Economic Geology of the Keysville Quadrangle Florida

GEOLOGICAL SURVEY BULLETIN 1128

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

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By JAMES B. CATHCART

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ECONOMIC GEOLOGY OF THE KEYSVILLE QUADRANGLE, FLORIDA

By James B. Cathcart

ABSTRACT

The Keysville quadrangle, in west-central peninsular Florida, is within the land-pebble phosphate district. The quadrangle is underlain by thin Tertiary and Quaternary formations that dip very gently to the southeast. Formations that crop out in the area are the Hawthorn formation of middle Miocene age, the Bone Valley formation of Pliocene age, and terrace sands of Pleistocene age. Formations older than the Hawthorn and known only from deep drill holes include the Ocala limestone of Eocene age, the Suwannee limestone of Oligocene age, and the Tampa limestone of early Miocene age.

The Ocala limestone underlies the entire quadrangle. Only a few drill holes reach the top of the Ocala, and thicknesses of the formation in the quadrangle are not known. The top of the formation is highest in the northwest part of the quadrangle and lowest in the southeast. The Suwannee limestone, which lies unconformably on the Ocala, ranges in thickness from 0 in the southeast to more than 200 feet in the northwest. The Tampa limestone, which unconformably overlies the Suwannee, ranges in thickness from about 50 feet in the northwest to about 250 feet in the east-central part of the quadrangle. All these subsurface formations are almost pure limestone, but each succeedingly higher formation contains more sand and clay than the one below it.

The Hawthorn formation, the oldest formation that crops out in the quadrangle, consists of interbedded and lenticular sand, clay, and limestone and dolomite, all containing phosphate nodules. Phosphate nodules are low in P_2O_5 content and make up about 10 percent of the rock, but much of the economic phosphate was reworked from the Hawthorn formation. The formation ranges from 13 to 120 feet in thickness, and thins gradually from southeast to northwest. The subsurface topography of the Hawthorn is similar to the present surface; ancestors of the present surface streams flowed on the surface of the Hawthorn at or close to their present positions. Ridges on the Hawthorn surface show a karst topography.

The Bone Valley formation of Pliocene age unconformably overlies the Hawthorn, and is divided into two units: a lower, phosphorite unit, and an upper, clayey sand unit. The formation underlies the entire quadrangle, except where it has been removed by erosion along the modern streams.

The lower unit of the Bone Valley formation consists of unconsolidated sand, clay, and gravel, all containing abundant phosphate. The unit, as mined, consists of nearly equal parts of quartz sand, phosphate sand or gravel, and silt and clay (—150-mesh material). The unit ranges from 0 to more than 50 feet in thickness; it is thickest over lows on the Hawthorn surfaee, and evidently filled the sinkholes on the karst topography.

The upper unit of the Bone Valley formation ranges from 0 to more than 20 feet in thickness and consists of clayey sand and sandy clay, with only a trace of phosphate. The contact between the upper and lower units is gradational.

The Bone Valley formation is overlain by a blanket of loose quartz sand of Pleistocene age. The contact is disconformable, is irregular in detail, and is marked by channels filled with loose sand cut into the Hawthorn formation.

The structure of the Keysville quadrangle is simple; the beds dip gently to the southeast away from the Ocala uplift. A small anticline which trends southeast from near the middle of the east edge of the quadrangle reverses, locally, the regional dip. Except for slumping at sinkholes, no faults have been mapped in the quadrangle.

Three, or perhaps four, periods of weathering have altered the rocks of the Keysville quadrangle. The first, after the deposition of the Hawthorn formation, produced karst topography on that formation. Chemical weathering at this time removed the soluble $CaCO_3$ and left a residuum enriched in phosphate and quartz. This residuum was reworked into the base of the Bone Valley formation. The reworking sorted the slightly heavier phosphate particles, and the particles were probably enriched in the Bone Valley sea. A second period of weathering followed the deposition of the Bone Valley formation and at this time the aluminum phosphate zone was formed. At the same time, the limestone of the Hawthorn formation was altered to calcareous clay and was dolomitized. A third period of weathering followed the deposition of the loose surficial sands, and a ground-water podsol (the Leon soil) was developed in the surficial materials or was superimposed on the aluminum phosphate zone. A fourth, thin, surficial weathering developed in Recent time.

The phosphate deposits, which were mined at least as early as 1915, are composed of rocks of both middle Miocene and Pliocene ages. Most of the material mined has been from the Bone Valley formation, and most of the remaining reserves are in it. Reserves of recoverable phosphate total almost 400 million long tons. This estimate is a total of all grades, and is made without regard to present economic conditions. A total of 477 million long tons of rock with an average content of about 6 percent P_2O_5 and 0.009 percent uranium is available from the aluminum phosphate zone in the quadrangle. An estimated additional 1 billion tons of phosphate in the Hawthorn formation represents a potential resource.

INTRODUCTION

The Keysville quadrangle is in west-central peninsular Florida between lat 27°45′ and 28° N. and long 82° and 82°15′ W. (fig. 1); it includes parts of western Polk and eastern Hillsborough Counties.

The topography of the quadrangle is flat or very gently rolling; elevations within the quadrangle range from less than 16 feet to more than 160 feet (fig. 2).

The quadrangle is drained by the Alafia River and its tributaries, Turkey Creek and Fishhawk Creek, and is characterized by three physiographic divisions: (a) the swamp lands along the river courses, (b) the pine flatwoods in the interstream divides, and (c) the rolling uplands or ridge area (fig. 3).

The stream valleys are generally shallow, with gradual slopes to the higher flatwoods. The valleys are characterized by swamps or

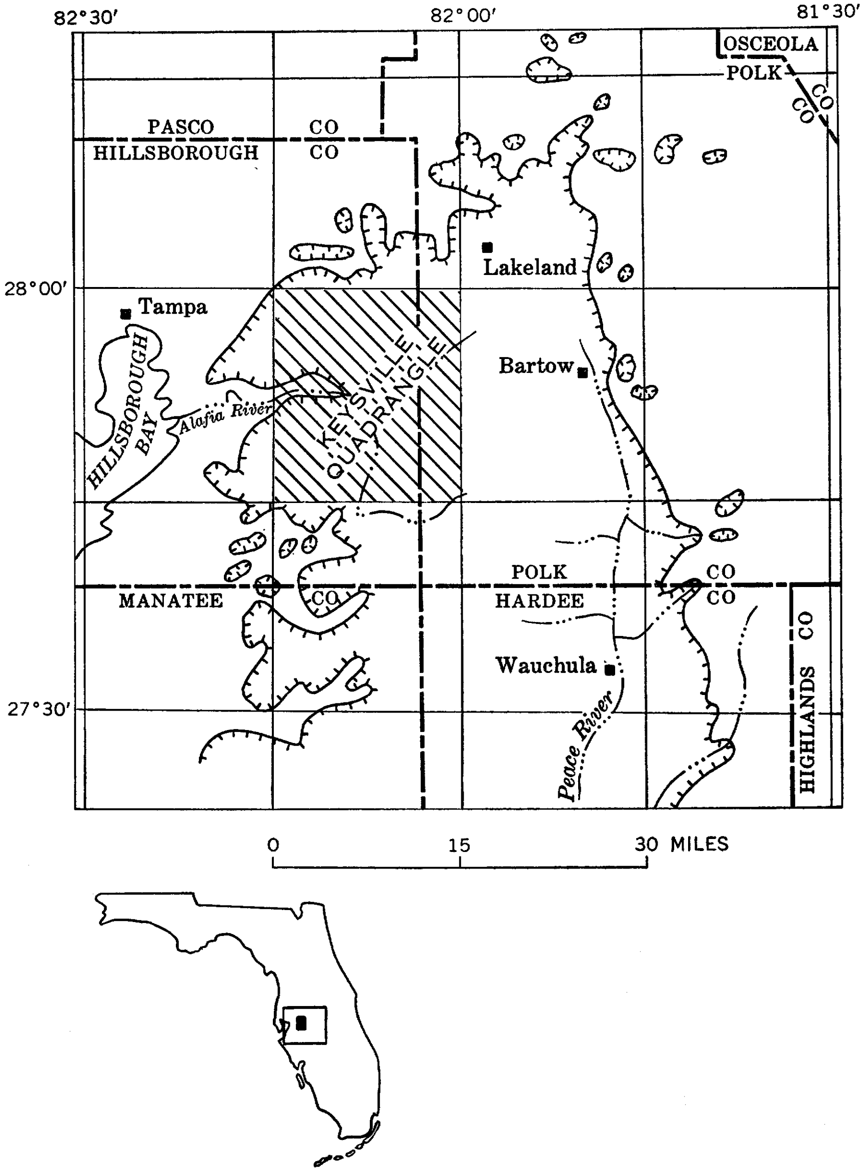
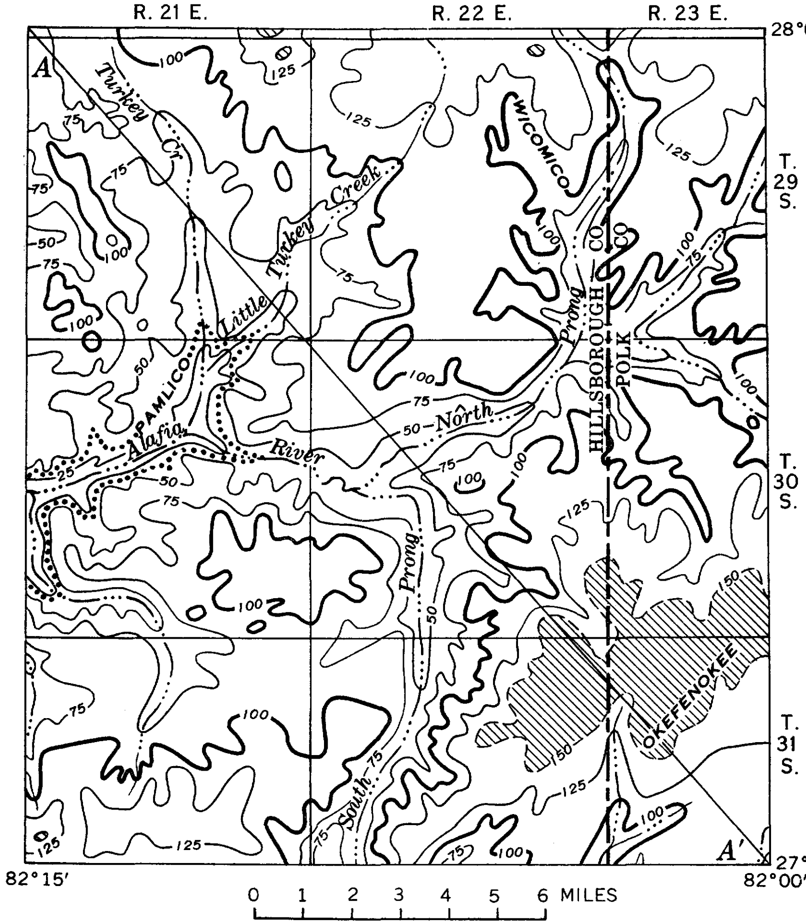


FIGURE 1.—Index map of west-central peninsular Florida, showing location of Keysville quadrangle. The area of the Keysville quadrangle is shown by diagonal lines, and the approximate limits of the land-pebble phosphate district are shown by the hachured line.

marshes and streams that readily overflow their poorly defined channels during the rainy season.

The flatwoods areas are low lying, nearly level, and wooded and are characterized by small depressions called bay heads or cypress ponds.



CONTOUR INTERVAL 25 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

Approximate Pleistocene shorelines (after MacNeil, 1950)

30-foot contour
Pamlico shoreline

100-foot contour
Wicomico shoreline

150-foot contour Okefenokee shoreline

Diagonal pattern shows unterraced land above 150 feet

FIGURE 2.—Sketch map of topography and drainage, Keysville quadrangle, showing approximate position of Pleistocene shorelines. Section A–A' is shown in figure 11.

Slash and longleaf pines are the common trees, with palmetto and wire grass as undergrowth.

The ridge area is higher in elevation than the flatwoods, is commonly poorly drained by streams, and supports a growth of small oak

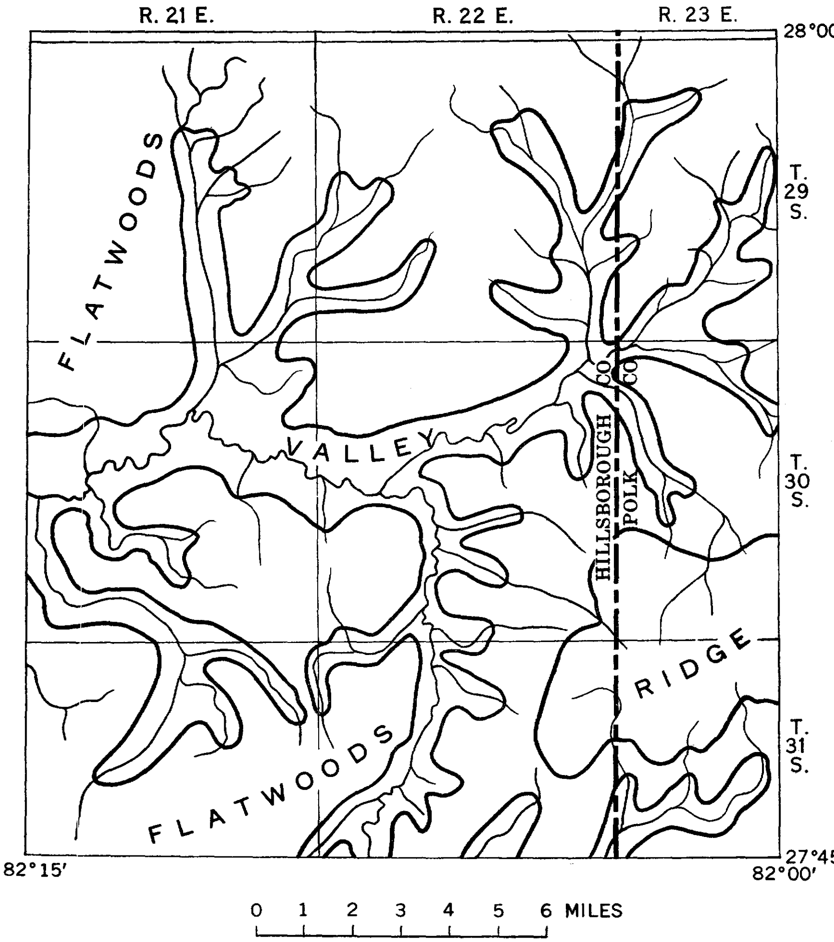


FIGURE 3.—Physiographic divisions, Keysville quadrangle, Florida.

and scattered longleaf pine. The ridge is characterized by numerous lakes, ponds, and small depressions.

Much of the information used in this report is from phosphate mining company records. These records show overburden and matrix thicknesses, the results of size, flotation, and chemical analyses, and reserve computations. Prospecting maps showing this type of information are reproduced in Mansfield (1942, pls. 2 and 3). Prospecting records also include a lithologic log of each drill hole. Interpretation of these logs is based on examination of mine pits and of U.S. Geological Survey drill holes in areas adjacent to the company drilling. Lithologic logs are available for only a part of the quadrangle.

ACKNOWLEDGMENTS

No investigation in a mining district can succeed without the cooperation of the mining companies. The active mining companies have cooperated fully with the Geological Survey during the course of the field investigation, and the writer thanks them for permission to publish the subsurface maps, which could not have been drawn without access to their drilling records.

All the companies allowed access to their mining properties, collected samples of both the aluminum phosphate and calcium phosphate zones for analysis by the Geological Survey, and made available chemical analyses of phosphate rock. All the active companies—the American Agricultural Chemical Co., the American Cyanamid Co., Coronet Phosphate division of Smith-Douglas Co., Inc., Davison Chemical Co. Division of W. R. Grace & Co., International Minerals & Chemical Corp., Swift & Co., and the Virginia-Carolina Chemical Corp.—gave free access to their data. Mr. Wayne Thomas, a consultant in phosphate lands, allowed access to his prospecting records and gave permission to publish the subsurface data. Many geologists of the Geological Survey participated in the field investigations. The ideas expressed in this report are the result of numerous informal conversations with these men and the writer can take credit only for expressing the ideas, not necessarily for originating them.

The radioactivity analyses of samples from the Keysville quadrangle were made by the following members of the U.S. Geological Survey: J. T. Bracken, W. R. Champion, E. A. Cisney, C. E. Cox, Jr., S. P. Furman, J. H. Goode, Jr., E. H. Humphrey, B. A. McCall, P. R. Moore, J. N. Rosholt, Jr., and J. J. Warr, Jr. The chemical analyses were made by: M. E. Appling, I. H. Barlow, Sam Bethea, G. W. Boyes, Jr., G. T. Burrow, A. B. Caemmerer, C. E. Cox, Jr., G. J. Daniels, M. H. Delevaux, David Diebler, George Dudley, R. F. Dufour, M. E. F. Eiland, T. A. Farley, S. P. Furman, J. H. Goode, Jr., J. L. Greene, N. K. Guttag, C. R. Johnson, J. Hunter, Nancy Jammer, H. B. Kessler, R. K. Fuyat, M. Landers, D. M. Lee, Harry Levine, J. W. T. Meadows, Henry Mela, Jr., R. L. Meyrowitz, R. G. Milkey, M. M. Schnepfe, Roosevelt Moore, Wayne Mountjoy, W. W. Niles, Helen Peterson, A. J. Robinson, I. B. Robinson, J. N. Rosholt, Jr., J. J. Rowe, J. P. Schuch, Leonard Shapiro, A. M. Smith, J. Smith, L. Steele, C. M. Stevens, R. C. Tripp, W. P. Tucker, David Venesky, James Wahlberg, and A. L. White.

