone and argillaceous sands.

Hawthorn clays containing attapulgite along with montmorillonite occur east of Bradenton in sec. 10, T. 34 S., R. 18 E., in Manatee County (Calver, 1957, p. 63). These clays occur within interbedded units of arenaceous clay, argillaceous sand, limestone and magnesium limestone.

Carr (1959, p. 32) notes the observation of Berman (1953) that attapulgite also occurs in the Bone Valley formation in Polk County. However, Cathcart (1959, p. 236) was unable to find attapulgite in a series of channel
samples within the Bone Valley, and reports no attapulgite from the underlying Hawthorn "bedclay." Nevertheless, magnesium limestone is known to occur in the Hawthorn beneath the Bone Valley formation.

At the foregoing locations it is noteworthy that magnesium limestone and phosphatic nodules are associated with the attapulgite, and in each instance the environment of deposition was brackish to nonmarine. The presence of attapulgite is generally thought to indicate a brackish to non-marine environment. However, some workers feel that there are exceptions to the concept that attapulgite always indicates this environment. Grim (1953, p. 354) thinks that probably the composition of the environment of deposition, chiefly in regard to the abundance of magnesium, leads to the formation of these minerals and Millot (1942) shows that minerals of the attapulgite-sepiolite type are found in Recent sediments accumulating in dry desert basins. Thus, in this latter instance attapulgite is found in environments other than those adjacent to a marine environment. Mumpton and Roy (1958, p. 142) state that the origin of these minerals is still in doubt though the presence of lime and a chain structure inherited from the parent amphibole or pyroxene must play an important role.

Thus the requirements for the formation of this mineral seem to be saline conditions in which magnesium, lime and an inherited chain structure are present.

Results

It is indicated from the interior samples of specimen L that deposition or formation of attapulgite was penecontemporaneous with the lithification of
the parent formation. This is indicated by the presence of attapulgite which has been trapped and preserved within the chert pebble (specimen L). This chert was introduced into the clay within the parent material of the phosphate pebbles, during which time the formation was subjected to a magnesium environment. Though chert emplacement generally precedes dolomitization as Dapples (1959, p. 36) points out, dolomitization apparently had already commenced and was to continue for a long time afterward.

It appears that attapulgite, which is a magnesium-bearing clay mineral, was present during lithification of the parent material from which specimen H originated. This is evidenced by the possible attapulgite identification in the central portion of specimen H. Dolomitization perhaps commenced soon after deposition and lithification of the parent material of specimens H and L and continued until erosion concentrated the phosphatic pebbles of the Hawthorn into a basal conglomerate referred to as the Bone Valley formation.

The span of environmental factors favorable for the persistence or formation of attapulgite such as magnesium, calcium, other near-shore to nonmarine factors, and the possible inherited chain structure, if not simply the primary deposition of attapulgite, persisted from the time of deposition and lithification of the parent material of pebble L and H and into the time of development of the Bone Valley formation where near its base attapulgite is reported by Carr (1959, p. 39).

Since deposition of the phosphate, it appears from the clays that the pebbles themselves have undergone leaching. This leaching is manifest in
the probable identification of montmorillonite on the outer areas of pebble H
and the inner probable identification of attapulgite in pebble L. In the former
instance it appears that the attapulgite of pebble H, though it need not
necessarily be the sole clay mineral since montmorillonite was probably
present, has been progressively altered inwardly to montmorillonite. In
the latter instance (specimen L), the change to montmorillonite has been
much slower and attapulgite is yet the principal clay mineral. The cherty
nature of this specimen apparently retards the clay diagenesis. The
probability of the alteration of attapulgite to montmorillonite is discussed
by Mumpton and Roy (1958, p. 136) who state that sepiolite and attapulgite
can be decomposed to yield montmorillonoids by mild hydrothermal treat-
ment at temperatures probably as low as 100° C. Though the temperatures
in the phosphate sediments probably never reached this degree, the clay
alteration may have been brought about by prolonged leaching of these
sediments at a temperature lower than that above. The Bone Valley "matrix"
yields montmorillonite which can be expected in such an environment.
However, this clay may represent both primary and diagenetic montmorillonite.

It is of interest to note that the outer 3 mm. of specimen L (cherty)
has undergone phosphate enrichment, which may be a process which is
continuing to the present.

In the upper beds of the Bone Valley formation Cathcart (1959, p. 239)
obscerved that the montmorillonite has weathered to kaolinite. This diagenetic
change could be expected in the better drained and acid environment of the
upper Bone Valley. Coprolites from this upper part of the Bone Valley

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X-rayed by the author gave kaolinite patterns. Thus further clay diagenesis is apparent.

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STRUCTURE AND DIADOCHIC SUBSTITUTIONS IN THE APATITE GROUP

E. W. Bishop

Abstract

The minerals species of the apatite group are in the hexagonal bipyramidal class of the hexagonal system and have the chemical formula $A_{10}(XO_4)_6Z_2$. The apatites show chemical variation in terms of: 1) $A=$Ca, Pb, Na, K, C and Sr; 2) $X=$P, As, V, S, Si and C; and 3) $Z=$F, Cl and OH.

Members of the apatite group are isostructural with fluorapatite. The substitution of larger ions generally results in an enlargement of the unit cell.

The unit cell of fluorapatite, $Ca_5(PO_4)_3 F$, has the dimensions $a_o 9.36 \text{ kX}$, $c_o 6.88 \text{ kX}$ and contains 10 Ca, 6P, 2F and 24 O. Phosphorus occurs in tetrahedral coordination with oxygen in a nesosilicate-like structure. Calcium occurs in two different positions: 1) in sevenfold coordination with 6 oxygen and one fluorine, and 2) in sixfold coordination with oxygen. The bonding of the cell is from phosphorus to oxygen to calcium to fluorine.

Diadochic substitutions as related to fluorapatite are: 1) Pb, Na, K, C and Sr for Ca; 2) As, V, S, Si and C for P; and 3) Cl and OH for F.

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1This paper was prepared for partial fulfillment of graduate studies in geochemistry under Dr. H. G. Goodell, Florida State University.
Introduction

Minerals of the apatite group crystallize in the hexagonal system, hexagonal bipyramidal class and have the formula $A_{10}(XO_{4})_6Z_2$. The apatites may show chemical variation in three ways: 1) in terms of cation $A=$Ca, Pb, Na, K, C, Al and Sr; 2) in terms of $Z=$F, Cl, OH; and 3) in terms of $X$ which is at the center of a tetrahedral group. The X position can be occupied in whole or in part by P, As, V, S, Si and C.

According to McConnell (1938a) the apatite group may also contain significant amounts of Mg and Mn. McConnell also reports that a number of analyses show BaO, CrO, $Cr_2O_3$, FeO, $Fe_2O_3$ and $Al_2O_3$. Cerium and the rare earths also occur, according to Starynkevic-Borneman (1924).

The exact number of species in the apatite group has not yet been agreed upon. Dana's (1951) system subdivides them into three series: apatite (4 species), pyromorphites (3 species), and svabites (2 species). In addition, there are five miscellaneous species outside of these three series. Strunz (1957) classifies the apatite group into 12 species in four series. Three of these are the same as Dana, except that oxy-apatite is placed in the apatite series and the svabite series has but one member - the mineral svabite. Following is a list of the species occurring in the apatite group, modified from Dana (1951) and Strunz (1957):

Apatite series, $Ca_{10}(PO_4)_6(F, Cl, OH)_2$

Fluorapatite, $Ca_5(PO_4)_3F$, $a_0 9.36 \text{ kX}, c_0 6.88 \text{ kX}$

Chlorapatite, $Ca_5(PO_4)_3Cl$, $a_0 9.52 \text{ kX}, c_0 6.85 \text{ kX}$

Hydroxylapatite, $Ca_5(PO_4)_3(OH)$ $a_0 9.40 \text{ kX}, c_0 6.93 \text{ kX}$
Carbonate-apatite, \( \text{Ca}_{10}(\text{PO}_4)_6(\text{CO}_3)\cdot\text{H}_2\text{O}, \ a_0 = 9.41 \text{ kX}, \ c_0 = 6.88 \text{ kX} \)

Oxy-apatite, formula not known.

Pyromorphite series, \( \text{Pb}_5(\text{PO}_4\cdot\text{AsO}_4\cdot\text{VO}_4)\cdot\text{Cl} \)

Pyromorphite, \( \text{Pb}_5(\text{PO}_4)_3\cdot\text{Cl}, \ a_0 = 9.95 \text{ kX}, \ c_0 = 7.31 \text{ kX} \)

Mimetite, \( \text{Pb}_5(\text{AsO}_4)_3\cdot\text{Cl}, \ a_0 = 10.24 \times \text{K}, \ c_0 = 7.34 \text{ kX} \)

Vanadinite, \( \text{Pb}_5(\text{VO}_4)_3\cdot\text{Cl}, \ a_0 = 10.31 \times \text{K}, \ c_0 = 7.34 \text{ kX} \)

Svabite series, \( (\text{Ca}, \text{Pb})_5(\text{AsO}_4\cdot\text{PO}_4)\cdot(\text{F}, \text{Cl}, \text{OH}) \)

Svabite, \( \text{Ca}_5(\text{AsO}_4)_3\cdot(\text{F}, \text{OH}) \)

Hedyphane, \( (\text{Ca}, \text{Pb})_5(\text{AsO}_4)_3\cdot\text{Cl} \)

Dehrnite, \( (\text{Ca}, \text{Na}, \text{K})_5(\text{PO}_4)_3\cdot(\text{OH}), \ a_0 = 9.33 \pm 2\times \text{K}, \ c_0 = 6.88 \pm 1 \text{ kX} \)

Lewistonite, \( (\text{Ca}, \text{K}, \text{Na})_5(\text{PO}_4)_3\cdot(\text{OH}), \ a_0 = 9.35 \text{ kX}, \ c_0 = 6.89 \text{ kX} \)

Fermorite, \( (\text{Ca}, \text{Sr})_5(\text{P},\text{AsO}_4)_3\cdot(\text{F}, \text{OH}), \ a_0 = 9.60 \text{ kX}, \ c_0 = 7.00 \text{ kX} \)

Wilkeite, \( \text{Ca}_5(\text{P},\text{S},\text{Si},\text{CO}_4)_3\cdot(\text{OH}), \ a_0 = 9.44 \pm 4 \times \text{K}, \ c_0 = 6.90 \pm 1 \times \text{K} \)

Ellestadite, \( \text{Ca}_5(\text{Si},\text{S},\text{P},\text{CO}_4)_3\cdot(\text{Cl}, \text{F}, \text{OH}), \ a_0 = 9.53 \text{ kX}, \ c_0 = 6.91 \text{ kX} \)

**The Structure of Fluorapatite**

The diadochic substitutions of the apatite group will be discussed in terms of the unit cell of fluorapatite. Naray-Szabo (1930), Mehmel (1930 and 1931) and McConnell (1938a) show that the structure contains the following ions: 10 Ca, 6P, 2F and 24 O. The positions of these ions are given in figure 1, slightly modified from McConnell (1938a).

