# Economic Geology of the Plant City Quadrangle Florida

By JAMES B. CATHCART

CONTRIBUTIONS TO ECONOMIC GEOLOGY

GEOLOGICAL SURVEY BULLETIN 1142-D

*Prepared on behalf of the*
*U.S. Atomic Energy Commission*

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

**For sale by the Superintendent of Documents, U.S. Government Printing Office**
**Washington, D.C., 20402**

# CONTENTS

# ILLUSTRATIONS

[All plates in plate volume]

# TABLES

CONTRIBUTIONS TO ECONOMIC GEOLOGY

# ECONOMIC GEOLOGY OF THE PLANT CITY QUADRANGLE, FLORIDA

By James B. Cathcart


## ABSTRACT

The Plant City quadrangle, located in the Gulf Coastal Plain province, includes the northern fringe of the land-pebble phosphate district. Formations within the quadrangle are thin and dip very gently to the southeast away from the Ocala uplift, except in the northern part of the quadrangle, where the dip is reversed on a dome or small anticline, called the Hillsborough high.

The Ocala limestone of Eocene age is known from drill data to underlie the entire quadrangle. The Suwannee limestone of Oligocene age, the Tampa limestone of early Miocene age, the Hawthorn formation of middle Miocene age, and the Bone Valley formation of Pliocene age crop out in the area. Terrace sands, referred to the Pleistocene or Recent, blanket the area except along the streams.

The Suwannee limestone is exposed along the Hillsborough River on the crest of the Hillsborough high. The Tampa limestone and the Hawthorn formation both thin markedly to the north and probably were eroded from the high. The lower phosphorite unit of the Bone Valley formation apparently was not deposited on the Hillsborough high, but the upper clayey sand unit of the formation extends over the high.

Several periods of weathering have affected the rocks in the Plant City quadrangle. The earliest periods of weathering are recorded in the unconformity between the Suwannee and Tampa limestones and in the possible unconformity between the Tampa limestone and the Hawthorn formation. After the deposition of the Hawthorn, weathering and erosion formed a ridge-and-valley topography on the surface of the Hawthorn; the ridges are modified by a well-developed karst topography. The phosphate-rich residuum that formed on the Hawthorn during this period of weathering was reworked into the Bone Valley formation.

Following the deposition of the Bone Valley formation, lateritic weathering altered the surficial rocks, forming the aluminum phosphate zone. A groundwater podsol, the Leon soil of Pleistocene age, overlies or extends downward into the aluminum phosphate zone. A very young soil occurs on sands containing pottery shards.

Phosphate nodules are sparse and very low in $P_2O_5$ content in the Tampa limestone. They are common in the Hawthorn formation and contain about twice as much $P_2O_5$ as the nodules in the Tampa limestone; they are abundant

and high enough in $P_2O_5$ content to be of economic value in the lower unit of the Bone Valley formation.

The calcium phosphate zone consists of unconsolidated sedimentary rocks characterized by abundant nodules of carbonate-fluorapatite. The zone is not a stratigraphic unit but includes rocks of the Tampa limestone, the Hawthorn formation, and the lower unit of the Bone Valley formation. Economic phosphate deposits occur only in the calcium phosphate zone and are limited to the southern half of the quadrangle, which is underlain by both the Bone Valley and Hawthorn formations. Almost all the economic phosphate is in the Bone Valley formation. The calcium phosphate zone ranges in thickness from 0 to almost 50 feet, and most of the thickening of the zone is due to thickening of the lower unit of the Bone Valley formation. The calcium phosphate zone is more than 20 feet thick only where sinkholes on the Hawthorn surface are filled with phosphorite of the lower unit of the Bone Valley formation.

Reserves of possibly minable phosphate in the calcium phosphate zone total about 50 million long tons of recoverable phosphate nodules containing more than 65 percent BPL (bone phosphate of lime=percent $P_2O_5 \times 2.185$) and about 0.016 percent uranium. The zone within the Hawthorn formation contains an additional resource of phosphate of about 65 million long tons with an average grade of about 50 percent BPL and 0.005 percent uranium.

The aluminum phosphate zone, a zone in which the calcium phosphate mineral was changed to aluminum phosphate, is largely limited to the upper unit of the Bone Valley formation, but phosphatic rocks of the lower unit of the Bone Valley of the Hawthorn formation or even of the Tampa limestone were altered to form the aluminum phosphate zone where these formations are at or near the surface. The aluminum phosphate zone is a potential source for uranium, phosphate, and alumina. About 390 million long tons of aluminum phosphate with an average grade of about 5 percent $P_2O_5$, 10 percent $Al_2O_3$, and 0.012 percent uranium is present in the quadrangle.

## INTRODUCTION

The Plant City quadrangle is in west-central peninsular Florida between lat 28°00′ and 28°15′ N. and long 82°00′ and 82°15′ W. (fig. 1), and includes parts of western Polk, northeastern Hillsborough, and southeastern Pasco Counties. Phosphate was mined at the southern edge of the quadrangle, near Plant City, and potentially minable deposits of phosphate underlie the southern third of the quadrangle.

The economic geology of the land-pebble phosphate district is described in a series of reports—of which this report is the second. The first report, on the Keysville quadrangle, has been published by Cathcart (1963). All the data gathered during the field investigation are incorporated in these two reports, and in four additional reports describing the remainder of the land-pebble district. The investigation was limited to the phosphate-bearing rocks; older rocks were not studied in detail. Fieldwork was done by geologists of the U.S. Geological Survey under the direction of the writer. L. J. McGreevy and R. G. Petersen prepared some of the original isopach and isograde maps for areas in the Plant City quadrangle. The maps were com-

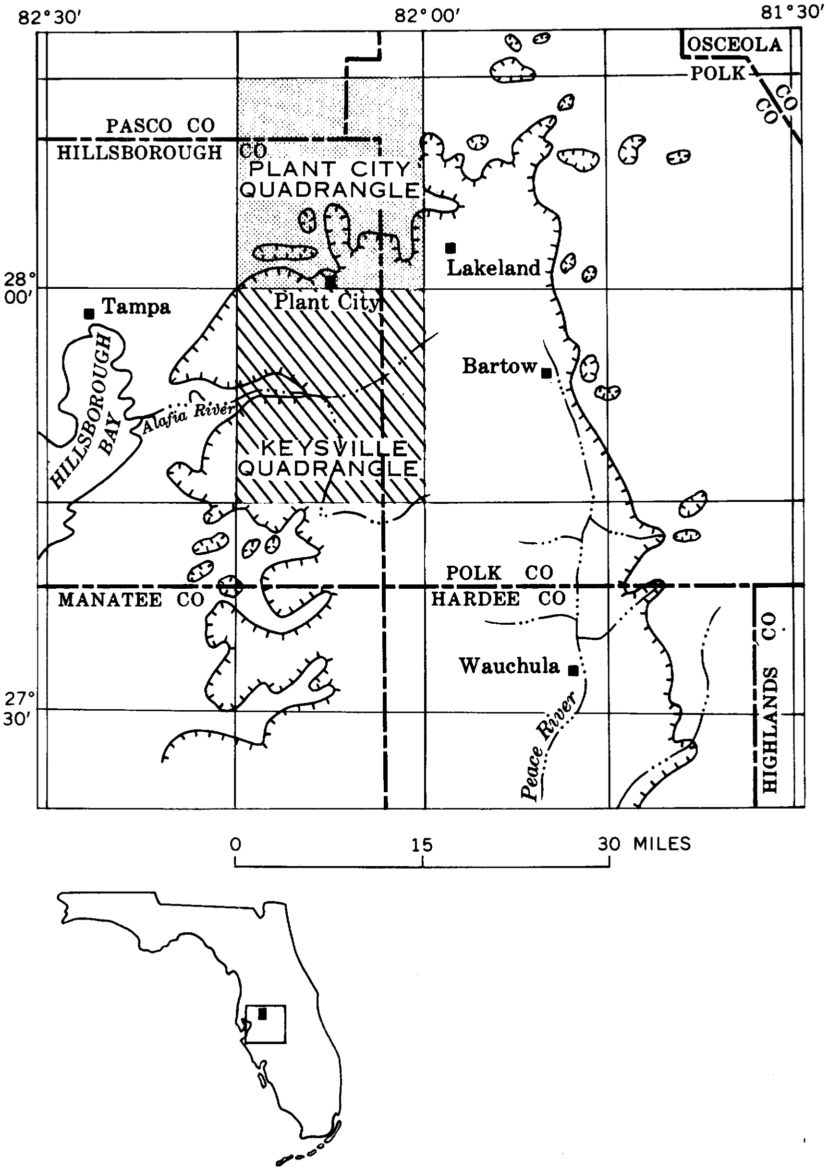



FIGURE 1.—Index map of west-central peninsular Florida, showing the location of Plant City quadrangle, Florida. Hachures indicate approximate limit of land-pebble phosphate district.

piled at publication scale by the writer with the assistance of Alice M. Coleman and Shirley L. Houser. Lithologic logs of some of the drill holes used for stratigraphic interpretations were made by D. C.

Alverson, W. J. Carr, H. L. Jicha, Jr., K. B. Ketner, L. J. McGreevy, Louis Pavlides, and T. E. Wayland. The work was done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

Except for two areas in the eastern part of the quadrangle, the topography is very flat; elevations range from less than 50 feet for the area at the west edge of the map to somewhat more than 125 feet in the eastern part of the quadrangle. At a small ridge northeast of Plant City, elevations exceed 150 feet, and a ridge at the east edge of the quadrangle in T. 27 S., R. 23 E. has elevations of about 225 feet (fig. 2).

The quadrangle is drained by the Hillsborough River and its tributaries, Blackwater and Itchepackesassa Creeks, and by Pemberton Creek. Drainage is north and west to the Hillsborough River, thence west to the Gulf of Mexico.

## DEFINITION OF TERMS

Throughout this series of reports, certain local terms are used. These terms are defined in the report on the Keysville quadrangle (Cathcart, 1963). Terms used in this report are defined as follows:

**Aluminum phosphate zone:** Zone of ground-water alteration, characterized by aluminum phosphate minerals.

**Leached zone:** A term used locally by the mining companies for the possibly economic part of the aluminum phosphate zone.

**Calcium phosphate zone:** Unconsolidated sandy clay or clayey sand, characterized by rounded particles of carbonate-fluorapatite.

**Matrix:** The economic part of the calcium phosphate zone.

**Pebble:** Coarse phosphate product, +14 mesh (+1 mm) in size.

**Concentrate:** Fine phosphate product, −14+150 mesh (−1 mm+0.1 mm) in size. Separated from quartz sand by flotation methods.

**Nodule:** Irregular rounded particle of any size. Used in this report to designate the phosphate particles.

**Slime:** −150 mesh (−0.1 mm). Includes silt and clay.

**Tailings:** −14+150 mesh quartz sand, separated from phosphate particles by flotation methods.

**Bed clay:** Plastic, water-saturated, calcareous clay with phosphate nodules. Residuum of Tampa limestone or Hawthorn formation.

**Overburden:** Waste material above the matrix.

**Sandrock:** Sand, cemented by aluminum phosphate minerals, or rarely, by silica.

**Hardpan:** Iron (limonite) cemented sand or clayey sand.

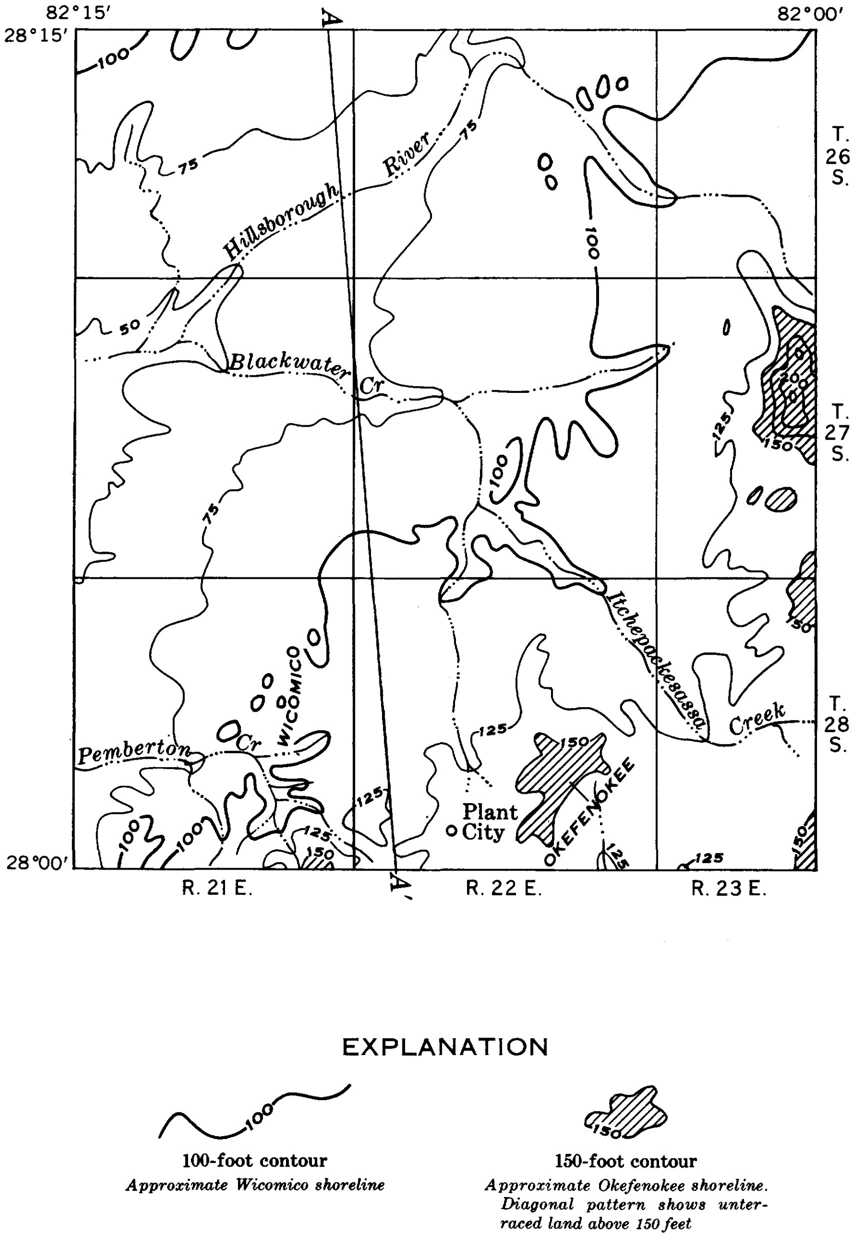



FIGURE 2.—Sketch map of topography and drainage, Plant City quadrangle, Florida, showing location of Pleistocene shorelines. Section *A–A′* shown in figure 7.

## PHYSIOGRAPHY

The area may be divided into three physiographic units: The well-drained highlands, called the ridge area; the flatwoods area between the ridge and the stream valleys; and the narrow valleys of the streams (fig. 3).

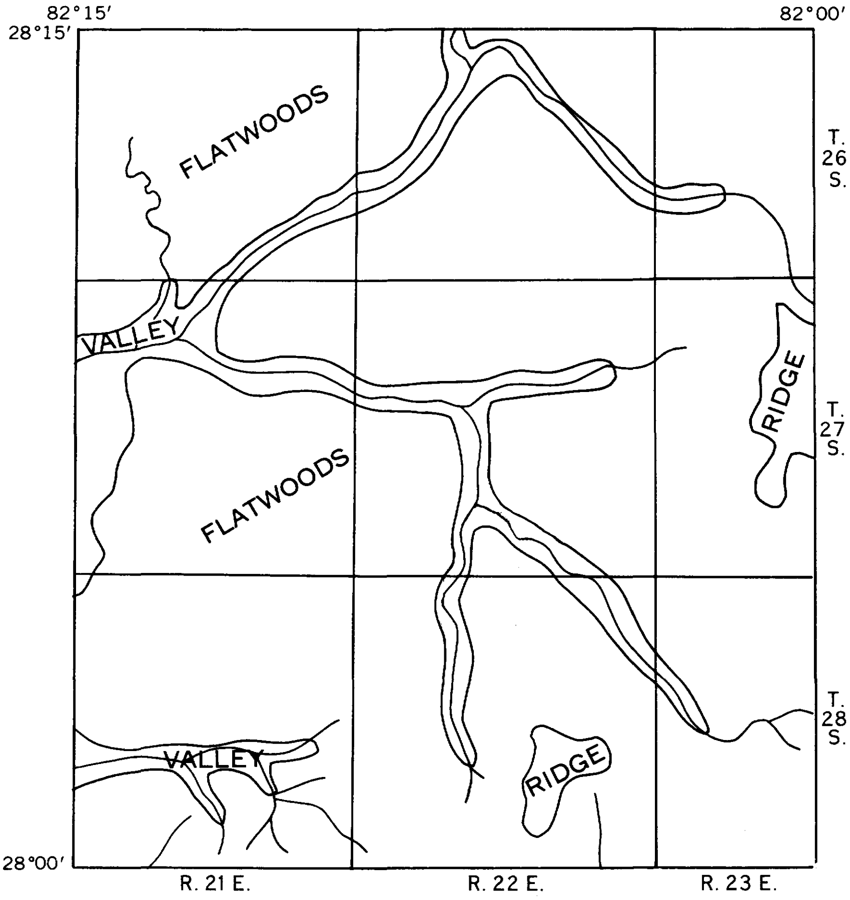



FIGURE 3.—Physiographic divisions, Plant City quadrangle, Florida.

The ridge area is a rolling upland in the eastern part of the quadrangle. It is characterized by well-drained sandy soil, planted with groves of citrus.

The flatwoods area is low lying, nearly level, wooded, and characterized by numerous small depressions called bayheads or ponds, some of which contain grass or cypress or both. Most contain water only intermittently, and many are joined by small narrow winding channels which contain water only during the rainy season. In the flatwoods the common trees are slash and longleaf pines, and the underbrush is wire grass and palmetto. Drainage in the flatwoods area is so poor that farms must be drained by canals or ditches.