DEFINITIONS

Many terms used in this report have a local or an industry-wide meaning that may be at variance with the more commonly accepted meaning. Therefore, these terms are defined, and the words are used in this report according to these definitions.

A diagrammatic sketch (fig. 4) shows the relation of stratigraphy to mining terminology.

OVERBURDEN

"Overburden," as used in this report, includes all material overlying the minable phosphate deposit. Driller's logs include the terms "sand," "sandy clay," "clay," "hardpan," and "sandrock," to describe the overburden.

When it was discovered that the aluminum phosphate zone might be of economic value, some of the companies modified the use of the term "overburden" to include only the waste material above the potentially economic aluminum phosphate zone. Other companies designated the aluminum phosphate zone as the basal unit of the overburden and continue to use "overburden" in the old sense. Figure 4 indicates these relations diagrammatically. At *A*, the overburden includes both the loose sand and the clayey sand; at *B*, it includes only the loose sand at the surface; at *E*, the aluminum phosphate zone is shown as the basal unit of the overburden.

Plate 7 was compiled from old company data and shows all the material above the minable phosphate. The aluminum phosphate zone is the basal part of this overburden.

Sand.—The driller's term "sand" always means loose quartz sand without clay. The term is often modified by a color adjective.

Sandy clay.—In driller's terminology, sandy clay is generally equivalent to clayey sand. The amount of clay varies from a trace (enough to bind the sand) to about 35 percent.

Clay.—The driller's term "clay" usually means sandy clay. The clay content can be any amount greater than about 35 percent. The modifying term "stiff" usually means a higher content of clay than the term "soft." Color adjectives are also used.

Sandrock.—"Sandrock" is the driller's term for sand or sandy clay cemented by material other than iron. Examination of drill cuttings indicates that "sandrock" generally refers to sand cemented by aluminum phosphate minerals. However, silica-cemented sand is also called sandrock.

Hardpan.—"Hardpan" refers to iron-cemented sand or clayey sand that cause difficulty in hand-auger drilling. Figure 4 shows the superposition of the hardpan on the section. At *E*, the hardpan is entirely in loose sand, at *F* the contact of the loose sand and clayey sand is obscured by the hardpan, and at *G*, the hardpan is within the clayey sand.

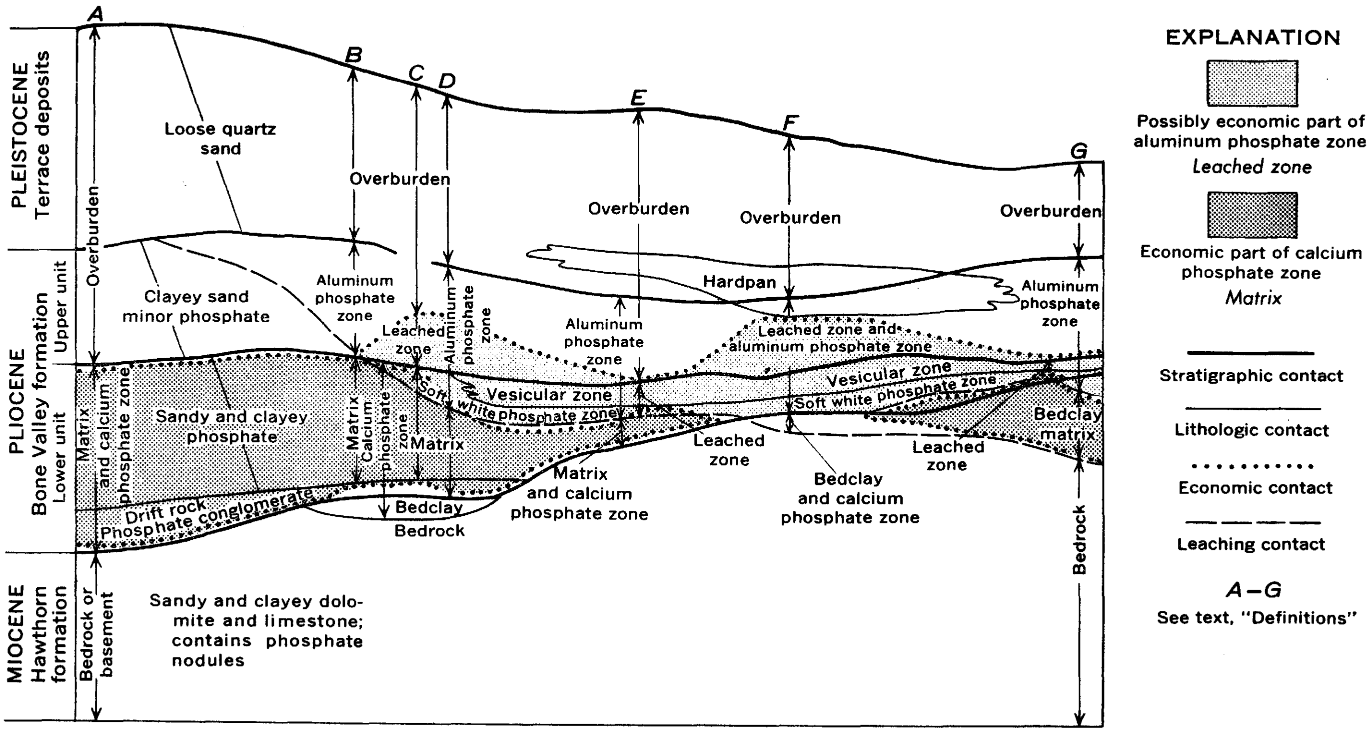


FIGURE 4.—Diagrammatic sketch showing relation of stratigraphy to mining terminology.

ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone is an irregular zone of leaching, characterized by (a) the aluminum phosphate minerals wavellite, crandallite, and, locally, millisite, (b) a relatively high uranium content, and (c) a dominantly white color. The zone cuts across stratigraphic units and may include only the upper clayey sand unit of the Bone Valley formation (as at *B*, fig. 4), the upper clayey sand and the top of the lower phosphorite unit of the Bone Valley formation (as at *C*, fig. 4), or both units of the Bone Valley plus the top of the Hawthorn formation (as at *G*, fig. 4). Where the leaching that formed the zone has altered the upper clayey sand, the zone is massive or structureless; where leaching has altered the pebbly sand of the lower unit of the Bone Valley, the zone may have a vesicular texture. The zone directly overlies the calcium phosphate zone, and in turn is overlain by loose quartz sand.

LEACHED ZONE

The leached zone is that part of the aluminum phosphate zone that may be of economic value. The aluminum phosphate zone and the leached zone may be coincidental. At *F*, figure 4, the zones coincide, except that the hardpan is never included as a part of the aluminum phosphate zone. Most often, the term "leached zone" refers to only a part of the aluminum phosphate zone. For example, if the zone of soft white phosphate, genetically a part of the aluminum phosphate zone, contains enough recoverable phosphate to be minable, it is excluded from the aluminum phosphate zone, as diagrammatically shown at *C* and *D*, figure 4. At *C*, the soft white phosphate is in the matrix; at *D*, it is in the aluminum phosphate zone. The top part of the aluminum phosphate zone may contain so little phosphate and uranium, because of thorough leaching, that it is excluded from the leached zone. This relation is shown at *C* and *E*, figure 4.

Economically, the base of the leached zone is the top of the matrix. The top of the zone is determined by assay data, where available, or it is put at the point where the radioactivity, as determined by the gamma ray log, rises sharply.

SOFT WHITE PHOSPHATE ZONE

The soft white phosphate zone, also called the white phosphate zone, is transitional between the leached zone and the matrix. The zone is from 1 to 3 feet thick and is composed of white phosphate nodules, quartz sand, and clay. The zone represents the start of leaching; the whitening of the nodules is due to the formation of aluminum or calcium aluminum phosphate minerals on their rims.

The white phosphate zone may or may not be minable, depending on the extent of leaching. If it is minable, it is a part of the matrix, as at *C*, figure 4; if it is unminable, it is a part of the leached zone, as at *D* and *E*, figure 4.

CALCIUM PHOSPHATE ZONE

The calcium phosphate zone is that part of the geologic section that contains abundant nodules of calcium phosphate. The use of the term is restricted to unconsolidated sediments (sand, clay, sandy clay, clayey sand, and calcareous clayey sand or sandy clay) that contain the nodules in potentially minable quantities. The zone rests on hard limestone or dolomite, which is excluded from the calcium phosphate zone because of the practical impossibility of mining and processing it, at least in the foreseeable future. The calcium-phosphate zone includes bedclay (see p. 11) and matrix and may include the soft white phosphate zone (*B* and *C*, fig. 4). The zone may coincide with matrix where the bedclay and the soft white phosphate zone either are not present (*A*, fig. 4) or are not minable (*D*, fig. 4). In most cases, however, the calcium phosphate zone includes a greater thickness of strata than the matrix (*B*, *C*, and *D*, fig. 4). At *B*, figure 4, the drift rock is not included in the matrix because of its low grade; however, it is a part of the calcium phosphate zone.

MATRIX

The term "matrix" designates the part of the geologic section that can be mined; it is synonymous with "ore." The matrix may include rocks of the Hawthorn formation (*G*, fig. 4), as well as rocks of the lower phosphorite unit of the Bone Valley formation (*A*, fig. 4).

Other terms used to describe units of the matrix include "barren beds" and "drift rock."

Barren beds.—Barren beds or barren clay beds usually consist of slightly sandy to sandy clays and have sparse phosphate nodules.

Drift rock.—"Drift rock" is a term describing conglomerate or coarse sand consisting of phosphate nodules, usually some quartz grains, and little or no clay. Drift rock is normally at or close to the base of the matrix, but may be underlain by the matrix or the calcium phosphate zone, usually bedclay or "bedclay matrix" of the Hawthorn formation (*B*, *C*, and *D*, fig. 4).

PHOSPHATE PARTICLES

The phosphate deposits of the land-pebble district contain rounded oval-shaped phosphate particles ranging in size from boulders to very fine sand. Commercially, the particles are called pebble and concentrate, and the terms, "oolite," "nodule," "granule," "pellet," and "fragment" have been applied to these particles.

The term "pebble" is used to designate a coarse phosphate product. In this report, "pebble" denotes phosphate particles that are coarser than 14 mesh and have a minimum diameter of 1.17 mm.

"Concentrate" refers to the fine phosphate product, −14 to +150 (−1.17 to +0.104 mm) in grain size. Material of this grain size is treated in flotation cells to separate the phosphate from the quartz sand. The phosphate product is the concentrate.

The term "oolite" cannot properly be applied to the particles of phosphate from the land-pebble district, because the term denotes a small rounded particle having accretionary texture. These textures have not been seen in the phosphate particles from Florida.

"Nodule" denotes rounded irregular masses of any size. This term will be used in this report to designate the phosphate particles.

"Granule" is a size term for particles 2 to 4 mm in diameter and is used in this sense.

"Pellet" is used for sedimentary apatite particles (Altschuler and others, 1958, p. 50).

"Fragment" is used to designate a phosphate particle that has been broken and is, therefore, angular or subangular.

BASEMENT

"Basement," "bedrock," and "hard bedrock" are terms designating material (either limestone or dolomite) below the matrix that is too hard for the drill to penetrate. These rocks, in the Keysville quadrangle, are in the Hawthorn formation. Soft bedrock is limestone or dolomite which can be penetrated with difficulty by the hand-auger drill.

BEDCLAY

"Bedclay" is the term used for a soft plastic, usually water-saturated calcareous clay which underlies the matrix. This clay is a residuum of the harder carbonate rocks beneath it. Bedclay that contains abundant phosphate grains is called bedclay matrix (*G*, fig. 4). The bedclay is a part of the calcium phosphate zone, but commonly, the phosphate nodules in the bedclay contain too little P_2O_5 to be economically minable (*B*, *C*, and *D*, fig 4).

COORDINATE SYSTEM OF DRILL-HOLE LOCATION

The coordinate system used by the phosphate mining companies to locate drill holes within a section is based on the empirical knowledge that 16 drill holes are needed to block out ore in a 40-acre tract. The drill holes are equally spaced in a square grid on 330-foot centers.

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The coordinates are lettered from A, which is 165 feet east of the west line of the section, through P, which is 165 feet west of the east line of the section, and are numbered from 1 through 16 from south to north. Hole A–1, then, is 165 feet east of the west line and 165 feet north of the south line of any section, and holes A–1 through 4, B–1 through 4, C–1 through 4, and D–1 through 4, are the coordinates of the 16 drill-hole locations in the SW¼SW¼ of any section. Half numbers and letters are used when drill holes are located between the main lines of the grid. For example; hole A½–1½ is located halfway between A and B, and halfway between 1 and 2.

The drill holes and mine face sections on the fence diagrams (pls. 3, 4, and 5) are numbered according to this coordinate system.

PROCESSING TERMS

Terms used in processing phosphate rock include: "feed," "slime," "BPL," "superphosphate," and "triple superphosphate."

Feed.—The feed is the fraction of the matrix that must be treated by flotation methods to separate phosphate and quartz sand; it ranges in size from −14 to +150 mesh.

Slime.—Slime is that fraction of the matrix that is −150 mesh in size. This slime fraction is the overflow of the hydroseparators; it consists of clay minerals, very fine grained quartz sand and silt, and very fine grained phosphate particles.

BPL.—BPL (bone phosphate of lime) is tri-calcium phosphate, $Ca_3(PO_4)_2$, and is equal to percent $P_2O_5 \times 2.185$. The term is derived from the erroneous early belief that the phosphorus in the deposits was present as tri-calcium phosphate. All industrial analyses are reported as percent BPL.

Superphosphate.—Superphosphate, also called ordinary superphosphate, O.S.P., or super, is manufactured by treating phosphate rock with sulfuric acid. The treatment forms a mixture consisting largely of mono-calcium phosphate and calcium sulfate; it contains from 18 to 21 percent available phosphoric acid (Siems, 1951, p. 394).

Triple superphosphate.—Treating finely ground phosphate rock with phosphoric acid produces a product containing from 43 to 50 percent available phosphoric acid. The names "double superphosphate," "treble superphosphate," "triple superphosphate," and "concentrated superphosphate" have been applied to such products.

GEOLOGIC MAP

The geologic map (pl. 1) shows the general distribution of the formations that immediately underlie the loose quartz sand of the Pleistocene. The formations shown on the map are present in the mining pits of the area, and include the Hawthorn formation of middle Miocene age and the lower phosphorite unit and the upper clayey sand unit of the Bone Valley formation of Pliocene age.

The limestone or dolomite which forms the bedrock of the mining pits and which also crops out along the Alafia River contains fossils that have been identified by F. S. MacNeil of the Geological Survey as middle Miocene in age (oral communication, 1953). Fossiliferous material assigned to the Hawthorn formation was cored in several drill holes during the drilling program in 1953. The fossil lists and description of the drilling are in a report by Cathcart and McGreevy (1959). Except for these fossil localities and one in the Bone Valley formation, all the formations are delineated on the basis of their lithologic characteristics. A summary of the lithologic characteristics used in stratigraphic correlation is shown on table 1, which is modified from a table in the report by Cathcart and McGreevy (1959, p. 245).

The lithologic succession varies near surface streams where the beds nearest the surface are progressively missing. Bedded phosphorite of the Bone Valley is overlain by loose sand near the streams, and, at or very close to the stream, strata (limestone, dolomite, or calcareous clay) assigned to the Hawthorn are directly overlain by loose sand. Near surface streams the higher strata have been removed by erosion.

The geologic map was constructed largely from private company data; it shows the distribution of the Bone Valley and Hawthorn formations but not the loose sand.

The lithologic characteristics are not invariable. As indicated, quartz sand is present in the terrace deposits in the lower unit of the Bone Valley formation and in the Hawthorn formation. However, in the Bone Valley and Hawthorn formations, the quartz sand almost invariably contains some phosphate nodules. Although individual characteristics may be present in several formations, a combination of these characteristics usually permits reasonably accurate placing of the lithologic unit. For example, a calcareous clay containing more than a trace of phosphate nodules is very likely in the Hawthorn formation, and noncalcareous clayey sand with abundant high P_2O_5 phosphate nodules can be correlated with the lower unit of the Bone Valley formation with some degree of confidence, especially where there is a "normal" sequence of the units. For example, most drill holes bottom on hard material, presumed to be limestone of the Hawthorn formation; above the hard material is the calcareous clay, and above the clay is bedded sandy, clayey phosphorite, which is overlain by clayey sand, with only minor phosphate; this in turn is overlain by loose sand. This lithologic succession is found throughout the quadrangle and is illustrated with lithologic logs in this report.