The dimensions of the unit cell of fluorapatite are \( a_0 = 9.36 \text{ kX} \) and \( c_0 = 6.88 \text{ kX} \). The ions in the unit cell are held together by ionic bonds.
FIG. 1
PROJECTION OF THE UNIT CELL OF FLUORAPATITE ON (0001)
THE HEIGHTS OF THE VARIOUS IONS ARE INDICATED AS
FRACTIONS OF CO.
Phosphorus and Oxygen

Phosphorus occurs in fluorapatite in fourfold or tetrahedral coordination with oxygen. The tetrahedra are independent units not linked together, and are analogous to the nesosilicates in structure. The phosphorus is in the center of the tetrahedron and has a plus charge of five with each P-O bond having a charge of 5/4. The oxygens at the corners of the tetrahedron have a total charge of minus 8. The overall unsatisfied charge on the tetrahedron is therefore minus three.

Calcium and Fluorine

The Ca²⁺ ions occur in two different positions in the fluorapatite cell: 1) as a hexagonal framework of 6 Ca²⁺ surrounding 2 F⁻ at the corners of the cell; and 2) as 2 columns of 2 Ca²⁺ each, centered at 1/3 and 2/3 the distance along the long diagonal of the unit cell on (0001). In the first position the calcuims are linked to PO₄ groups and form hexagonal cells extending through the structure in the c-direction. These hexagonal cells contain the fluorine ions. In this position, calcium is surrounded by 6 oxygen and 1 fluorine and is in sevenfold coordination. In the second position, the calcium is also linked to PO₄ groups but the resultant structure is a prism extending in the c-direction. The 2 calcium ions are located at the center of the prism along a line in the c-direction. In this position each calcium ion is in sixfold coordination. In the first position 6 of the 10 total calcium ions form 36 bonds with oxygen and 6 bonds with fluorine. The charge on the 6 calcium ions totals 12. As the 6 calcium ions are in contact with 2 fluorine ions which have a total charge of minus 2, ten plus charges are left to be
divided among the 36 bonds with oxygen which gives each Ca-O bond a value of 5/18. The 6 PO₄ groups have a total excess of 18 minus charges, 10 of which are used in bonding with calcium in the first position.

In the second position, 4 calcium ions with a total charge of plus 8 are in contact with 24 oxygen ions which now have a total charge of minus 8, giving each Ca-O bond in the second position a value of 1/3, and establishing electrostatic equilibrium for the unit cell.

**Substitution for Calcium**

As may be seen in list of mineral species in the apatite group, several elements are known to substitute either fully or in part for calcium. Those having similar electrostatic charges are Pb²⁺ and Sr²⁺. Pb²⁺ which has a much larger ionic radius (1.32 kX as compared to 1.06 kX for calcium, in sixfold coordination) is accommodated by an increase in size of the unit cell. Sr²⁺(with a large radius of 1.27 kX) substitutes for part of the calcium in fermonite whose unit cell is larger than fluorapatite. Na⁺ and K⁺ whose radii are 0.74 and 1.33 kX respectively, substitute for a small part of the calcium in dehrnite and lewistonite. Valence compensation may be accounted for in these minerals, according to Dana (1951), by substitution of C for P, Al for Ca or OH for O. The great difference in the size of potassium over calcium suggests that the unit cells of dehrnite and lewistonite should be much larger than that of fluorapatite, but this is not the case. The coupled substitution of Al³⁺ whose ionic radius is 0.57 kX for calcium, 1.06 kX, probably makes room for the large potassium ion without increasing the cell size.
Substitutions for Phosphorus

Known substitutions for P$^{5+}$, whose radius ratio with oxygen in fourfold coordination is 0.27, are As$^{5+}$, 0.30; V$^{5+}$, 0.3; S$^{6+}$, 0.21; Si$^{4+}$, 0.30; and C$^{4+}$, 0.14. The substitutions of As$^{5+}$ and V$^{5+}$ do not upset the electrostatic balance of the unit cell and in minette, vanadinite, svabite and hedyphane there is complete substitution. The chemical formula of fermorite shows partial substitution of P$^{5+}$ by As$^{5+}$. Wilkeite and Ellestadeite show partial substitution of P$^{5+}$ by S$^{6+}$, Si$^{4+}$ and C$^{4+}$. Here there is an increase of the negative charges associated with the tetrahedra having Si$^{4+}$ and C$^{4+}$ at their centers but the electrostatic neutrality is maintained by the substitution of S$^{6+}$ for P$^{5+}$.

Substitutions for Fluorine

In the apatite series of the apatite group, F$^-$, Cl$^-$ and OH$^-$ can substitute mutually to form a complete series to the essentially pure end members. In fluorapatite, fluorine is more abundant than chlorine or hydroxyl. In chlorapatite, chlorine is more abundant than fluorine or hydroxyl. In Hydroxylapatite hydroxyl is more abundant than fluorine or chlorine. The substitution of OH$^-$, ionic radius 1.33 kX, for F$^-$, ionic radius 1.33 kX is easily understood, but the substitution of Cl$^-$ ionic radius 1.81 kX presents a problem. Theoretically the unit cell of chlorapatite should measure a$_{o}$ 10.36 kX and c$_{o}$ 7.81 kX, but actually the dimensions are a$_{o}$ 9.52 and c$_{o}$ 6.85 kX which is very close to those for fluorapatite. This discrepancy can be accounted for by the difference in the electronegativity of the two ions. Fluorine with an electronegativity of 4 as compared
to 3 for chlorine, forms stronger bonds with the surrounding calcium ions. This results in the calcium ions being pulled away from the oxygen ions thereby forming a smaller framework around the fluorine. Chlorine with a smaller electronegativity does not exert as much pull so therefore the calcium ions are held closer to the oxygen ions, resulting in a larger framework which will admit the chlorine ion without changing the size of the unit cell.

The chemical formula of carbonate-apatite shows that \( \text{CO}_3 \) substituted for fluorine. McConnell (1938a) does not believe that this is so and presents evidence to prove that carbon displaces calcium in the second position of calcium with the formation of \( \text{CO}_3 \) groups. The four carbon ions in this position occur in threefold coordination and have the height values in the unit cell of .25, .75, .25 and .75 replacing calcium ions having height values of .05, .45, .55 and .95 (fig. 1).

**Substitutions for Oxygen**

McConnell (1938a) states that there is a strong indication that \( \text{OH}^- \) substitutes for \( \text{O}^{2-} \) in apatite to compensate for the substitution of monopositive ions for bipositive ions.

**Summary and Conclusions**

Mineral species of the apatite group seem to be remarkably stable, permitting a large number of unusual types of substitutions and involving a considerable number of ions. The four ions in fluorapatite can be replaced by several different ions:
(1) Calcium is replaced by lead, strontium, sodium, potassium, carbon and aluminum, and possibly magnesium and manganese.

(2) Phosphorus is replaced by arsenic, vanadium, sulfur, silicon and carbon.

(3) Fluorine is replaced by chlorine and by hydroxyl groups.

(4) Oxygen is possibly replaced by hydroxyl groups.

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THE REGIONAL LITHOSTRATIGRAPHY OF THE POST-EOGENE ROCKS OF FLORIDA

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Abstract

Lithologic cross sections and correlations of those strata lying on top of the upper Eocene or older rocks of Florida are presented together with their lithofacies. Two main interfingerling lithosomes are responsible for the resulting facies patterns. Basal and basinal downdip are bioclastic limestones which intertwine over tectonic hinge-lines with upper and updip shelf terrigenous clastics which are somewhat heterogeneously composed of sandy phosphoritic green clay, sands and light colored lenses of clay. Oligocene and lower Miocene tectonic stability are succeeded by unstable tectonic conditions during middle Miocene. Overall Oligocene transgression of the sea is followed by sporadic withdrawal during all of post-Oligocene with the resulting fluctuation of strand-lines. Terrestrial clastics encroach upon the panhandle and peninsula beginning in latest lower Miocene and continue to increase in dominance throughout and following that epoch as marine conditions moved intermittently but steadily south. Facies patterns and the parameters of sedimentation are interpreted in light of these tectonics.

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Introduction

This paper is in the nature of a progress report on investigations of the complex stratigraphy of those rocks lying above the Eocene strata in peninsular and panhandle Florida. It is a part of a somewhat longer range project which has as its object a detailed reexamination of all of Florida regional stratigraphy using modern methods of stratigraphic and litho-graphic analysis. The investigations reported in this paper are in part concerned with perhaps the most heterogeneous sequence of strata in the Florida column. There are two main lithosomes involved; deposited in response to relatively unstable tectonic conditions under shifting environmental conditions from marine to transitional to continental, from south to north and from bottom to top respectively. The interfingering of the bioclastic carbonate lithosome with the predominantly terrestrially derived clastic lithosome are the most complex in those areas where the strand-line had the shortest period of fluctuation. These interfingering areas coincide with regions of predominant hinge-line tectonics between the northern shelf and basins marginal to the Gulf coast geosyncline to the south and west. The interpretation of the interstratification of these two lithosomes, although of radically different lithologies, is further compounded by the fact that the hinge-line appeared not to act tectonically neutral with simple transition from stability to active downwarp but rather often, especially in the western panhandle and central peninsula of Florida, as a tectonically positive sill over which there were periods of active erosion which removed those strata
which recorded the earlier records of the fluctuation of environment. Further, these areas of hinge-line and strand-line fluctuation are those where the greatest and most rapid facies change occur and the removal of rocks recording interstratification greatly hinders precise lithologic correlation.

Widespread transgression of the sea in Oligocene initiated the final depositional sequence of sediments in Florida, followed by sporadic regression throughout post-Oligocene time, so that a "natural" base for the unit under consideration was chosen as any pre-Oligocene rocks. These are usually one of the formations in the Ocala group but are rarely, over tectonically positive areas, older strata. The pre-Oligocene rocks are lithologically distinct almost everywhere from the overlying strata so that the base of the sequence even in the subsurface is usually easily recognized.

The decision to include all of those strata resting on the Eocene rocks stems in part from the inability of the authors to delineate between upper Miocene, Pliocene, and Pleistocene rocks where those rocks are predominantly of a transitional and/or continental nature and therefore devoid of any invertebrate fossil record. The sequence was therefore analyzed as a whole and in those places where individual series and stages could not be differentiated time lines are drawn by inference only.

Acknowledgments

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Robert O. Vernon, Director of the Florida Geological Survey, was generous of his time in consultation and with the resources of the Survey. Gratitude is expressed to Mr. Harry Whitehead who prepared the illustrations. The endeavors of the many geologists who went before prepared the way and without them this synthesis would not be possible.