The stream valleys are shallow, and the channels of all streams except the Hillsborough River are so poorly defined that drainage canals have been dug along them. Streams are bordered by areas of swampy land into which they overflow during the rainy season. The valleys slope very gradually to the adjacent flatwoods. The waters of the streams are dark brown because of their high content of organic matter, and they generally are free of suspended detrital material. The climate is subtropical, and rainfall averages about 50 inches per year.

## REGIONAL GEOLOGY

The Plant City quadrangle is a part of the Gulf Coastal Plain and is characterized by thin Tertiary formations that dip very gently to the southeast. In the northern part of the quadrangle, however, the regional dip is reversed by a small structural feature called the Hillsborough high.

Exposed rocks include the Suwannee limestone of Oligocene age, the Tampa limestone of early Miocene age, the Hawthorn formation of middle Miocene age, and the Bone Valley formation of Pliocene age. Exposures of these formations are limited to the valleys of the Hillsborough River and its tributaries. Unconsolidated quartz sands assigned to the Pleistocene and Recent cover the rest of the quadrangle. Rocks older than the Hawthorn formation were not studied in detail. Descriptions and data on these older rocks are based on logs from a few drill holes and on the literature.

## ACKNOWLEDGMENTS

It is a pleasure to acknowledge the cooperation of the mining companies. The American Agricultural Chemical Co., American Cyanamid Co., Coronet Phosphate Co. division of Smith-Douglas Co., Inc., Davison Chemical Co. division of W. R. Grace and Co., International Minerals and Chemical Corp., and Swift & Co. gave free access to their prospecting and chemical data. Mr. Wayne Thomas, a consultant in phosphate lands, was most cooperative in allowing the writer to examine his voluminous files.

Chemical and radiometric analyses for uranium as percent U or percent equivalent U were made in the Denver and Washington laboratories of the U.S. Geological Survey. Radiometric analyses were made by the following members of the U.S. Geological Survey: C. E. Cox, Jr., S. P. Furman, J. H. Goode, Jr., B. A. McCall, J. N. Rosholt,

Jr., and J. J. Warr, Jr. Chemical analyses were made by Margaret E. Appling, Sam Bethea, G. W. Boyes, Jr., G. T. Burrow, Alice B. Caemmerer, G. J. Daniels, David Diebler, R. F. Dufour, M. E. F. Eiland, Claude Huffman, Jr., Nancy Jammer, Carmen R. Johnson, J. W. T. Meadows, Roosevelt Moore, Wayne Mountjoy, J. N. Rosholt, Jr., C. M. Stevens, W. P. Tucker, and James Wahlberg.

## METHODS OF MAPPING

The geologic map (pl. 1) was prepared almost exclusively from drill-hole data, especially in the southern part of the quadrangle. In the northern part, the work of Carr and Alverson (1959) was modified by the drill data that were available. Samples from drill holes were examined with the binocular microscope to determine lithologic character; where samples were not available, drill logs were studied. Stratigraphic interpretations were made from the lithologic data. The geologic map was drawn as though the loose, surficial sands were not present. At each drill-hole location, the stratigraphic unit immediately underlying the loose sand was plotted on the map. Surface mapping along the streams and roadcuts was done mostly in the southern part of the quadrangle.

## METHODS OF CORRELATION

Formations in the land-pebble phosphate district are lithologically distinct, and because most of the information on the Plant City quandrangle is from drilling, not many fossils were found. Stratigraphic correlations, therefore, are based for the most part on lithologic studies. The few fossiliferous samples that were collected were used to further substantiate the lithologic correlations.

Examination of the analytical data and tonnage calculations prepared by the phosphate companies from drilling samples for which the age was known provided data that were useful in correlation. The analytical data showed that phosphate nodules from the lower phosphorite unit of the Bone Valley formation, the Hawthorn formation, and the Tampa limestone, had different $P_2O_5$ contents. The amount of phosphate nodules, expressed as tons per acre-foot, also differs in the three formations. These differences are summarized in table 1.

Stratigraphic correlations can be made from company logs by using the tonnage and grade of the phosphate particles where more than one sample was taken. At those drill holes where only one sample was taken or analyzed, it is difficult to tell whether the sample represents the Bone Valley or the Hawthorn or both. Phosphate nodules from the Tampa limestone are so low in $P_2O_5$ content that there is no

TABLE 1.—*Comparison of $P_2O_5$ content and abundance of +14-mesh phosphate nodules in the Bone Valley formation, the Hawthorn formation, and the Tampa limestone*

[Analytical data from company laboratories, used with permission]

| Formation | Number of samples | $P_2O_5$ content (percent) | | Tons of pebble (+14 mesh) per acre-foot | |
|---|---|---|---|---|---|
| | | Average | Range | Average | Range |
| Bone Valley | 400 | 32.5 | 28.4–36.8 | 150 | 21–370 |
| Hawthorn | 66 | 23.2 | 12.4–31.7 | 50 | 10–150 |
| Tampa [1] | 25 | 9.8 | 1.4–14.2 | 90 | 24–300 |
| Tampa [2] | 14 | .6 | 0.2– 1.0 | 280 | 150–550 |

[1] Phosphate nodules.
[2] Probably limestone fragments.

difficulty in identifying this unit. At many of the drill holes, where only one sample was analyzed, a bottom sample called bed clay is present. In these places the material not analyzed was too low in phosphate nodules, and the analyzed material is probably the Bone Valley, the bed clay is either Hawthorn or Tampa, and the location of the drill hole can be used to guess the possible age of the bed clay.

## STRATIGRAPHY

The stratigraphy of the Plant City quadrangle is summarized in the following table 2. Formations are thin and nearly horizontal. Although the Suwannee limestone of Oligocene age is the oldest formation exposed, water wells in the quadrangle penetrate the Ocala limestone of Eocene age. The Ocala limestone, therefore, will be briefly discussed.

The geologic map (pl. 1) shows the distribution of the formations in the Plant City quadrangle. The Suwannee limestone of Oligocene age and the Tampa limestone of early Miocene age are exposed only along the Hillsborough River and Blackwater Creek; in the rest of the area they are covered by the upper clayey sand unit of the Bone Valley formation. The Hawthorn formation of middle Miocene age is present only in the southern and eastern parts of the quadrangle; it has been eroded from the Hillsborough high in the northern part of the quadrangle. The lower phosphorite unit of the Bone Valley formation is present only in the southern third of the quadrangle, where it fills low areas on the Hawthorn surface. The upper clayey sand unit of the Bone Valley formation is present over the entire quadrangle, except where it has been removed by erosion along the courses of the present streams.

TABLE 2.—*Summary of stratigraphy and lithology, Plant City quadrangle*

| Age and formation or deposit | | | Lithologic description | |
|---|---|---|---|---|
| | | | Unweathered material | Weathered material |
| Quaternary | Recent | | Loose quartz sand; swamp deposits. | Loose quartz sand; swamp deposits. |
| | | | Gradational | |
| Quaternary | Pleistocene | Terrace deposits | Loose quartz sand; trace of very slightly clayey sand. | Loose quartz sand. |
| | | | Gradational, but locally channels are cut into lower beds | |
| Tertiary | Pliocene | Bone Valley formation. | Upper unit: Clayey sand; trace of phosphate. Phosphate increases at base.<br>Gradational<br>Lower unit: Clayey, sandy phosphorite. Locally phosphate conglomerate at base. $P_2O_5$ content and amount of nodules high. | Sand cemented by aluminum phosphate minerals; vesicular texture in lower part where the pebbly phosphate of the lower unit has been altered.<br>Irregular<br>Clayey, sandy phosphorite; phosphate is dull, white, soft.<br>Gradational<br>Clayey, sandy phosphorite. |
| | | | Unconformity | |
| Tertiary | Miocene (middle) | Hawthorn formation | Impure limestone or dolomite, sand, clay. All beds contain phosphate nodules; low in $P_2O_5$ content and tonnage. | Calcareous sandy clay; contains phosphate nodules.<br>Gradational<br>Impure limestone or dolomite. |
| | | | Contact relations uncertain | |
| Tertiary | Miocene (early) | Tampa limestone | Slightly sandy and clayey limestone. Traces of phosphate nodules, very low in $P_2O_5$ content. | Calcareous sandy clay; traces phosphate nodules. |
| | | | Unconformity | |
| Tertiary | Oligocene | Suwannee limestone | Limestone; traces of fine sand and clay. No phosphate. | Silicified limestone where exposed or very close to the surface. |
| | | | Unconformity | |
| Tertiary | Eocene | Ocala limestone | Pure limestone. | Known only from drill holes. |

Many papers have been written on the stratigraphy of the Tertiary rock of Florida. The ages of these formations and the history of the uses of their names have been discussed by Cooke (1945), Vernon (1951), Carr and Alverson (1959), and Cathcart (1963).

## EOCENE SERIES

### OCALA LIMESTONE

The Ocala limestone of late Eocene (Jackson) age (Cooke, 1945, p. 117; Vernon, 1951, p. 111–113) does not crop out in the Plant City quadrangle. The Ocala, however, is penetrated by three drill holes within the quadrangle (holes D1, D19, and D23, table 3), and many drill holes in the surrounding quadrangles, indicating that it underlies the entire area. Vernon (1951, p. 111) divided the Ocala limestone into the Moodys Branch formation at the base and the Ocala limestone (restricted) at the top. Because of lack of data, it is not possible to follow Vernon's classification; in this report, the Ocala limestone includes all deposits of late Eocene (Jackson) age.

The upper surface of the Ocala is at an elevation of 91 feet below sea level in the northern part of the quadrangle and is at an elevation of 220 feet below sea level in the southwestern part of the quadrangle (holes D1 and D23, table 3). Vernon (1951, pl. 2) shows the upper surface of the Inglis member of the Moodys Branch formation dipping to the southwest in the area of the Plant City quadrangle.

The thickness of the Ocala limestone is not known in the Plant City quadrangle, but according to Vernon (1951, p. 158), the Ocala may reach a maximum thickness of about 200 feet in this area.

The Ocala limestone unconformably overlies rocks of Claiborne age and is unconformably overlain by the Suwannee limestone of Oligocene age (Vernon, 1951, p. 158). The two limestones are lithologically similar, but both are fossiliferous; and the contact is based on fossil evidence. The Ocala limestone is typically a white to cream soft massive fossiliferous pure limestone.

## OLIGOCENE SERIES

### SUWANNEE LIMESTONE

The Suwannee limestone of Oligocene age (MacNeil, 1947) is present in the subsurface throughout the Plant City quadrangle. The top of the formation is nearly 90 feet above sea level in the northeastern part of the quadrangle (holes D3, D4, table 3) and is about 50 feet below sea level in the southern and western parts of the quadrangle (hole D14, table 3). The formation crops out along the Hillsborough River on the Hillsborough high.

Only two drill holes penetrated the Suwannee limestone in the Plant City quadrangle. The thickness at the northern drill hole (D1, table 3) is 125 feet and at the southern drill hole (D23, table 3), 210 feet.

The Suwannee is white, tan, or cream limestone, generally fairly soft, and granular. Impurities include a small percentage of very fine grained quartz sand and some clay. Where it is not deeply buried, the top of the formation is silicified in some places.

In the Plant City quadrangle, the Suwannee limestone is overlain unconformably by the Tampa limestone, except on the Hillsborough high where the Tampa limestone is absent and the Suwannee limestone is overlain by clayey sand of the upper unit of the Bone Valley formation or by loose sands of Pleistocene age.

Drill hole D7 in sec. 19, T. 27 S., R. 22 E., is typical of the shallow holes that were completed in the Suwannee limestone. The thin, surficial shell of silicified limestone, called chert or flint rock by the drillers, is characteristic of the Suwannee limestone where it is not deeply buried. Most drill holes bottom on the flint rock. Fossiliferous limestone underlies the flint rock.

681383 O—63——3

TABLE 3.—*Summary of data from deep-well logs, Plant City quadrangle*

[Source of data: 1, Log by F. S. MacNeil, U.S. Geol. Survey; 2, Cathcart and McGreevy (1959); 3, Cooke (1945); 4, Log from Florida Geol. Survey; 5, Log by R. H. Stewart, U.S. Geol. Survey. Elevations are feet above or below mean sea level. TD, total depth]

| Source of data | Hole | Location: Sec. | Location: Township South | Location: Range East | Elevation of collar | Hawthorn formation: Elevation top of formation | Hawthorn formation: Thickness (feet) | Tampa limestone: Elevation top of formation | Tampa limestone: Thickness (feet) | Suwannee limestone: Elevation top of formation | Suwannee limestone: Thickness (feet) | Ocala limestone: Elevation top of formation | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | D1 | 13 | 26 | 21 | 79 | ---------- | ---------- | +54 | 20 | +34 | 125 | −91 | No additional data. |
| 2 | D2 | 1 | 26 | 22 | 95 | ---------- | ---------- | +86 | 8 | +78 | ---------- | ---------- | Do. |
| 2 | D3 | 8 | 26 | 23 | 100 | ---------- | ---------- | +94 | 13 | +81 | ---------- | ---------- | Do. |
| 2 | D4 | 27 | 26 | 23 | 120 | ---------- | ---------- | +105 | 18 | +87 | ---------- | ---------- | Do. |
| 2 | D5 | 6 | 27 | 22 | 80 | ---------- | ---------- | ---------- | (1) | +23 | ---------- | ---------- | Do. |
| 3 | D6 | 18 | 27 | 22 | 70 | ---------- | ---------- | +70 | 0 | +70 | ---------- | ---------- | Contact of Suwannee and Tampa limestones. |
| 2 | D7 | 19 | 27 | 22 | 95 | ---------- | ---------- | +76 | 5 | +71 | ---------- | ---------- | TD 26½ ft in Suwannee. |
| 2 | D8 | 31 | 27 | 22 | 100 | +78 | 30 | +48 | ---------- | ---------- | ---------- | ---------- | No additional data. |
| 4 | D9 | 21 | 27 | 23 | 150 | +95 | 40 | +55 | 65 | −10 | ---------- | ---------- | Do. |
| 2 | D10 | 6 | 28 | 21 | 50 | +28 | 17 | +11 | 17 | −6 | ---------- | ---------- | Do. |
| 4 | D11 | 7 | 28 | 21 | 50 | +30 | 36 | −6 | 14 | −20 | ---------- | ---------- | Do. |
| 2 | D12 | 8 | 28 | 21 | 65 | +31 | 14 | +17 | ---------- | ---------- | ---------- | ---------- | Do. |
| 4 | D13 | 18 | 28 | 21 | 60 | +45 | 10 | +35 | 50 | −15 | ---------- | ---------- | Do. |
| 5 | D14 | 18 | 28 | 21 | 70 | +15 | 29 | −14 | 33 | −47 | ---------- | ---------- | TD 231 ft in Suwannee. |
| 4 | D15 | 26 | 28 | 21 | 100 | +50 | 35 | +15 | ---------- | ---------- | ---------- | ---------- | No additional data. |
| 4 | D16 | 28 | 28 | 21 | 90 | ---------- | ---------- | +20 | ---------- | ---------- | ---------- | ---------- | Do. |
| 4 | D17 | 29 | 28 | 21 | 78 | +58 | 40 | +18 | 50 | −32 | ---------- | ---------- | Do. |
| 2 | D18 | 35 | 28 | 21 | 120 | +78 | 34 | +44 | ---------- | ---------- | ---------- | ---------- | Do. |
| 5 | D19 | 17 | 28 | 22 | 120 | +100 | 42 | +58 | ---------- | ---------- | ---------- | ---------- | TD 393 ft in Ocala. |
| 2 | D20 | 17 | 28 | 22 | 120 | +101 | 20 | +81 | ---------- | ---------- | ---------- | ---------- | No additional data. |
| 2 | D21 | 5 | 28 | 22 | 107 | +93 | 2 | +91 | ---------- | ---------- | ---------- | ---------- | Do. |
| 5 | D22 | 28 | 28 | 22 | 130 | +102 | 62 | +40 | ---------- | ---------- | ---------- | ---------- | Do. |
| 4 | D23 | 29 | 28 | 22 | 135 | +115 | 40 | +75 | 85 | −10 | 210 | −220 | Do. |
| 4 | D24 | 28 | 28 | 22 | 140 | +110 | 90 | +20 | 30 | −10 | ---------- | ---------- | TD 235 ft in Suwannee. |
| 4 | D25 | 30 | 28 | 22 | 120 | +95 | 62+ | ---------- | ---------- | ---------- | ---------- | ---------- | TD 87 ft in Hawthorn. |

[1] No Tampa limestone.

*Log of drill hole D7 in sec. 19, T. 27 S., R. 22 E.*

[After Cathcart and McGreevy (1959)]

| | *Thickness (feet)* |
|---|---|
| Pleistocene: | |
| Terrace sands: | |
| Sand, light-gray, loose. (At surface, not cored) | 5.0 |
| Pliocene: | |
| Bone Valley formation (upper unit): | |
| Sand, light-gray or tan, clayey, iron-stained; trace of dull, soft, white phosphate, and traces of aluminum phosphate minerals | 14.0 |
| Miocene: | |
| Tampa limestone: | |
| Clay, gray-blue and yellow, sandy; contains abundant fragments of soft limestone; laminated, and contains fragments of chert near base of the unit | 5.0 |
| Oligocene: | |
| Suwannee limestone: | |
| Limestone, brown, silicified. Very hard drilling. Only one fragment of brown chert recovered | .5 |
| Limestone, white to cream, granular, fossiliferous | 2.0 |
| Limestone | 2.5 |
| Bottom of drill hole. | |

Fossiliferous Suwannee limestone core, from drill hole D3 in sec. 8, T. 26 S., R. 23 E., is nearly identical lithologically with the limestone at the drill-hole locality (D7, table 3) in sec. 19, T. 27 S., R. 22 E., except that it contains traces of very fine grained clear angular quartz.

Fossiliferous limestone assigned to the Suwannee was cored at drill holes in sec. 6, T. 28 S., R. 21 E. (D10, table 3), and in sec. 1, T. 26 S., R. 22 E. (D2, table 3). The latter drill hole is about half a mile north of the northern boundary of the Plant City quadrangle. Fossil determinations from the limestone cored at these drill holes were made by F. S. MacNeil of the U.S. Geological Survey; fossils are listed by Cathcart and McGreevy (1959).