TABLE 1.—*Summary of lithologic criteria used in stratigraphic correlation*

[Modified from Cathcart and McGreevy, 1959, p. 245. A, abundant; x, present; Tr, trace amounts]

Formation	Quartz sand	Clayey sand	Organic material	Iron cement hardpan	Aluminum phosphate	Calcium phosphate nodules			Chert fragments	Green or blue sandy, silty clay	Calcareous clay	Limestone				
						High P_2O_5	Low P_2O_5	Amount of nodules				Very pure	Slight impurities	Moderate impurities	Abundant impurities	Silicified
Pleistocene terrace deposits	A	----	x	x	------	----	----	------	------	----	----	----	----	----	----	----
Bone Valley formation:																
Upper unit	----	x	----	----	A	x	----	Tr	------	----	----	----	----	----	----	----
Lower unit	x	x	----	----	Tr	x	----	A	------	----	----	----	----	----	----	----
Hawthorn formation:																
Clastics	x	x	----	----	Tr	----	x	x	Tr	x	x	----	----	----	----	----
Limestone	----	----	----	----	------	----	x	x	------	----	----	----	----	----	x	----
Tampa limestone:																
Clastics	----	----	----	----	------	----	x	Tr	x	x	x	----	----	----	----	----
Limestone	----	----	----	----	------	----	x	Tr	x	----	----	----	----	x	----	----
Suwannee limestone	----	----	----	----	------	----	----	------	------	----	----	----	x	----	----	x
Ocala limestone	----	----	----	----	------	----	----	------	------	----	----	x	----	----	----	----

Company logs are commonly of two kinds. The first type shows only the total thicknesses of the overburden and of the matrix; these logs could not be used in making the geologic map. The second type, the driller's lithologic logs, distinguishes sand, sandy clay, matrix, drift rock, bedclay, and bedrock. Stratigraphic sections of mine faces and lithologic logs of drill holes made by the Geological Survey were compared with company lithologic logs. Several generalizations can be made as a result of the comparison: (a) The drilling term "sand" can be assumed to represent deposits of probable Pleistocene age; (b) material in the overburden called sandy clay or clay by the driller is probably the upper unit of the Bone Valley formation; (c) matrix is either the lower unit of the Bone Valley formation, or residual clay of the Hawthorn formation, or both; (d) the term "drift rock" is useful in determining the base of the Bone Valley formation; (e) drift rock probably represents the basal conglomerate of the Bone Valley formation; (f) bedclay is a distinctive lithologic unit, and the term, as used by the drillers, can be assumed to mean residual clay developed from the Hawthorn.

The geologic map, therefore, is primarily lithologic and the stratigraphic units in parts of the map may be in error. In general, however, the map is probably accurate.

GENERAL GEOLOGY

The Keysville quadrangle is entirely within the limits of the land-pebble phosphate district of Florida. The area is a part of the Gulf Coastal Plain and is underlain by thin formations of Tertiary and Quaternary age that dip very gently to the south and southeast away from the Ocala uplift. Peninsular Florida was stable during a large part of Mesozoic and Cenozoic time (King, 1951, p. 166), and the sedimentary rocks consist largely of limestone with only minor amounts of land-derived sediments.

The only natural outcrops in the Keysville quadrangle are in the bed of the Alafia River where limestone of the Hawthorn formation is exposed. Fossiliferous limestone of the Hawthorn formation is present at the bottom of all the mining pits in the quadrangle. The Bone Valley formation of Pliocene age was deposited on the eroded surface of the Hawthorn formation. The mapped area is covered by a blanket of loose quartz sand of probable Pleistocene age. Windblown sand, swamp deposits, and bars and flood plains of the Alafia River and its tributaries are probably Recent.

Formations older than the Hawthorn are known only from deep drilling. These rocks include the Ocala limestone of Eocene age, the Suwannee limestone of Oligocene age, and the Tampa limestone of early Miocene age. Table 2 summarizes information from all the deep wells in the quadrangle.

TABLE 2.—*Summary of data from deep-well logs, Keysville quadrangle*

[Datum is mean sea level. Elevations of formations at top. Measurements in feet]

Source of data	Location			Elevation of collar	Hawthorn formation		Tampa limestone		Suwannee limestone		Ocala limestone
	Section	Township, South	Range, East		Elevation	Thickness	Elevation	Thickness	Elevation	Thickness	Elevation
1	7	29	21	60	+38	27	+11	--------	--------	--------	--------
2	21	29	21	80	+58	58	0	--------	--------	--------	--------
2	17	29	22	117	+81	31	+50	--------	--------	--------	--------
2	29	29	22	105	+60	13	+47	--------	--------	--------	--------
3	6	30	22	84	+35	85	−50	35	−85	231	−316
4	18	30	22	70	+20	120	−100	120	−220	150	−370
2	26	30	22	110	+66	70	−4	251	Not present		−255
5	32	30	22	100	+56	96	−40	200	−240	--------	--------
2	5	30	23	115	+45	40	+5	80+	Total depth 190 ft. in Tampa limestone		--------
2	19	31	22	115	−30	50	−80	40	−120	215	−335

1. Cathcart and McGreevy (1959).
2. Log from Florida Geological Survey.
3. Log by F. S. MacNeil, U.S. Geological Survey.
4. Mansfield (1942, p. 54).
5. Log by R. H. Stewart, U.S. Geological Survey.

STRATIGRAPHY

Stratigraphy and lithology of weathered and unweathered sections are summarized in table 3.

TABLE 3.—*Summary of stratigraphy and lithology, Keysville quadrangle*

Age	Formation or deposit	Lithologic description	
		Unweathered material	Weathered material
Pleistocene	Terrace deposits	Loose quartz sand.	Loose quartz sand.
		Contact gradational; locally, channels cut into lower beds	
Pliocene	Bone Valley formation	Upper unit: Clayey sand, trace of phosphate. Phosphate increases at base.	Sand cemented by aluminum phosphate minerals. Vesicular textures in lower part where the pebbly phosphorite of the lower unit has been leached.
		Contact gradational	Contact irregular
		Lower unit: Clayey, sandy phosphorite. Locally, the base of the unit is a phosphate conglomerate.	Clayey, sandy phosphorite. Phosphate is dull, soft, white.
			Contact gradational
			Sandy, clayey, phosphorite.
		Contact disconformable	
Miocene (middle)	Hawthorn formation	Exposed in mining pits: Sandy, clayey dolomite, interbedded with sand and clay. All units have phosphate nodules.	Sandy, calcareous clay; contains phosphate.
			Contact gradational
			Sandy, clayey phosphate-bearing dolomite.
		Deeper material (from drill holes): Sandy and clayey limestone, interbedded with sand and clay. All units contain phosphate nodules.	
		Contact relations uncertain	
Miocene (lower)	Tampa limestone	Sandy and clayey limestone; has chert nodules and trace of phosphate.	
		Unconformity	
Oligocene	Suwannee limestone	Limestone; contains minor chert, fine-grained sand, and clay.	
		Unconformity	
Eocene	Ocala limestone	Very pure limestone.	

EOCENE SERIES

OCALA LIMESTONE

The history of the use of the names "Ocala limestone" and "Jackson group" is adequately covered in Cooke (1945, p. 53). Vernon (1951, p. 111–113), following the division of the Jackson group by Applin and Applin (1944) into an upper and a lower member, divided the Ocala into the Ocala limestone (restricted) at the top and the Moodys Branch formation at the base. The Moodys Branch formation was divided by Vernon into a lower member, the Inglis, and an upper, the Williston member. Subsequently the Inglis was given formational rank as the Inglis limestone (Cooke, 1959, p. 3).

In the Keysville quadrangle, the Ocala limestone is known only from a few deep drill holes. It was not possible, from the limited data available, to subdivide the Ocala, and the term is used in this report to mean the Jackson group (upper Eocene).

The Ocala is a very pure white, cream, or tan limestone. The limestone varies in texture from coarse granular to fine-grained and generally contains abundant fossils.

The Ocala limestone is uniform in chemical composition. It consists almost entirely of calcium carbonate, and in places contains less than 1 percent impurities.

The Ocala limestone underlies all the Keysville quadrangle. The top of the formation is about 150 feet below sea level in the northeastern part of the quadrangle, and is more than 400 feet below sea level in the southwestern part of the quadrangle. The thickness of the formation in the Keysville quadrangle is not known; however, elsewhere in the state the thickness ranges from about 40 feet to several hundred feet.

Stratigraphic relations of the Ocala limestone to older and younger formations cannot, of course, be seen in the Keysville quadrangle. However, Cooke (1945, p. 56) pointed out that deposits of Jackson age lie unconformably on older beds. The top of the Ocala limestone was a land surface before any younger marine deposits were laid down on it.

OLIGOCENE SERIES

SUWANNEE LIMESTONE

The Suwannee limestone, named by Cooke and Mansfield (1936, p. 71), includes rocks of both middle and late Oligocene age (MacNeil, 1947).

The Suwannee is commonly a soft and granular yellow to cream, nearly pure limestone. Impurities in the limestone were reported to range from 2 to 9 percent (Mossom, 1925). Later work by Carr and Alverson (1959) placed the average impurity content at 13 percent.

The Suwannee limestone underlies almost all the Keysville quadrangle. At one deep drill hole in sec. 26, T. 30 S., R. 22 E. (table 2), the Tampa limestone rests on the Ocala limestone. This drill location is east of section *A–A′* (fig. 11), which shows an abrupt thinning of the Suwannee limestone over an Ocala high. The Suwannee limestone either was not deposited over this high, or was thinner over the high and was subsequently eroded from it. The Suwannee limestone is also absent in the southeastern part of the quadrangle (fig. 11). This area is another Ocala high, and is projected from data from deep wells in the Ft. Meade quadrangle to the southeast.

The top of the formation is about 25 feet below sea level in the northwestern part of the quadrangle and is more than 200 feet below sea level in the southeast (table 2). The formation is thin or absent over the Ocala highs in the southeastern part of the quadrangle, and is more than 200 feet thick in the northwest (table 2).

The Suwannee limestone lies unconformably on the Ocala, and is unconformably overlain by the Tampa limestone (Cooke, 1945, p. 88; MacNeil, 1947; Vernon, 1951, p. 67).

MIOCENE SERIES

TAMPA LIMESTONE

The name "Tampa formation", first used by Johnson (1888), was changed by Cooke and Mossom (1929, p. 78–93) to Tampa limestone. According to Cooke (1945) and MacNeil (1947), the Tampa limestone is of early Miocene age.

The Tampa limestone in the Keysville quadrangle is white to cream sandy and clayey limestone; it contains abundant chert fragments and a trace of phosphate nodules. (See log A, p. 21.) When weathered, the limestone is commonly covered with a thin residual mantle of greenish-gray calcareous clay that contains chert and limestone fragments and sparse phosphate nodules.

The Tampa limestone lies unconformably on the Suwannee limestone, and, in the land-pebble phosphate district, the contact between the Tampa and the Hawthorn is marked by an erosional interval. This interval is indicated by a residual mantle on the Tampa (Carr and Alverson, 1959). To the south of the land-pebble district deep wells penetrated no residual mantle; there limestone of the Tampa conformably underlies limestone of the Hawthorn. This sequence indicates that, after the deposition of the Tampa limestone, the sea withdrew and after a short interval readvanced in the middle Miocene to cover more of the Floridan Plateau than the sea of the early Miocene.

The Tampa limestone underlies all the Keysville quadrangle. In the northern part of the quadrangle the top of the formation is at an altitude of about 50 feet above sea level; in the southern part of the quadrangle, the top of the formation is at an altitude of 100 feet below sea level. The formation ranges in thickness from less than 50 feet in the northwestern part of the quadrangle to about 250 feet in the east-central part of the quadrangle (table 2).

HAWTHORN FORMATION

The Hawthorn formation, named by Dall and Harris (1892, p. 107), was thought by Cooke (1945) and MacNeil (1947) to be of middle Miocene age.

The Hawthorn formation is the oldest formation that crops out in the Keysville quadrangle, and forms the bedrock or basement rock of the phosphate district.

The distribution pattern of the Hawthorn formation, as shown on plate 1, indicates that present, Pleistocene, or pre-Pleistocene streams cut their channels down to the hard limestone or dolomite of the Hawthorn formation. The Hawthorn formation is present along the course of the Alafia River and the North Prong of the Alafia

River from the west edge of the quadrangle to about the Hillsborough-Polk County line (pl. 1). Small patches of Hawthorn are scattered along several tributaries of the Alafia River.

THICKNESS

The Hawthorn formation in the Keysville quadrangle ranges in thickness from 13 to 120 feet (table 2), and averages about 60 feet. The formation thickens from northwest to southeast, except in the west-central part of the quadrangle, where there is a troughlike thinning. The position of the thinning suggests that it is due to erosion by the Alafia River or its predecessors.

SURFACE

Plate 2, the subsurface contour map of the top of the Hawthorn formation, was drawn from company drill data, from a few deep well logs, and from drilling data, mine maps, and sections of the Geological Survey; most data came from company drill records. The company drill foreman customarily stops the drilling when all likelihood of intersecting economic phosphate has passed; hence most holes are drilled to hard bedrock but a few are stopped on bedclay. In the Keysville quadrangle, bedrock is almost certainly hard limestone or dolomite of the Hawthorn formation. The driller's logs usually indicate the thickness of bedclay penetrated before the drills hit bedrock. In constructing the map (pl. 2), the top of the bedclay was assumed to be the top of the Hawthorn formation. Driller's logs were not available for much of the quadrangle, however, and the only information available from the companies was the total thickness of the overburden and the total thickness of the minable phosphate rock beneath the overburden at each hole. For these holes, it was assumed that the thickness of the overburden plus the thickness of the matrix is the depth to the top of the Hawthorn. The error introduced by this assumption is relatively minor because, although some of the material called minable phosphate rock may be residual Hawthorn formation, examination of mines in the quadrangle indicates that only in a few limited areas is all the phosphorite in the Hawthorn formation. Elsewhere, the mined material is mostly in the Bone Valley, although commonly a few feet of residual Hawthorn is mined.

Collar elevations of the drill holes were estimated from topographic maps. The elevations from which plate 2 was drawn probably are correct to within about 5 feet, half the contour interval of the map.

The ridge area on the Hawthorn surface, particularly in Tps. 30 and 31 S., R. 23 E., shows pronounced karst topography, and little surface drainage. Most sinkholes, many occupied by lakes, are on the present ridges at elevations in excess of 150 feet. The sinkholes are not all of the same age. Some are forming at the present time, and some were formed on the Hawthorn surface and are filled with phosphorite of the lower part of the Bone Valley formation. Sinkholes were also formed after the deposition of the Bone Valley formation and prior to the deposition of the sand of Pleistocene age.

STREAM PATTERN ON THE HAWTHORN SURFACE

An examination of plate 2 shows a shift in the stream courses from post-Hawthorn time to the present. The present Alafia River, at the west edge of the quadrangle, is about half a mile north of the ancestral channel (pl. 2).

The present junction of the North and South Prongs of the Alafia River is 1½ miles west of the junction on the Hawthorn surface; other shifts can also be seen on plate 2. However, the South Prong of the Alafia River follows very closely the same course as the ancestral South Prong.

The present drainage pattern differs from that of Miocene age in some ways: (a) In T. 29 S., R. 22 E., the present drainage is southward to the North Prong of the Alafia River, whereas the drainage on the Hawthorn surface is to ancestral Little Turkey Creek, thence southwest to the Alafia River; (b) present Lake Branch drains T. 31 S., R. 23 E., toward the southwest and eventually to the South Prong of the Alafia River; on the Hawthorn surface this area is a karst topography with no apparent surface drainage.

Elevations on the Hawthorn surface range from more than 140 feet above sea level in sec. 6, T. 31 S., R. 23 E., to about 10 feet below sea level along the course of the ancestral Alafia River at the west edge of the quadrangle. Along the ancestral Alafia River particularly in sec. 15, T. 30 S., R. 21 E., maximum relief is more than 50 feet.

The close resemblance of the possible stream pattern on the surface of the Hawthorn (pl. 2) to the present stream pattern can be partly explained by erosion by the present streams, which have cut through the surficial materials and are flowing on limestone or dolomite of the Hawthorn formation. However, the differences in position of the stream pattern on the Hawthorn surface from the position of the present stream pattern are significant. The contact between the Hawthorn and the overlying Bone Valley formation is nonconformable; there was a period of erosion between the deposition of the Hawthorn and the Bone Valley. It seems likely that the stream pattern on the surface of the Hawthorn is due to a combination of erosion in the Hawthorn-Bone Valley interval and of erosion by modern and Pleistocene streams.

PHYSICAL CHARACTERISTICS

The Hawthorn formation is interbedded clay, sand, clayey sand, sandy clay, and impure sandy or clayey limestone or dolomite, all containing varying amounts of phosphate nodules. Attempts to zone the formation lithologically have not been successful; the different lithologic units are lenticular, and not enough deep holes have been drilled through the Hawthorn formation to furnish sufficient data for correlation of units.

Several holes that have been drilled through the Hawthorn formation in the Keysville quadrangle illustrate the variations in thickness and lithology of the formation. The Hawthorn formation is about 27 feet thick at a drill hole in sec. 7, T. 29 S., R. 21 E., as shown in the following lithologic log.

Log A.—Drill hole in sec. 7, T. 29 S., R. 21 E.

[After Cathcart and McGreevy (1959, pl. 18, & hole 1)]

	Feet
Pleistocene:	
Terrace sands: Sand, quartz, loose	7.0
Total, terrace sands	7.0
Pliocene:	
Bone Valley formation (upper unit): Clay, very sandy, gray-green to gray, with a trace of soft white phosphate	5.0
Bone Valley formation (lower unit): Clay, sandy, or sand, clayey, gray to white; contains about 30 percent phosphate nodules. Phosphate nodules contain 36 percent P_2O_5	4.1
Total, Bone Valley	9.1
Miocene:	
Hawthorn formation:	
Clay, green, laminated	5.1
Clay, sandy, blue-green; trace of phosphate	2.9
Clay, slightly sandy, brownish-green, laminated	4.3
Clay, sandy, gray-green to gray; contains about 3 percent black and tan phosphate pebbles. Phosphate pebbles contain 30 percent P_2O_5	15.1
Total, Hawthorn	27.4
Tampa formation:	
Clay, calcareous, sandy, tan and gray. Sand is fine grained; contains less than 1 percent phosphate. Some silica-cemented sand fragments	16.4
Limestone, slightly sandy and clayey; contains abundant chert fragments	2.2
Partial total, Tampa	18.6
Bottom of drill hole.	