**Stratigraphic Nomenclature**

The authors use lithosome as originally defined by Wheeler and Mallory (1956) as a lithostratigraphic body of essentially similar lithology which may be mutually intertongued with one or more bodies of differing lithic constitution. A lithotope, as defined by Krumbein and Sloss (1951), is a two dimensional concept representing essentially the depositional interface and records instantaneously distinct areas of sedimentation within an environment. Therefore, each specific portion of an environment in which sediments of a different nature are deposited represents a lithotope so that an environment may consist of one or more abutting lithotopes. A lithosome is composed therefore of an infinite number of lithotopes vertically superimposed. Biosome and biotope are the faunal correlatives of the lithologic terms above and should be used with the same restrictions.

Facies is one of the most maligned terms in stratigraphy. As defined by Moore (1949) the term applies to objective lateral changes in lithology and/or paleontology within a genetically related body of sediments and is synonymous with "aspect." This, however, restricts the usage to bodies of sedimentary rocks which are "genetically related," a subjective interpretation
at best. A more widespread and generally accepted usage of the concept is in the delineation of lateral changes in lithology of strata whether the sequence under investigation is a rock or a time-rock unit. You may have then, for example, facies of systems, series, or stages or of formations and groups. In the case of formational facies the change must be of somewhat a limited nature geographically or lithologically so that the basic definition of formation is not exceeded. If such a change is of a large magnitude then an arbitrary cutoff becomes necessary which separates lithologies and a new distinct lithologic unit that is mappable is raised to formational rank and given a geographic name corresponding to a type locality. In practice, then, formational facies must be of a much less distinct nature than facies of either groups or of time-rock units.

Since facies means aspect, correct terminology used in conjunction with facies should include adjectives descriptive of the lithology (or paleontology in the case of biofacies). Such terms as green shale facies, carbonate facies, or arkosic facies are examples. It is usually considered poor terminology to use geographic names with facies. Such usage as "Hawthorn facies" means literally Hawthorn aspect and since the Hawthorn has perhaps an infinite number of aspects some confusion arises as to what exactly is "Hawthorn." Further, stratigraphers have accepted geographic terminology for formational nomenclature and facies are not synonymous with formation. Other somewhat loose usage of facies terminology includes the equation of facies with environment. Lagoonal facies, continental facies,
etc., are meaningless since in any environment a number of different types of lithology may be deposited, often synchronously. In addition, the assignment of lagoonal or continental adjectives is a subjective interpretation by the investigator and one that might be argued by different interpretation. Facies should be as objective as possible; i.e., they represent the lithologies and faunal assemblages that actually are present within a sequence.

By definition and in theory facies may not succeed themselves vertically (formations, however, do); therefore, when two lithosomes, which are also facies, interfinger an infinite set of new facies are generated composed of varying proportions of the two lithosomes. It is considered incorrect therefore by many stratigraphers to use facies terminology of a single formation when the unit under analysis is composed of more than one superimposed formation the facies terminology of the sequence under consideration takes precedence over terminology applied to a single formation in such a case. Wheeler and Mallory (1956) give examples.

**Previous Investigations**

The first comprehensive report on the geology of Florida was by Cooke and Mossom (1929) in which the broader aspects of Florida stratigraphy and geology were first synthesized. Cooke (1945) revised this earlier work and brought it up to date in light of 25 years of geological investigations. Since Cooke's last report there has been no attempt at geological synthesis that covers the entire column in the whole state other than Puri and Vernon's
Figure 1.
summarization (1959). Applin and Applin (1944) published the first regional stratigraphic analysis of Florida based largely on the subsurface information gleaned from the information of oil tests then drilled in the State. Toulmin (1955) followed this with a regional presentation of the Cenozoic rocks of the southeastern United States. In neither the Applins' or in Toulmin's papers, however, were the strata presented in a complete three dimensional analysis. Five papers since 1940 have made significant contributions to the interpretation of Florida stratigraphy. Vernon (1942, 1951), Puri (1954, 1957), and Bishop (1956) discuss the complexities of Florida stratigraphic relationships and point out or allude to some of the intertonguing lithosomes which especially comprise the post-Eocene sediments in the particular area in which they were investigating. Puri (1954) and Bishop (1956) in particular demonstrated the lateral complexities of some of the post-Eocene sediments. In addition to these papers, there have been numerous papers published since the war by the Florida Geological Survey or the United States Geological Survey in the form of county or area reports dealing largely with water supply or economic problems but present much stratigraphic information. Most recently Carr and Albersen (1959) and Marsh (1960) have presented the results of investigations in north central Florida and the western panhandle, respectively.

**Analytical Procedures**

Data from approximately 90 wells (fig. 1), both oil tests and water, from the files of the Florida Geological Survey, which penetrated the entire interval, were actively used in the study. Nearly half again as many were
LITHOSTRATIGRAPHIC CROSS SECTION OF POST-EOCENE STRATA OF FLORIDA

Figure 2.
LITHOSTRATIGRAPHIC CROSS SECTION
OF
POST-EOCENE STRATA OF FLORIDA

Figure 4.
consulted that either because of incomplete samples, faulty sampling, or missing sample intervals could not be used in their entirety, but often were helpful in a particular portion of the section where they helped clarify important correlations. Both the written lithologic descriptions of prior workers as well as the samples themselves were consulted so that a uniformity in description was obtained. Most of the wells used in this report were examined by the junior author, who also made stratigraphic correlations in the panhandle and in north Florida.

Lithologic correlations based on position in sequence and distinctive key intervals, most of which were good only for short intervals, were constructed spanning the state west to east along the panhandle (fig. 2) and north to south down the peninsula (fig. 3). In addition Stone, working under the direction of the senior author, constructed a west to east lithologic correlation across the peninsula from Pinellas County to Brevard County as a part of a Master's thesis (fig. 4). A final short section which shows downdip correlations from Jackson County south to Gulf County in the western panhandle is presented (fig. 4). In the presentation of the stratigraphic correlations the authors chose to present the simplest possible interpretation of the data based on sound sedimentalogical concepts.

The facies maps are entirely objective. They were constructed on principles summarized in Krumbein and Sloss (1951). Lithologies pertinent to the investigation were summed in each well and noted on data sheets. The following lithologies were tallied: limestone, microbioclastic, usually cream to tan or gray and composed almost entirely of the tests of microfauna;
CROSS SECTION SHOWING TIME STRATIGRAPHIC RELATIONSHIP OF POST-EOCENE STRATA OF FLORIDA

Figure 5.
CROSS SECTION SHOWING TIME STRATIGRAPHIC RELATIONSHIP OF POST-EOCENE STRATA OF FLORIDA
LEGEND

- POST-MIOCENE
- UPPER AND MIDDLE MIOCENE
- LOWER MIOCENE
- OLIGOCENE

CROSS SECTION SHOWING TIME STRATIGRAPHIC RELATIONSHIP OF POST-EOCENE STRATA OF FLORIDA

Figure 7.
limestone, sandy phosphatic macrobioclastic, in shades of gray to white composed almost entirely of the shell fragments of mollusks with smaller amounts of echinoid spines and microfossil shells; dolomite, microcrystalline of any color; dolomite, saccharoidal of any color; sand, quartose; sand, phosphoritic, argillaceous and pebbly; clay, green to olive, or in all shades of gray, often highly sandy and phosphoritic; clay, red to yellow, often sandy; and clay, white. From the percentages of each of these lithologies the following ratios were computed for each well: sand + clay/carbonate; sand/ clay; limestone/dolomite. These ratios were plotted on standard facies triangle employing as end members carbonate, sand, and clay and upon a second triangle using the end members sand + clay, limestone, and dolomite. The ratios, together with the total thickness of the interval present, were plotted on base maps and contoured using isopleths indicated on the facies triangles and 100-foot isopach contours (pl. 1,2). Finally cross sections were prepared based upon all available information which gives our interpretation of the time stratigraphic relationships of the strata involved in the study (figs. 5, 6, 7).

Stratigraphic Cross Sections

Discussion of the lithologic cross sections (figs. 2, 3, 4) will be presented by cross section generally following west to east and north to south directions. Section A-A’ and section C-C’ in panhandle Florida (figs. 2, 4):

West of well W-1750 in Holmes County the post-Eocene rocks thicken rapidly and abruptly into the Gulf coast geosyncline. Resting on top of the
Eocene Crystal River formation, which in this area is a gray micro and macro
bioclastic glauconitic limestone containing numerous Lepidocyclina ocalana, is
the brown Bucatunna shale, predominantly illitic in composition, which shows
little relative thickening to the west in this portion of the Gulf coast. It
intertongues updip and is overlain with typical creamy to buff to white micro-
bioclastic dolomitic limestones of Suwannee lithology and dolomites. The entire
Oligocene section shows only slight thickening westward. Overlying the
microbioclastic limestones is a gray macrobioclastic and often glauconitic
interval sometimes containing thin intercalated green sandy clays which are
typical of Tampa lithology lower Miocene in age (fig. 2). This unit too shows
little westward thickening. Overlying these Tampa strata in turn is a unit
of rather homogeneous green to gray-green sandy clay which shows radical
westward thickening into the geosyncline. No attempt was made to subdivide
this unit chronologically and it is interpreted as both middle and upper
Miocene in age and records the first large relative downwarping of the
geosyncline during post-Eocene time. The uppermost unit is one pre-
dominantly of coarse clastics composed of sand, stringers of pebbles, and
some clay. It is impossible, at this time, to assign an age to this unit other
than post-Miocene but the relative rate of downwarp during its deposition is
as great or greater than is recorded in the underlying green sandy clay.

From well W-1750 in Holmes County to well W-1356 in Jackson County,
correlations are tenuous. The cross section in this area passes obliquely
over one of the hinge-line areas where all of the Miocene, as well as the
upper Eocene Crystal River formation, is missing. The interpretation chosen by the authors of this part of the section is one of uplift during post-Miocene during which all of the Miocene, Oligocene, and uppermost Eocene rocks were removed by intensive erosion. All of the present sediments are of post-Miocene age. The small sag, or microbasin, illustrated in well W-2295, must have come into existence during this time for prior to post-Miocene the area was both hinge-line and sill. An alternate interpretation which needs further investigation is that the clay lentil in wells W-2295 and W-2415 is actually equivalent to the middle and upper Miocene green clays of the far western panhandle. In this latter instance, the clastics below this clay lentil would be lower Miocene in age and represent a facies change in the lower Miocene sediments in near shore environments. Since there appears to be only slight thinning in Oligocene age carbonates but somewhat more in lower Miocene age beds adjacent to the arch, active uplift is concluded to have begun in middle Miocene and to have continued to post-Miocene. This is the Chattahoochee arch. These events are compatible with active tectonism in other related parts of Florida.