## MIOCENE SERIES

### TAMPA LIMESTONE

The Tampa limestone of early Miocene age (Cooke, 1945; MacNeil, 1947) is present throughout the quadrangle, except on the Hillsborough high where it has been removed by erosion. The top of the formation ranges in elevation from 105 feet above sea level in the northeastern part of the quadrangle to 14 feet below sea level in the southwestern part (holes D4 and D14, table 3). The Tampa limestone crops out along the Hillsborough River and Blackwater Creek.

The Tampa limestone contains more impurities (clay, sand, and chert fragments) than either the Ocala or Suwannee limestones. The

Tampa is a white to yellow or cream sandy and clayey limestone. It is only locally fossiliferous. Lenses of calcareous clayey sand or sandy clay are present in the formation, and a residual mantle of green calcareous sandy clay with chert and limestone fragments is found in many places at the present top of the formation. At the few localities where it was sampled in the Plant City quadrangle, the Tampa contained from a trace to about 15 percent of phosphate nodules (table 1).

The lithologic character of the Tampa limestone in the Plant City quadrangle varies from south to north. In the southern part of the quadrangle the formation consists of sandy limestone with traces of black phosphate. The limestone is softened by weathering in the top few feet and is commonly called "rotten" limestone by the drillers. Four feet of "rotten" limestone was cored at drill hole D22 (fig. 4, and p. D19), and an additional 3 feet of limestone was penetrated before the drill hole was abandoned.

The Tampa limestone ranges from 0 to 85 feet in thickness. North of the Hillsborough River the formation is thin, seldom exceeding about 20 feet in thickness. The formation thickens to the south, off the Hillsborough high. A drill hole (D7, fig. 4, and p. D13) in sec. 19, T. 27 S., R. 22 E., penetrated 5 feet of sandy clay assigned to the Tampa. The clay is underlain by a thin bed of chert, which is underlain by fossiliferous Suwannee limestone. To the south, at a drill hole (D21, fig. 4, and p. D20) in sec. 5, T. 28 S., R. 22 E., 3 feet of sandy clay, underlain by 3.8 feet of clayey limestone is assigned to the Tampa; the hole was abandoned in the Tampa. Still farther south, at a drill hole (D23, table 3) in sec. 29, T. 28 S., R. 22 E., the Tampa limestone is 85 feet thick, and in the Keysville quadrangle (Cathcart, 1963; table 2), the Tampa limestone is as much as 250 feet thick.

The range in thickness is due in part to recent erosion and in part to erosion prior to the deposition of the Bone Valley.

Fossiliferous Tampa limestone was identified in drill cores from sec. 31, T. 27 S., R. 22 E. (D8, table 3), and sec. 8, T. 28 S., R. 21 E. (D12, table 3). For fossil lists, see Cathcart and McGreevy (1959).

### ANALYTICAL DATA, PHOSPHATE PARTICLES

Although phosphate particles are not abundant, they do occur in the formation. Phosphate nodules have been separated from only a few samples of the Tampa limestone. The samples were obtained with the hand auger from sandy clay or soft limestone. Analytical data are for the pebble fraction only. The samples were screened on 14 mesh, and the undersize contained so little visible phosphate that it was discarded. Tonnages of phosphate particles were computed by the phosphate companies, and analyses were made by company chemists. Analytical results of the so-called pebble fraction

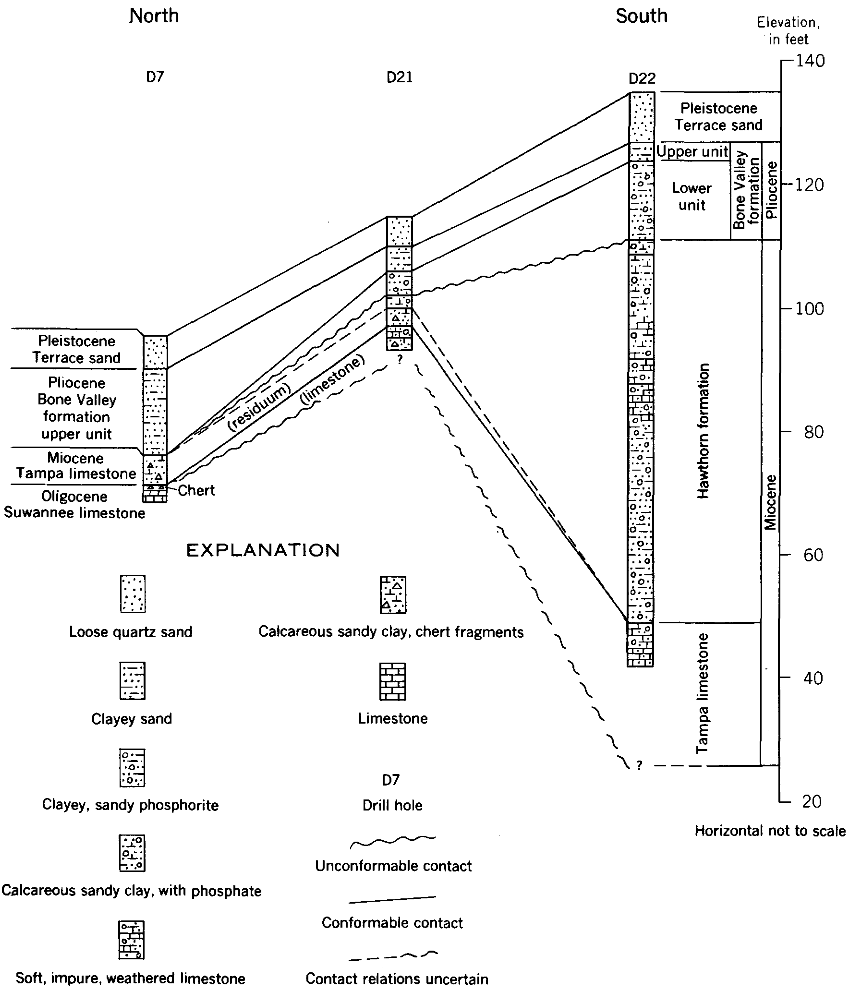



FIGURE 4.—Diagrammatic section, Plant City quadrangle, Florida, showing lithologic changes and northward thinning of the Tampa limestone, the Hawthorn formation, and the lower unit of the Bone Valley formation. See plate 1 for location of drill holes.

fall into two distinct groups (table 1). Samples in the first group range from 1.4 to 14.2 percent $P_2O_5$, and tonnages of the phosphate particles are low, averaging about 90 tons of pebble per acre-foot. This group of samples, obtained from rock described in the driller's logs as green or gray clay with white, brown, or gray rock, may represent the average grade of the very impure phosphate nodules of the Tampa limestone.

Samples from the second group range from 0.2 to 1.0 percent $P_2O_5$, and average about 0.6 percent. Tonnages from samples in this group are high; the average is about 280 tons of pebble per acre-foot. Samples from this group were not described in the driller's logs. They probably represent soft limestone, and the pebble fraction consists of fragments of limestone. Inasmuch as the average grade of the +14-mesh fraction is of the same order of magnitude as the average $P_2O_5$ content of Tampa limestone (0.3 percent) as reported by Carr and Alverson (1959), these samples probably represent a partially weathered limestone of the Tampa.

### TAMPA-HAWTHORN CONTACT

The contact between the Hawthorn formation and the underlying Tampa limestone may be conformable, as postulated by Cooke (1945, p. 145), or the contact may be unconformable, as suggested by Carr and Alverson (1959). The contact is not well exposed, and evidence from drill cores is not conclusive. Almost all drill holes in the Plant City quadrangle that went through the Hawthorn and into the Tampa limestone first penetrated a clayey sand or sandy clay, probably residuum of the Tampa. This residuum can be interpreted as a soil zone that formed on the Tampa prior to the deposition of the Hawthorn. However, where this zone is thickest in the Plant City quadrangle, it is close to the surface and is overlain by more or less permeable rocks. The residuum, therefore, could have formed during post-Hawthorn weathering.

A drill hole in sec. 28, T. 28 S., R. 22 E., in the southern part of the quadrangle penetrated a zone of "rotten" limestone which is interpreted as a soil profile that formed on the Tampa limestone prior to the deposition of the Hawthorn. The log of the drill hole (D22, fig. 4 and p. D19) shows a weathering profile that formed in limestone beds of the Hawthorn. This zone of weathering is underlain by 32 feet of clay which contains fresh phosphate nodules. Under the clay is a bed 4 feet thick, called "rotten" limestone, which grades downward into hard limestone of the Tampa. The "rotten" limestone is probably the remains of a weathering profile that had formed on the Tampa. Because this profile underlies the weathering profile on the Hawthorn and is separated from it by a thick bed of relatively impermeable clay, it seems likely that this profile was formed prior to the deposition of the Hawthorn formation. If this interpretation is correct, the contact between the Tampa and the Hawthorn is marked by a slight erosional break. The interval of erosion was probably of short duration, and probably only a part of the Floridian plateau was exposed to weathering. The Tampa-Hawthorn contact, therefore, may be conformable somewhere to the south of the land-pebble district.

### TAMPA-BONE VALLEY CONTACT

In the northern part of the quadrangle, sandy clay, probably a residuum of the Tampa limestone, is overlain by light-gray clayey sand of the upper unit of the Bone Valley formation. The sandy clay contains fragments of limestone in some places, and the clayey sand contains traces of phosphate. (See logs of drill holes D7, p. D13, and D31, p. D35.) The contact is not exposed in the Plant City quadrangle and is known only from drilling. The exact nature of the contact is, therefore, not known, but the absence of such stratigraphic units as the Hawthorn formation and the lower unit of the Bone Valley formation indicates that the contact is disconformable. The lower unit of the Bone Valley formation is nowhere in contact with the Tampa limestone.

### HAWTHORN FORMATION

Dall (Dall and Harris, 1892, p. 107) named the Hawthorn formation from exposures near the town of Hawthorn in Alachua County. According to most of the recent workers, the Hawthorn formation is middle Miocene in age (F. S. MacNeil, oral communication, 1956; Vernon, 1951, p. 188).

#### DISTRIBUTION AND THICKNESS

The Hawthorn formation crops out only in a few of the deeper stream valleys in the quadrangle, but it is known from drilling data to be present in the southern and eastern parts of the quadrangle. The formation is absent north and west of a northeastward-trending line extending from the center of sec. 6, T. 28 S., R. 21 E., at the west edge of the quadrangle, to about the center of sec. 10, T. 26 S., R. 23 E., at the east edge of the quadrangle (pl. 1).

The Hawthorn formation is absent over the Hillsborough high, but is present to the north of the high beyond the quadrangle boundary.

The Hawthorn formation ranges in thickness from 0 to about 100 feet (fig. 5). The isopachs shown in figure 5 outline a series of subparallel elongate areas where the Hawthorn is thick, separated by elongate areas where the Hawthorn formation is thin. In the eastern part of the quadrangle these features trend to the north; whereas, in the western part of the quadrangle, they trend more to the northeast.

#### PHYSICAL CHARACTERISTICS

The Hawthorn formation varies both laterally and vertically in composition, from sand and clayey sand to impure limestone and

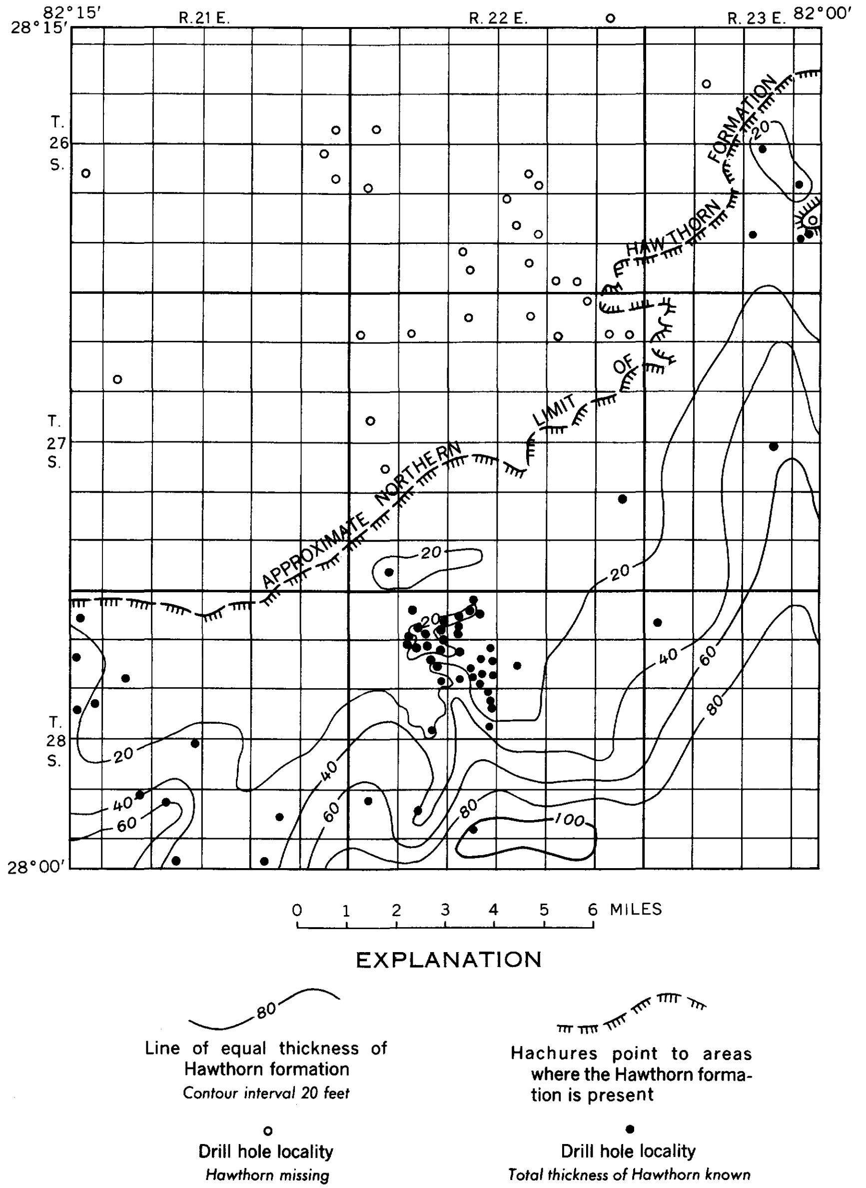



FIGURE 5.—Isopach map of the Hawthorn formation, Plant City quadrangle, Florida.

dolomite. Phosphate nodules are present in various amounts throughout the formation. Although exposures are very poor and the drill data are not abundant, some generalizations about the distribution of lithologic types can be made. Company drill holes in the south part of T. 28 S., R. 22 E., and in T. 28 S., R. 23 E., all bottomed in material too hard to penetrate with the hand auger, probably limestone or dolomite of the Hawthorn formation. This supposition is confirmed by the log of a well (D22) in sec. 28, T. 28 S., R. 22 E., where limestone of the Hawthorn formation underlies the lower phosphorite unit of the Bone Valley formation. This log is probably typical of the Hawthorn formation in this area.

*Log of drill hole D22 in sec. 28, T. 28 S., R. 22 E.*

[Adapted from lithologic log by R. H. Stewart]

| | *Thickness (feet)* |
|---|---|
| Debris: | |
| Sand, phosphate, and clay (tailings from old phosphate mine) | 4 |
| Pleistocene: | |
| Terrace sand: | |
| Sand, loose, white; gray in top few inches | 8 |
| Pliocene: | |
| Bone Valley formation: | |
| Upper unit: | |
| Sand, white, clayey; trace of white phosphate nodules | 3 |
| Lower unit: | |
| Sand, brown, clayey; very abundant pebble- and sand-sized phosphate particles | 13 |
| Total Bone Valley formation | 16 |
| Miocene: | |
| Hawthorn formation: | |
| Clay, sandy, calcareous; contains some phosphate nodules | 2 |
| Limestone or dolomite, buff and brown, sandy and clayey; abundant phosphate sand and pebble; soft, weathered, "rotten" limestone; grades into bed below | 22 |
| Limestone, buff to cream, sandy and clayey | 6 |
| Clay, gray-blue and green, sandy; contains trace to abundant fresh shiny black and brown phosphate nodules and medium- to coarse-grained quartz sand | 32 |
| Total Hawthorn formation | 62 |
| Tampa limestone: | |
| Limestone, clayey, soft; trace of phosphate; "rotten" limestone | 4 |
| Limestone, grayish-white hard; contains minor amounts of clay and fine-grained sand; traces of black phosphate | 3+ |
| Part of the Tampa limestone | 7+ |
| Bottom of log. | |

The Hawthorn formation thins to the north. The thinning is shown in the logs of two drill holes; the drill hole at locality D22 intersected 62 feet of strata assigned to the Hawthorn, whereas the drill hole at locality D21, 4 miles north of locality D22, intersected only 2 feet of strata assigned to the Hawthorn formation.

*Log of drill hole D21 in sec. 5, T. 28 S., R. 22 E.*

[After Cathcart and McGreevy (1959)]

| | Thickness (feet) |
|---|---|
| Pleistocene: | |
| Terrace sands: | |
| Sand, gray, loose | 5.0 |
| Pliocene: | |
| Bone Valley formation: | |
| Upper Unit: | |
| Sand, brown, clayey, iron-stained | 4.0 |
| Lower unit: | |
| Sand, gray, slightly clayey, contains white, fresh phosphate nodules | 4.0 |
| Total Bone Valley formation | 8.0 |
| Miocene: | |
| Hawthorn formation: | |
| Clay to clayey sand, gray and greenish-gray, sandy, calcareous; trace of white phosphate | 2.0 |
| Tampa limestone: | |
| Clay, grayish-yellow, slightly sandy; contains chert nodules | 3.0 |
| Limestone, white to light-gray, clayey; upper half soft; contains abundant chert nodules | 3.8 |
| Part of the Tampa limestone | 6.8 |
| Bottomed in limestone, as above, but hard. | |

At drill-hole locality D21, the Hawthorn formation consists of calcareous clay, which probably is residual from limestone. The contact of the Tampa limestone and the Hawthorn formation is placed at the top of the clay containing chert nodules; this clay may be residual from the underlying limestone. The residual clay assigned to the Tampa at locality D21 probably was affected by the weathering cycle that formed the residual clay assigned to the Hawthorn formation.