At least 145 feet of sandy limestone or calcareous sand of the Hawthorn formation was penetrated by a drill hole at sec. 19, T. 31 S., R. 22 E. The hole was logged by J. S. Cullison, III, of the U.S. Geological Survey, from cuttings stored with the Florida Geological Survey.

Log B.—Drill hole in sec. 19, T. 31 S., R. 22 E.

NOTE: The first sample, at 50 feet, was assigned to limestone of the Hawthorn.

	Feet
Limestone, sandy, dolomitic, with phosphate nodules	45.0
Limestone, sandy, dolomitic, or calcareous sandstone, with tan phosphate nodules	50.0
Limestone, white, sandy, or calcareous sandstone	50.0
Partial total, Hawthorn	145.0

The logs of these two drill holes—log A from the northwestern part of the quadrangle, and log B from the southern part of the quadrangle—illustrate the southward thickening of the formation. A variation in lithology, from sandy limestone at the south to clays and sandy clays at the north, is also apparent from the logs.

The clay, sand, sandy clay, and clayey sand of the Hawthorn formation are characteristically green to gray-green, and the sand fraction is medium or coarse grained. Phosphate nodules which range in diameter from about 0.1 mm to several centimeters are present in varying amounts throughout the Hawthorn formation. The coarse phosphate particles are phosphatized limestone, commonly with an outer crust or rim that is much more highly phosphatized than the interior. Many of the larger nodules contain casts or molds of fossils, which, according to MacNeil (oral communication, 1955), are the same age as the fossils in the matrix.

A green laminated clay, with thin films of quartz sand between the clay laminae and with minor amounts of phosphate nodules, overlies limestone or dolomite at places in the Sydney and Boyette mines and at the Fishhawk tract to the north of the Boyette mine (pl. 1). As shown in figure 5, the laminated clay overlies residual calcareous clay, and both are overlain unconformably by bedded phosphorite of the lower part of the Bone Valley. This section is somewhat unusual, because most drilling data indicate that hard limestone or dolomite underlies the green laminated clay. The calcareous clay is a residuum of limestone; it is not present under the impervious green clay except at the edges of lenses of the clay where lateral solution has taken place (pl. 3). At hole E–1, 3 feet of light-gray calcareous clay, called bedclay by the drilling foreman, is present above the hard bedrock. At hole G–1, 660 feet to the east, 7 feet of hard green clay is above the hard bedrock, and no calcareous clay is present at this location. The same relation is shown between holes I–1 and K–1. At

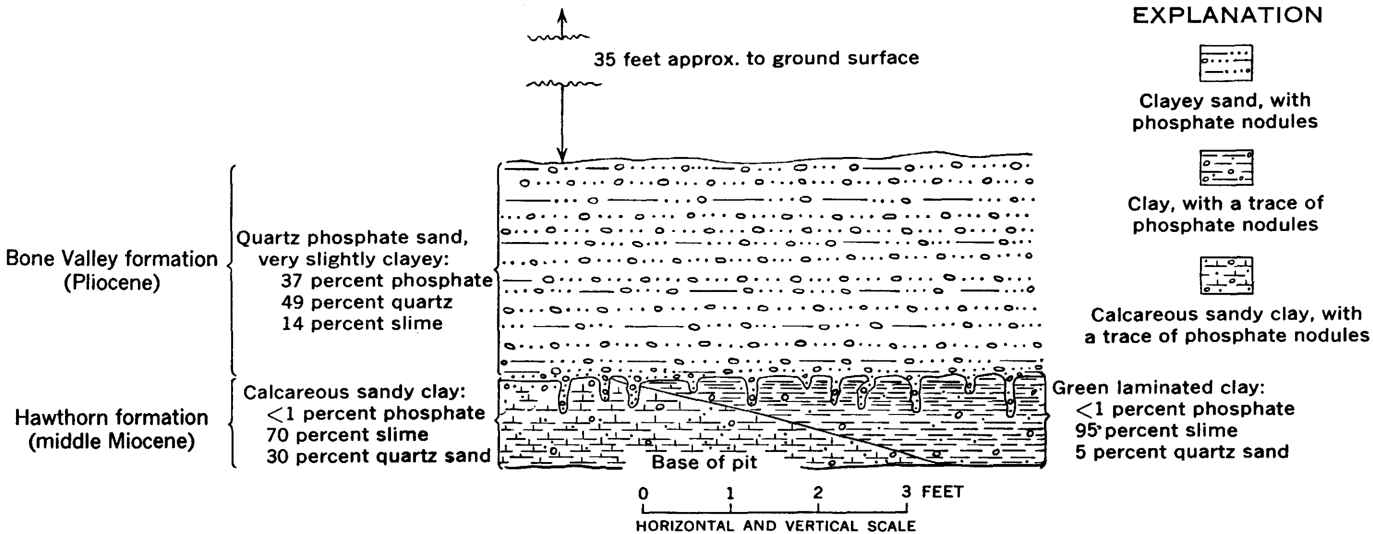


FIGURE 5.—Sketch of the contact between the Bone Valley and Hawthorn formations in the Boyette mine, NE¼NE¼ sec. 23, T. 31 S., R. 21 E., Hillsborough County, Fla.

hole I–1, a lens of quartz sand containing phosphate nodules separates two lenses of green clay. Hard limestone was not reached at hole I–1; the Hawthorn at this locality apparently fills a low area. At hole K–1, 1 foot of calcareous clay overlies hard bedrock (presumably limestone or dolomite); no green clay is present at locality K–1.

The surface of the Hawthorn (pl. 2) is either bedrock or bedclay. The bedrock consists of impure limestone or dolomite that contains clay, grains of quartz sand and silt, and black, tan, white, and gray phosphate nodules. The average bedrock contains about 50 to 60 percent clay-sized calcite or dolomite particles mixed with clay, 20 to 30 percent quartz, 10 percent feldspar, and 10 percent phosphate nodules. Heavy minerals and chert and carbonate fragments are present in trace amounts.

The phosphate nodules vary considerably in amount and size. In some samples, phosphate nodules from 0.1 to about 0.5 mm in diameter make up less than 1 percent of the rock; other samples contain as much as 30 percent nodules as much as 2 cm in diameter. The phosphate nodules are rounded and polished, and tend to be larger in diameter than the grains of quartz. In thin section, the nodules are structureless except for a slightly darker rim, and consist of the phosphate mineral, a carbonate-fluorapatite (Altschuler, Cisney, and Barlow, 1952), quartz silt, clay dust, and calcium carbonate. Much of the phosphate is present as discrete nodules, but some apparently replaces calcite. The quartz and feldspar are subangular to subrounded; the feldspar is usually microcline. The clay mineral is montmorillonite, but attapulgite has been found (Berman, 1953).

Figure 6, a sketch of a thin section of limestone of the Hawthorn, shows a phosphate nodule replacing the calcite of the matrix. The phosphate nodule cuts across two "beds" of quartz and phosphate grains, and two of the quartz grains are on the contact of the phosphate grain and the matrix. The rock in figure 7 is a mixture of quartz and phosphate grains in a cement of very fine grained carbonate and clay dust. In this photomicrograph the phosphate grains are well rounded, in contrast to the quartz grains, and the phosphate nodules enclose silt-sized grains of quartz and clay dust.

Chemical analyses of the "limestone" of the Hawthorn formation are not abundant, but the partial chemical analyses shown in table 4 are thought to be typical of the so-called bedrock.

In the lower phosphorite unit of the Bone Valley, immediately above the bedrock, the magnesium content drops to less than 0.5 percent, the phosphate content rises, and the alumina and iron contents stay about the same.

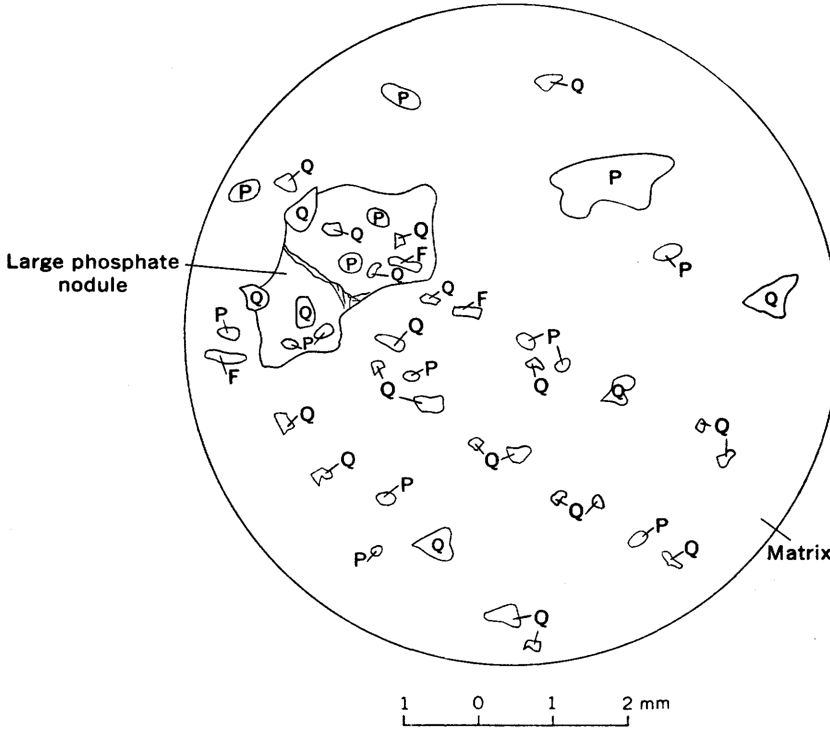


FIGURE 6.—Sketch of thin section of limestone of the Hawthorn formation, showing a phosphate nodule replacing carbonate matrix. Matrix is a very fine grained mixture of carbonate and clay dust with an average diameter of less than 0.02 mm. Fracture across center of nodule is cemented with phosphate. The quartz (Q), phosphate (P) and feldspar (F) grains are cemented by phosphate, mixed with clay and carbonate.

TABLE 4.—*Partial chemical analyses of limestone of the Hawthorn formation*

[Oxide analyses by Frank Grimaldi; uranium analyses: sample 621-33B, Leonard Shapiro and H. B. Kessler; sample 611-30I, A. L. White]

Lab. and sample no.	Constituent, in percent						Field description
	P_2O_5	CaO	MgO	Al_2O_3	Fe_2O_3	U	
621-33B [1]	6.8	28.6	12.7	3.0	0.4	0.001	Limestone (bedrock).
611-30I [2]	21.7	24.9	9.9	1.5	.9	.001	Weathered dolomite "rotten limestone" (bedrock).

[1] From bottom of pit of the Eleanor mine, sec. 16, T. 30 S., R. 22 E.
[2] From bottom of pit of the Boyette mine, sec. 13, T. 31 S., R. 21 E.

Phosphate particles in the bedrock have been separated and analyzed from only a few samples. The P_2O_5 content of these particles ranges from 14 to 31 percent and averages about 18 percent (Cathcart and McGreevy, 1959). The uranium content averages less than 0.005 percent. Analyses of the other constituents are too few for any general-

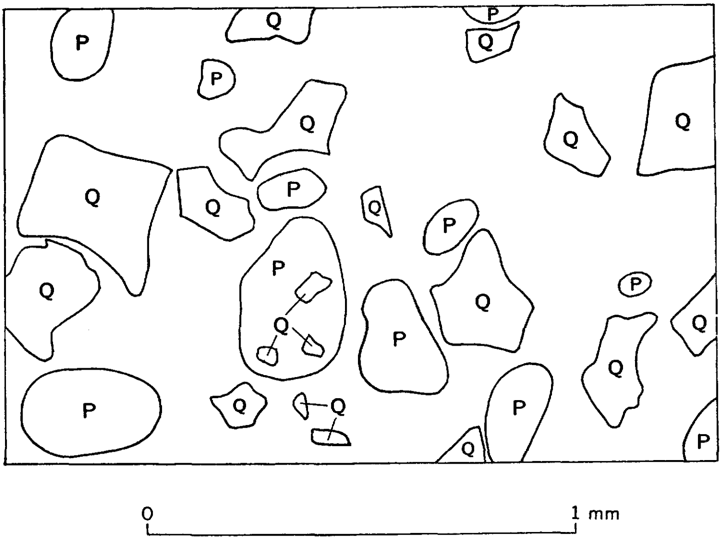


FIGURE 7.—Sketch of thin section of phosphatic limestone of the Hawthorn formation, showing phosphate (P), and quartz (Q) grains in a very fine grained matrix of carbonate and clay.

izations to be made, except that generally the CaO content is high and the MgO content is low.

The bedclay is a green, gray-green, or white plastic water-saturated calcareous clay that contains sand-sized quartz and phosphate grains and that is texturally identical with the underlying bedrock. The bedclay contains more quartz and phosphate and less carbonate than the underlying bedrock. For example, the bedrock at the Boyette mine in sec. 13, T. 31 S., R. 21 E., was estimated to contain 15 percent quartz, 10 percent phosphate nodules, and 75 percent carbonate and clay, whereas the overlying residual bedclay contained an estimated 30 percent quartz, 20 percent phosphate nodules, and only 50 percent carbonate and clay.

HAWTHORN-BONE VALLEY CONTACT

The contact between the Hawthorn and Bone Valley formations is nonconformable. It is almost always near the base of the mining pits and, because of slumping, is seldom seen. The contact is difficult to detect from drilling because cuttings of the bedclay (Hawthorn residuum) are similar to cuttings of the lower phosphorite of the Bone Valley. However, in some mine exposures in the Keysville quadrangle a stratigraphic break between the massive, structureless residuum of the Hawthorn (the bedclay) and the bedded phosphorite of the Bone Valley formation can be seen.

Detailed contact relations between the Bone Valley and the Hawthorn formations are shown in figures 5 and 8. Figure 8 is a sketch of location M–10, sec. 16, T. 30 S., R. 22 E., at the Eleanor mine. At this locality, the bedrock is a buff to cream sandy, clayey dolomite or dolomitic limestone of the Hawthorn formation with a trace of fine- to medium-grained phosphate particles. It grades upward to gray calcareous sandy clay that contains more abundant phosphate nodules. Texturally, the bedclay and bedrock are identical. The fact that the contact of the bedclay and bedrock at this locality passes through the center of a large phosphate nodule (fig. 8) proves this is a leaching contact; the contact is indistinct and gradational over a few inches. The bedclay at the Eleanor mine is obviously a residuum of the hard dolomite beneath.

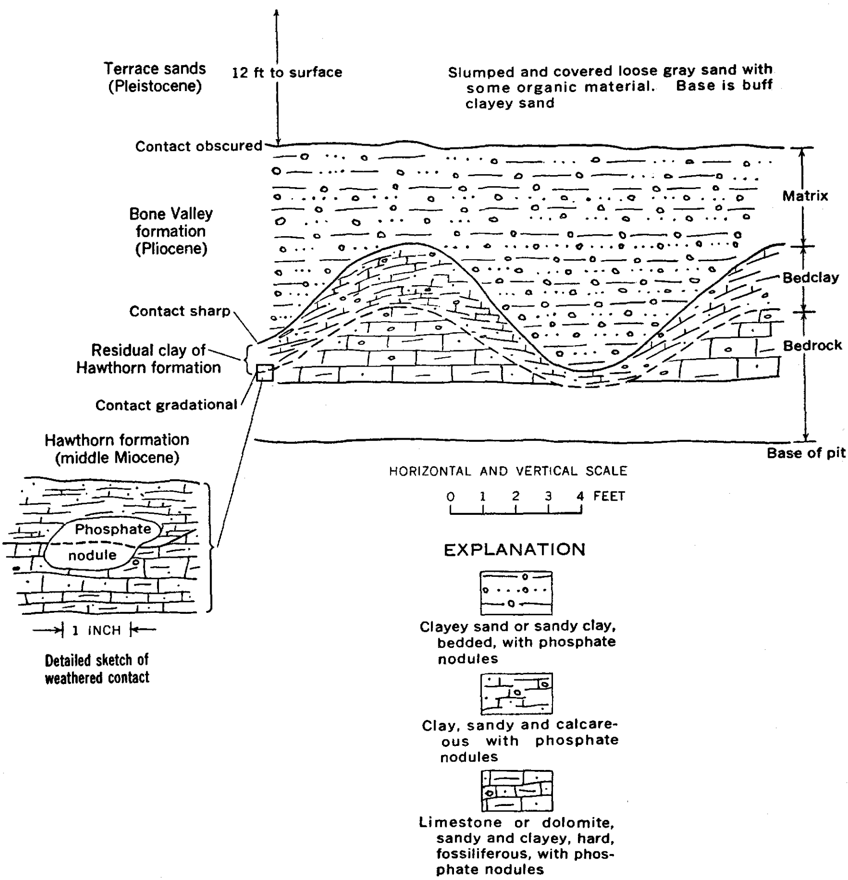


FIGURE 8.—Sketch of contact between the Bone Valley and Hawthorn formations, Eleanor mine, Location M–10, SE¼NE¼, sec. 16, T. 30 S., R. 22 E.

The contact of the residual bedclay with the bedded phosphorite above is sharp and irregular, and the contrast between the massive, structureless bedclay and the bedded phosphorite is clear and striking. At location M–10, slumping above the phosphorite covered the contact of the Bone Valley formation and the overlying sediments.