The cross section from well W-1356 in Jackson County to well W-703 in Suwannee County, cuts across a basin marginal to the Gulf coast geosyncline and is termed the Apalachicola basin. Beds lying immediately over the Ocala group are dolomitic or dolomite interbedded with cream to buff microbioclastic limestones herein termed Suwannee. The unit thickens sharply into the basin showing active downwarping during Oligocene. Overlying these basal beds are microbioclastic phosphatic sandy dolomitic limestones
and dolomites interbedded with green sandy phosphoritic clays and a few thin argillaceous sands, all of which are interpreted as the Tampa lithology and of lower Miocene in age. Further south in peninsular Florida the Tampa sediments are limestones in their basal section, contain no green clays, and only become interbedded with these strata in their uppermost section. However, since the source of these terrestrial clastics was undoubtedly to the north it is reasonable to assume that initiation in clay deposition would occur in the north at an earlier date. Overlying these Tampa limestones and green clays is a unit that consists predominantly of lenses and lentils of green and white clay, sand, and some minor beds of nodular limestone. These beds are assigned to the Hawthorn formation and may represent both middle and, in part, upper Miocene. The entire sequence in this area is capped with red silt and sand clastics containing thin stringers of kaolin. Doering (1960) and Cooke (1945) regard this surficial material as Citronelle correlative and assign a Quaternary age. The almost complete dolomitization of portions of the carbonate sequence throughout the central part of the cross section is regarded as due in part to its marginal position on the geosyncline to the south with the incorporation of magnesium into original predominantly calcium carbonates. The Oligocene rocks to the east in this part of the cross section maintain an almost even thickness, although the section as a whole thins rapidly over the Ocala arch as redefined by Vernon (1951). The arch, as far as this sequence of strata is concerned, is certainly a post-Oligocene feature as Vernon has suggested. Since Tampa beds thin eastward the influence of the arch on deposition was probably felt all through lower
Miocene as at least a positive tectonic feature. However, active uplift and attendant erosion is interpreted as commencing in middle Miocene.

East of well W-703 in Suwannee County and continuing eastward to the Atlantic coast beyond Jacksonville, the facies of the sequence changes greatly from its westward sections. Structurally, the sediments fill a depression herein called the Jacksonville basin and are composed almost entirely of green to gray-green phosphatic and sandy clays, with some incorporated mollusk shells, typical of Hawthorn lithology. Interbedded are discontinuous lenses of phosphatic sand. On the updip western edge of the basin, these clastics are interfingered with sandy dolomite. No basal carbonate lithologies are present that appear to be correlative with Suwannee lithologies elsewhere in the state. Capping the unit, exclusive of the uppermost terrace deposits, is a relatively thin macrofossiliferous sandy limestone composed of casts and shells of mollusks. The apparent absence of Oligocene strata implies that the area was initially tectonically positive during immediate post-Oligocene times and only commenced sinking in latest lower Miocene. Whether Oligocene rocks were originally present is conjectural but the fact that the Suwannee limestones just west show no evidences of thinning or of facies change that might imply a nearby coast line suggests that Oligocene did indeed once cover the area but perhaps with some thinning. Few fossil remains have been dated from these clays and sands. However, on the same sedimentallogical reasoning used before, the source of the terrestrial clastics of presumed middle and upper Miocene ages in peninsular Florida to the south was from the north. The encroachment of
these clastics was undoubtedly time transgressive with their first deposition at an earlier date the farther north they appear. Further, uppermost beds of Tampa age in the central panhandle contain tongues of similar lithologies. On these grounds the authors feel that the lower portion of these basinal sediments are of lower Miocene and the upper middle to late Miocene age. The Jacksonville basin is undoubtedly tectonically related to the Ocala arch development. If renewed uplift along the Peninsular Arch (Applin, 1951) preceded the uplift along the Ocala arch, subparallel with it and to the west, during immediate post-Oligocene time, any Oligocene would have been removed. As the Ocala arch in turn began active uplift, coupled with sinking of the Jacksonville basin in lower and especially middle and upper Miocene, the sequence of sedimentation would be that observed.

Cross section C-C' runs south from well W-1750 in Holmes County to well W-1455 in Gulf County. Stratigraphic relationships are fairly straightforward. The basal cream to buff microbioclastic Oligocene limestones of Suwannee lithology are everywhere present and thicken southward, although the center of downwarp appears to have shifted slightly southward post-Oligocene from well W-1468 to well W-1455 both in Gulf County. The updip and uppermost beds of the Suwannee are almost completely dolomitized. Locally, bedded chert appears in the uppermost beds. A brown clay resembling the Bucatunna clay appears in the depths of the section in Bay and Gulf counties.

Overlying these Oligocene beds are predominantly macrofossiliferous sandy limestones typical of lower Miocene Tampa lithology. Updip, like the
underlying beds, these are almost completely dolomitized. These limestones thicken almost uniformly southward with the shift in maximum downwarp as previously noted. The strata which overly this section are somewhat heterogeneous, composed of green sandy clays and sands in their updip regions which intertongue southward with limestones which have lithologies almost identical with those below them in the section. These updip green sandy clays and interbedded thin sands are probably equivalent to the middle Miocene Hawthorn and upper Miocene Choctawhatchee. The downdip intertongued strata are of Tampa lithology. A question of terminology arises. That is, in basinal regions of Florida, and this is especially apparent in peninsular Florida, the Tampa beds are lower and middle and perhaps even upper Miocene in age. This is not incompatible with the definition of a formation, but does require a readjustment of thinking. The Tampa, as originally defined from more northern exposures, is almost certainly of lower Miocene age but as the flood of terrestrial clastics encroached from the north, conditions for limestone deposition were pushed southward, but Tampa lithologies continued to be deposited in basinal areas away from the influence of these terrestrially derived materials.

Cross sections B-B' and D-D' in peninsular Florida (figs. 3, 4):

The long north-south cross section B-B' down the peninsula of Florida starts in the Jacksonville basin and continues south into the Keys. The southern margin of the Jacksonville basin is somewhat different lithologically from the eastern margin where the basinal clastics are interfingered with
sandy dolomite. To the south the basinal green sandy clays interfinger with a basal phosphatic sand containing mollusk shells which is vertically superseded by a calcareous sand crowded with mollusk shells. It has all of the characteristics of a littoral deposit marginal to a marine basin. From well W-3527 in Volusia County to well W-2869 in Polk County the sequence is thin and incomplete. The geographic region across which the section traverses has been called the Sanford high by Vernon (1951) and was consistently either a high stable shelf area or exhibited positive tectonism periodically during deposition of post-Eocene sediments. In reality, this part of Florida is perhaps the southern extension of the peninsular arch of Applin (1951) which has dominated and controlled Florida stratigraphy since at least the Paleozoic. Throughout Volusia and Seminole counties the authors recognize no beds which might either be lithologically similar to or facies changes of Oligocene or lower Miocene strata to the south or west. Immediately overlying the Ocala group and in places resting on the Avon Park formation is a series of green sandy clays which carry abundant molluscan fauna. These beds are often intercalated with thin and discontinuous sandy layers and discontinuous limestones, often dolomitized. Overlying these beds which are interpreted as upper Miocene in age are terrace deposits. In all probability, lower Miocene and Oligocene beds equivalent to the Tampa and Suwannee formations once covered the area although greatly thinned as compared to the overall thicknesses in southern Florida.
From well W-4560 in Orange County south to well W-1997 in Polk County the basal portion of the sequence to the south consists of thin macrofossiliferous sandy phosphoritic dolomitized limestones and dolomites which are tentatively assigned to the Tampa formation. These beds rest on eroded Ocala group limestones and no Oligocene strata appear to be present. Overlying these basal carbonates and on Eocene rocks where the basal carbonates are missing are a succession of green sandy phosphatic clays often containing abundant mollusk shells. The upper portion of this section contains many less phosphorite grains and is more shelly. The authors interpret the lower and somewhat thinner section of green clays as Hawthorn; the upper as being equivalent to Choctawhatchee. The sill-like character of the hinge-line is clearly demonstrated in the cross section. South from well W-1997 to just past well W-4750 in Glades County is one of the most unique sections of post-Eocene rocks in Florida. From well W-2842 south the basal carbonate is the familiar creamy microbioclastic limestone identified as Suwannee. Immediately overlying this basal unit and with some unconformity in the updip portions are sandy phosphoritic, often cherty and dolomitized, gray to dark gray limestones and dolomites recognized as Tampa. The updip portions of this unit are more highly dolomitized than those deeper in the basin. The fluctuation of shoreline in response to rates of terrestrial clastic supply from the north, coupled with periods of downwarping in the southern marginal basin, are clearly demonstrated in the overlying beds. These are a succession of interbedded green sandy phosphatic clays and gray sandy phosphoritic microbioclastic limestones. The former are
interpreted as Hawthorn lithology; the latter as Tampa beds. When the former predominate the whole is referred to as Hawthorn in this paper and an arbitrary cutoff is suggested about the southern margin of Highlands County south of which no Hawthorn will be recognized. Lying conformably upon these middle Miocene strata are another series of green sandy shelly clay beds, perhaps equivalent to the Choctawhatchee formation, which in turn interfinger downdip to the south with macrofossiliferous sandy phosphatic limestones. Lenses and pods of argillaceous phosphatic sand are interbedded in the upper portions of these Choctawhatchee beds in southern Highlands County. The uppermost sequence of strata consists of a thick series of coarse terrestrial clastics consisting of pebbly sands, usually red in color, and white kaolinitic sandstones which contain interbedded lenses of kaolinite and montmorillonite (Stone, 1960). While these may be latest Miocene in age, the authors prefer to think of them as genetically related to those uppermost beds of similar lithology in the western panhandle of Florida and therefore probably of post-Miocene age. Bishop (1956) describes these lithologies more fully in his Highlands County report.

From just north of well W-820 in Collier County to the southern end of the cross section in the Florida Keys the section is almost uniformly carbonate. The basal cream colored microbioclastic Suwannee limestone thickens southward and has at its top a five to ten foot interval of cherty beds. Probably conformably overlying these basal carbonates are presumed lower Miocene carbonates consisting of microbioclastic gray sandy limestones which, to the north, have significant amounts of brown and black sand-sized phosphate grains.
which entirely disappear in the southernmost wells. The uppermost section of these lower Miocene limestones contains much less sand and phosphate than the lower portion although these less sandy strata become less distinct downdip as the underlying limestone progressively lose sand. An occasional thin green sandy clay lentil may be observed which roughly separates these lithologies.