The northward thinning and the change in lithologic character from sandy limestone to sandy clay or clayey sand are due, in part, to weathering and solution of calcium carbonate. However, in the northern part of T. 28 S., R. 22 E. closely spaced drilling for which detailed core descriptions were available indicates that carbonate deposition was succeeded by deposition of clay. The clay ranges in thickness from 0 to about 34 feet, is brown, and contains minor coarse- to medium-grained quartz sand. The clay is thick where it overlies hard limestone or dolomite and thin where it overlies a calcareous, phosphatic clay ("bed clay"), probably a residuum of limestone that was formed by lateral movement of acid ground waters.

### HAWTHORN-BONE VALLEY CONTACT

The contact of the Bone Valley and Hawthorn formations is not exposed in the Plant City quadrangle. Sellards (1915, p. 61–62) reports an unconformity at the base of the phosphate bed on the "bedrock" marl from the only mine in the quadrangle, the Coronet or Upper mine, which was abandoned many years ago. The contact relations between the Hawthorn and Bone Valley cannot be seen in drill cuttings, but drill cores are of some help. A drill hole (D25) in sec. 30, T. 28 S., R. 22 E., penetrated a conglomerate of brown sandstone pebbles at the base of the phosphorite section, probably in unconformable contact with residual calcareous clay of the Hawthorn formation.

*Log of drill hole D25 in sec. 30, T. 28 S., R. 22 E.*

| | *Thickness (feet)* |
|---|---|
| Pleistocene: | |
| Terrace sands: | |
| Sand, gray to white, loose, quartz | 3 |
| Pliocene: | |
| Bone Valley formation: | |
| Upper unit: | |
| Sand, white, clayey, traces of soft white phosphate; aluminum phosphate zone | 8 |
| Lower unit: | |
| Clay, sandy, or clayey sand, brown and gray; contains abundant, fresh, brown, white, and gray phosphate nodules | 16 |
| Conglomerate, sandy; trace of clay; contains brown sandstone boulders | 1 |
| Total Bone Valley formation | 25 |
| Miocene: | |
| Hawthorn formation: | |
| Clay, white, calcareous, sandy; trace of phosphate nodules | 6 |
| Limestone (or dolomite), white to cream, sandy and clayey, soft; trace of phosphate nodules | 5 |
| Part of the Hawthorn formation | 11 |
| Bottom of drill hole in material too hard to penetrate—probably hard limestone or dolomite. | |

Brown sandstone of the type that forms the conglomerate boulders at the base of the Bone Valley in drill hole D25 is not known from outcrop or from drilling data elsewhere in the area. These boulders probably are erosional remnants of a very thin sandstone deposited late in the middle Miocene or early in late Miocene and represent a basal conglomerate of the Bone Valley formation. A post-Hawthorn period of erosion would indicate an unconformity between the Hawthorn and Bone Valley formations.

Evidence of the unconformity between the Hawthorn and the lower unit of the Bone Valley formation can be inferred from core from drill hole D26 (p. D27). The contact is marked at the locality (SW¼NE¼ sec. 33, T. 28 S., R. 22 E.) by a pebbly and clayey sand of the Bone Valley that rests on calcareous clay without pebbles—evidence of a break or change in deposition. The calcareous clay is probably residual from the underlying limestone.

### UPPER CONTACT OF THE HAWTHORN

The upper contact of the Hawthorn as shown on plate 2 is an erosion surface and consists of three subparallel ridges separated by valleylike lows. Details of the Hawthorn surface, on a smaller scale, are shown on figure 11 of the Knights tract.

The ridges are dotted by numerous sinkholes filled by either phosphorite of the lower unit of the Bone Valley formation, clayey sand of the upper unit of the Bone Valley or by Pleistocene sand. Pleistocene sand fills the large sinkhole on the westernmost ridge, the large sinkhole (southernmost) on the central ridge, and the shallow, broad sinkhole at the north end of the east ridge. Most of the other depressions are filled with phosphorite of the lower unit of the Bone Valley formation, but some are filled with clayey sand of the upper unit of the Bone Valley formation. Details of sinkhole filling are shown on figures 12–14 of the Knights tract.

The ridges are separated by valleylike troughs representing paleostreams on the Hawthorn surface. The drainage between the east and central ridges heads in the southeastern part of the quadrangle and trends northwest to about the center of the quadrangle, where it apparently turns to the west. This drainage parallels, but does not coincide with, the present Blackwater Creek.

A westward-trending paleodrainage separates the central ridge from the west ridge. The drainage is roughly parallel to several streams—Mill Creek, Pemberton Creek, and Hollomans Branch.

The Hawthorn formation is generally thicker in the areas of the ridge and, conversely, thinner in the areas of the troughs (compare fig. 5 and pl. 2).

The present distribution of the Hawthorn formation in the Plant City quadrangle is controlled by erosion. The structurally high area in the northern part of the quadrangle, the Hillsborough high, is a part of the Ocala uplift, which began to rise in early Miocene time (Vernon, 1951). The Hawthorn formation probably was deposited across the high but was much thinner in this area than to the north and to the south and was subsequently removed by erosion.

## PLIOCENE SERIES

### BONE VALLEY FORMATION

The Bone Valley formation, as originally described (Matson and Clapp, 1909; Sellards, 1910) included all the minable phosphate and the overlying sand or clayey sand with traces of phosphate nodules. The loose surficial sand of probable Pleistocene age was excluded from the Bone Valley formation. The inclusion of all the minable phosphate in the lower unit of the Bone Valley formation is incorrect, because in most areas some phosphate that is residual from the Hawthorn is mined and is, therefore, referable to that formation. All residual phosphate is excluded from the Bone Valley formation in this report.

The Bone Valley formation is divided into two units: a lower phosphorite unit, conformably overlain by an upper clayey sand unit. The contact between the two units is gradational over a few inches and is marked by the sharp contrast between abundant phosphate nodules of the lower unit and only traces of phosphate in the upper unit. Thus the contact between the two units is ordinarily at the top of the possibly economic phosphate deposit. At places, however, the lower phosphorite unit has been leached. Leaching may extend almost to the base of the lower unit, and where this is true, the contact with the economic deposit may be well below the stratigraphic contact.

The Bone Valley formation is Pliocene in age. No fossils have been found in the formation in the Plant City quadrangle, but fossil evidence from elsewhere in the land-pebble phosphate district indicates a Pliocene age for the formation. South of the district, the Bone Valley formation may include beds that are late Miocene in age; Bergendahl (1956) shows an interfingering of the lower part of the Bone Valley formation with sand of late Miocene age.

#### DISTRIBUTION AND THICKNESS

The lower unit of the Bone Valley formation is irregular in thickness and distribution. It ranges in thickness from 0 to about 45 feet and averages about 5 feet. The unit is present only in the southern third of the Plant City quadrangle but is missing along parts of Spartmans Branch and Pemberton, Blackwater, and Itchepackesassa Creeks, and their tributaries. The lower unit occurs as thin erosional remnants on interstream divides in the northern part of its area of extent but thickens to the south and blankets the southern part of the quadrangle.

The upper unit of the Bone Valley formation is present throughout the Plant City quadrangle, except where it has been removed by erosion along the streams. The upper unit ranges in thickness from

0 to about 50 feet and probably averages somewhat less than 20 feet. The greatest thickness is in a sinkhole in sec. 6, T. 27 S., R. 22 E.

### STRATIGRAPHIC RELATIONS

The lower phosphorite unit of the Bone Valley formation unconformably overlies the Hawthorn formation but does not overlap it. The upper clayey sand unit of the Bone Valley formation conformably overlies the lower unit; it overlaps the lower unit to the north and rests on successively older beds—the Hawthorn formation, the Tampa limestone, and the Suwannee limestone (fig. 6).

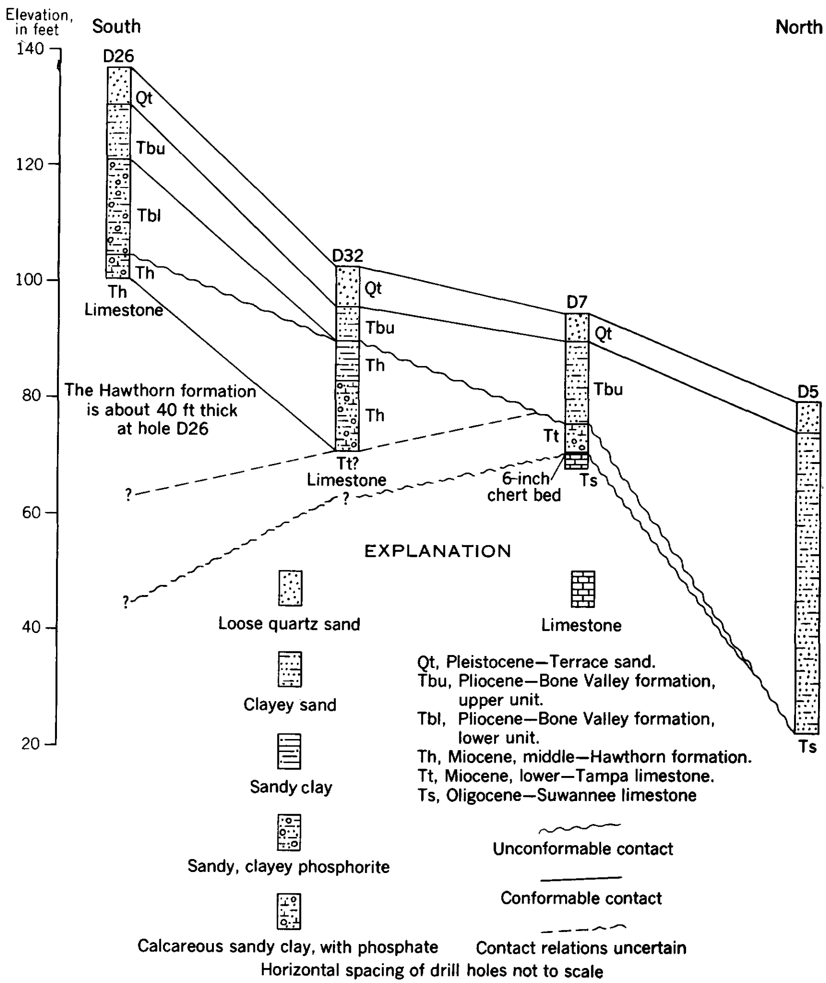



FIGURE 6.—Section showing relations of the upper unit of the Bone Valley formation to underlying rocks, Plant City quadrangle, Florida. See plate 1 for location of drill holes.

Figure 6 shows the upper unit of the Bone Valley formation overlying the lower unit at hole D26, the Hawthorn formation at hole D32, the Tampa limestone at hole D7, and the Suwannee limestone at hole D5.

The contact between clayey sand of the upper unit of the Bone Valley formation and the overlying terrace sand of Pleistocene age is arbitrarily placed at the bottom of the unconsolidated sand. The selection of the contact may be in error stratigraphically, because clayey sand deposits of Pleistocene age are known. The lithologic contact, however, is close to the series contact, and the only practical method of distinguishing the formations by use of drilling data is on a lithologic basis.

### PHYSICAL CHARACTERISTICS

#### LOWER UNIT

The lower phosphorite unit of the Bone Valley formation consists of sandy clay and clayey sand, with a few thin beds of sand and clay. All the lithologic units contain granule- to fine sand-sized phosphate nodules. Conglomeratic phosphate beds are common in the lower unit of the Bone Valley formation only at the Coronet mine in the southern part of the quadrangle (Sellards, 1915).

Phosphate nodules in the lower unit of the Bone Valley formation are well rounded, highly polished, and range in size from less than 0.1 mm to several centimeters in diameter. The size distribution of nodules in surrounding areas is regular and mappable (Cathcart and Davidson, 1952). Data on size distribution of nodules in the Plant City quadrangle are meager, mainly because many of the data are for the pebble fraction only, so that the ratio of coarse to fine phosphate could not be computed. The data available, however, show that the phosphorite in the lower unit of the Bone Valley formation follows the pattern established in other parts of the phosphate field, where coarse grains of phosphate predominate on basement ridges and near present streams and where fine phosphate particles predominate in low areas on the Hawthorn surface between the stream valleys and the ridges.

Detailed study shows that the color of the phosphate nodules is different in different formations. Brown, white, tan, and gray phosphate particles are characteristic of the Bone Valley formation. Black nodules are common in the Hawthorn. A further breakdown shows that gray and white phosphate nodules are more common in the uppermost beds of the lower phosphorite unit of the Bone Valley formation, whereas brown and tan phosphate nodules are more common in the lower beds. The lighter color of the nodules in the top beds of the lower unit may be due to partial leaching.

The $P_2O_5$ content of the phosphate nodules is varied with respect to the color of the nodules. The white and gray nodules in the top beds are high in $P_2O_5$. This may be due to addition of $P_2O_5$ by the ground waters that have leached the particles, or by removal of excess $CaCO_3$, or both. The brown and tan nodules in the lower beds of the lower unit of the Bone Valley contain less $P_2O_5$ than the white nodules in the top beds; and the black nodules, characteristic of the Hawthorn formation, generally contain much less $P_2O_5$ than the brown and tan nodules. A typical sequence is shown in the log of a drill hole from sec. 16, T. 28 S., R. 22 E.

*Log of a drill hole in SE¼ NE¼ sec. 16, T. 28 S., R. 22 E.*

[Phosphate analyses by American Cyanamid Co. chemists; used with permission of the company]

| | *Thickness (feet)* |
|---|---|
| Pleistocene: | |
| Terrace sands: | |
| Sand, loose, black | 2.0 |
| Pliocene: | |
| Bone Valley formation: | |
| Upper unit: | |
| Sand, gray to white, slightly clayey; contains fragments of sand cemented by aluminum phosphate minerals | 4.5 |
| Lower unit: | |
| Clay, blue-gray, sandy; contains white and gray, sand- to pebble-sized phosphate nodules; sand-sized nodules contain 36.2 percent $P_2O_5$; pebbles contain 32 percent | 5.5 |
| Sand, brown, clayey; contains gray, white, and brown phosphate nodules; pebble fraction abundant, and contains 29 percent $P_2O_5$ | 7.0 |
| Total Bone Valley formation | 17.0 |
| Miocene: | |
| Hawthorn formation (part): | |
| Clay, cream-tan to brown, calcareous, sandy, with black phosphate nodules containing 13.2 percent $P_2O_5$ | 5.0 |
| Bottom of drill hole in material too hard to penetrate—probably limestone or dolomite. | |

Because of poor exposures, the details of bedding in the lower unit of the Bone Valley formation could not be seen in the Plant City quadrangle; however, some of the logs suggest graded bedding. Graded bedding can be inferred from a lithologic log by Sellards (1915, p. 61), where phosphate sand (bed 2) is described as "grading below into a coarse conglomerate of phosphate pebbles." A lithologic log of drill hole D26 in sec. 33, T. 28 S., R. 22 E., also shows a possible sequence of graded bedding.

*Log of drill hole D26 in sec. 33, T. 28 S., R. 22 E.*

[Adapted from lithologic log by Louis Pavlides]

| | *Thickness (feet)* |
|---|---|
| Pleistocene: | |
| Terrace sands: | |
| Sand, loose, black in top foot, grading downward to gray, then red-brown (iron-stained) | 6.0 |
| Pliocene: | |
| Bone Valley formation: | |
| Upper unit: | |
| Sand, tan, slightly clayey; fragments of sand cemented by aluminum phosphate ("sandrock") | 9.5 |
| Lower unit: | |
| Sand, white, clayey; sand-sized white and tan phosphate nodules | 3.0 |
| Clay, green, stiff; minor amounts of sand of phosphate and quartz | 2.0 |
| Clay, gray-green, sandy; brown, tan, and white phosphate nodules that are coarse pebble size at base | 4.0 |
| Sand, brown to green, clayey; abundant brown and tan phosphate sand and pebbles; pebbles more abundant with depth | 7.5 |
| Total Bone Valley formation | 26.0 |
| Miocene: | |
| Hawthorn formation: | |
| Clay, green, to brown and red (iron-stained) at base, calcareous; minor amounts of medium-grained quartz and phosphate sand | 4.5 |
| Bottom of drill hole in rock too hard to penetrate with the hand auger—probably a limestone or dolomite of the Hawthorn formation. | |

The basal part of the lower unit of the Bone Valley formation is sand containing abundant coarse phosphate pebbles. The sand grades upward to a sandy clay, then to a clay. This may be a graded bedding set. The clay bed is overlain by a bed of clayey sand, which grades upward into slightly clayey leached sand of the upper unit. This is possibly the lower part of a second set of graded bedding.

### UPPER UNIT

The upper unit of the Bone Valley formation is uniform throughout the Plant City quadrangle and is a white, light-gray, gray, or tan clayey to slightly clayey sand. At the drill holes shown on figure 6, the upper unit is in contact with all the formations of the quadrangle, and the upper unit of the Bone Valley formation is uniform in lithology at all the drill holes. Phosphate nodules, present only at the base of the upper unit, are sparse, uniformly dull, soft, white, and leached. Aluminum phosphate cementing the sand is common, though generally not abundant in the unit. The upper unit of the Bone Valley formation has been thoroughly leached.

## PLEISTOCENE SERIES

### TERRACE SAND

Well-sorted quartz sand of Pleistocene age covers the entire quadrangle, except along the streams where it has been removed by recent erosion. The sand ranges in thickness from 0 feet along the streams to a maximum of about 100 feet in a sinkhole in sec. 21, T. 28 S., R. 21 E., the average thickness is about 8 feet. The sand is thin on the Hillsborough high and is thickest to the south and east, on the high terrace.

The contact between the unconsolidated terrace sand of Pleistocene age and the upper clayey sand unit of the Bone Valley formation, as seen in the mining pits to the south, is irregular in detail. The loose sand is in contact with all the formations from Oligocene to Pliocene age in the quadrangle; an erosional break prior to the deposition of the loose sand is therefore indicated.