At location O–14, sec. 23, T. 31 S., R. 21 E., at the Boyette mine (fig. 5), green laminated clay with a trace of phosphate particles and with only minor quartz overlies calcareous sandy clay, also with a trace of phosphate nodules. The contact between the green clay and the calcareous clay is nearly flat-lying—slumping and the high level of water in the pit prevented accurate measurement of the dip of the contact. Elsewhere in the Boyette pit the laminated clay is lenticular and overlies hard dolomite. The lower unit of the Bone Valley formation, bedded phosphorite sand containing abundant coarse black phosphate nodules and only minor clay, unconformably overlies both the calcareous clay and the laminated clay at location O–14. Borings, which extend vertically downward into both the calcareous clay and the laminated clay, are filled with phosphate sand identical with the material above. The content of phosphate nodules in the Bone Valley formation is about 37 percent by volume, whereas both the underlying laminated and calcareous clays of the Hawthorn formation contain less than 1 percent phosphate nodules. The clay content of the phosphorite of the Bone Valley, on the other hand, is much less than the clay content of the underlying beds of the Hawthorn formation at this location.

These examples indicate that the relations between the Bone Valley and Hawthorn formations are unconformable or disconformable. Other examples can be inferred from cross sections compiled from drilling information. In most of the quadrangle, exposures are poor and drill data are not clear; therefore the contact relations cannot be observed directly.

PLIOCENE SERIES

BONE VALLEY FORMATION

The name "Bone Valley gravel" was first used by Matson and Clapp (1909, p. 138–141); they divided the formation into lower beds containing abundant phosphate nodules, which could be profitably mined, and upper beds, which were noneconomic, and contained only traces of phosphate. The name was later changed to Bone Valley formation because gravel makes up only a small part of the formation (Sellards, 1910, p. 33).

Age.—The Bone Valley formation is generally regarded as Pliocene in age on the basis of vertebrate fossils (Simpson, 1929; Brodkorb, 1955). Few fossils have been found in the Bone Valley formation in the Keysville quadrangle. A tooth found in the lower phosphorite member of the Bone Valley formation at the Boyette mine was identified by C. L. Gazin of the U.S. National Museum (written communication, 1952) as:

A single tooth, broken on arrival, but apparently not worn and presumably not reworked, looks very much like the Pliocene *Teleoceras proterus*, but I would not like to say that it could not be a Miocene form.

The Bone Valley formation may be very late Miocene in age, at least in part. In Hardee and DeSoto counties, Bergendahl (1956) showed an interfingering of "undifferentiated phosphate," in part equivalent to the Bone Valley formation, with a sand containing very late Miocene invertebrate fossils. The transgressing sea which deposited the Bone Valley formation may have started to move northward in the latest Miocene and may have reached the area of the Keysville quadrangle during the early Pliocene.

Although the exact age of the Bone Valley formation is questionable, it is younger than, and separated by an interval of erosion from, the Hawthorn formation of middle Miocene age. The Bone Valley formation is overlain by loose sand of probable Pleistocene age, in some places with a disconformable contact. A soil profile of Pleistocene age is clearly younger than and is superimposed on the aluminum phosphate zone, a weathering profile formed on the Bone Valley formation. This relation indicates that there is a stratigraphic break between the Bone Valley formation and the overlying Pleistocene sand. Thus, the Bone Valley formation is younger than middle Miocene and older than Pleistocene.

DISTRIBUTION AND THICKNESS

The Bone Valley formation is divided into two units: a lower, phosphorite unit and an upper, clayey sand unit. The upper unit generally contains only minor amounts of phosphate nodules.

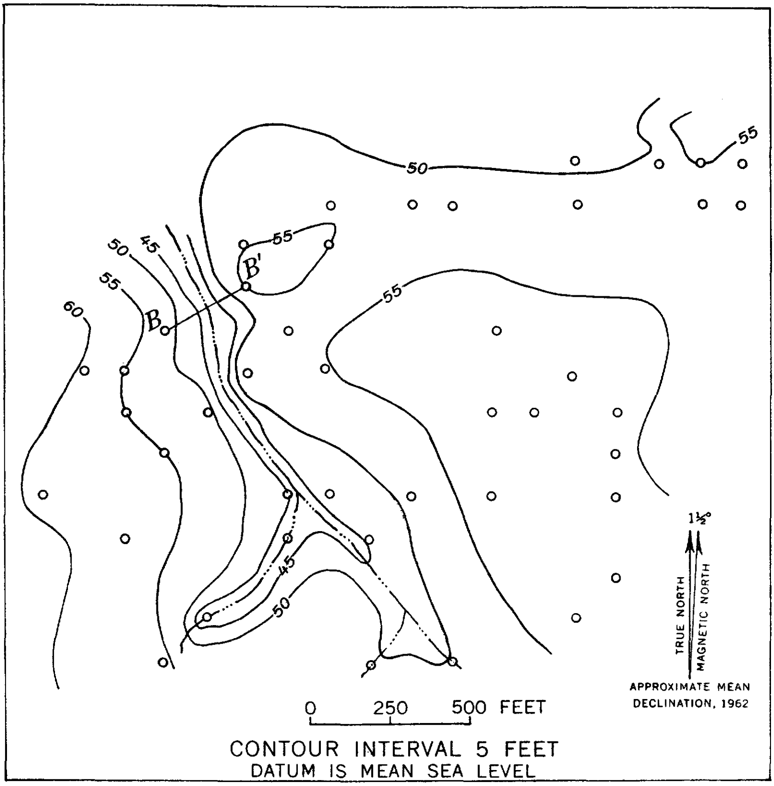
The lower unit underlies the entire quadrangle, except along the present streams and along the buried courses of pre-Pleistocene streams where the unit has been removed by erosion. The lower unit ranges in thickness from 0 at the present streams to more than 50 feet in sec. 9, T. 31 S., R. 23 E. The unit probably averages about 15 feet in thickness.

The upper, clayey sand unit differs from the lower unit in an abrupt lessening in the amount of phosphate nodules. The contact between the two units in gradational. The change from one unit to the other takes place over a few inches, and the abrupt change in phosphate content makes the contact appear very sharp. The geologic map (pl. 1) shows the general distribution of the upper unit of the Bone

Valley formation. As shown on this map, the upper unit also underlies the entire quadrangle except where it has been removed along present-day streams. The upper unit ranges in thickness from 0 along the streams to a maximum of more than 20 feet, but probably averages less than 10 feet in thickness.

UPPER SURFACE

The irregular upper surface of the Bone Valley formation follows, in general, the present surface topography. Figure 9 is a



EXPLANATION

o
Drill hole
Holes drilled by Coronet Phosphate Co.

———···———··——
Buried stream course
Pleistocene or pre-Pleistocene

FIGURE 9.—Contour map of the erosion surface on the Bone Valley formation, NE¼ sec. 16, 2. 30 S., R. 22 E., Eleanor mine. Section *B–B'*, across a channel, is shown on plate 4. At the channel, the Bone Valley has been eroded, and loose sand rests on the Hawthorn formation.

contour map of the upper surface of the Bone Valley formation in a small area in sec. 16, T. 30 S., R. 22 E., at the Eleanor mine. No surface stream is in this area. The channel (fig. 9) was filled with loose quartz sand of probable Pleistocene age, hence, the channel was probably cut by an early Pleistocene stream. Other channels probably are in the area but data are inadequate to delimit them.

PHYSICAL CHARACTERISTICS

The lower unit of the Bone Valley formation consists of interbedded and lenticular sand, clay, clayey sand, sandy clay, and gravel, all containing varying amounts of brown, tan, amber, red, black, gray, and white phosphate nodules. The nodules are highly polished, all are well rounded, and they range from less than 0.1 mm to several centimeters in diameter. Although individual beds vary from almost barren clay or sand to almost all phosphate nodules, the lower unit, as mined, contains nearly equal amounts of quartz sand, phosphate sand or gravel, and slime.

The lower unit is bedded, crossbedded, and locally shows good graded bedding.

The lenticular individual beds within the lower unit of the Bone Valley formation are shown in plate 3 and figure 10. Individual beds are irregular; they pinch and swell, and can be traced only for short distances; they range from slightly clayey sand to slightly sandy clay. The clay bed (bed 6, fig. 10) contains practically no visible phosphate, but assays showed 13.3 percent P_2O_5. Assays of the beds above and below bed 6, which contain abundant visible phosphate, showed more than 20 percent P_2O_5. Bed 8 just below the leached material of bed 9 is sand, with little phosphate, and contains only 11.7 percent P_2O_5. The bedclay matrix (bed 1) at the base of the section contained only 12.4 percent P_2O_5, and the contact between Hawthorn and Bone Valley formations is marked by a very thin, irregular crust of phosphate (bed 2) possibly precipitated because of the chemical changes at the top of the calcareous clay.

The upper unit of the Bone Valley formation is a clayey sand. It is usually gray to white or greenish-gray and normally contains visible phosphate nodules only at its base. The contact between the upper and lower units is gradational over a few inches, through upward diminution in amount of phosphate particles; this contact forms the upper limit of economic phosphate. However, because phosphate nodules are sparse in the upper unit, the economic contact coincides with the stratigraphic contact.

Variations in thickness and lithology of the upper and lower units of the Bone Valley formation are shown in the following stratigraphic sections.

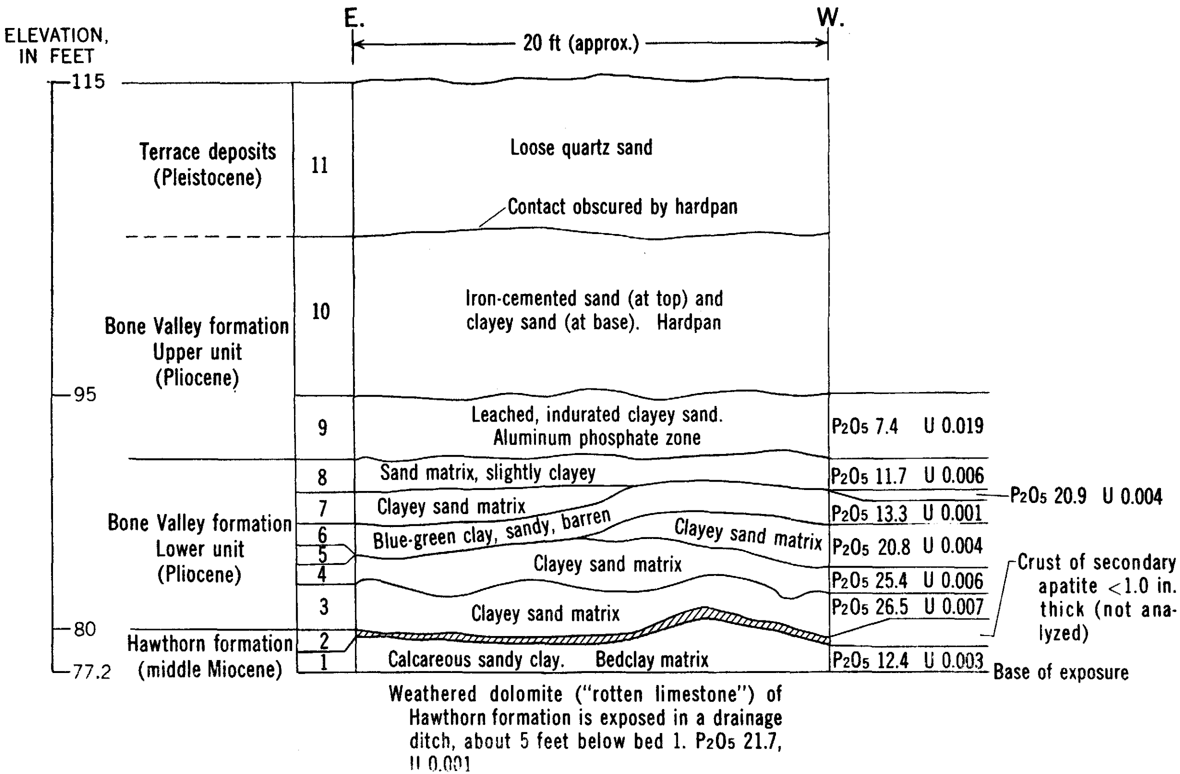


Figure 10.—Lithologic section, Boyette mine, sec. 13, T. 31 S., R. 21 E., showing interfingering of beds in the Bone Valley formation. The clayey sand matrix beds (3, 4, 5, and 7) are easily distinguished in the field by their physical properties (color, amount, size, color of the phosphate nodules, and so forth). (Uranium analyses by D. Venesky and A. L. White, P_2O_5 analyses by F. S. Grimaldi, U.S. Geological Survey. All analyses are in percent.)

Log C.—Drill hole in sec. 6, T. 29 S., R. 21 E.

[Assay data by American Cyanamid Co.; published with permission]

	Feet
Pleistocene:	
Terrace sands: Sand, quartz, loose	12.0
Total terrace sands	12.0
Pliocene:	
Bone Valley formation (upper unit): Sand, tan-gray, clayey, leached	3.0
Bone Valley formation (lower unit):	
Clay, brown, sandy, with soft white phosphate nodules; leached	7.0
Sand, tan, slightly clayey, with abundant white and tan phosphate nodules; 50 percent quartz, 25 percent phosphate nodules, 25 percent slime	5.0
Total Bone Valley	15.0
Miocene:	
Hawthorn formation: Clay, white, sandy, calcareous, with a trace of very fine grained black phosphate nodules.	
Bottom of drill hole.	

The two leached beds in the Bone Valley were analyzed as a unit; they contained 14 percent P_2O_5 and 0.016 percent U_3O_8. The phosphate nodules in the lower bed of the lower unit of the Bone Valley formation contained 34 percent P_2O_5.

The drill hole penetrated 22 feet of strata assigned to the overburden and 5 feet of minable phosphorite. The overburden includes the loose quartz sand, the clayey sand of the upper unit of the Bone Valley formation, and the top bed of the lower unit of the Bone Valley formation. The aluminum phosphate zone is the bottom 10 feet of the overburden, and includes both the top of the lower unit of the Bone Valley formation and all the upper unit. The sharp break in lithology between calcareous clay of the Hawthorn formation and phosphorite of the lower unit of the Bone Valley formation is evident.

Log D.—Drill hole in sec. 21, T. 30 S., R. 21 E.

	Feet
Pleistocene:	
Terrace sands: Sand, tan to white, loose, fine- to medium-grained	17.0
Total terrace sands	17.0
Pliocene:	
Bone Valley formation (upper unit): Sand, white, clayey; trace of white phosphate at base; leached	6.0
Total, upper unit of Bone Valley	6.0
Bone Valley formation (lower unit):	
Clay, white, sandy, with soft white phosphate; leached	2.0
Sand, green and gray, clayey; abundant white and tan phosphate nodules; both sand and phosphate coarser at base	3.0
Clay, rust and green; trace of dark-brown phosphate	5.0
Sand, gray, clayey; white and tan phosphate nodules abundant; both sand and phosphate coarser at base	5.0
Total, lower unit of Bone Valley	15.0

Log D.—Drill hole in sec 21, T. 30 S., R. 21 E.—Continued

	Feet
Miocene:	
Hawthorn formation: Clay, white, sandy, calcareous, with a trace of fine black phosphate	3.0
Hole bottomed in hard rock (limestone?).	

The cuttings suggest graded bedding in this hole. The sand beds of the lower unit of the Bone Valley formation are coarser toward the base and are separated by a barren clay bed; the green and gray clayey sand bed grades upward into the white sandy clay bed at the top of the lower unit of the Bone Valley formation. The phosphate nodules are fine grained in the clay beds, and are increasingly coarse grained toward the base of the sand beds.

The aluminum phosphate zone includes the upper unit and the top bed of the lower unit of the Bone Valley formation. The calcium phosphate zone is the rest of the lower unit of the Bone Valley and the calcareous clay of the Hawthorn formation. The matrix, however, does not include the calcareous clay of the Hawthorn, which contains too little phosphate to be minable.

Log E.—Section at the Eleanor mine near the Alafia River in sec. 16, T. 30 S., R. 22 E.

	Feet
Pleistocene:	
Terrace sands: Sand, loose, white; some organic material in top 1 foot	8.0
Total, terrace sands	8.0
Pliocene:	
Bone Valley formation (upper unit?): Clay, sandy, gray	1.0
Bone Valley formation (lower unit):	
Sand, pebbly, brown; very abundant coarse phosphate nodules, particularly at the base; only a trace of clay. Drift rock	7.0
Total, Bone Valley	8.0
Miocene:	
Hawthorn formation: Limestone or dolomite, buff, sandy, clayey; exposed only in ditch in the bottom of the pit. Contact between limestone and pebbly sand not exposed. Area between ditch and pebbly sand covered. Vertical distance between top of limestone or dolomite and pebbly sand about 2 feet.	

The gray sandy clay is assigned to the upper unit of the Bone Valley formation, but the unit is very thin, contains somewhat more clay than the normal upper clayey sand, and is so close to the Alafia River that it could be a flood-plain deposit of Pleistocene age. The pebbly sand of the lower phosphorite unit of the Bone Valley formation is not leached. The phosphate nodules are brown, highly polished, hard, and compact. Although the phosphate content of the nodules is not known, the area was mined and the grade must have been in excess of 31 percent P_2O_5. The phosphorite, then, is probably a part of the lower unit of the Bone Valley formation rather than a flood-plain deposit (river-pebble). River pebble seldom contains more than 25 percent P_2O_5, and most samples contain less; furthermore, river-pebble shows some evidence of leaching, and the nodules are visibly porous, or are dull, and are usually black.