Overlying these lower Miocene carbonates are macrobioclastic, sandy and phosphatic, gray limestone sometimes dolomitized in streaks quite similar to beds below. On their updip portions these limestones are often yellowish or white and chalky but grade downdip into the lithologies described above. The question of nomenclature again arises with the problem the same as presented before in the case of the downdip section into the Apalachicola basin. These downdip limestones interfinger updip with the beds which were tentatively assigned to middle and upper Miocene. The downdip lithologies are, however, similar to and in some cases identical with Tampa lithologies. Since formations are defined on lithology, the authors believe these strata should be assigned to the Tampa formation and in the basin areas of Florida the time of deposition of the Tampa formation would cover the entire Miocene epoch.

The upper succession of strata in southern Florida have a larger terrestrial clastic content than do the underlying units. They consist of a lower green sandy phosphoritic clay which in its northern reaches contains sandy limestone and argillaceous sand beds which laterally interfinger with presumed post-Miocene strata. Overlying these beds are sandy carbonates
containing abundant mollusk shells and intercalated and interbedded sands. These are also post-Miocene in age and are considered to be part of the Tamiami (?) formation. Capping the entire sequence is a thin layer of sandy mollusk shell limestone which interfingers to the south with the Miami oolite.

The south Florida basin shows a long and continued history of downwarping and the authors feel that no important unconformities occur in the succession. Although the succession of strata in central Florida are predominantly of nonmarine or transitional nature following the Miocene epoch, the area was of a slight negative tectonic nature during the accumulation of these sands and clays. The rate of supply of detritus from the north was, however, fast enough to prevent marine conditions from prevailing. The fact that clearly demonstrated Pleistocene terrace deposits are perhaps missing over much of this area is indicative of the Plio-Pleistocene uplift which was synchronous over much of the United States.

Cross section D-D' cuts transversely across the peninsula from Pinellas County on the west to Brevard County on the east and is a part of a Master's thesis by Stone (1960) under the direction of the senior author. The section is worked in considerable detail and Stone made X-ray analyses of the more important clay deposits to determine mineralogy. The western portion of the section begins on the Gulf coast and is fairly straightforward as far as well W-4621 in Hillsborough County. Lying immediately above the Ocala group limestones is a creamy microbioclastic limestone containing some macrofauna and is assigned to the Suwannee formation of Oligocene age.
The formation thickens westward into an Oligocene age Tampa basin, the southern extension of peninsular arch again controlling deposition to the east. Lying on top of these Oligocene beds are the gray sandy phosphoritic macro-bioclastic limestones of the Tampa formation of lower and perhaps in part of middle Miocene in age. These beds are interfingered in their uppermost vertical reaches with sandy green clays that Stone assigns tentatively to the Alachua formation and which may be derived locally from erosion of previously existing lower Miocene rocks to the east and north. Thin terrace deposits cover the area.

The central part of the section from well W-4621 to well W-2163 in Osceola County is again in its upper part a complex series of strata representing nonmarine and transitional environments. The basal Oligocene limestones thin partly due to the tectonics of nondeposition over the neutral to positive peninsular arch and partly due to post-Oligocene erosion. Since none of the Oligocene beds show a facies change which might be indicative of shoaling water, perhaps the latter is quantitatively more important. Tampa limestones interfinger over the arch with sandy dolomites construed to be their dolomitized equivalent. Overlying Tampa strata and interfingering in part with these same dolomites are creamy montmorillonitic and illitic sandy and phosphatic clay beds. These clay beds and the dolomite are in turn vertically succeeded by a distinctive orange sandy kaolinitic clay which, to the east, intertongues with gray sandy phosphatic limestones which contain in their upper portions lenses and pods of clay and phosphatic sandstone. The lower sandy dolomite and
the overlying sandy limestones laterally interfinger eastward with green sandy phosphatic clays which often contain thin lentils of sand. The latter clays are considered Hawthorn and perhaps Choctawhatchee, and rest directly on the eroded surface of the Williston formation of the Ocala group. Capping the entire sequence in the central portion of the section are coarse red to orange, clayey and pebbly, clastics which often contain lenses of white kaolinitic clay. Clearly recognized terrace deposits of presumed Pleistocene age are thin or missing over most of the area.

The eastern portion of the section from well W-2163 to well W-1381 on the east coast in Brevard County contains only Miocene and younger beds. These rest on the eroded surface of the Ocala group. The section thickens eastward to the Osceola County line where a normal fault abruptly terminates the depression with almost three hundred feet of vertical relief. This graben-like structure is termed the Osceola graben in part after Vernon (1951). The eastern portion of this depression is predominantly carbonate containing gray sandy phosphoritic macrobioclastic limestones and buff sandy dolomites similar to Tampa lithologies. The western parts of the depression are predominantly green sandy phosphoritic clays, the uppermost strata of which continue entirely across the basin and fault line to rest on Ocala group limestones in Brevard County. Faulting therefore occurred, as the strata are here interpreted, during middle Miocene and the tectonism is therefore related chronologically to the formation of the Jacksonville basin. The uppermost strata in this easternmost part of the section are gray-green sandy phosphatic clays which often contain large numbers of mollusk shells.
and which are interbedded to the west with clayey sands. Their age is doubtful but they are tentatively considered as post-Miocene. Terrace deposits cover the eastern section.

**Facies Maps**

Facies maps are constructed to show the broad lateral regional relationships of strata from which may be drawn interpretations as to provenance areas, transportation systems, environments of deposition, and often diagenetic changes of the sediments comprising the sequence under consideration. To accomplish this as rigorously as possible with the above aims in mind, a spacing of data must be selected which is computable with the complexity of the unit. In areas of rapid facies change, much more data need be gathered and correlated than in areas where little lateral change occurs. In this investigation, a well every twelve or so miles was deemed sufficient to portray most of the lateral relationships of strata. Fortunately, in southern peninsular Florida where only a few widely spaced wells are available, there is little facies change in the sequence as a whole. In a study of this scale, small details of stratigraphy are often missed as are minor structures as discussed below. Essentially, then a lithofacies map is a lithologic inventory of the rocks present in the area of investigation. However, both the isopachs and the facies must be interpreted so as to deduce the sedimentary parameters listed above, all of which depend ultimately on tectonics; that is, the interrelationships between rates, types, and amounts of sediment supplied versus the extent of downwarping in the
loci of sedimentation. The result of this interplay is the deposition of sediments of a particular lithology in every conceivable environment under either rapid or slow conditions of burial.

The isopachs of the post-Eocene sediments of Florida cannot be interpreted entirely as an existing structural surface on the Ocala group (or older units where this is missing) for reasons which are obvious. Instead, it gives a generalized picture of structural conditions immediately after deposition but prior to any late stage uplift of the area. Faulting in underlying units, unless of large magnitude is often "smoothed out" or beds may actually be so draped over previously existing faults that no apparent dislocations are seen. Further, any structural evidences of faulting that may have occurred prior to deposition, may have been, especially in easily eroded sediments, removed. Only large scale faulting penecontemporaneous with the sedimentation of the unit under consideration, that might disrupt patterns of sedimentation by its presence, or faulting which occurs after sedimentation and so alters sediment patterns by removal of beds, is usually recognized. As an example, Vernon (1951) maps many faults, some of small magnitude, on his structure map on top of the Inglis formation, lowest formation in the Ocala group. One of these is clearly apparent in the isopachs and cross sections which the authors present. This is the large normal fault on the eastern boundary of the Osceola graben-like depression in east central Florida (fig. 4). However, this does not negate Vernon's findings but may be due to any or all of the reasons above stated. Because of the broad scale of this investigation and, since only the large fault bounding
the Osceola graben radically altered patterns of sedimentation, other
faulting did not appear. It must be kept in mind that the study is primarily
lithologic and secondarily is in the interpretation of the tectonics which
controlled these conditions of sedimentation.

The three dimensional stratigraphy of Florida is demonstrated by the
isopachous-lithofacies maps. The broad tectonic framework of the panhandle
and peninsula which controlled sedimentation is also clearly evident.
Figure 8 summarizes the tectonic status of the state during post-Eocene
deposition. Two basins marginal to the Gulf coast geosyncline are apparent,
one in panhandle Florida termed the Apalachicola and the other in peninsular
Florida called the South Florida marginal basin. Both are predominantly
carbonate basins (pl. 1). Terrestrial clastics in the panhandle were largely
shunted to the west into the geosyncline by the Chattahoochee arch which acted
as an effective barrier to direct southward sediment transport. The quantity
and rate of sediment supply south to the peninsula was never great enough to
penetrate over the hinge-line sill in Polk County and far into the southern
reaches of the state. The eastern side of the peninsular arch is interpreted
as the transportational route for most of the peninsular sediments of terrestrial
origin. Evidence for this is twofold. First, the lithofacies patterns show
that the eastern margin of Florida was consistently a clastic area throughout
Miocene time with the greatest southward penetration of clastics also occurring
in the eastern part of the state while the western portion of the peninsula was
predominantly carbonate facies. For example, areas as far north as Pasco

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POST-EOCENE TECTONIC MAP
OF FLORIDA

Figure 8.
County north of Tampa are predominantly carbonate throughout most of Miocene, while even northern Palm Beach County in the southeast are predominantly green sandy clay and sand. These conditions of sediment supply by and large continue even today. Secondly, the effectiveness of the Chattahoochee-Ocala-Peninsular arch system as a barrier to sedimentation from the north is clearly seen in the carbonate facies patterns throughout the south central panhandle in the Apalachicola basin, although these are partly due to the removal of most of any post-Miocene sediments that may have been deposited. These interpretations relegate sediment supply routes throughout and after Miocene to the eastern Florida coast although that coast line was most certainly further west than today.