MacNeil (1950) recognized four marine terraces of Pleistocene age between present sea level and an elevation of 150 feet. He regarded the high terrace, the dissected surface above 150 feet, as subaerial in origin. The terraces below 150 feet are marine, and MacNeil recognized shorelines at 150 feet (Okefenokee), at 100 feet (Wicomico), at 25–35 feet (Pamlico), and at 8–10 feet (Silver Bluff). According to MacNeil (1950), the highest shoreline is the oldest, the lowest shoreline is the youngest.

Terrace sand deposits of the Pamlico and Silver Bluff shorelines contain abundant invertebrate shells, but shells are not present in the deposits of the Okefenokee and Wicomico shorelines. The calcium carbonate shells of these two oldest terraces may have been removed by the acid ground waters which formed the aluminum phosphate zone.

The 100-foot contour (the approximate position of the Wicomico shoreline) extends diagonally across the center of the Plant City quadrangle from southwest to northeast, and only two small areas (one near Plant City, the other at the east edge of the quadrangle) are above 150 feet (fig. 2). The terrace deposits in the Plant City quadrangle, therefore, are of the Wicomico and Okefenokee stages. A very small area is underlain by deposits of the high terrace.

## RECENT SERIES

### RIVER PEBBLE DEPOSITS

Phosphate sand deposited in the streams, as bars, and on the flood plains forms the so-called river pebble deposits. Although deposits of this type have not been reported from the streams in the Plant City quadrangle, Blackwater, Itchepackesassa, and Pemberton Creeks drain phosphatic terranes, and probably river pebble deposits occur along these streams.

### OTHER RECENT DEPOSITS

Windblown sand and swamp deposits (muck and peat) are classified as Recent. The deposits are only a few feet thick and are very irregular in distribution.

## STRUCTURE

The Plant City quadrangle is a part of the Gulf Coastal Plain, and the structure is basically simple. The beds, except the Bone Valley formation and the terrace sand of Pleistocene age, dip very gently to the southeast, away from the Ocala uplift. The beds of the Bone Valley formation and the terrace sand of Pleistocene age seem to be dipping slightly to the north in the structure section (fig. 7). These beds are nearly flat and were deposited on an erosion surface that was inclined toward a paleostream in about the position of Blackwater Creek. This northward dip, therefore, is an initial dip and is not structural.

The general southeast dip is reversed by the Hillsborough high in the northern part of the quadrangle. Whether the crest of this high is a dome or small anticline is difficult to determine with the meager evidence available, but the strike seems to be northeastward, and the feature cannot be traced beyond the center of the north edge of the Plant City quadrangle. The structure is indicated by a slight steep-

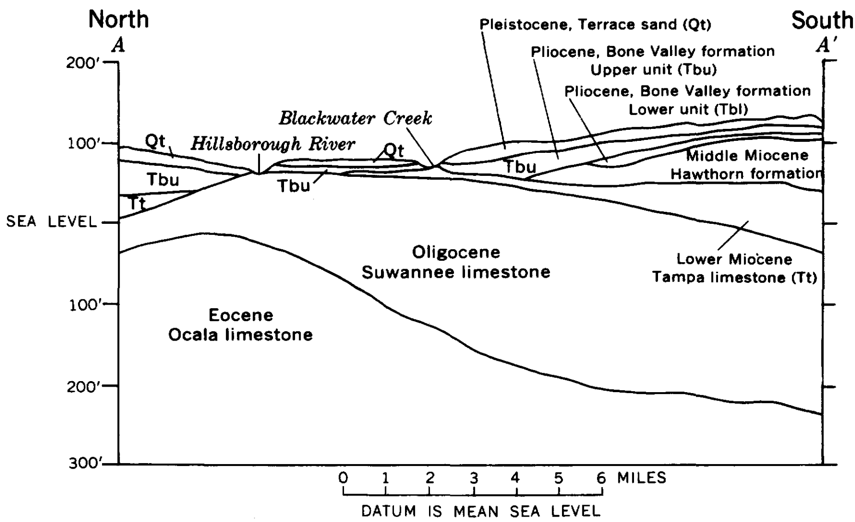



FIGURE 7.—Section, Plant City quadrangle, Florida, showing general structure. Data from logs of deep wells. Surface of Ocala limestone in part from Vernon (1951, pl. 2).

ening of the regional dip on the structure map by Vernon (1951, pl. 2).

The Suwannee limestone of Oligocene age thins northward over the crest of the structure (fig. 7). This thinning is in part due to erosion, but it may also reflect an original depositional thinning of the formation. The Tampa limestone and the Hawthorn formation are missing from the crest of the high, and both formations thicken to the north and south, away from the high.

The Hillsborough high was folded at the same time as the Ocala uplift. According to Vernon (1951, p. 62), movements that formed the Ocala uplift are early Miocene in age. Cooke and Mossom (1929) indicate that there was some movement in Oligocene time and again in early Miocene time.

The interpretation of figure 7 seems to substantiate the statements of Vernon and Cooke and Mossom. Movements that formed the high may have started prior to the deposition of the Suwannee limestone and were repeated prior to the deposition of the Tampa limestone in early Miocene time. Although the lower unit of the Bone Valley formation does not extend across the high, the upper unit is thin on the crest of the high, indicating that the high was a positive area during the deposition of the lower unit of the Bone Valley formation.

The Hillsborough River flows at or near the crest of the Hillsborough high. The position of the river in the Plant City quadrangle seems to be controlled by the high.

## GENESIS

Phosphate nodules, low in $P_2O_5$ content, are characteristic of the Hawthorn formation. The Hawthorn formation is an impure marine limestone that contains many broken fossils, abundant quartz sand and silt, and montmorillonite clay. The Hawthorn was deposited in relatively shallow water, at least above wave base, on the flank of the rising Hillsborough high. The phosphate nodules in the formation are clastic components—phosphate either replaced broken and rounded shell fragments or was precipitated from solution, forming nodules with sand or minute shell fragments as nuclei. Phosphate nodules in the carbonate rock of the Hawthorn formation are much too low in $P_2O_5$ content and are too sparse to be of economic value, but the nodules are the source for the economic phosphate in the "bed clay" residual from the limestone and for much of the economic phosphate in the lower unit of the Bone Valley formation.

Intense weathering has altered the rocks of the land-pebble phosphate district several times. Three or four cycles of weathering ranging in age from Miocene to Recent have directly affected the phosphatic rocks. The first period of weathering is of major importance in the concentration and enrichment of the phosphate nodules; the later periods of weathering changed the calcium phosphate minerals to aluminum phosphate minerals, forming the aluminum phosphate zone.

Earlier cycles of weathering and erosion, after the deposition of the Ocala limestone, the Suwannee limestone, and possibly the Tampa limestone, are recorded in the unconformities between the formations. Soil zones, if they were formed, were completely reworked into the next succeeding formation, and the reworking is reflected in the character of the rocks; each younger formation contains more sand and clay than the formation which underlies it.

The weathering of the Hawthorn formation in late Miocene time is recorded in the unconformity between the Hawthorn formation and the overlying Bone Valley formation of Pliocene age. The weathering was chemical as indicated by the formation of a residual calcareous clay (the bed clay) and by the formation of numerous sinkholes on the surface of the Hawthorn (pl. 2), now filled with phosphorite of the lower unit of the Bone Valley formation. Phosphate nodules in the limestone of the Hawthorn are sparse and are low in $P_2O_5$ content, but, locally, the bed clay contains abundant phosphate nodules that are high enough in $P_2O_5$ content to be minable. Thus, the phosphate nodules were enriched and were concentrated by removal of calcium carbonate in this period of weathering.

The lower phosphorite unit of the Bone Valley formation is marine, bedded, shows good graded bedding, and has a basal conglomerate of phosphate nodules, rounded phosphatized limestone boulders, and fossil bones and teeth at many places. The unit fills sinkholes and other irregularities on the Hawthorn surface and contains very abundant phosphate nodules that are high in $P_2O_5$ content. It is likely that the soft poorly consolidated calcareous clay (bed clay) was completely reworked into the lower unit of the Bone Valley formation, and in places the Bone Valley formation rests on hard limestone of the Hawthorn formation. Phosphate nodules were further concentrated and enriched in the Bone Valley sea, and relatively hard unweathered limestone fragments were phosphatized, rolled, rounded, and deposited with the basal conglomerate of the Bone Valley formation.

The Bone Valley formation was altered by intense lateritic weathering in the interval following its deposition and prior to the deposition of the Pleistocene sands. The alteration, by downward moving ground water, changed the relatively insoluble apatite (calcium phosphate) to wavellite (aluminum phosphate) in the upper part of the zone of alteration, and to millisite and crandallite (calcium aluminum phosphates) in the lower part of the zone. Montmorillonite, the dominant clay mineral in unaltered sections, was changed to kaolinite (Altschuler and others, 1956). Apatite is soluble in acid solutions, and the ground water at the present time has a pH of 5.0–5.5, as measured with hydrion paper. Kaolinite, the principal clay mineral in the zone of alteration, is the stable clay mineral in an acid environment (Grim, 1953). The leaching of montmorillonite to form kaolinite releases MgO (Cathcart, 1963) which may have altered the limestone of the Hawthorn formation to dolomite. The carbonate rock of the Hawthorn formation is dolomitic only near the surface; deep cores of the Hawthorn formation are limestone. The residual calcareous clay of the Hawthorn formation (the bed clay, part of which is minable) and of the Tampa limestone probably was formed in this weathering cycle, although in some areas the residual clay may be that formed in the late Miocene weathering.

The lateritic alteration is generally limited to the upper unit of the Bone Valley formation and to the top of the lower phosphorite unit, but aluminum phosphate minerals are found in the Hawthorn formation and the Tampa limestone where these formations are close to the surface.

The leaching was done by downward-moving acid ground waters in most of the quadrangle. Impermeable clay beds, however, caused the ground water to move laterally in some areas. Figure 8 is a section that shows the effects of both lateral and downward movement of ground water.

At hole 1 on figure 8, the lower unit of the Bone Valley is absent and the upper unit is leached to the top of the clay bed assigned to the Hawthorn. The clay is relatively impermeable, and leaching stopped at the upper surface of the clay.

At holes 2 and 3 leaching affected only the upper unit of the Bone Valley. The lower unit is present at both holes but contains fresh highly polished phosphate high in $P_2O_5$ content. The lower unit at holes 2 and 3 is very clayey. The acid ground water, therefore, probably moved laterally at the top of the lower unit, and leaching altered only the upper unit of the Bone Valley formation.

At hole 4, the upper unit is very thin. The unit is leached and, as at holes 2 and 3, is underlain by impervious clay containing fresh polished phosphate nodules high in $P_2O_5$ content. Underlying the clay unit is a thin (2.5-ft) bed of gray-white sandy clay containing fragments of aluminum phosphate cemented sand. The coarse fragments contain only 2.7 percent $P_2O_5$. This bed is thoroughly leached; no calcium phosphate nodules are left. Underlying this leached bed is a thick bed of phosphorite, with fresh shiny phosphate nodules containing 32.0 percent $P_2O_5$.

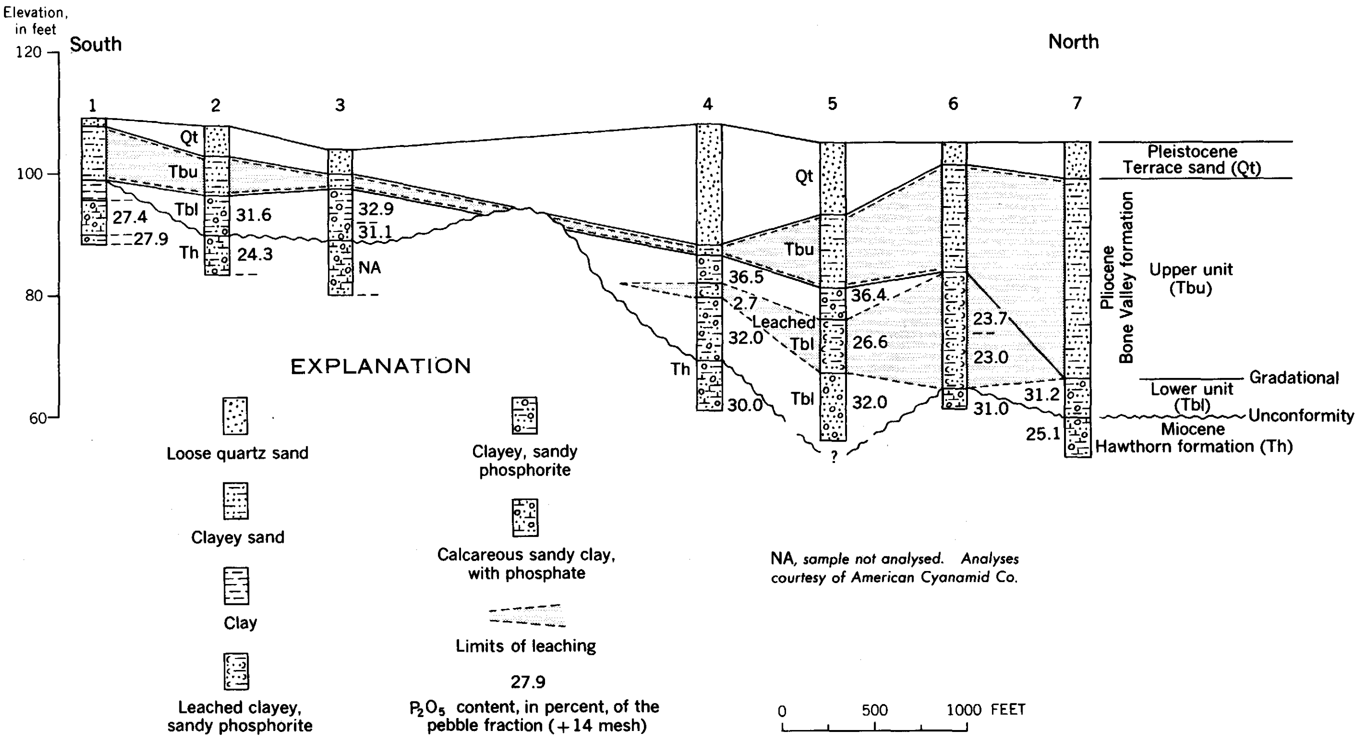



**FIGURE 8.**—Section showing zones of leaching within the Bone Valley formation. See plate 1 for location of section.

At hole 5, as at hole 4, the upper unit is leached, and in the lower unit a leached phosphorite bed is between beds of unleached phosphorite. The leached bed at hole 5 is thicker than at hole 4 and not as much $P_2O_5$ per unit volume has been removed.

At hole 6, all the upper and lower units of the Bone Valley formation are leached. The lower phosphorite is lithologically identical with the leached bed of phosphorite at hole 5 and contains phosphate nodules with comparable $P_2O_5$.

At hole 7, the thick upper unit of the Bone Valley formation is leached, but the thin rather deeply buried lower unit is fresh and unaltered.

The dashed line on figure 8 shows the approximate extent of leached material. The distribution of this material indicates that ground waters must have moved laterally through the lower unit of the Bone Valley formation.

Examples of leaching, and the formation of aluminum phosphate minerals in the Hawthorn formation are given in the drill-hole logs that follow.

*Log of drill hole D8 in sec. 31, T. 27 S., R. 22 E.*

[After Cathcart and McGreevy (1959)]

| | *Thickness (feet)* |
|---|---|
| Pleistocene: | |
| Terrace sand: | |
| Sand, gray, loose | 6 |
| Pliocene: | |
| Bone Valley formation (upper unit): | |
| Clay, brown, sandy, leached; coarse fraction contained 16.4 percent $P_2O_5$ and 0.84 percent CaO | 15 |
| Miocene: | |
| Hawthorn formation: | |
| Alternate beds of sandy clay and clayey sand; some aluminum phosphate cement. Analysis of a single bed in this unit showed the pebble fraction contained 18.5 percent $P_2O_5$ and 0.10 percent CaO | 30 |
| Tampa limestone: | |
| Sand, clayey, fine-grained calcareous | 27 |
| Limestone, traces clay and sand, fossiliferous | 3 |
| Part of the Tampa limestone | 30 |
| Bottom of drill hole. | |

The two analyses shown on log D8 are of aluminum phosphate minerals. Only one bed from the Hawthorn formation was analyzed, but the entire unit probably is leached. In addition to the analyses shown on log D8, the slime (−150 mesh) fraction of the top bed of the Tampa limestone was analyzed and contained 0.55 percent $P_2O_5$

and 0.50 percent CaO. The phosphate mineral in this bed of the Tampa is probably apatite (calcium phosphate), indicating that leaching did not extend into the Tampa limestone.

*Log of drill hole D30 in sec. 25, T. 27 S., R. 22 E.*

[Analyses by American Cyanamid Co. chemists]

| | *Thickness (feet)* |
|---|---|
| Pleistocene: | |
| Terrace sands: | |
| Sand, loose, gray | 2.0 |
| Miocene: | |
| Hawthorn formation: | |
| Clay, white, sandy; includes leached dull white phosphate nodules containing 7 percent $P_2O_5$ | 5.0 |
| Clay, brown, sandy; includes fresh phosphate nodules containing 20 percent $P_2O_5$ | 3.0 |
| Clay, gray-white, sandy; includes leached dull-white phosphate nodules containing 5.5 percent $P_2O_5$ | 5.0 |
| Clay, yellow-white, calcareous; includes fresh brown and black phosphate nodules containing 21 percent $P_2O_5$ | 3.5 |
| Total Hawthorn formation | 16.5 |

Hole D30 bottomed in buff calcareous clay (bed clay), with traces of phosphate nodules, possibly referable to the Tampa limestone. Alternate beds in the Hawthorn formation are leached, and the unleached beds probably are lenticular like most of the beds in the Hawthorn formation. The leaching of the middle bed in the Hawthorn probably is due to the lateral movement of acid ground waters.

An example of leaching extending into the Tampa is shown in the log of drill hole D31.

*Log of drill hole D31 in sec. 1, T. 26 S., R. 22 E.*

[After Cathcart and McGreevy (1959)]

| | *Thickness (feet)* |
|---|---|
| Pleistocene: | |
| Terrace sand: | |
| Sand, gray, loose | 4.0 |
| Pliocene: | |
| Bone Valley formation (upper unit): | |
| Sand, brown and gray, clayey, medium-grained | 3.0 |
| Miocene: | |
| Tampa limestone: | |
| Clay, sandy, and fine grained clayey sand; contains siliceous concretions | 10.0 |
| Oligocene: | |
| Suwannee limestone (part): | |
| Limestone, white, soft, fossiliferous | 9.0 |

Bottom of drill hole in soft white limestone.