In sec. 26, T. 30 S., R. 22 E., the upper unit of the Bone Valley formation and the loose sand assigned to the Pleistocene are thick, as indicated by log F; the lower unit of the Bone Valley is 20.5 feet thick, slightly more than average. The calcium phosphate zone includes both the Hawthorn and the Bone Valley formations, but the matrix consists only of the lower three beds assigned to the Bone Valley formation.

Log F.—Drill hole in sec. 26, T. 30 S., R. 22 E.

	Feet
Pleistocene:	
Terrace sands: Sand, loose, quartz; black at top, then gray to white at base	21.0
Total, terrace sand	21.0
Pliocene:	
Bone Valley formation (upper unit): Sand, buff, clayey	23.0
Total upper unit of Bone Valley	23.0
Bone Valley formation (lower unit):	
Clay, gray and buff, sandy, with abundant black and some white phosphate nodules	10.0
Clay, sandy, gray-green, with abundant pebble-size phosphate nodules	6.0
Clay, sandy, green, with abundant black pebble-size phosphate nodules	4.5
Total, lower unit of Bone Valley	20.5
Miocene:	
Hawthorn formation:	
Clay, buff, sandy, calcareous, with a trace of phosphate nodules	6.5
Clay, green, sandy, calcareous, with pebble-size phosphate nodules	3.0
Limestone, or dolomite, buff to light-gray, sandy and clayey. Some black and tan phosphate	—
Bottom of drill hole. Partial total, Hawthorn	9.5

Log G.—Drill hole in sec. 35, T. 30 S., R. 22 E.

[Driller's log]

	Feet
Pleistocene:	
Terrace sands: Sand, loose, quartz	13.0
Total, terrace sands	13.0

Log G.—Drill hole in sec. 35, T. 30 S., R. 22 E.—Continued

	Feet
Pliocene:	
Bone Valley formation (upper unit):	
Sandrock, hard, probably clayey sand cemented by aluminum phosphate minerals	7.0
Clay, stiff	16.0
Clay, brown	2.0
Total, upper unit of Bone Valley	25.0
Miocene:	
Hawthorn formation:	
Bedclay, soft, blue, with white and black phosphate nodules	5.0
Partial total, Hawthorn	5.0
Bottomed in bedrock.	

All the calcium phosphate zone at locality G is assigned to the Hawthorn formation. A calcareous clay, called bedclay by the driller, is probably a part of the Hawthorn formation. The clay beds assigned to the Bone Valley formation are perhaps in the Hawthorn; if so, only the hard sandrock bed—the aluminum phosphate zone—is Bone Valley.

Log H.—Drill hole in sec. 9, T. 31 S., R. 23 E.

[Driller's log]

	Feet
Pleistocene:	
Terrace sands:	
Sand, loose, quartz	3.0
Sand, loose, quartz, with fragments of sandrock	5.0
Total, terrace sands	8.0
Pliocene:	
Bone Valley formation (upper unit):	
Clay, sandy	8.0
Sand, clayey, with some sandrock	8.0
Sand, slightly clayey	6.0
Total upper unit of Bone Valley	24.0
Bone Valley formation (lower unit): Matrix, clayey	46.0
Total lower unit of Bone Valley	46.0
Miocene:	
Hawthorn formation: Bedclay	1.0
Partial total, Hawthorn	1.0
Bottomed in hard bedrock.	

The above log is included because it shows the thick section of the lower unit of the Bone Valley as all matrix. Some of this matrix may be in the Hawthorn formation, but the matrix was not divided by the driller; a contact may be within the 46-foot thick bed.

Log I.—Drill hole near the Alafia River in sec. 11, T. 30 S., R. 21 E.

[Driller's log]

	Feet
Pleistocene or Recent:	
Undifferentiated sand: Sand, loose, white, quartz	12.0
Miocene:	
Hawthorn formation: Hard bedrock (limestone or dolomite)	——
Bottom of drill hole.	

Log I shows a typical section very close to a major river. Loose quartz sand of Pleistocene or Recent age rests directly on hard limestone or dolomite of the Hawthorn formation. Both units of the Bone Valley formation and weathered material of the Hawthorn formation are missing.

STRATIGRAPHIC RELATIONS

The contact of the Bone Valley formation with the underlying Hawthorn formation is unconformable or disconformable (p. 26). The contact of the Bone Valley formation and the overlying loose sand of Pleistocene or Recent age is also nonconformable. In most places, the contact between clayey sand of the upper unit of the Bone Valley formation and loose quartz sand of the Pleistocene is gradational over very short vertical distances. However, drill logs A through I show that loose sands may overlie the hard dolomite of the Hawthorn, the leached or unleached lower unit of the Bone Valley formation, or the upper unit of the Bone Valley. This relation indicates stripping by erosion prior to the deposition of the loose quartz sand.

The contact between the Bone Valley formation and the sand of Pleistocene age is irregular and is marked by channels cut into the Bone Valley or into the Hawthorn and filled with loose quartz sand of Pleistocene age. In addition, carbonaceous clay and lenses of reworked fragments of phosphorite and of aluminum phosphate-cemented sand from the Bone Valley formation are at the base of or in the loose sand assigned to the Pleistocene.

Plate 4 shows the details of two of the channels and the irregular and unconformable relations between the Bone Valley formation and the terrace sands of Pleistocene age at the Eleanor mine.

The contact of the Bone Valley formation and the sand of Pleistocene age is placed at the contact of the loose sand with the underlying clayey sand.

PLEISTOCENE SERIES

TERRACE SANDS

Loose quartz sand ranging in thickness from 0 to about 30 feet overlies the Bone Valley formation throughout the Keysville quadrangle. MacNeil (1950, p. 99) recognized four marine shorelines in the

Pleistocene: one at 150 feet, one at 100 feet, one near 30 feet, and the youngest at 10 feet. He regarded all these shorelines as inland limits of marine transgressions.

The sand of the Pleistocene terraces is well sorted, and consists of fine- to medium-grained quartz, with a trace of "heavy" minerals, almost always including some apatite, and practically no clay. Quartz grains are clear or milky, and commonly are stained yellow or brown with iron compounds, or black, with organic material. Hardpan, a sand cemented with iron oxide, is common but not persistent, and is not confined to rocks of Pleistocene age. Clayey sand of the upper unit of the Bone Valley formation may be cemented by iron when it is close to the present surface. The relations of the iron-cemented sand (hardpan) to stratigraphy are clearly shown in plate 5. In places, the hardpan is entirely within the loose quartz sand of probable Pleistocene age. Elsewhere it is in the clayey sand of the upper unit of the Bone Valley formation, or it is within both units and the contact is obscure (fig. 10). In some places, hardpan directly overlies, and may extend into, the lower phosphorite unit of the Bone Valley formation.

The contact between the Bone Valley formation and the sands of Pleistocene age has been discussed on page 37. In areas where all the available information is from drill cuttings, the contact is arbitrarily placed between the loose sand and the clayey sand.

Much of the clastic material in the terrace sands of Pleistocene age was undoubtedly derived from the underlying clayey sand of the upper unit of the Bone Valley formation. Probably only minor amounts of primary clastic material were deposited. Thus the upper unit of the Bone Valley formation is lithologically very similar to the sands of the Pleistocene; they differ only in the amount of clay.

One lower cheek tooth of a bison of Quaternary age (C. L. Gazin, written communication, 1952) has been found in the loose sand in the Keysville quadrangle. Invertebrate marine fossils are found only in the sand of the two lower shorelines, the 10- and 30-foot shorelines. Fossil shells of the higher, and older, shorelines may have been removed by leaching by the acid ground waters.

The evidence presented by MacNeil (1950) regarding the marine features of these shorelines, combined with the meager fossil evidence, indicates that the terrace deposits are marine. Higher sediments above 150 feet in elevation may be fluviatile.

RIVER-PEBBLE DEPOSITS

Deposits of phosphorite and of quartz sand in the flood plains and bars along the Alafia River and its tributaries were eroded from the phosphorite of the lower unit of the Bone Valley formation and of the Hawthorn formation. Fine sand, phosphate, and clay have been removed by the sorting action of the stream and have left behind a concentration of pebble-size phosphate nodules and some quartz grains. These river-pebble deposits probably range in age from early Pleistocene to the present.

RECENT DEPOSITS

Windblown sand, soil, swamp deposits, and muck at the surface are probably of Recent age. The deposits are surficial and, at the Eleanor mine, for example, overlie the sands filling channels. A thin surficial deposit of peat overlies loose sand in a restricted area at the Sydney mine.

STRUCTURE

In general, the structure of the Keysville quadrangle is simple. The formations dip gently to the southeast away from the Ocala uplift. Minor structural features are very difficult to determine in the quadrangle because only a few deep drill holes reach the top of the Ocala limestone. The contour map on the top of the Hawthorn formation (pl. 2) cannot be used to interpret structure because it represents an erosion surface; the erosional relief is much greater than the structural relief.

A cross section (fig. 11) across the Keysville quadrangle was con-

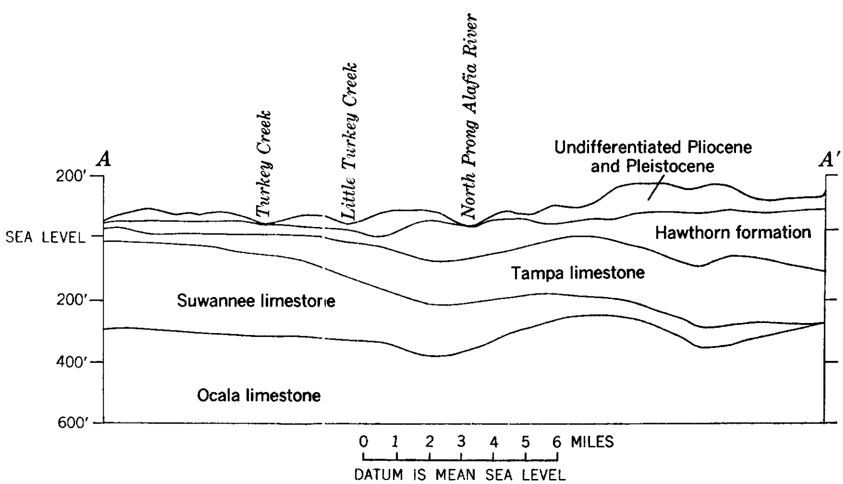


FIGURE 11.—Cross section showing general structure of the Keysville quadrangle. See figure 2 for line of section. Data from deep wells; surface of Ocala limestone in part from Vernon (1951, pl. 2).

structed by using all available deep-well logs plus the structure map of the Ocala limestone by Vernon (1951, pl. 2).

The cross section must be interpreted with caution because each of the formations is separated from the other formations by erosional breaks. However, the rise in the upper surface of the Ocala limestone in the southeastern area of the section seems too large to be an erosional feature. This rise is reflected in the Suwannee and Tampa limestones, and in addition, is opposite to the regional dip. The sharp rise, therefore, possibly represents a small southwest-trending anticline.

The Hawthorn formation is not as strongly affected by the folding as are the underlying formations. The top surface of the Hawthorn, however, has been strongly modified by erosion; both Turkey Creek and the Alafia River have cut down through the surficial sediments and are flowing on the Hawthorn formation. Therefore, folding probably began prior to the deposition of the Hawthorn and continued after its deposition; it probably was contemporaneous with the folding of the Ocala uplift (Cooke, 1945; Vernon, 1951).

No faults have been noticed in the quadrangle except for very small slump faults around sinkholes.

Recent tilting of the Florida peninsula toward the west is suggested by the shape of the coast lines. On the west coast, Tampa Bay and Charlotte Harbor are typical drowned river valleys; the west coast is submergent. The east coast is almost straight; it resembles a coast line of emergence.

Tilting may be inferred also from the outcrops of limestone of the Hawthorn in the valleys of streams and at elevations higher than would normally be expected toward the heads of streams. Limestone of the Hawthorn is at much higher elevations in the eastern part of the quadrangle than in the western part. Although the surface of the Hawthorn is similar to the present surface (topographic highs on the Hawthorn surface tend to be under the present ridge), the surficial sand beds are much thicker under the present ridge than they are on the adjacent flatwoods areas. Present stream valleys also cut deeper into the ridges than they do into the flatwoods, but not deep enough to explain the outcrop of limestone of the Hawthorn in the stream valleys high on the present ridge. Westward tilting of the Florida peninsula may explain this feature.

MINERALOGY

The principal minerals of the aluminum phosphate zone are apatite, crandallite, millisite, and wavellite, and of these, crandallite (calcium-aluminum phosphate) and wavellite (aluminum phosphate) are the most abundant (Altschuler and others, 1956, p. 498).

The distribution of the minerals in the aluminum phosphate zone is shown in the following section. The samples were taken from a face at the Boyette mine; they were screened at 200 mesh, and the −200 mesh fraction was analyzed in the X-ray diffractometer. The X-ray diffractometer trace was interpreted by L. V. Blade of the Geological Survey.

Face section at the Boyette mine, SE¼NW¼ sec. 11, T. 31 S., R. 21 E.

[Mineral constituent: Q, quartz; K, kaolinite; C, crandallite; W, wavellite; M, montmorillonite; A, apatite; Ca, calcite; At, attapulgite]

Epoch	Formation	Bed			
		Character	Mineral constituent		Thickness (feet)
			Major	Minor	
Pleistocene	Terrace sands	Loose white quartz sand	Q		2.5
		Loose brown quartz sand	Q		5.0
		Loose gray sand	Q		1.0
		Organic black sand	Q	K	2.0
Pliocene	Bone Valley: Leached upper unit.	Clayey sand with lumps of aluminum phosphate-cemented sand (sandrock).	K, C, W	Q	3.5
	Leached lower unit.	Sandy clay with soft white phosphate nodules.	M, K, C, A	Q, W	2.0
	Unleached lower unit.	Phosphorite (matrix)	M, A	Q, C, W, K	2.0
		do	A	M, Q, W, K, C, Ca(?)	1.5
		do	M, A	Ca, Q, C	1.0
		do	M, A	Ca, Q	1.0
Micoene	Hawthorn	Calcareous clay	M, A, Q	Ca, At(?)	1.0

The mineral distribution in this section is probably due to downward leaching by acid ground waters.

In the leached upper unit of the Bone Valley formation, kaolinite is the principal clay mineral and crandallite and wavellite are the phosphate minerals. The highest appearance of apatite and montmorillonite is in the leached lower unit of the Bone Valley formation, and here wavellite is a minor constituent.

In the unleached lower phosphorite of the Bone Valley formation, apatite and montmorillonite are major constituents, and wavellite and crandallite are minor constituents. However, wavellite is present only in the upper two beds, crandallite in all but the lower bed, and calcite as a minor constituent in the basal beds of the Bone Valley formation. In the Hawthorn formation, quartz, apatite, and montmorillonite are major constituents, and calcite and attapulgite(?) are minor constituents.

WEATHERING AND EROSION

The exact history of weathering and erosion in the mapped area is difficult to decipher because of poor outcrops. However, at least three, and probably four, weathering periods altered the rocks in the land-pebble phosphate district. Three of these periods are represented by soil profiles. The oldest of these is the weathered zone on the phosphate deposits; soils of intermediate age are represented by the Leon soil; the youngest soils are thin and only slightly leached (Hunt and Hunt, 1957). An earlier period of weathering which antedates the earliest soil profile occurred between the deposition of the Hawthorn and the Bone Valley formations. The weathering then was largely chemical; it produced a calcareous clay that was residually enriched in phosphate nodules, and formed a karst topography on limestone of the Hawthorn formation. The residuum on the Hawthorn formation was reworked into the Bone Valley formation. Unweathered limestone boulders and fragments were phosphatized, rolled, and rounded. After deposition, the Bone Valley formation was weathered; the weathered zone formed the oldest soil profile on the phosphate deposit. During this weathering, phosphate minerals were dissolved, and phosphate and alumina from clay minerals combined to form aluminum phosphate minerals. The clay minerals in the zone of weathering were altered from montmorillonite to kaolinite (Altschuler and others, 1956, p. 502). The limestone of the Hawthorn formation, underlying the Bone Valley formation, was dolomitized, and a zone of calcareous clay high in MgO content is commonly between the hard dolomite and the phosphorite of the Bone Valley formation. Phosphate nodules of the Bone Valley formation contain only traces of MgO; many are phosphatized limestone fragments, and they contain the same fossils as the Hawthorn formation beneath. Dolomitization therefore is younger than the phosphatization of the limestone. Dolomitization and the development of the calcareous clay are related to the pre-Pleistocene surface. Deep-well logs show that unaltered carbonate rock in the Hawthorn formation is limestone (Berman, 1953) and that calcareous clay, derived from carbonate rock of the Hawthorn formation, is present only when the Hawthorn is close to the surface.

The calcareous clay and the dolomite of the Hawthorn formation probably formed at the same time as the aluminum phosphate zone.

The magnesium that altered the limestone to dolomite perhaps was derived from montmorillonite during alteration to kaolinite. Montmorillonite ($5Al_2O_3 \cdot 2MgO \cdot 24SiO_2 \cdot 6H_2O$ (Na_2O, CaO)) contains an average of 3.42 percent MgO, but kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) contains an average of only 0.20 percent MgO (Kerr and others, 1950).