Diagenetic alterations to these post-Eocene sedimentary deposits of Florida are principally those of dolomitization, chertification and kaolinitization. The geochemical mechanisms for dolomitization are now beginning to be understood and require the addition and ordering of magnesium ions within an original calcite crystal lattice. The patterns of dolomitization in the post-Eocene sediments are shown in plate 2. Almost all of the dolomite in the sequence is concentrated in areas updip of basins on or about the hinge-line sills, and secondarily on the shelf areas. These are the areas through which magnesium-rich waters squeezed out of basinal strata downdip migrate. These are also areas in which major chertification occurs, probably due to similar reasons. The persistent chert bed occurring on top of the Oligocene strata in south Florida and intermittently present in basins in the panhandle need more study. The authors do not believe that these chert beds necessarily
LITHOFACIES MAP OF POST-EOCENE STRATA OF FLORIDA

GOODELL-YON
ILLUSTRATION, WHITEHEAD
1960

PLATE 1
indicate unconformities of any magnitude, if such are at all present, occur in the basins. Such would be incompatible with the consistent downdip thickening and the patterns of continued marine sedimentation. Sedimentation was probably constant in these deep marginal basins, even though deposition was probably at varying rates. The development of chert in upper Oligocene strata in these areas may then depend upon local changes in porosity from overlying Miocene beds to Oligocene beds below. This, coupled with a slight change in pH, might lead to chertification. The development of kaolin in the upper Miocene and post-Miocene strata of central peninsular Florida might be due in part to the source rocks from which predominantly kaolinitic minerals were originally derived, but the senior author believes that the conditions following the burial of whatever mineralogy the original clays were, was favorable for further kaolinitization. That is, good porosity in the relative coarse clastics coupled with the nonmarine conditions that have continued throughout much of that section of the peninsula subsequent to their deposition led to further kaolinitization in the relatively high rainfall and subtropical climates that have prevailed in this section of North America. Finally, it might be noted that phosphate is restricted to the Miocene and post-Miocene sediments. Whatever conditions are necessary for its formation and concentration began in early Miocene and may have been unique to that epoch, since post-Miocene deposits may be concentrations of Miocene phosphorite.
The post-Eocene rocks of Florida are composed of two primary interfingering lithosomes: a bioclastic marine carbonate, one which is basal and downdip in the marginal basins; and a somewhat heterogeneous green sandy clay and sand lithosome deposited in transitional and continental environments above and updip of the basins. The terrestrial clastics were derived predominantly from the north, probably in the area of the southern piedmont, and delivered by two main transportation systems; one to the west, west of the Chattahoochee arch; the other down the then east coast of the peninsula. The terrestrial clastics began their encroachment in latest early Miocene time, continued to increase in rate and amount during middle and late Miocene, and reached their culmination in post-Miocene. This clastic flood was coupled with a general change in the tectonic behaviour of the state, especially in the peninsula. In Oligocene time, the western hinge-line sill into the Gulf coast geosyncline was a minor feature, for only a little thinning occurs over it in Oligocene rocks, and the geosyncline itself had only moderate rates of downwarp. The Apalachicola marginal basin was more active at this time than later in Cenozoic for a relatively thick Oligocene section in some areas of the east central panhandle extends north as the Florida-Georgia line (Applin and Applin, 1944). In peninsular Florida, the peninsular arch probably exerted only minor influence on Oligocene deposition with minor basinal conditions prevailing to its west in the Tampa area. The Oligocene rocks thicken uniformly southward indicating continued subsidence in the south Florida basin. Some general
uplift of the peninsular arch occurred immediately post-Oligocene for
Oligocene rocks over the arch in northern and central Florida are missing
due to erosion. With downwarp again initiated, however, Miocene limestones
were again deposited northward. Tectonic conditions during lower Miocene
were somewhat similar to those prevailing during Oligocene except that the
Chattahoochee-Ocala-Peninsular arch system was more positive and a
greater thinning of lower Miocene sediments occurs over these growing
arch systems. General uplift north of Florida must have occurred in lower
Miocene for clastics begin to encroach to the south. Concurrent with and
perhaps related to this northern uplift was a period of relatively great
instability in Florida. The arch systems previously described began active
uplift coupled with the marginal downdropping of the Jacksonville basin and
Osceola graben. Normal faulting in the eastern flank attended the formation
of the latter. As a result of this instability and relative uplift of the arch
systems, the seas moved successively off of the upper portions of the
peninsula. The somewhat negative tendency of the east coast permitted
terrestrially derived sediments to continue south into the peninsula where
they interfingered with bioclastic carbonates further and further to the south.
Intermittent sinking of the southern peninsula after Miocene time and con-
tinuing into Pleistocene allowed carbonate deposition to occur sporadically
as far north as Highlands County. Doering's (1960) map of the distribution of
the Citronelle formation illustrates the importance of the Chattahoochee-
Ocala arch system as a deterrent to southward movement of clastics as late
Quaternary, and even today no important amounts of terrestrial clastics
reach the south and west coasts of Florida east of the Apalachicola River that are not locally derived.

In response to this tectonic behaviour depositional environments fluctuated from marine to transitional to increasingly nonmarine throughout the post-Eocene period. The sequence of sedimentation is initiated in Oligocene by encroachment of the sea out of the marginal basins and the geosyncline, where probably sedimentation never ceased entirely, and widely across the deeply eroded surface of the Ocala group limestones. The long felt influence of the tectonic hinge-line sills and arch systems outlined in this paper might be noted in the state of erosion of the underlying Ocala group. In many of those areas destined to be again active during post-Eocene, the Ocala group is most deeply eroded and sometimes entirely missing and the overlying Oligocene rests on the middle Eocene Avon Park limestone.

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DESCRIPTIVE ROAD LOGS
May 6, 1960

Mileage  Interval

0.00  Geology Building, University of Florida, Gainesville. Proceed north on Newell Drive to West University Avenue.

0.05  Intersection Newell Drive and West University Avenue. Turn left (west) on West University Avenue (State Highway 26).

2.55  Turn right on State Highway S26A.

2.60  0.70  Turn right on State Highway S329, Devil's Mill Hopper Road.

3.10  Sharp turn in highway to left.

6.40  0.30  Turn right on paved road.

6.70  0.20  STOP 1. Devil's Mill Hopper, sec. 15, T. 9 S., R. 19 E., Alachua County. Park along paved road. The following section was measured by E. C. Pirkle.

6.90  0.65

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<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Sand. Loose, gray to white............................</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Hawthorn

10  Abundant pebbles and grains of phosphorite in a matrix of sand and clay.......................... 25.0

9   Sandy limestone or calcareous sandstone. Cream to white, containing in places abundant molds and casts of marine pelecypods and gastropods. Locally phosphate particles are common...................... 30.0

8   Dolomitic limestone. Whitish to gray, dense. At some places around the sink a grayish to blue-gray sandy clay occurs between this dense dolomitic limestone and the sandy limestone or calcareous sandstone of Bed 9.................... 3.0
MAP SHOWING ROUTES AND SCHEDULED STOPS

Figure 1.
Mainly blocky clay. Toward top of bed, in places a grayish to blue-gray sandy clay containing occasional impressions and silicified shells of marine mollusks........................................ 30.0

Limestone. Similar to Bed 4 ................................. 2.5

Largely clay. Greenish gray to gray, similar to Bed 3 ......................................................... 4.5

Sandy limestone. Numerous calcite fossil shells, angular blocks and rounded pebbles of clay, and phosphate pebbles and grains............................... 1.5

Blocky clay. Greenish gray to gray, a few phosphate pebbles and rare impressions of marine fossils.......................................................... 13.0

Dolomitic limestone. Dense, dark colored, with stringers of quartz sand. Grades down into a loosely cemented, calcareous sandstone. Both dense limestone and sandstone contain blocks of clay. Locally, this bed is highly silicified and rests directly on Ocala limestone. In such cases, the upper surface of the Ocala is silicified.............. 2.5

Sand. White to gray, loose to slightly cemented. A few brown phosphate pebbles and grains.......... 3.0

Total thickness................................................ 123.0

Mileage Interval

7.55 3.15 Sharp turn to right

10.7 0.60 Turn left on State Highway S26A.

11.3 2.85 Intersection of State Highways S26A and 26. Turn left onto State Highway 26 leading east. Continue on State Highway 26 to Putnam Hall in Putnam County.

14.15 Intersection of State Highway 26 and U.S. Highway 441 in Gainesville. Continue straight ahead on State
Highway 26.


34.00 Melrose city limits.

40.45 Intersection of State Highways 26 and 100. Turn right on State Highway 100.

41.9 STOP 2. Sand pit of Southern Materials Company. North of State Highway 100, sec 1, T.9 S., R.23 E., Putnam County. The following section was measured by E.C. Pirkle and H.K. Brooks, 50 feet west of a dead tree at the southern corner of the pit near railroad tracks.

<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Citronelle formation&quot;</td>
<td>?Plio-Pleistocene</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Sand, medium, tan to slightly buff.</td>
<td>9.0</td>
</tr>
<tr>
<td>2</td>
<td>Sand, medium to coarse, orange, ochre to red, lower five feet gradational into white and well laminated. Occasional lenses and stringers of very coarse sand and quartz gravel. Abundance of coarse sand and gravel increases with depth</td>
<td>11.0</td>
</tr>
<tr>
<td>1</td>
<td>Sand, medium to coarse, white. Lenses and stringers of quartz gravel common. Discoidal quartzite pebbles occur disseminated throughout bed and concentrated in small lenses and stringers. Bedding varies from irregular to laminated. Some crossbedding. Clay balls and laminations of clay. To water level</td>
<td>32.5</td>
</tr>
</tbody>
</table>

Total thickness | 52.5 |
Mileage    Interval

43.40      Continue on State Highway 100 to Grandin.

43.70      New pit of Keystone Sand Company on left.

43.75      Intersection of State Highways 100 and 315 at Grandin. Turn left on dirt road at small store.

43.90      Turn sharp left (west) across railroad tracks on dirt road paralleling railroad.

44.00      Take dirt road to right (north).

STOP 3. Sand pit of Keystone Sand Company, sec. 8, T. 9 S., R. 24 E., Grandin, Putnam County. The following section was measured in the southeastern part of pit by H. K. Brooks and E. C. Pirkle.

Bed       Description                          Thickness (feet)

"Citronelle formation"  ?Plio-Pleistocene  

3          Sand, coarse to medium, tan to buff. Contains abundant quartz and quartzite pebbles. Grades upward into dark grayish brown humus zone................. 7.0

2          Sand, coarse to medium, orange. Abundant quartz and quartzite pebbles disseminated throughout sediments and concentrated in small lenses and stringers................................. 8.5

1          Sand, coarse to medium, white. High content of kaolinite. Quartz gravel and quartzite pebbles occur disseminated throughout the sediments and concentrated in lenses and stringers. To water level 6.5

Total thickness........................................ 22.0

Mileage    Interval

44.30      Return to intersection of State Highways 100 and 315 at Grandin. Proceed on State Highway 315 (south) toward Interlachen.

49.4       Active sand pit on right or west of highway.
52.00  Interlachen city limits.

52.35  Intersection of State Highways 315 and 20.
Proceed west on State Highway 20.

53.70  Turn left on dirt road.

53.90  STOP 4. Sand pit of Diamond Interlachen Sand Company,
sec. 16, T. 10 S., R. 24 E., Putnam County, west of
Interlachen. The following section was measured
near a group of large oak trees on the north side of
a pit, by E. C. Pirkle and H. K. Brooks.