Although no samples from this drill hole were analyzed, the gamma-ray log of the drill hole showed a sharp rise in radioactivity in the interval from 9 to 12 feet below the surface. No visible phosphate minerals are present, and this rise probably represents the rise found in the aluminum phosphate zone in other parts of the district. The rise comes well within the Tampa, which is very close to the surface at this locality.

A ground-water podsol, of which the Leon soil is an example, overlies or extends down into the aluminum phosphate zone. A typical Leon soil profile (Fowler and others, 1927, p. 27) has fine-grained, light-gray sand, 18 to 24 inches thick at the surface. The top half foot of this zone contains enough finely divided organic material to color the sand a dark-gray or black. Underlying the surface layer is a brown, dark-brown, or black "hardpan" layer about one-half foot thick. This grades downward through 6 to 8 inches of loose brown sand into a gray or white sand. According to Hunt and Hunt (1957, p. 799) this soil is younger than the aluminum phosphate zone and formed above distinctive archeological remains that do not contain pottery. The youngest soil in the area formed on deposits containing pottery, introduced shortly before the beginning of the Christian era.

The acid water that formed these two soil zones probably continued the lateritic leaching of the phosphate deposits.

## ECONOMIC GEOLOGY

Phosphate rock is the only important economic mineral product in the Plant City quadrangle. Mining in the area was carried on at Coronet's Upper property between 1913 and late in the 1920's.

The Suwannee limestone has been quarried from pits in the northern part of the quadrangle for use as road metal. The Suwannee limestone is at, or close to, the surface through much of the northwestern part of the quadrangle. Although generally a pure limestone, exposures in this area contain abundant chert, much of which is concentrated at the surface of the formation. Drilling (see log D7, p. D13) showed relatively pure limestone underlying a thin chert bed, and drilling elsewhere in the northwestern part of the quadrangle may reveal limestone that could be used for agriculture.

The factors involved in deciding on the economic value of phosphate deposits have been discussed previously (Cathcart and McGreevy, 1959; Cathcart, 1963). To briefly recapitulate: phosphate nodules should contain more than 66 percent BPL; the amount of recoverable phosphate should exceed 400 long tons per acre-foot; the iron and alumina content should be less than 5 percent; and the ratio of cubic yards of material moved to obtain 1 ton of product should be less than about 25. The thickness of the economic calcium phosphate zone (the matrix) should be greater than about 3 feet.

The thickness of the overburden must be less than a certain maximum. This is calculated as a part of the ratio of cubic yards of rock moved per ton of product recovered. The thickness of the overburden is shown on plate 3. The overburden is all the material from the surface to the top of the economic phosphate deposit. It includes loose sand of Pleistocene age, clayey sand of the upper unit of the Bone Valley formation, and the aluminum phosphate zone. The thickest overburden fills a sinkhole east of Plant City, where it exceeds 110 feet. A sinkhole north of Plant City is filled to a depth of about 50 feet with overburden, and one area on the ridge at the east edge of the quadrangle is underlain by about 60 feet of overburden. The overburden is less than 10 feet thick in the stream beds.

The phosphate deposits in the quadrangle have been divided into the calcium phosphate zone (which includes the economic deposits) and the aluminum phosphate zone (currently discarded with the overburden, but a potentially economic deposit).

## CALCIUM PHOSPHATE ZONE

### LITHOLOGIC CHARACTER

The calcium phosphate zone consists of unconsolidated sedimentary rocks, sand, clay, and sandy clay and is characterized by abundant rounded nodules of calcium phosphate (carbonate fluorapatite). The zone is not a stratigraphic unit and generally includes phosphorite of the lower part of the Bone Valley; it also includes residual phosphorite of the Hawthorn formation and, in some places, of the Tampa limestone. The variation in stratigraphic position of the calcium phosphate zone is shown on figure 9. The calcium phosphate zone was penetrated by all drill holes in the cross section, except hole 11, where clayey sand of the upper unit of the Bone Valley rests directly on limestone assigned to the Hawthorn.

The calcium phosphate zone coincides with the lower unit of the Bone Valley formation only at hole 8. The zone consists of phosphorite of the Bone Valley and phosphorite of the Hawthorn formation at holes 1, 3, 5, 6, 9, and 10. At hole 4, the calcium phosphate zone is entirely in the Hawthorn formation; at hole 7, the zone consists of rocks of Hawthorn and Tampa ages; and at hole 2, the zone includes the Bone Valley, the Hawthorn formation, and the upper beds of the Tampa limestone.

The calcium phosphate zone, at the drill-hole localities shown on figure 9, ranges in thickness from 0 to more than 48 feet, and most of the variation in thickness is in the phosphorite of the lower part of

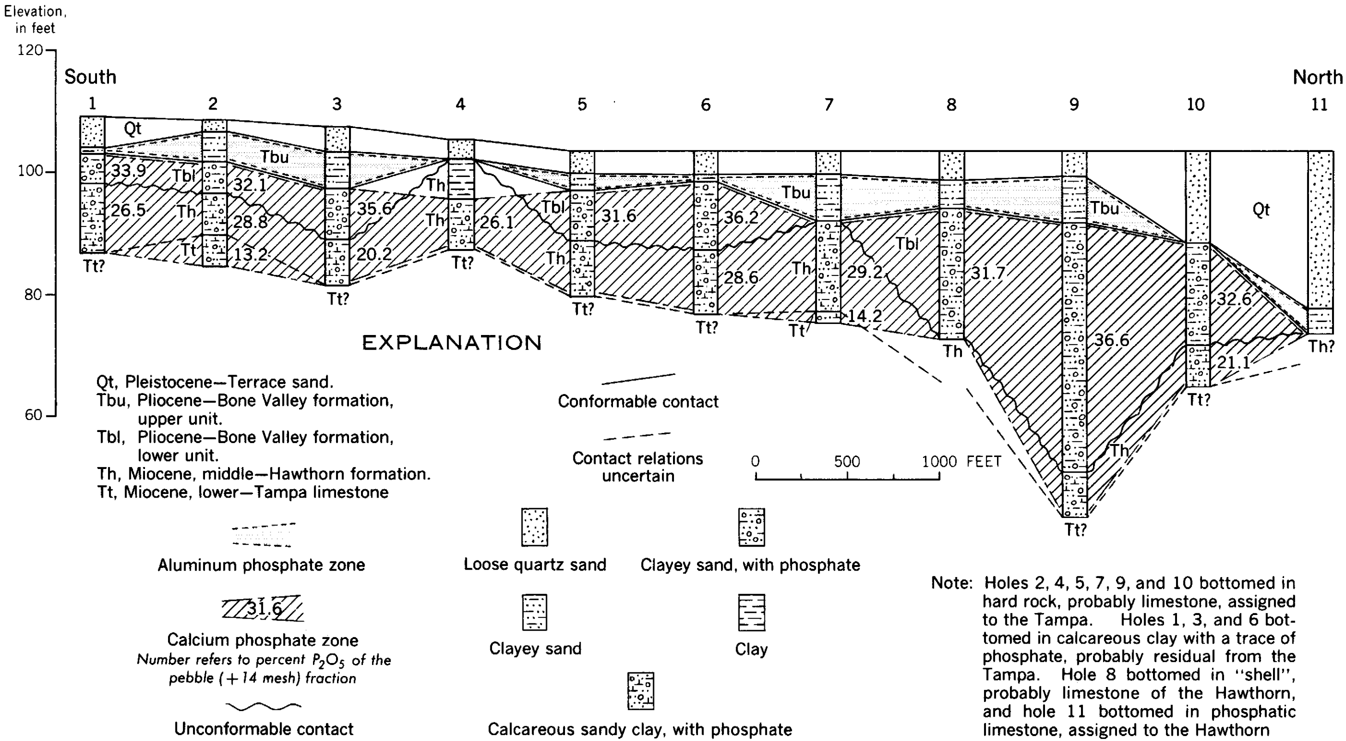



**FIGURE 9.—Section showing variation in stratigraphic position of the calcium phosphate zone. See plate 1 for location of section.**

the Bone Valley. Phosphorite of the Tampa limestone was penetrated only by hole 2, where it is 5 feet thick, and at hole 7, where it is 1.5 feet thick. Phosphorite of the Hawthorn formation was cored at all drill holes except hole 8, which was abandoned in what the driller described as "shell"—probably limestone of the Hawthorn formation, and hole 11, which was abandoned in hard limestone assigned to the Hawthorn. Where present, the phosphorite in the Hawthorn is relatively uniform in thickness, ranging from 7 to 15 feet and averaging 9 feet. Phosphorite of the lower part of the Bone Valley was cored at holes 1, 2, 3, 5, 6, 8, 9, and 10; it ranges in thickness from 5 to 41.5 feet and averages 15 feet. The phosphorite of the Bone Valley is absent from highs on the Hawthorn, as at holes 4 and 7, and fills depressions on the Hawthorn surface, as at holes 8, 9 and 10.

The calcium phosphate zone is not equivalent to the matrix (the economic phosphate deposit.) The upper part of the zone may contain too little phosphate that is too low in $P_2O_5$ content to be minable, especially where the upper part of the unit has been partially leached. (See fig. 8, hole 6.) Nodules in the lower part of the zone, particularly in the Tampa or Hawthorn formations, may be too low in $P_2O_5$ content to be of economic value. Nodules in the Tampa limestone (fig. 9) contain only 13.2 to 14.2 percent $P_2O_5$, much too low to be minable. Nodules in the Hawthorn formation range from 20.2 to 29.2 percent $P_2O_5$, but even this is too low to be of economic value. Bone Valley phosphate nodules, however, range from 31.2 to 36.6 percent $P_2O_5$, only slightly higher than the $P_2O_5$ content of the phosphate nodules in the Hawthorn, but within the limits of economic value. This section (fig. 9) is a particularly good illustration of the difference in phosphate content of nodules in the Tampa, Hawthorn, and Bone Valley formations.

In addition to being of low grade, the lower parts of the calcium phosphate zone, particularly that part that is residual from the Hawthorn, may contain too low a percentage of recoverable nodules to be of economic value. For example, the phosphate beds of the calcium phosphate zone assigned to the Hawthorn in the area of the cross section (fig. 9) contain about 50 tons of recoverable phosphate nodules per acre-foot. The overlying Bone Valley formation, however, contains about 150 tons per acre-foot—a threefold greater concentration.

Variations in the $P_2O_5$ content and tonnages of coarse phosphate nodules (the pebble fraction) in the Bone Valley and Hawthorn formations and in the Tampa limestone are summarized on table 1. The $P_2O_5$ content of nodules is different in the three formations, but there is an overlap in the range of the $P_2O_5$ content of nodules between the Bone Valley and Hawthorn and between the Hawthorn and Tampa but not between the Bone Valley and the Tampa. In fact, the highest reported phosphate content of Tampa nodules is only half as large as the lowest reported phosphate content of Bone Valley nodules (table 1).

The amount of phosphate nodules (expressed as tons per acre-foot) also is varied but not as regularly as the phosphate content of the nodules. The average concentration of phosphate nodules in the Bone Valley and Hawthorn formations is only about half of the average concentration of nodules in these formations in the rest of the land-pebble district. The figures for the Tampa limestone (table 1) are probably of the right order of magnitude but are based on so few samples that they may not represent the true average of concentration of nodules in the formation.

Although individual beds within the calcium phosphate zone may range in composition from nearly pure clay to quartz or phosphate sand or conglomerate, most of the beds in the zone are clayey sand or sandy clay, and the average calcium phosphate zone, as mined, contains about equal amounts of recoverable phosphate nodules, quartz sand, and slime (−150 mesh material).

### DISTRIBUTION AND THICKNESS

The calcium phosphate zone ranges in thickness from 0 to 50 feet. In only a few small areas throughout most of its extent in the Plant City quadrangle is the calcium phosphate zone more than 10 feet thick (pl. 4). Two areas to the north of Plant City are underlain by more than 40 feet of calcium phosphate zone. In these areas, phosphorite (mostly referable to the Bone Valley formation) fills sinkholes on the Hawthorn surface. Except in the southern third of the quadrangle, prospecting has not been extensive enough for discovery of all of the sink holes which may be present.

The hachured line on plate 4 shows the northern limits of the lower phosphorite unit of the Bone Valley formation. This line probably delimits the calcium phosphate deposits of economic value. The calcium phosphate zone is thickest and most persistent in the southern third of the quadrangle, where both the lower unit of the Bone Valley and Hawthorn are present.

The Hawthorn formation is not present north of the heavy solid line (pl. 4). A part of the calcium phosphate zone, containing minor tonnages of nodules of phosphate low in $P_2O_5$ content, is known to be present in the area between the two lines, but it is nowhere greater than 10 feet thick and, therefore, is not shown by the contour lines. For example, in sec. 25, T. 27 S., R. 22 E., north of Blackwater Creek, 3.5 feet of calcium phosphate zone is present. A hole drilled south of the creek in the same section did not intersect any calcium phosphate.

The drill hole north of Blackwater Creek penetrated 16.5 feet of phosphatic beds associated with the Hawthorn formation (see log of drill hole D30, p. D35) under 2 feet of loose sand of Pleistocene age. The top 13 feet of phosphatic material consists of three beds: a 5-foot bed of leached rock, a 3-foot bed of unleached rock, and a 5-foot bed of thoroughly leached rock. The entire 13 feet would be considered aluminum phosphate zone, because it would not be possible to differentiate the 3-foot bed of unleached material. Thus, only the basal 3.5 feet of the phosphate rock could be considered as calcium phosphate zone. The phosphate particles in this 3.5 feet contain too little $P_2O_5$ to be of economic importance.

## MINERALOGY

The calcium phosphate zone consists of phosphate nodules, quartz sand, clay, and a trace of the "heavy" minerals, principally ilmenite, zircon, rutile, garnet, and tourmaline. The dominant clay mineral is montmorillonite, but some kaolinite is present everywhere. The phosphate nodules consist of the phosphate mineral carbonate-fluorapatite (Altschuler, Cisney, and Barlow, 1952), enclosing grains of silt-sized quartz, and smaller nodules of phosphate, clay, and calcite. The nodules are generally structureless; some have a darker rim that is higher in phosphate content. Most of the coarse nodules are limestone, partially replaced by apatite. Some secondary vivianite (iron phosphate) has been reported from drill cuttings taken near Plant City.

## COMPOSITION OF THE PHOSPHATE NODULES

Phosphate nodules are separated by washing, screening, and flotation into two sizes—pebble (+14 mesh) and concentrate (−14+150 mesh). In general, the pebble fraction contains less $P_2O_5$, more acid-insoluble material, and more CaO than the concentrate fraction. The content of iron oxide and aluminum oxide (reported as "percent I and A") is consistently between 2 and 4 percent in both the pebble and concentrate fractions; no significant differences have been observed.

Analytical data for phosphate nodules from the Plant City quadrangle are sparse, except for $P_2O_5$ analyses and a few analyses for uranium. Though, as a consequence, generalizations are hard to make, the data available in the Plant City quadrangle are consistent with the generalizations made in the report on the Keysville quadrangle (Cathcart, 1963).

Briefly, these generalizations are as follows: (1) Fluorine content of the nodules varies directly with the $P_2O_5$ content, and is generally about one-tenth of the phosphate content. (2) $CaCO_3$ content is higher in phosphate nodules from the limestone of the Hawthorn formation than in nodules from the Bone Valley formation; evidence in the Plant City quadrangle indicates that nodules from the Tampa limestone contain more $CaCO_3$ than nodules from the Hawthorn formation. (3) The $P_2O_5$ content of the nodules is low where the nodules are at or near one of the present streams. (4) In the recoverable phosphate products, the $P_2O_5$ content is highest in the smallest nodules and decreases with increasing nodule size. (5) About one-third of the phosphate content of the calcium phosphate zone is in the slime fraction and is lost in processing.

### URANIUM CONTENT

Although only a few samples were analyzed for uranium, they follow the general pattern established in the land-pebble phosphate district. In general, the quartz sand of the calcium phosphate zone contains little or no uranium. The slime fraction of the zone generally contains small amounts of uranium. Some samples, however, are high in uranium content, and they are also high in $P_2O_5$ content. In general, uranium is concentrated in the recoverable phosphate fractions and is higher in the +14 mesh, or pebble fraction, than in the −14+150 mesh, or concentrate fraction.

Plate 5 shows the distribution of uranium in the pebble and concentrate fractions of the calcium phosphate zone. The lines of equal uranium content in both fractions are similar to topographic contour lines; they are deeply indented headward along the present streams, and form small closed contours in the interstream divides.

The isopleth contours for both the pebble and concentrate fractions coincide closely. Areas along the main streams are underlain by pebble- and concentrate-sized nodules that contain less than 0.010 percent uranium, and the areas on the interstream divides, which are underlain by pebble that is high in uranium content, also are the source of concentrate that is high in uranium content. Although the highs coincide, the amount of uranium in the pebble fraction generally exceeds the amount in the concentrate fraction; thus, in sec. 36, T. 28 S., R. 21 E., the pebble fraction contains a maximum in excess of 0.025 percent uranium, whereas the concentrate fraction contains only 0.015 percent uranium.

The decrease in uranium content of both the pebble and concentrate fractions toward the streams is probably due to leaching of uranium from the apatite of the phosphate nodules by acid ground waters. This type of leaching has been demonstrated by Altschuler and others (1958, p. 59). Findings of the writer and P. F. Fix of the U.S. Geological Survey indicate that streams that drain phosphatic terranes contain anomalous amounts of uranium in solution, whereas, streams that drain limestone terranes do not contain uranium.

The $P_2O_5$ content of the phosphate nodules decreases toward the stream in the same way that the uranium content decreases. Odum (1953) has stated that streams draining phosphatic terranes in Florida contain high amounts of phosphorus in solution. He also states that the pH of the waters apparently is a controlling factor in the leaching of phosphorus. Alkaline streams do not contain much phosphorus; acid streams are high in phosphorus.