A soil profile, the Leon soil (Fowler and others, 1927), overlies or is superimposed on the aluminum phosphate zone. The Leon soil is loose gray quartz sand at the surface, underlain by organic or iron-stained or cemented sand or clayey sand. The easily distinguished iron-cemented material is locally called hardpan. Hardpan may be entirely within loose sand of Pleistocene age or entirely within clayey sand of the upper unit of the Bone Valley formation, but it most commonly conceals the contact between the loose and the clayey sand (fig. 10). Plate 5 shows the variations in position of the hardpan and clearly indicates that the hardpan, and therefore the Leon soil profile, is superimposed on an earlier soil profile that formed the aluminum phosphate zone. The weathering which formed this soil profile is Pleistocene in age. According to Hunt and Hunt (1957, p. 799) "non-pottery" artifacts are found in the soil profile.

The youngest soils are difficult to see in the field, but according to Hunt and Hunt (1957, p. 799) "have developed on deposits containing pottery, which was first introduced into this region shortly before the beginning of the Christian era."

Erosion modified each of the weathering surfaces. The surface of the Hawthorn formation is a karst topography at higher elevations but shows stream patterns on lower elevations (pl. 2). The surface of the Hawthorn was modified by the transgressing sea in which the Bone Valley formation was deposited. The loose residual material was moved and sorted, and the low areas were filled, many of them with phosphorite from the lower part of the Bone Valley.

Stream channels cut into the Bone Valley formation during or following formation of the aluminum phosphate zone are filled with loose sand, or carbonaceous clayey sand of Pleistocene age, and in many places, this loose sand rests directly on unweathered phosphorite of the lower part of the Bone Valley formation.

ECONOMIC GEOLOGY

Phosphorite underlies the entire quadrangle, except where it has been removed along present and pre-Pleistocene streams. In 1962 mining was in progress at the Sydney mine of the American Cyanamid Co. in T. 29 S., R. 21 E., and at the Boyette mine of the American Agricultural Chemical Co. in T. 31 S., R. 21 E.

HISTORY OF MINING

River pebble was mined to the west of the Keysville quadrangle along the Alafia River beginning in 1888; mining continued for a few years. The Marvinia Phosphate Co. operated mines on both sides of the Alafia River, in secs. 17, 18, 19, and 20, T. 30 S., R. 21 E., west of Lithia Springs. Mining continued during 1898–99 and perhaps until 1904 (Wayne Thomas, written communication, 1958).

The first record of land-pebble phosphate mining in the Keysville quadrangle is from the Coronet Phosphate Co.'s Upper or Coronet mine in secs. 34 and 35, T. 28 S., R 22 E., and sec. 2, T. 29 S., R. 22 E., at the northern edge of the quadrangle. Mining was started prior to 1915 and continued until about 1921. Examination of the remaining pits and overburden dumps shows the area was mined by hydraulic methods. Washer debris (material finer than 14 mesh in size, and containing the flotation feed) was separated from the overburden piles, and therefore is available for remining and recovery of fine-grained phosphate. Coronet began to mine the Hopewell area in secs. 26–34, T. 29 S., R. 22 E., in 1921. Early mining was for pebble only; sometime during the 1930's flotation was first used to recover fine phosphate, and some of the segregated washer debris was mined. Mining ceased in the Hopewell area in 1945. Coronet moved to the Eleanor mine which was worked for pebble- and flotation-size phosphate from 1945 until 1950. The Eleanor mine is in T. 30 S., R. 22 E., both north and south of the Alafia River.

Swift & Co. mined part of secs. 3, 4, and 10, T. 30 S., R. 22 E., probably during the 1920's. The area probably was mined with steam shovels and by hydraulic methods. No data are available from this mining.

The American Agricultural Chemical Co. mined their Carmichael tract from 1930 to 1947 by dragline methods. Some washer debris was reported to have been remined and treated by flotation. This company began mining at the Boyette mine in 1945, and the mine was active in 1962. Draglines are used for mining, and flotation methods are used in processing.

The American Cyanamid Co. started mining their Sydney tract late in 1949. The mine was in operation in 1962. They mine with large draglines, and use flotation methods in processing.

The Phosphate Mining Co. (The Virginia-Carolina Chemical Corp.) operated a mine in T. 30 S., R. 23 E., near Nichols, Fla., many years ago. This area was mined by hydraulic methods.

CALCIUM PHOSPHATE ZONE

The calcium phosphate zone ranges in thickness from 0 to more than 50 feet; it underlies all the Keysville quadrangle except at the present streams, where it has been removed by erosion (pl. 6). The extent of erosion is shown by the hachured line on plate 6, which encloses areas underlain by 1 foot or less of calcium phosphate zone. The 1-foot contour line is emphasized because it best shows the extent of the calcium phosphate zone available for possible mining.

The zone is not a stratigraphic unit; it may consist of residual material of the Hawthorn formation, of phosphorite of the lower unit of the Bone Valley formation, or of both. Furthermore, the zone does not correspond exactly to the matrix, although the matrix is always a part of the calcium phosphate zone. The matrix, the material mined, may be nearly all a residuum from rocks of Miocene age, or may be nearly all reworked material of Pliocene age. Commonly, about two-thirds to three-fourths of the phosphate rock mined is reworked material of Pliocene age from the Bone Valley formation.

The differences between the matrix and the calcium phosphate zone are shown in logs A (p. 21) and F (p. 35).

The calcium phosphate zone at drill hole A consists of the lower unit of the Bone Valley formation and the basal bed of the Hawthorn formation. These two beds are separated by three beds of clay which contain little or no phosphate. The matrix is restricted to the upper bed of the calcium phosphate zone (the lower unit of the Bone Valley formation). The basal bed of the Hawthorn formation is not a part of the matrix because of thickness of the barren beds between it and the Bone Valley. The calcium phosphate zone at drill hole F includes all the lower unit of the Bone Valley formation plus the upper two beds of the Hawthorn formation, but only the beds of the Bone Valley formation contain enough phosphate of high enough P_2O_5 content to be economic. The upper two beds assigned to the Hawthorn formation, therefore, are excluded from the matrix.

The critical limits of the factors that separate economic from noneconomic deposits of phosphate have been considered elsewhere in some detail (Cathcart and McGreevy, 1959). These factors and their limits are enumerated in table 5.

TABLE 5.—*Critical limits of factors defining economic matrix*

[From Cathcart and McGreevy (1959, p. 241)]

	Maximum	Minimum
Cubic yards overburden per ton of product	15–20	
Cubic yards matrix per ton of product	5–7	
Thickness (in feet) of matrix		3.0
Tons per acre-foot of recoverable product		400.0
Percent BPL ($P_2O_5 \times 2.185$) in recoverable product		66.0
Percent combined iron and alumina (I&A) in recoverable product	5.0	

The factors shown in table 5 are not absolute; for example, the tons per acre-foot of recoverable product must be greater for the rock of lower BPL content than for that of the higher grades. In addition, because each company has slightly different standards, the figures are approximate.

Although lithology and thickness vary greatly from place to place, the matrix, as mined, consists of nearly equal parts of quartz sand, slime, and recoverable phosphate nodules. After disintegration in log washers, the matrix is washed over 14-mesh screens. The oversize is a product called pebble. The undersize is sent to hydroseparators, where the overflow—the slime fraction—is sent to settling areas, from which clear water is returned to the plant. The underflow of the hydroseparator is the flotation feed.

The flotation feed is separated into coarse (−14 to +35 mesh) and fine (−35 to +150 mesh) fractions. The coarse quartz and phosphate sands are separated on belts, spirals, agglomerating screens, or tables. The finer phosphate and quartz sands are separated in flotation cells. The quartz sand, called tailings, is a waste product; the phosphate sand, called concentrate, is the final product.

RELATIONS TO SURFACE OF THE HAWTHORN FORMATION

A comparison of plates 2 and 6 shows that the calcium phosphate zone, where it is thickest, overlies sinkholes or depressions on the surface of the Hawthorn formation.

In sec. 9, T. 31 S., R. 23 E., the thickest part of the calcium phosphate zone is in the deepest part of a small sinkhole. In sec. 6, T. 31 S., R. 23 E., the thick calcium phosphate zone is in a sinkhole on the Hawthorn surface, and adjacent to the sink, to the southwest, on a small basement ridge, the zone thins to less than 10 feet in thickness.

Many low areas on the Hawthorn surface, particularly those that are apparently through-going drainages, are overlain by thin calcium phosphate zone. Because most of the present drainage is in the same relative position as the drainage on the surface of the Hawthorn, these thin areas of calcium phosphate zone can be explained by subsequent erosion.

At almost every place where the calcium phosphate zone is more than 20 feet thick, it fills a depression on the surface of the Hawthorn formation.

The relation is not absolute. For example, in secs. 13 and 14, T. 31 S., R. 21 E., the calcium phosphate zone is represented by a series of small, closed 10-foot contour lines (pl. 6), which have no discernible relation to the surface of the Hawthorn (pl. 2) in this area.

Some sinkholes on the Hawthorn surface are not filled with abnormally thick calcium phosphate zone. For example, the depression in sec. 20, T. 31 S., R. 21 E., is overlain by an only average thickness of calcium phosphate zone. Possibly this sink formed after deposition of the phosphate, and prior to deposition of the upper unit of the Bone Valley.

RELATIONS TO THE OVERBURDEN

The isopach map of the overburden (pl. 7) is similar to the isopach map of the calcium phosphate zone (pl. 6) in that it shows a characteristic thinning of the overburden under the present streams. The overburden ranges in thickness from a featheredge to over 70 feet in a sinkhole in sec. 20, T. 29 S., R. 22 E. Except for such local thickening, the thickest overburden is generally in the southeastern part of the quadrangle, on the ridge, and in the western and southwestern parts of the quadrangle, where thicknesses in excess of 50 feet are common.

Except for thinning along streams, the relation of the calcium phosphate zone to the overburden is not consistent, although in some areas thick overburden overlies thin calcium phosphate zone.

PHOSPHATE NODULES

The phosphate nodules in the calcium phosphate zone are structureless and white, brown, amber, black, and gray except for a darker, more highly phosphatized rim on many of the coarse nodules. Mineralogically, the nodules consist of carbonate-fluorapatite, quartz, calcite, and extremely fine grained clay. Thin sections of the larger nodules show no evidence of growth around a nucleus; most of the coarse nodules are phosphatized limestone. Quartz sand grains and fine phosphate grains are common in the nodules, but show no preferred orientation. The smaller nodules are almost pure apatite; most contain a few grains of silt-sized quartz and minor amounts of calcite and clay. The clay is an iron-rich montmorillonite (Altschuler and others, 1956).

Most of the phosphate nodules are rounded; some are almost spherical, but others are very irregular in shape.

SIZE VARIATION OF PHOSPHATE NODULES

Cathcart and Davidson (1952, fig. 1) pointed out that the variation in phosphate particle size in the land-pebble district can be mapped and that it is related to both present and Hawthorn topography. Davidson (1952, p. 13) correlated phosphate-particle size and the topography of the Hawthorn formation: fine material (0.1 to 1.0 mm in diameter) is on lows on the Hawthorn surface, coarse material (1.0 mm to several centimeters in diameter) is on Hawthorn highs. He also noted that the relation changes along the course of the Peace River, where coarser material predominates.

Figure 12 shows the distribution of coarse and fine phosphate in the Keysville quadrangle in terms of the ratio of coarse phosphate particles (+14 mesh) to fine phosphate particles (−14 to +150

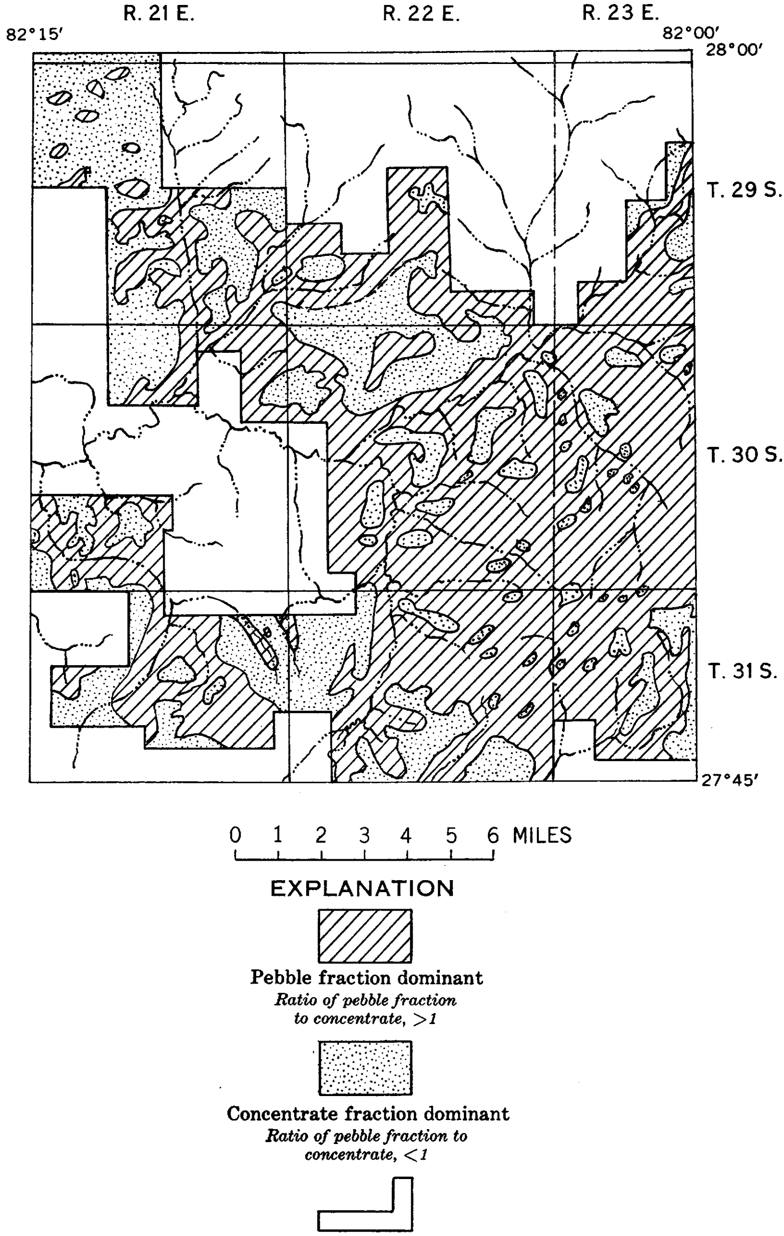


FIGURE 12.—Distribution of pebble and concentrate fractions in the calcium phosphate zone, Keysville quadrangle, Florida.

mesh). In general, the southeastern part of the quadrangle (a ridge area) is underlain by coarse material. In the remainder of the quadrangle, fine-grained phosphate predominates. The low interstream divides in the flatwoods areas between Turkey Creek and Little Turkey Creek, between Little Turkey Creek and the North Prong of the Alafia River, between Fishhawk Creek and the South Prong of the Alafia River, and between Fishhawk and Little Fishhawk Creeks are all characterized by a predominance of fine phosphate.

The valleys of all the major streams and tributaries are characterized by coarse phosphate, low in BPL content; probably the streams removed the fines and the acid ground waters leached the finer grained particles that contain more P_2O_5. Stream removal of some of the fines is indicated by the character of the phosphate nodules near streams. The percentages of fine-grained phosphate drops near streams, but about a quarter of a mile from a stream the percentage of fines abruptly drops to zero, the percentage of the slime fraction drops sharply, and the matrix consists of coarse sand-size quartz and phosphate particles. The writer infers that this coarse sand matrix is a Pleistocene flood-plain deposit, the so-called river pebble.

CHEMICAL COMPOSITION OF PHOSPHATE NODULES

In the routine handling of prospecting or mine samples, chemical analyses are made only for P_2O_5, acid insoluble, and Fe_2O_3 and Al_2O_3 (the Fe_2O_3 and Al_2O_3 are reported together in a single amount, called I and A). Many thousands of samples have been analyzed for these constituents, and in recent years, thousands of samples were analyzed for uranium by the Geological Survey. Very few complete analyses are available; only 11 samples from the Keysville quadrangle (5 of concentrate and 6 of pebble) were analyzed for all major constituents. These 11 analyses are given in table 6. In addition, weighted averages of the routine analyses for 44 samples from holes drilled in the northern part of the quadrangle (group A), and for 47 samples from holes drilled in the southern part of the quadrangle (group B), are given in table 6. The weighted averages for groups A and B represent millions of long tons of phosphate rock.

The P_2O_5 content of both the pebble and concentrate fractions has a positive relation to the CaO content; that is, as the phosphate content increases, the CaO content also increases.

The CO_2 content ranges from 2.50 to 2.95 percent and averages 2.71 percent in the pebble fraction; in the concentrate fraction it ranges from 2.25 to 2.45 and averages 2.34 percent. The CO_2 content tends to decrease as the P_2O_5 increases. Jacob and others (1933, p. 32) pointed out the same relation.