3.15

<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Sand, fine to medium grained, loose, light tan.</strong></td>
<td>3.5</td>
</tr>
<tr>
<td>11</td>
<td>Sand, predominantly medium grained, reddish to orange, crossbedded. Lower four feet banded. In basal five feet a lens of coarse gravel and discoidal quartzite pebbles occurs. Some pebbles over one inch in longest dimension. Kaolin &quot;caps&quot; on flat-lying quartzite pebbles.</td>
<td>14.5</td>
</tr>
<tr>
<td>10</td>
<td>Sand, medium grained, dominantly white but bands of red and orange. Transition zone between overlying reddish sediments and underlying whitish sediments. Pronounced banding with major banding one inch to two inches and subordinate banding about one-fourth inch in most beds. Iron stain tends to follow bedding but also occurs obliquely, especially along joints. Intercalated beds from one to two inches containing a high content of heavy minerals.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Covered.</td>
<td>5.5</td>
</tr>
<tr>
<td>8</td>
<td>Sand, coarse with some quartzite pebbles, white. Light banding, from one-half to four inches with one to two inches average, crossbedding.</td>
<td>3.5</td>
</tr>
<tr>
<td>7</td>
<td>Sand, medium with granules and pebbles, white. High content of kaolinite. Abundant quartzite pebbles. Major bedding ranging from $1\frac{1}{2}$ to 3 feet with much crossbedding. Maximum size of</td>
<td></td>
</tr>
</tbody>
</table>
quartzite pebbles \(\frac{1}{2}\) inches.......................... 12.5

6  Sand, fine to medium, kaolinitic, white...................... 0.5

5  Covered..................................................... 10.5

4  Sand, coarse to very coarse, white .......................... 2.5

3  Sand, fine to medium, white. High content of kaolinite .......... 3.5

2  Sand, coarse with granules and pebbles, white ............... 0.5

1  Sand, coarse, white. To water level......................... 5.0

Total thickness............................................... 68.0

The results of mechanical analysis of sediment exposed in this section are given on pages 32-35.

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>57.05</td>
<td>Return to paved road and turn left (west) on State Highway 20.</td>
</tr>
</tbody>
</table>

STOP 5. Devil's Pit sink. Park along paved road and walk north toward sink. Devil's Pit, a sink hole in sec. 13, T. 10 S., R. 23 E., north of Lake Galilee and three miles west of Interlachen, Putnam County. The following section was measured by H.K. Brooks.

<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Citronelle formation&quot; ? Plio-Pleistocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Sand, coarse with varying amounts of clay matrix, lenses and beds are present that contain abundant granules and discoidal pebbles, iron stained.............. 35.0</td>
<td></td>
</tr>
</tbody>
</table>

Disconformity
Hawthorn formation, Miocene

| 1 | Limestone, finely granular, white to tan; 2% phosphate grains, \(\frac{1}{4}\)-1 mm. diameter, light tan, olive |
and dark gray; 10% insoluble residue consisting of equal portions of fine sand and clay. To water level ... 5.0

Total exposed thickness ............................................................... 40.0

The following underwater section was measured by H. K. Brooks, James Floyd, James Ward, Jon Thompson, John Sargent and James Fyfe. With few exceptions, samples were taken every five feet. Depth intervals were measured by depth gauges and description of samples was prepared from dried samples.

<table>
<thead>
<tr>
<th>Description</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone, finely granular, white, sandy; 1% phosphate grains, 1/4-1 mm. diameter, rounded, chocolate brown and orange; 45% insoluble residue consisting of 60% medium, subangular, quartz sand and 40% clay.</td>
<td>Water level</td>
</tr>
<tr>
<td>Limestone, finely granular, white; 5% phosphate grains, 1/2-1 mm. diameter, rounded, brown and gray; 20% insoluble residue consisting of 70% clay and 30% fine and very fine subangular quartz sand.</td>
<td>5.0</td>
</tr>
<tr>
<td>Sand, very fine with occasional coarse grains, subangular; 30% clay matrix, white; 10-30% phosphate grains, 1-2 mm. diameter, irregular, subangular to rounded, brown.</td>
<td>10.0</td>
</tr>
<tr>
<td>Sand, medium, subangular; 10% clay matrix, gray; 10% phosphate grains, 1-3 mm., diameter, subrounded, chocolate brown to dark brown and gray.</td>
<td>15.0</td>
</tr>
<tr>
<td>Clay, light gray, small flecks of muscovite; 0-10% quartz sand, medium, subangular; 20-30% phosphatic grains, 2 mm. diameter, rounded, dark to light brown.</td>
<td>20.0</td>
</tr>
<tr>
<td>Sand, medium, subangular; 10% clay matrix, white; 5% phosphate grains, 1/4-1/2 mm. diameter, rounded, brown, olive and black; Pecten acanikos Gardner.</td>
<td>25.0</td>
</tr>
<tr>
<td>Sand, fine, subangular; 20-30% clay matrix, light gray; 5% phosphate grains, 1-3 mm. diameter, rounded, black.</td>
<td>30.0</td>
</tr>
</tbody>
</table>
Clay, light gray, fine flecks of muscovite; 10% quartz sand, medium, subangular; 5% phosphatic grains, $\frac{1}{8}$-1 mm. diameter, rounded, dark gray to black. ........................................ 31.0

Clay, white; 10% quartz sand, coarse, subrounded; 15-30% phosphatic grains, $\frac{1}{4}$-1 mm. diameter, rounded, brown. .............................................................. 35.0

Clay, white; 20% quartz sand, medium, subangular; 10-20% phosphatic grains, $\frac{1}{4}$-$\frac{1}{2}$ mm. diameter, rounded, orange, brown and black.................................................. 40.0

Clay, micaceous, light gray; 30-40% quartz sand, medium, subangular to subrounded; 10-20% phosphatic grains $\frac{1}{4}$-$\frac{1}{2}$ mm. diameter, rounded, orange, brown and black........................................ 45.0

Sand, medium, subrounded; 10-30% clay matrix, gray; 20-30% phosphatic grains, 1/8-1/2 mm. diameter, rounded, orange, brown and black.............................................................. 50.0

Clay, gray; 5-10% quartz sand, medium to coarse, subangular to rounded; 10-20% phosphatic grains, 1/8-1 mm. diameter, rounded, black to brown.................................................. 55.0

Clay, micaceous, olive to gray; 5% quartz sand, coarse, subrounded; lenses of phosphatic grains, 0-40%, $\frac{1}{4}$-1 mm. diameter, rounded, brown, gray and black................................. 60.0

Clay, micaceous, olive green, grains of phosphate are rare.................................................. 65.0

Sand, fine to medium, subangular; 5% clay matrix, gray; 10% phosphatic grains, 1/8-1 mm. diameter, rounded, black, orange and brown.............................................................. 75.0

Sand, medium to coarse, subangular to subrounded; 10-20% clay, olive green occurring as thin stringers; 5% phosphatic grains, 1/8-1 mm. diameter, well rounded, brown, black and gray.................................................. 80.0

Clay, gray, micaceous; 10-50% quartz sand, medium to coarse, subangular to subrounded; 5% phosphatic grains, 1/8-1 mm. diameter, rounded, black, brown and gray.................................................. 85.0

Sand, medium, subangular to subrounded; 5-10% clay matrix, gray; 5% phosphatic grains, 1/8-1 mm. diameter, rounded, orange, brown, gray and black. Intraformational conglomerate was observed at about -93 feet.................................................. 140.0

Total thickness of exposed and underwater section .................................................. 180.0
Five lithologic zones can be distinguished in the known section of Hawthorn formation in this sink hole. These are:

**Zone I**  
Limestone, impure, phosphatic white to cream in color .......... 5 to 8 Feet below sea level

**Zone II**  
Clayey sands and sandy clays, gray, abundant phosphate .......... 8 to 58

**Zone III**  
Clay, green to gray, minor amounts of quartz sand and phosphate.................. 58 to 69

**Zone IV**  
Clayey sands and sandy clays, gray, minor amounts of phosphate. (Sea level)................... 69 to 90

**Zone V**  
Clayey sands, gray, minor amounts of phosphate. Intraformational conglomerate at -93 feet. 90 to 140

---

**Mileage**  
**Interval**

Continue west on State Highway 20 to Intersection of U. S. Highway 301 in Hawthorn.

64.10  
2.00  
Putnam-Alachua county line.

66.10  
2.00  
Intersection of State Highway 20 and U. S. Highway 301. Turn left (south) on U. S. Highway 301 to Citra.

76.70  
10.60  
Island Grove.

79.50  
2.80  
Citra. Turn right on State Highway 318.

85.80  
6.30  
Top of a hill developed in white, kaolinitic unnamed coarse clastics.

86.10  
0.30  
Junction U. S. 441. Turn left (south).

89.4  
0.60  
Reddick. Bus station on right.
90.00 Turn left at Pure Oil Station and sign "Dixie Lime Products Company."

0.40 Sharp turn to left.

0.10 Sharp turn right across railroad tracks.
Follow road around left side of lime plant.

0.25 STOP 6. Abandoned limestone quarry 50 yards east of lime plant.

0.75

According to S. J. Olsen (personal communication) of the Florida Geological Survey, this pit has supplied the largest collection of Pleistocene rodents of any locality in the state. Also, the remains of a cave bear, horses, camels, sabertooth tigers, and vampire bats have been found here.

Return to U. S. Highway 441.

91.50 Turn left (south) on U. S. Highway 44.

6.90 Zuber limestone pits on left.

99.00 Railroad crossing at Kendrick.

99.4 STOP 7. Park on right. This is an active quarry developed in the Crystal River and Williston formations. Kendrick pit of the Cummer Lime and Manufacturing Company, Kendrick, Marion County. The following is a composite section measured by H. S. Puri.