Uranium and phosphorus are closely allied in the phosphate nodules (Altschuler and others, 1958). It is probable that the leaching by acid ground water released both uranium and phosphorus, and the pH of the water, as suggested by Odum, is a controlling factor in the leaching of the phosphate nodules.

## ALUMINUM PHOSPHATE ZONE

### LITHOLOGIC CHARACTER

The aluminum phosphate zone is characterized by the presence of the aluminum phosphate mineral wavellite and the calcium aluminum phosphate minerals crandallite and millisite. The zone is white or gray, friable, and highly porous and may have a vesicular texture. The zone was formed by weathering and the downward movement of acid ground water. The zone thus shows progressive downward changes in mineralogy. The top of the zone is characterized by wavellite, with kaolinite as the principal clay mineral; the middle by crandallite and millisite, with kaolinite and some montmorillonite; and the bottom of the zone by slightly leached carbonate-fluorapatite, with montmorillonite as the dominant clay mineral (Altschuler and others, 1956). A detailed section showing the changes in mineralogy is given in the paper on the Keysville quadrangle (Cathcart, 1963).

The textural characteristics of the aluminum phosphate zone are influenced by the original textures of the material from which the zone was formed. For example, where only the clayey sand of the upper unit of the Bone Valley formation is altered, the aluminum phosphate zone is a massive white clayey sand, with the aluminum phosphate minerals concentrated in the clay fraction and possibly with some secondary cementation of quartz sand. The cementing results in lumps or fragments of "sandrock." Where the pebbly lower phosphorite of the Bone Valley has been altered, a very coarse vesicular texture may result. The changes are either the result of phosphatization of clay, of aluminum alteration of apatite, or both (Altschuler and others, 1956).

The aluminum phosphate zone, like the calcium phosphate zone, is not limited stratigraphically but cuts across strata. The relations of the zone are illustrated in figure 10.

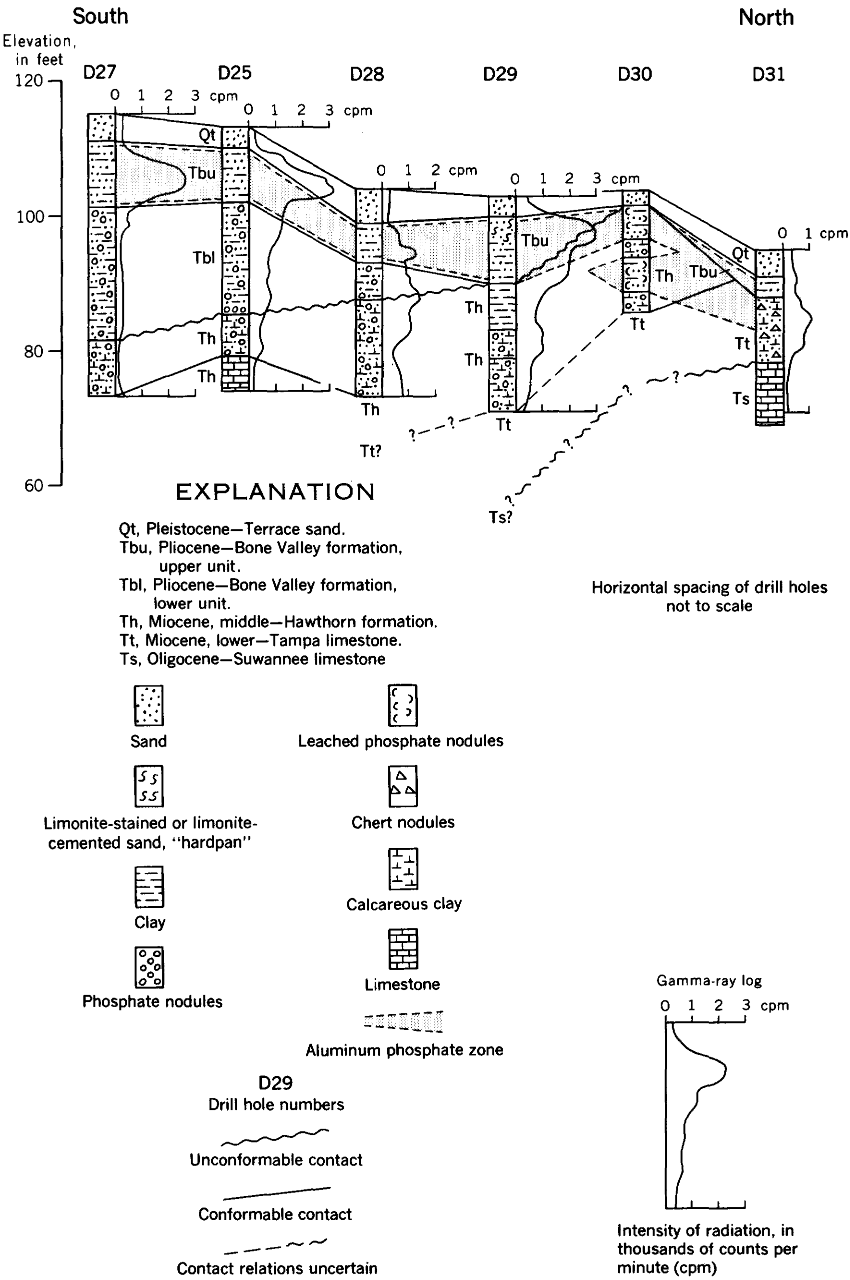



FIGURE 10.—Section showing relations of the aluminum phosphate zone. See plate 1 for location of drill holes.

The aluminum phosphate zone is within the upper unit of the Bone Valley formation at holes D27, D25, D28, and D29 (fig. 10). At hole D29, the highest radioactivity is in the hardpan, an example of the superposition of the Leon soil profile on the aluminum phosphate zone. The lower unit of the Bone Valley thins markedly to the north and is absent at hole D29. At hole D30, both the upper and the lower units of the Bone Valley formation are absent, and phosphorite of the Hawthorn is leached. At this hole, two leached beds are separated by a thin bed that has not been leached. The lower leached bed must have been formed by lateral movement of the acid ground waters. At hole D31, the upper unit of the Bone Valley formation and the top part of a bed of clay assigned to the Tampa limestone form the aluminum phosphate zone. The section also shows how the base of the aluminum phosphate zone follows the surface topography.

### DISTRIBUTION AND THICKNESS

The aluminum phosphate zone ranges in thickness from 0 to about 20 feet and probably averages about 5 feet. The zone is thin or absent along the streams and is thickest on the interstream divides (pl. 6). The aluminum phosphate zone extends beyond the limits of the calcium phosphate zone, and the northern limits are not known. The zone probably does not contain deposits of economic value north of the Hillsborough River, although clayey sand of the upper unit of the Bone Valley formation is known to be present in this area. The upper unit of the Bone Valley formation in this area may have contained so little phosphate that leaching did not form abundant aluminum phosphate minerals. Thus, although the clayey sand may be leached, it is not a part of the aluminum phosphate zone.

### CHEMICAL COMPOSITION

Only a few samples of the aluminum phosphate zone taken from drill holes in the Plant City quadrangle have been analyzed. A few uranium assays and some gamma-ray logs were used to make the map of uranium distribution (pl. 7).

The uranium content of the aluminum phosphate zone ranges from less than 0.005 percent to more than 0.020 percent and probably averages about 0.012 percent. A comparison of plates 6 and 7 indicates that, in a general way, the highest uranium contents are in the thicker parts of the zone. This equivalence is, in part, due to the fact that the thinnest and lowest grade areas are along the streams where erosion and leaching of uranium from the zone by acid ground waters are most effective.

The chemical composition of the aluminum phosphate zone and the relation of uranium content to the other elements of the zone have been discussed previously (Altschuler and others, 1956; Cathcart, 1963). Data from the Plant City quadrangle are insufficient to add any new generalizations, but they seem to confirm those already made. Briefly, these generalizations are as follows:

1. Uranium is associated with the phosphate minerals, particularly apatite. In the normal profile of leaching, the uranium content increases downward, reaching a maximum at the base of the zone in the soft white phosphate, a partially leached material, where uranium contents of the order of magnitude of 0.X percent have been found.
2. Uranium shows a direct correlation with $P_2O_5$, F, and CaO—all elements of the apatite mineral—and little or no correlation with $Fe_2O_3$ or $Al_2O_3$. Uranium and silica show a strong inverse correlation.
3. Uranium and phosphate are concentrated in the slime (−150 mesh) fraction. The pebble (+14 mesh) fraction, generally present only in small amounts, commonly consists of lumps of aluminum phosphate cemented sand, and is low in uranium and phosphate. However, where the pebble fraction consists of apatite, softened and whitened by leaching, both uranium and phosphate may be high.
4. The slime fraction of the aluminum phosphate zone contains about two-thirds of the uranium and phosphate content in about one-third of the total volume of the rock.

### ECONOMIC VALUE

At the present time, the aluminum phosphate zone is discarded with the overburden, and no attempt is made to segregate the material. Several millions of tons of the material are mined each year in the land-pebble district, and the material averages about 6 percent $P_2O_5$.

An appreciable tonnage of $P_2O_5$ (probably in excess of one-half a million tons) is therefore discarded each year.

Both phosphate and uranium are concentrated in the slime fraction of the aluminum phosphate zone; and a sand-slime separation would result in the recovery, in the slime fraction, of about two-thirds of the uranium and phosphate of the total sample in about one-third of the original volume—a consequent three-fold enrichment of the uranium and phosphate content. A sand-slime separation can easily be made on the material of the aluminum phosphate zone, but a method of handling the very dilute slurry that results from the sand-slime separation must be devised before the process can be made economically feasible.

The Tennessee Valley Authority has worked out a process that involves the use of all the material. The rock is calcined, acidulated to recover both phosphate and uranium, and nitrogen and potash are added to make a complete fertilizer (Hignett and others, 1957). A demonstration plant for producing fertilizers from the aluminum phosphate zone was operated intermittently in 1959 at Wilson Dam, Ala., by the Tennessee Valley Authority (J. H. Walthall, written communication, 1960). Alumina is not recovered in this process. About half of the total alumina in the raw material is present in the product, probably as aluminum phosphate minerals.

## TONNAGE CALCULATIONS

### CALCIUM PHOSPHATE ZONE

Only about 22 percent of the total area of the Plant City quadrangle (about 35,000 acres) is underlain by the lower phosphorite unit of the Bone Valley formation. An additional 20 percent (30,000 acres) is underlain by the Hawthorn formation and may contain some calcium phosphate. Only the part of the quadrangle underlain by the lower phosphorite unit of the Bone Valley formation can be considered to be of possible economic value. About 9,000 acres of the area underlain by phosphorite in the Bone Valley has been prospected by drilling. The total tonnage of recoverable phosphate in this area is 12.3 million long tons of the pebble fraction and 17.9 million long tons of the concentrate fraction. The prospected area is about one-fourth of the area underlain by possibly minable calcium phosphate zone. Thus, very conservatively, there could be an additional 20 million long tons of recoverable phosphate in the quadrangle. Total reserves of recoverable phosphate in the Plant City quadrangle are about 50 million long tons with a phosphate content in excess of 65 percent BPL.

The uranium content of the pebble fraction averages about 0.017 percent; that of the concentrate averages 0.015 percent uranium. The pebble average is based on samples from 264 drill holes, the concentrate from 164. The pebble fraction thus contains about 2,090 long tons of uranium, and the concentrate fraction about 2,690 long tons. The 20 million long tons of inferred reserves would contain 3,200 tons of uranium, if the phosphate has the same uranium content as the analyzed material.

### ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone underlies about 45,000 acres in the Plant City quadrangle (pl. 6). The average thickness of the zone is about 5 feet, and the average uranium content is about 0.012 percent. The phosphate content is not known, but it should be about the same as the content in other areas—about 6 percent $P_2O_5$.

A bed, 1 foot thick, contains 1,613 cubic yards per acre (Cathcart and McGreevy, 1959), and the thickness, in feet, times 1,600 equals the total cubic yards per acre. Therefore, with an average thickness of 5 feet, the aluminum phosphate zone represents 8,000 cubic yards per acre. If half of the area that is underlain by the aluminum phosphate zone is minable, 180 million cubic yards of material is present in the quadrangle. The approximate average weight of aluminum phosphate zone material is 1.088 long tons per cubic yard, and 185 million long tons of material is present in the quadrangle. This tonnage of aluminum phosphate zone contains 11 million long tons of $P_2O_5$ and almost 22,000 tons of uranium, if the average $P_2O_5$ content is 6 percent and the average uranium content is 0.012 percent.

#### PHOSPHATE RESOURCES OF THE HAWTHORN FORMATION

The Hawthorn formation underlies about 65,000 acres in the Plant City quadrangle. The formation may average about 50 tons of phosphate nodules per acre-foot, and the formation averages about 20 feet in thickness; therefore, a total of about 1,000 tons per acre of phosphate may be present. This phosphate will probably average less than 50 percent BPL. The total phosphate resource of the Hawthorn formation is about 65 million tons. The material is much too low in both BPL content and tons per acre-foot and, except at the north end of the area underlain by the formation, is much too deep to be minable under present conditions.

## MINE AND TRACT DESCRIPTIONS

### CORONET MINE

The Coronet or Upper mine of the Coronet Phosphate Co. is in secs. 26, 27, 34, 35, and 36, T. 28 S., R. 22 E., in the south-central part of the Plant City quadrangle (pl. 1). The area was prospected by the company prior to 1913, the date on the completed prospect map. Mining started about 1913 and continued until the late 1920's. Processing in the plant was for the coarse grains of phosphate (pebble) only; fine grains were discarded, but the washer debris containing the flotation-sized phosphate was kept separated from the overburden; and this material therefore can be mined again. Mining was by hydraulic methods, resulting in small rectangular lakes and low rolling hills of debris.

The area has no exposures, either natural or manmade, and no logs of the drilling are available. However, Sellards (1915, p. 61) has a lithologic section taken at the mine. The stratigraphic interpretations are taken partly from Sellards and are partly the writer's responsibility.

*Section at the Coronet mine, southeast of Plant City (probably in sec. 34, T. 28 S., R. 22 E.)*

[Adapted from Sellards (1915, p. 61)]

| | *Thickness (feet)* |
|---|---|
| Pleistocene: | |
| Terrace sands: | |
| Sand, pale-yellow, incoherent | 4.0 |
| Pliocene: | |
| Bone Valley formation: | |
| Upper unit: | |
| Sand, gray, indurated. Aluminum phosphate zone(?) | 4.0 |
| Lower unit: | |
| Conglomerate of phosphate pebble, bone fragments, waterworn flint and pebbles | 1.5 |
| Clay, buff-yellow and olive-green, with phosphate pebble | 2.0–5.0 |
| Miocene: | |
| Hawthorn formation | .1 |

Yellow clay and marl bedrock. At bottom of pit.

The contact between the buff-yellow clay and the conglomerate in the lower unit of the Bone Valley formation is an unconformity, but Sellards (1915, p. 62) indicates that it is local; he points out that the contact between the yellow clay at the bottom of the Bone Valley and the "bedrock" is present over the entire land-pebble district and that the irregular surface is due to erosion on the Hawthorn formation before deposition of the Bone Valley. The upper unit of the Bone Valley formation is an indurated gray sand; the induration may be due to secondary aluminum phosphate cement.

The contour map of the surface of the Hawthorn (pl. 2) is generally a flat surface with little overall relief, except that the area is covered with small nearly circular depressions and knobs—a typical karst topography. The calcium phosphate zone (pl. 3) ranges in thickness from 0 to 17 feet and averages about 5 feet. The map of the calcium phosphate zone is a series of nearly circular thick and thin areas (pl. 3). A comparison of plate 3 with plate 2 shows that the thick calcium phosphate zone generally fills low areas on the Hawthorn surface and that thin areas of calcium phosphate zone overlie highs on this surface. The overburden ranges in thickness from about 3 feet to more than 40 feet and has no general relation to the other maps, except that the thin areas of overburden are along streams.

## KNIGHTS TRACT

The Knights tract, in secs. 4, 5, 8, 9, 16, and 17, T. 28 S., R. 22 E., was prospected by the American Cyanamid Co. Two holes were core drilled by the U.S. Geological Survey in 1953—one at the north end of the area and the other at the south end. The stratigraphic interpretations of the company drill holes are based on correlation with the two cored holes. Chemical analyses of the phosphate nodules, made by the company, have been used in interpreting the stratigraphy.

The deposit has not been mined and, except for loose sands of Pleistocene age, there are no exposures in the area.

The area is on the north fringe of the land-pebble phosphate district, and the detailed contour and isopach maps show the form and distribution of phosphate deposits (figs. 11, 12, 13, and 14).

The map of the surface of the Hawthorn formation (fig. 11) is the surface on which the lower phosphorite of the Bone Valley formation was deposited. This map shows a modified karst topography with a southeastward-trending ridge extending from the SE¼ sec. 5 to the NE¼ sec. 16. The ridge splits at the northwest corner of sec. 9, and the western prong of the ridge extends to about the center of sec. 8. A small trough heads in the SE¼ sec. 5 and extends to the southwest to about the center of the west edge of sec. 8.

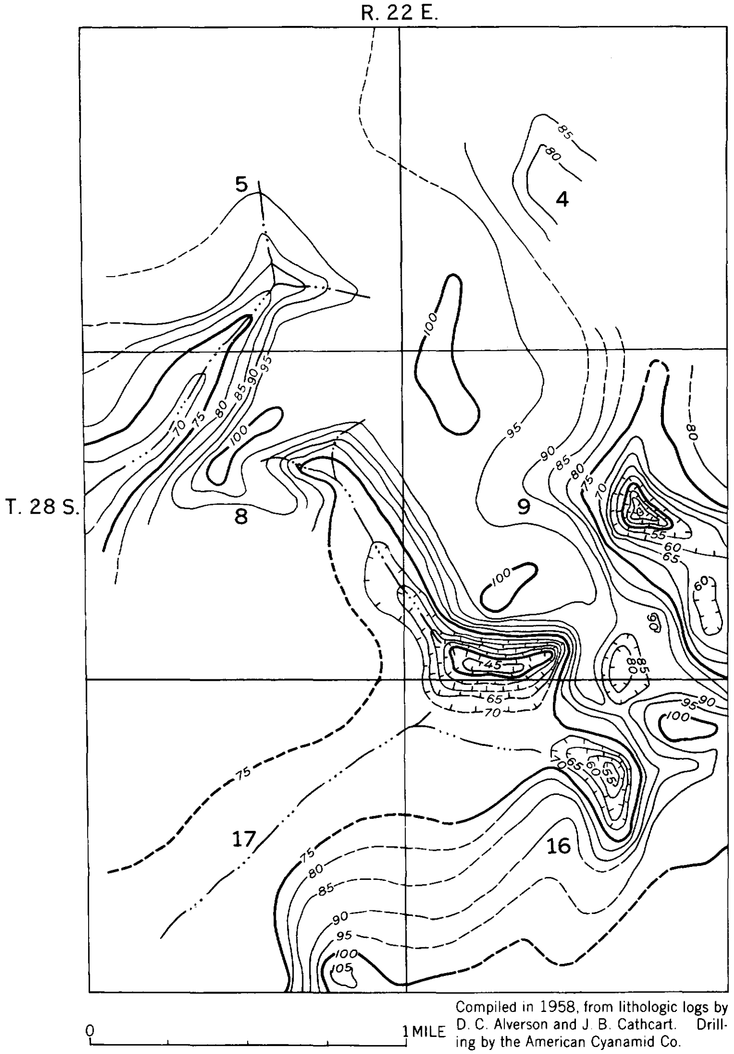
Three deep depressions and two shallow ones are present in secs. 9 and 16. These depressions are sinkholes that do not extend to the present surface. The trough in secs. 5 and 8 is probably the trace of an ancient channel on the pre-Bone Valley surface.

The isopach map of the lower phosphorite unit of the Bone Valley formation (fig. 12) when compared with the "basement" map (fig. 11) clearly shows that the unit partly fills sinkholes and low areas on the Hawthorn surface. The sinkhole at the boundary of the SW¼ sec. 9 and the NW¼ sec. 16 is not filled with phosphorite, nor is the shallow low area in the center of sec. 4.

Phosphate deposits are absent from the area of the ridge on the Hawthorn, from the southeast part of sec. 5, and from sec. 4. Regional distribution maps of the lower phosphorite of the Bone Valley formation show that the unit is thinning to the north. No phosphorite of the Bone Valley formation is present to the north of the Knights area.

The distribution of the lower unit of the Bone Valley formation indicates that the unit was deposited after the formation of the sinkholes, probably by an advancing sea. The sea apparently did not advance much farther to the north than the Knights area, as indicated by the absence of phosphatic sediments on the basement ridges and by the fact that in sec. 5 a maximum of 4 feet of lower phosphorite is present at a drill hole near the center of the section. The 4-foot thickness in sec. 5 is probably the total thickness of the lower unit deposited here, as the phosphorite is overlain with a gradational contact by clayey sand of the upper unit.

The distribution of the upper clayey sand unit of the Bone Valley formation is shown by the isopach map (fig. 13). The pattern of distribution is similar to that of the lower unit. Clayey sand of the




Compiled in 1958, from lithologic logs by D. C. Alverson and J. B. Cathcart. Drilling by the American Cyanamid Co.

EXPLANATION

95

Contour

*Drawn on calcareous clay or sandy clay, top of the Hawthorn formation, dashed where inferred. Contour interval 5 feet; datum is mean sea level*

Position of possible stream course on the Hawthorn formation

**FIGURE 11.**—Contour map of the erosion surface of the Hawthorn formation, Knights tract.

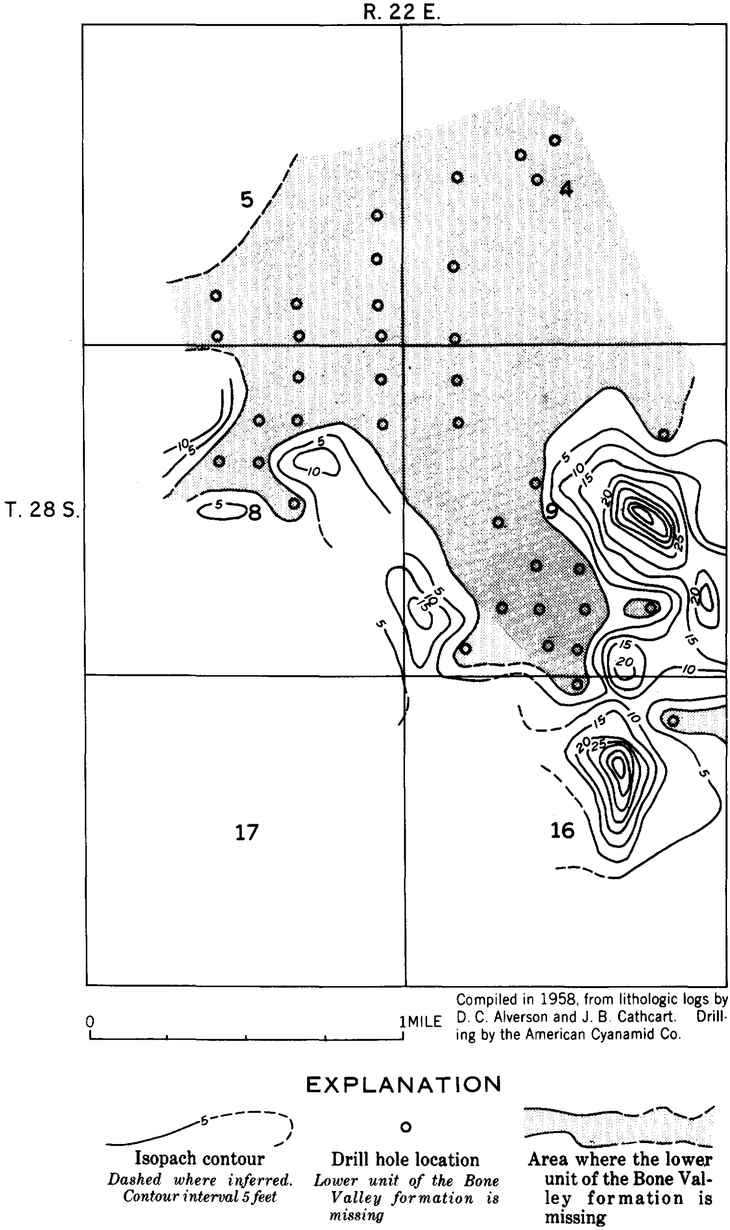



**FIGURE 12.—Isopach map of the lower unit of the Bone Valley formation, Knights tract.**

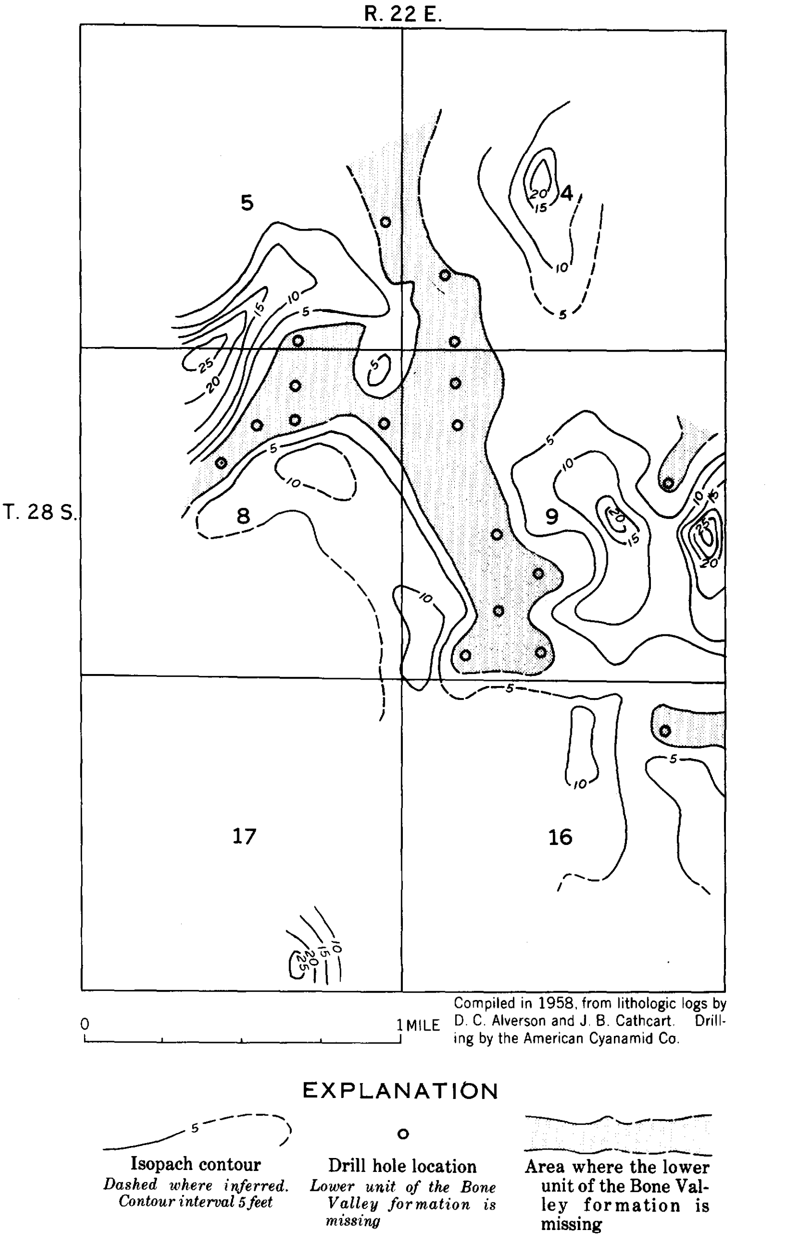



**FIGURE 13.**—Isopach map of the upper unit of the Bone Valley formation, Knights tract.

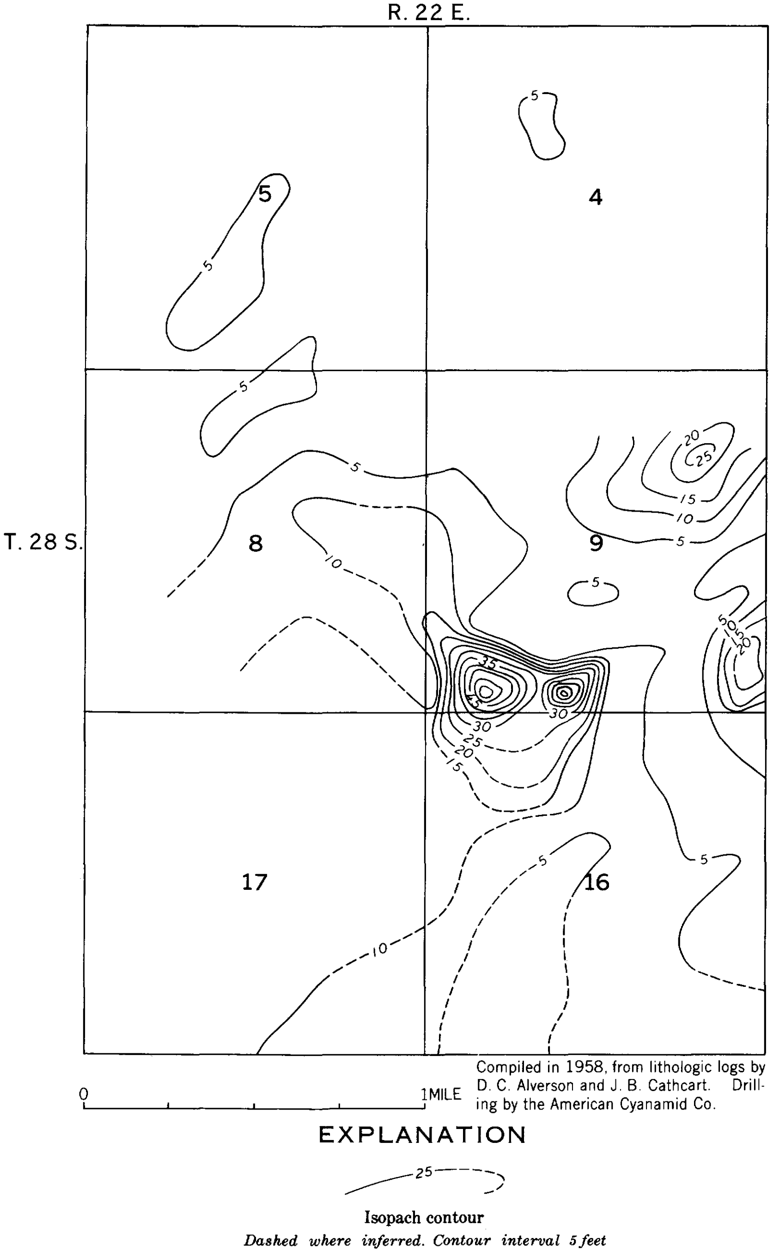



FIGURE 14.—Isopach map of sand of Pleistocene age, Knights tract.

upper unit of the Bone Valley formation is absent from the area of the subsurface ridge on the Hawthorn and thickens close to the same sinkholes where the lower unit thickens. The upper unit also thickens in the low area on the Hawthorn surface in sec. 4, where the lower unit is absent, and also fills the channel on the Hawthorn surface in secs. 5 and 8.

The contact between the upper and lower units is gradational at the places in the Keysville quadrangle where the contact has been studied (Cathcart, 1963). Therefore, the thickening of the upper unit in the low area in sec. 4 indicates that the sea from which the upper unit was deposited advanced farther to the north than the sea that deposited the phosphorite. Both units of the Bone Valley formation are absent from the ridge area. Because this was a ridge at the time of deposition, it is probable that sediments of the Bone Valley were originally very thin over the ridge area, and the thin sediments were removed by erosion prior to the deposition of the sands of Pleistocene age.

The isopach map of loose sands of Pleistocene age (fig. 14) shows that these sands are uniformly thin, except where they fill the sinkhole at the south edge of sec. 9 and in the north and east parts of sec. 9, where the sands thicken. The isopach maps of the upper and lower units of the Bone Valley formation, which show no thickening in the area of the sinkhole at the south edge of sec. 9, indicate that this sink was formed after the deposition of the Bone Valley and prior to the deposition of the loose sands. Both drill holes that penetrated the sink were abandoned in sands of Pleistocene age; the sink, therefore, is deeper than shown on the map.

## REFERENCES CITED

Altschuler, Z. S., Cisney, E. A., and Barlow, I. H., 1952, X-ray evidence of the nature of carbonate-apatite [abs]: Geol. Soc. America Bull., v. 63, no. 12, p. 1230–1231.

Altschuler, Z. S., Clarke, R. S., Jr., and Young, E. J., 1958, Geochemistry of uranium in apatite and phosphorite: U.S. Geol. Survey Prof. Paper 314–D, p. 45–90.

Altschuler, Z. S., Jaffe, E. B., and Cuttitta, Frank, 1956, The aluminum phosphate zone of the Bone Valley formation, Florida, and its uranium deposits, *in* Page, L. R., Stocking, H. E., and Smith, H. B., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 495–504.

Bergendahl, M. H., 1956, Stratigraphy of parts of DeSoto and Hardee Counties, Florida: U.S. Geol. Survey Bull. 1030–B, p. 65–98.

Carr, W. J., and Alverson, D. C., 1959, Stratigraphy of middle Tertiary rocks in part of west-central Florida: U.S. Geol. Survey Bull. 1092, 111 p.

Cathcart, J. B., 1963, Economic geology of the Keysville quadrangle, Florida: U.S. Geol. Survey Bull. 1128, 82 p.

Cathcart, J. B., and Davidson, D. F., 1952, Distribution and origin of phosphate in the land-pebble district of Florida: U.S. Geol. Survey Trace Elements Inv. Rept. 212, issued by U.S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, Tenn., 12 p.

Cathcart, J. B., and McGreevy, L. J., 1959, Results of geologic exploration by core drilling, 1953, land-pebble phosphate district, Florida: U.S. Geol. Survey Bull. 1046–K, p. 221–298.

Cooke, C.W., 1945, Geology of Florida: Florida Geol. Survey Bull. 29, 339 p.

Cooke, C. W., and Mossom, D. S., 1929, Geology of Florida: Florida Geol. Survey 20th Ann. Rept., p. 29–227.

Dall, W. H., and Harris, G. D., 1892, Correlation papers; Neocene: U.S. Geol. Survey Bull. 84, 349 p.

Fowler, E. D., and others, 1927, Soil survey of Polk County, Florida: U.S. Dept. Agriculture, Soil Survey Rept. 39, 39 p.

Grim, R. E., 1953, Clay mineralogy: New York, McGraw-Hill Book Co., 354 p.

Hignett, T. P., Siegel, M. R., Kelso, T. M., and Meline, R. S., 1957, Utilization of high-alumina phosphate ore from the Florida leached-zone ore deposits: TVA Chem. Eng. Bull. No. 3.

Hunt, C. B., and Hunt, A. P., 1957, Stratigraphy and archeology of some Florida soils: Geol. Soc. America Bull., v. 68, no. 7, p. 797–806.

MacNeil, F. S., 1947, Correlation chart for the outcropping Tertiary formations of the eastern Gulf Coastal Plain: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 29.

——— 1950, Pleistocene shorelines in Florida and Georgia: U.S. Geol Survey Prof. Paper 221–F, p. 95–107.

Matson, G. C., and Clapp, F. G., 1909, A preliminary report on the geology of Florida with special reference to the stratigraphy: Florida Geol. Survey 2d Ann. Rept. p. 25–173.

Odum, H. T., 1953, Dissolved phosphorus in Florida waters, Pt. 1: Florida Geol. Survey Rept. Inv. 9, 40 p.

Sellards, E. H., 1910, A preliminary paper on the Florida phosphate deposits: Florida Geol. Survey 3d Ann. Rept., p. 17–41.

——— 1915, The pebble phosphates of Florida: Florida Geol. Survey 7th Ann. Rept., p. 25–116.

Vernon, R. O., 1951, The geology of Citrus and Levy Counties, Florida: Florida Geol. Survey Bull. 33, 256 p.

U.S. GOVERNMENT PRINTING OFFICE: 1963 O—681-383