<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>?Hawthorn (marine) facies</td>
<td>Elevation 115.39'</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Pale to cream colored hard molluscan limestone with abundant, large Turritella sp.</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Unconformity
Crystal River formation

4 Amusium bed. White chalky limestone with beds
of calcite and chert. *Lepidocyclina ocalana* and vars. common; abundant specimens of *Amusium* sp. .......................................................... 22.0

3 White chalky limestone, in places a larger *Foraminifera* coquina, abundant large specimens of *Lepidocyclina ocalana* and vars., *Heterostegina ocalana* and *Operculinoides ocalanus*. .................. 15.0

2 Cream to white, soft limestone, chalky in places, with large specimens of *Lepidocyclina ocalana* very common. .......................... 3.0

Williston formation

1 Cream to white, granular limestone with dwarfed *Lepidocyclina ocalana*, *Operculinoides moodybranchensis*, *Operculinoides willcoxi*. .................. 5.0

Total thickness................................................................. 55.0

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>104.20</td>
<td>Continue south on U. S. Highway 441.</td>
</tr>
<tr>
<td>121.50</td>
<td>Unnamed coarse clastics exposed on hilltop.</td>
</tr>
<tr>
<td>17.50</td>
<td></td>
</tr>
<tr>
<td>139.00</td>
<td>City limits Fruitland Park.</td>
</tr>
<tr>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>139.60</td>
<td>OPTIONAL STOP. Road cut in clayey sands shows good crossbedding and scattered quartz pebbles. The sand is kaolinitic.</td>
</tr>
<tr>
<td>2.20</td>
<td></td>
</tr>
<tr>
<td>141.80</td>
<td>City limits Leesburg. Slow down - motel is just ahead.</td>
</tr>
<tr>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>141.85</td>
<td>Mid Lakes Motel on right (stop for night).</td>
</tr>
</tbody>
</table>

125
May 7, 1960

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>Mid Lakes Motel in Leesburg. Turn right (south) on U. S. Highway 27.</td>
</tr>
<tr>
<td>5.95</td>
<td>Unnamed coarse clastics are exposed in many road cuts along this road in Lake and Polk counties.</td>
</tr>
<tr>
<td>17.70</td>
<td>Citrus Tower.</td>
</tr>
<tr>
<td>23.65</td>
<td>Pit in coarse clastics on left.</td>
</tr>
<tr>
<td>24.95</td>
<td></td>
</tr>
<tr>
<td>1.70</td>
<td>STOP 8. Road cut in unnamed coarse clastics. This is a section of moderate reddish brown, yellow and yellowish gray, clayey, slightly micaceous, fine to very coarse, average coarse, quartz sand. Beds 6 to 12 feet thick in a monoclinal fold. The folding may be due to collapse of underlying limestones. Continue south on U. S. Highway 27.</td>
</tr>
<tr>
<td>26.65</td>
<td>3.25 Road cut in coarse clastics. This exposure shows a large number of quartz pebbles.</td>
</tr>
<tr>
<td>29.90</td>
<td>3.05 STOP 9. Road cut. A small anticline exposes one to six foot thick beds of varicolored clayey sand and shale. Ant spoil shows that these beds overlie very coarse white quartz sand. A fault is visible in the east side of the roadcut. Continue south on U. S. Highway 27.</td>
</tr>
<tr>
<td>32.95</td>
<td></td>
</tr>
<tr>
<td>8.50</td>
<td>Polk-Lake county line.</td>
</tr>
<tr>
<td>41.45</td>
<td>18.50 Center of overpass over U. S. Highway 92 just west of Haines City.</td>
</tr>
<tr>
<td>59.95</td>
<td></td>
</tr>
<tr>
<td>15.10</td>
<td></td>
</tr>
</tbody>
</table>

126
Between Haines City and Lake Wales U.S. Highway 27 lies on a high marine plain just west of the Central Highlands Ridge.

75.05  Turn left (east) on State Highway 60. Follow State Highway 60 through Lake Wales.  
1.00  
76.05  Junction U.S. Highway Alternate 27. Continue on State Highway 60.  
4.40  Cross Central Highlands Ridge.  
80.45  Turn right on sand road at sign "Lou-Lou's Fish Bait."  
0.10  
80.55  Sand road forks, keep left. Follow road to the washer.  
0.30  
80.85  STOP 10. Sand pit, Lake Wales Concrete Sand Company mine, NE ¼ sec. 10, T. 30 S., R. 28 E. The following section was measured by E. W. Bishop.  
0.45

<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Quartz sand, very light gray to pale yellowish orange, dark gray in upper one foot (soil), fine to pebbles, average - very coarse, with scattered waterworn cobbles of pale yellowish orange sandstone up to 5 pounds in weight, small one-half inch in diameter, round kaolinitic - sand concretions. Quartz pebbles to 1 1/2 inch long - generally elongated and flat. Pebbles occur in the sand in all positions, even vertical. In some sections of the pit, the sand is in a pale yellowish orange clayey matrix - in other sections, the sand contains finely divided kaolin. Sample taken at water level.</td>
<td>10.0</td>
</tr>
<tr>
<td>1</td>
<td>This section is reported by the owner to be very similar to the material above water level except for thin bedded lenses of coarse sand and very pure hard, white to yellow kaolin. Chunks of this material were seen on dredge where they had been taken from suction pipe.</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Total thickness......................................................... 30.0
<table>
<thead>
<tr>
<th>Mileage</th>
<th>Interval</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>81.30</td>
<td></td>
<td>Turn around and return to State Highway 60.</td>
</tr>
<tr>
<td>100.45</td>
<td>19.15</td>
<td>Turn left on State Highway 60 and proceed to Bartow.</td>
</tr>
<tr>
<td>100.70</td>
<td>0.25</td>
<td>Peace River.</td>
</tr>
<tr>
<td>100.75</td>
<td>0.05</td>
<td>State Highway 60 forks, keep left.</td>
</tr>
<tr>
<td>101.30</td>
<td>0.55</td>
<td>City limits of Bartow.</td>
</tr>
<tr>
<td>106.15</td>
<td>4.85</td>
<td>Junction State Highway 60 and U.S. Highways 17 and 98. Turn left (south) on U.S. Highways 17 and 98.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>STOP 11.</strong> Active phosphate mine of Virginia-Carolina Chemical Corporation. Those who want, may board the dragline &quot;Queen Bee!&quot; 17-yard capacity. A section of about 15 feet of phosphatic Hawthorn is being mined in this newly opened pit.</td>
</tr>
<tr>
<td>111.05</td>
<td>0.30</td>
<td>Continue south on U.S. Highways 17 and 98.</td>
</tr>
<tr>
<td>111.35</td>
<td></td>
<td>City limits, Fort Meade.</td>
</tr>
<tr>
<td>113.80</td>
<td>0.75</td>
<td>Sand &quot;mountain&quot; on right - elevation 320 feet. Sand &quot;mountain&quot; is a Swift and Company tailings pile.</td>
</tr>
<tr>
<td>114.30</td>
<td>0.50</td>
<td>Turn right on paved road at sign &quot;Swift and Company.&quot; Follow paved road to plant at foot of sand &quot;mountain.&quot;</td>
</tr>
<tr>
<td>114.50</td>
<td>0.20</td>
<td>Turn left on dirt road. Follow road between washer and the shop buildings.</td>
</tr>
<tr>
<td>115.15</td>
<td>0.65</td>
<td>Fork in road, turn left.</td>
</tr>
<tr>
<td>115.45</td>
<td>0.30</td>
<td>Fork in road, keep left.</td>
</tr>
<tr>
<td></td>
<td>1.05</td>
<td><strong>STOP 12.</strong> Abandoned phosphate pits. Swift and Company's Watson mine, NE&lt;sup&gt;1&lt;/sup&gt; SE&lt;sup&gt;1&lt;/sup&gt; sec. 5, T. 32 S., R. 25 E. The following section was measured by E. W. Bishop at SE corner of intersection of mining roads.</td>
</tr>
<tr>
<td>Bed</td>
<td>Description</td>
<td>Thickness (feet)</td>
</tr>
<tr>
<td>-----</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Pleistocene</td>
<td></td>
<td>Elevation 100± feet</td>
</tr>
<tr>
<td>6</td>
<td>Sand, quartz, pale yellowish brown, fine to very coarse - average medium. (Soil). Grades into Bed 5.</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td>Sand, quartz, as above but pale yellowish orange with pipes (roots?) of dark yellowish orange, fine to coarse quartz sand. Grades into Bed 4.</td>
<td>5.5</td>
</tr>
<tr>
<td>4</td>
<td>Sand, quartz, white, fine to some very coarse - average fine with root? fillings of dark yellowish orange quartz sand. Grades into Bed 3.</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>Sand, quartz, pale yellowish brown, fine to medium - average fine with splotches of irregular masses of dark yellowish brown, slightly clayey quartz sand.</td>
<td>3.0</td>
</tr>
<tr>
<td>2</td>
<td>Sand, quartz, white, very fine to fine - average fine (looks like Daytona Beach sand).</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Unconformity.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hawthorn formation, Miocene</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Pebble phosphorite bed. Indistinct beds of white to light brown pebble phosphate in sandy, clayey matrix, and beds of light green clay. Contains sharks teeth and bones. To water level.</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total thickness.</td>
<td>25.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A Pleistocene bone bed was noticed at water level south and east of this section.</td>
<td></td>
</tr>
</tbody>
</table>

**Mileage** | **Interval** | **Turn around and return to Bartow.**

116.50    | 0.50         | Hard surfaced road, turn right.
117.00    | 2.05         | U. S. Highway 17, turn left.
119.05    | 10.40        | Junction U. S. Highway 17 and 98, continue straight ahead.
Junction State Highway 60, turn left (west) on State Highway 60 through Bartow.

Turn left on mining road opposite large abandoned buildings.

STOP 13. Phosphate mine of Armour and Company, NE:\NE\ sec. 11, T. 30 S., R. 24 E., 2 miles west of Bartow. The following section was measured by E. W. Bishop.

<table>
<thead>
<tr>
<th>Bed</th>
<th>Description</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleistocene</td>
<td>Elevation - 145 feet</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Sand, quartz, yellowish gray, fine to very coarse - average medium. Upper one-half foot gray. This bed and Bed 6 extend down into Bed 5 - probably following decayed tree roots</td>
<td>2-4</td>
</tr>
<tr>
<td>6</td>
<td>Sand, quartz, as above but pale brown (organic stain). &quot;Hardpan.&quot; Grades into Bed 5</td>
<td>0.5-1</td>
</tr>
<tr>
<td>5</td>
<td>Sand, quartz, and clayey quartz sand, yellowish gray to light brown (oxidized) quartz sand, fine to very coarse - average medium, clayey quartz sand occurs as irregular masses and splotches in the sand, shows oxidized colors, contains yellowish gray to light brown sandstone and ironstone fragments (pebbles to small boulders) in base. In places sand is white near base</td>
<td>3-5 Unconformity</td>
</tr>
<tr>
<td>4</td>
<td>Sand, quartz, yellowish gray to light brown and yellowish gray to light brown clayey sandstone rubble. Rubble most abundant near base. In places rubble is absent. Entire bed shows some silicification (harsh)</td>
<td>7.5-9.5</td>
</tr>
<tr>
<td>Bone Valley formation, Miocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Clay, very sandy, slightly phosphoritic (white, round pebbles), yellowish gray to white, slightly vesicular. Grades rather sharply into Bed 2</td>
<td>4-5</td>
</tr>
</tbody>
</table>
Phosphorite, very rich brown floatation (fine to very coarse sand size) in some sandy, some clayey, light green to light yellow matrix. Contains light green to dark yellowish orange thin clay beds near base. ...................... 2.5-3.5 Unconformity.

Hawthorn formation, Miocene

A series of thin beds (up to one foot thick) of dark yellowish orange, clayey phosphate (fine to pebble, brown), light green, plastic clay, dark yellowish orange, plastic, massive clay, white, kaolinitic clay and thin discontinuous soil zones. Entire series of thin beds very highly weathered. Evidence of slump. Individual beds not traceable for any distance. Contains pockets of phosphate as in Bed 5. Some of the barren clay beds in this interval are stripped off during mining. To water level........ 8-9

Total thickness.......................................................... 31.0
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