TABLE 6.—*Chemical composition of phosphate particles, Keysville quadrangle*

[Analyses, in percent, by company chemists; published with permission. na, not analyzed]

Sample	P_2O_5	CaO	SiO_2	F	CO_2	Al_2O_3	Fe_2O_3	SO_3	$CaCO_3$	U_3O_8
	Pebble fraction									
1	31.65	46.25	6.52	3.60	2.87	1.50	1.17	0.42	na	na
2	32.79	46.40	8.65	3.84	2.65	1.20	.88	.49	6.03	na
3	33.15	47.00	7.75	3.71	2.95	.89	.94	.58	6.71	na
4	33.68	47.71	7.21	3.48	2.80	1.07	1.01	.50	6.37	na
5	33.70	46.90	8.10	3.64	2.50	1.00	.85	.43	5.69	na
6	34.54	49.15	5.36	3.64	2.50	1.02	.86	.45	5.69	na
Arithmetic average, samples 1-6	33.25	47.24	7.27	3.64	2.71	1.11	.95	.48	6.10	------
Weighted average, 44 samples, group A	34.22	na	7.24	na	na	[1]2.20		na	na	.0155
Weighted average, 47 samples, group B	33.15	na	6.76	na	na	[1]2.16		na	na	.0166
	Concentrate fraction									
7	33.93	48.38	6.20	3.89	2.28	1.08	0.98	0.66	5.19	na
8	34.32	48.60	5.65	3.76	2.25	1.12	1.00	.64	5.12	na
9	34.58	48.94	5.84	3.68	2.40	1.02	.74	.30	5.46	na
10	35.04	49.04	5.00	3.70	2.32	1.00	.92	.50	5.28	na
11	35.30	50.02	4.42	3.73	2.45	.88	.66	.24	5.57	na
Arithmetic average, samples 7-11	34.63	49.00	5.42	3.75	2.34	1.02	.86	.47	5.32	------
Weighted average, 44 samples, group A	35.77	na	3.00	na	na	[1]2.08		na	na	.0113
Weighted average, 47 samples, group B	33.23	na	7.68	na	na	na	na	na	na	.0075

[1] Total Al_2O_3+Fe_2O_3 (I&A).

The amounts of carbonate present are within the range indicated as characteristic for carbonate-fluorapatite by Altschuler, Clarke, and Young (1958, p. 48). Thin section studies of phosphate particles have shown that most contain some calcite. The $CaCO_3$ analyses shown in table 6 may have been computed by assigning the CO_2 content to calcite. Therefore, the amounts shown on the table may be too high, for most of the CO_2 is probably a part of the apatite. In any case, the amount of calcite does not vary greatly, although there is slightly less in the concentrate fraction than in the pebble fraction.

The relation of phosphate to acid-insoluble content is shown in figure 13. The samples plotted in this figure are from group A. Samples from group B show the same relation. The acid-insoluble content is probably as finely divided quartz, and mostly silica, and ranges from 1 to 27 percent. The samples containing the greatest amount of phosphate contain the least amount of acid insoluble. The inverse relation, as shown in figure 13, is a strong one.

The fluorine content of the few samples analyzed ranges from 3.48 to 3.84 percent and averages 3.64 percent in the pebble fraction; it ranges from 3.68 to 3.89 percent and averages 3.75 percent in the concentrate fraction. The fluorine content of the mineral fluorapatite is about one-tenth the P_2O_5 content (Palache and others, 1951, p. 883), and this

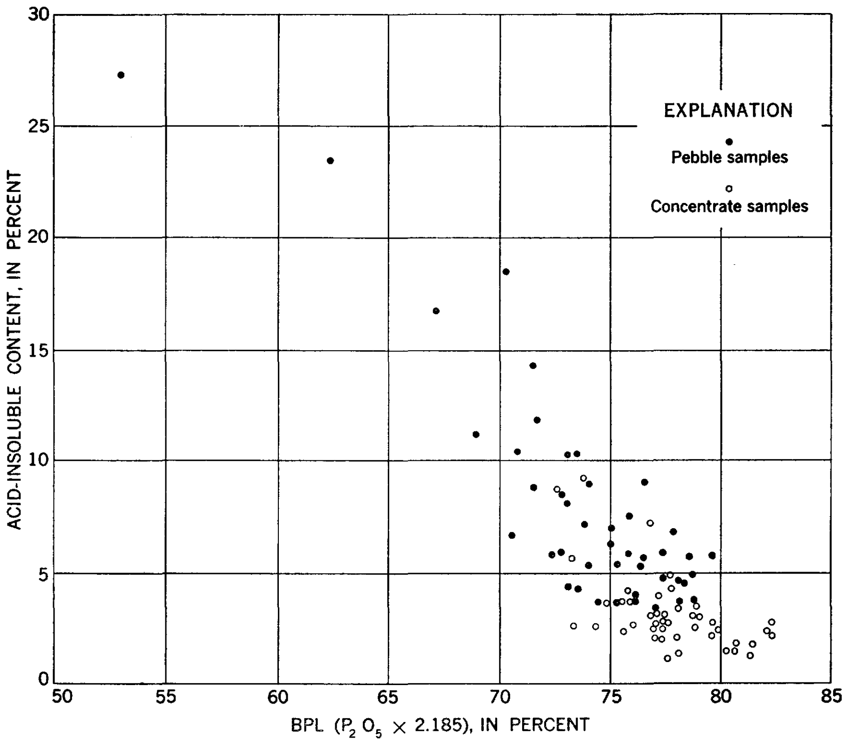


FIGURE 13.—Scatter diagram showing relation of BPL to acid-insoluble content in phosphate particles of the calcium phosphate zone. All samples are from group A; pebble and concentrate fractions were split from each sample. (See table 6 and p. 50.)

ratio should be constant. In these samples, however, the fluorine-phosphate ratios decrease with increasing phosphate content. Jacob and others (1933, p. 34) pointed out that this relation is a distinguishing characteristic of the Florida land-pebble phosphate rock.

The iron and alumina contents are small and relatively uniform. The alumina content is slightly more than 1 percent, the iron content is slightly less than 1 percent. There is a very slight tendency for the iron and alumina contents to decrease as the phosphate content increases. In the 44 samples of group A, the total iron and alumina content (I and A) ranges from 1.30 to 5.25 and averages 2.20 percent in the pebble fraction; it ranges from 1.22 to 5.10 and averages 2.08 percent in the concentrate fraction. In these samples, there is also a slight tendency for the I and A content to decrease as the phosphate content increases. The correlation, however, is very poor.

The SO_3 content of the phosphate particles in the samples analyzed varies within rather narrow limits: it averaged 0.48 percent for the pebble fraction and 0.47 for the concentrate. There is no apparent correlation between SO_3 and P_2O_5 in these samples. Jacob and others (1933, p. 48), however, pointed out that samples that are high in phosphate content usually contain the smallest amounts of SO_3.

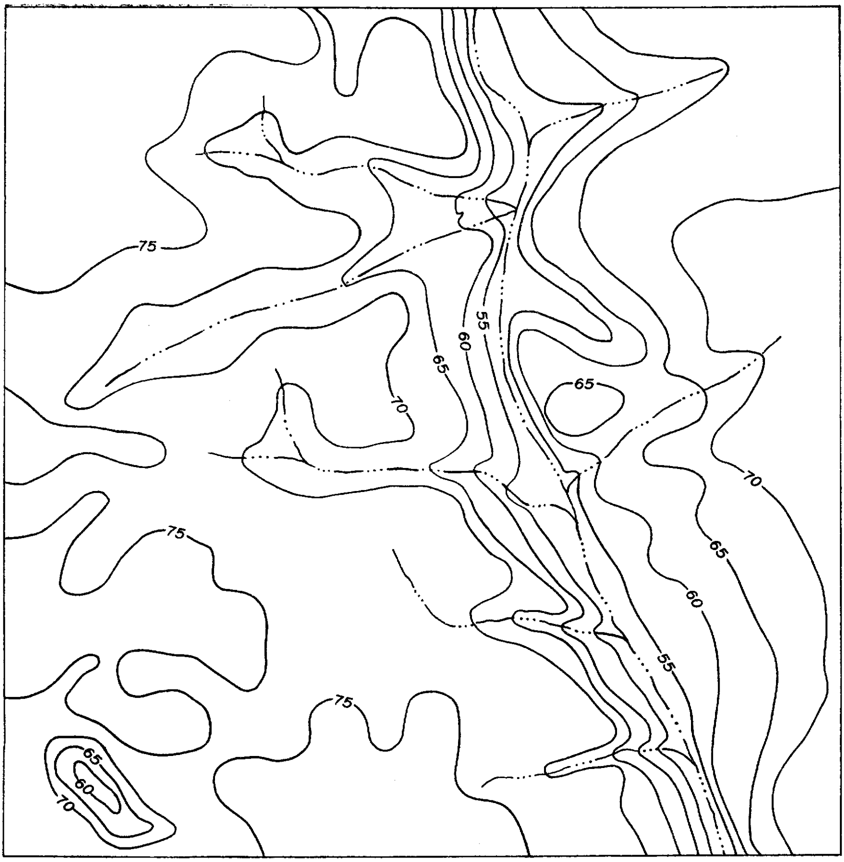
The analytical data suggest either that apatite and calcium carbonate were precipitated together and enclosed quartz grains and clay minerals or that the phosphate mineral replaced an impure limestone. If the replacement hypothesis is accepted, replacement proceeded to about the same degree in all particle sizes with the larger fragments containing less P_2O_5 than the smaller fragments because they contain more and larger grains of quartz.

P_2O_5 DISTRIBUTION

Details of P_2O_5 distribution are considered confidential by the companies. It can be said, nevertheless, that near the surface streams the phosphate content of the nodules is much lower than that of the nodules in the interstream divides. Figure 14 is an isograde map of the phosphate content of the pebble fraction near a small stream. The concentrate fraction of the matrix shows the same pattern of P_2O_5 distribution as the pebble fraction. The lines showing the grade variations are deeply indented upstream, even on the very small tributaries. Odum (1953) pointed out that the streams which drain areas underlain by phosphate deposits contain uncommonly large amounts of dissolved phosphorous. All streams containing large amounts of dissolved phosphorous are acid. Basic streams have a low phosphorous content which suggests a control of phosphorous solubility by pH. Acid ground waters probably removed P_2O_5 from the phosphate nodules, and the flow of the ground water toward the streams may explain the regular diminution of phosphate content near surface streams.

URANIUM CONTENT

The uranium contents of the pebble and the concentrate fractions of the calcium phosphate zone are shown on plates 8 and 9. Both fractions contain less uranium near the present surface streams. Isograde lines representing high uranium percentages are closed contours on the interstream divides. The isograde lines resemble topographic contours that are strongly indented upstream. Both the pebble and concentrate fractions in the present stream valleys contain less than 0.010 percent uranium. The diminution of the uranium content of the phosphate nodules near the stream valleys probably results from the leaching of both uranium and phosphate by acid ground waters moving toward the streams. Analyses of water samples taken by P. F. Fix and the writer show that the uranium content of streams draining phosphatic terranes is much higher than the uranium content of



EXPLANATION

55
60

Lines of equal BPL content of pebble fraction,
in percent; contour interval 5 percent.
BPL=percent $P_2O_5 \times 2.185$.

FIGURE 14.—Sketch map showing variation in phosphate content of the pebble fraction of the calcium phosphate zone in 1 square mile of eastern Hillsborough Country. Based on mining company analyses.

streams draining nonphosphatic terranes. The distribution pattern of uranium content is the same for pebble and concentrate, and seems to indicate a progressive removal of uranium from the phosphate nodules since the surface streams began flowing at their present locations.

The principal difference between the two maps is that the pebble isograde map shows a much larger area underlain by more than 0.010 percent uranium. This indicates that generally the pebble fraction contains more uranium than does the concentrate fraction. The higher uranium content of the pebble fraction is clearly shown in T. 30 S., R. 23 E., where the pebble fraction contains as much as 0.045 percent uranium, whereas the concentrate fraction in the same locality reaches a maximum of only 0.030 percent. The general trend is reversed in some areas, as, for example, in the SE¼ sec. 19, T. 30 S., R. 23 E., where the concentrate contains 0.030 percent uranium and the pebble only 0.020 percent.

Although assay data are not available for some large areas, the pebble fraction will probably average about 0.015 percent uranium, and appreciable tonnages of this fraction will contain more than 0.020 percent. The concentrate fraction, on the other hand, will probably average about 0.010 percent uranium and large tonnages of it will average 0.015 percent.

RELATION OF PHOSPHATE TO URANIUM

The relation of phosphate to uranium in the calcium phosphate zone has been discussed previously (Cathcart, 1956, p. 493). This relation may be briefly restated here.

Uranium in the calcium phosphate zone is almost exclusively in apatite. Samples of clay minerals segregated from the matrix contain only trace amounts of uranium; the quartz sand fraction of the matrix is virtually barren of uranium. The coarsest phosphate nodules contain the smallest percentage of P_2O_5 (table 6), and the finest nodules contain the highest P_2O_5 percentages. The pebble fraction of the calcium phosphate zone contains a higher percentage of uranium than the concentrate. Obviously there is an inverse relation between phosphate content and uranium content in all the nodules. The coefficient of correlation for phosphate and uranium is -0.64 for deposits in all parts of the land-pebble phosphate district, a rather strong inverse correlation (Cathcart, 1956, fig. 170*A*).

During 1951 and 1952, the mining companies, under contract to the Atomic Energy Commission, drilled one hole in each 40-acre tract of land that was included in their then-current mining plans. A single sample, representing all the matrix, was taken from each drill hole, and the pebble, concentrate, and slime fractions were separated and analyzed for BPL and U_3O_8. These samples were used in preparing the scatter diagram (fig. 15). Taken together, the scatter of the concentrate and pebble plots indicates little or no correlation between U_3O_8 and BPL. However, on the diagram most of the pebble samples can be separated from most of the concentrate samples. The plotted positions of about two-thirds of the concentrate samples are low and to the right of the diagonal line; they are on that part of the diagram representing higher phosphate and lower uranium content. Con-

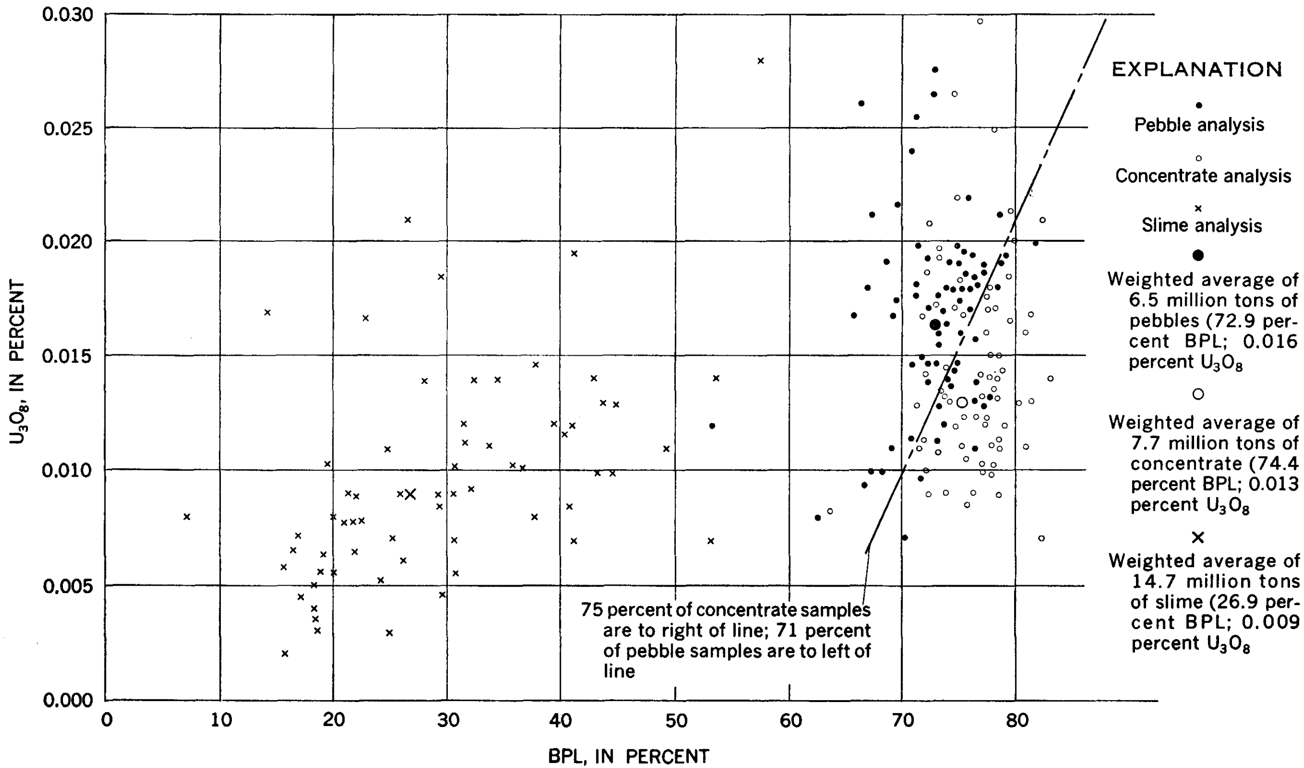


FIGURE 15.—Scatter diagram showing relation of U_3O_8 to BPL in the calcium phosphate zone, Keysville quadrangle, Florida.

versely, about two-thirds of the plots of the pebble samples are above and to the left of the diagonal line; they are on the lower phosphate and higher uranium part of the diagram. The weighted averages shown on the diagram confirm this generality. These averages and totals were computed by the phosphate companies from the drilling in 1951 and 1952. The pebble fraction represents 6.5 million long tons, and contains an average of 72.9 percent BPL and 0.016 percent U_3O_8. The concentrate fraction represents 7.7 million tons that contained an average of 74.4 percent BPL and 0.013 percent U_3O_8. These relations suggest an inverse correlation between phosphate and uranium contents for apatite nodules of all sizes. The scatter diagram for the slime fraction indicates a slight positive correlation between uranium and phosphate.

TRACE-ELEMENT CONTENT

Phosphate rock from the land-pebble district contains traces of other metals in addition to uranium. Jacob and others (1933, p. 77) pointed out that:

> Phosphoric acid, lime, alumina, iron, silica, carbon dioxide, fluorine, and, in most samples, sulphate are the predominating constituents of domestic phosphate rock. Magnesium, titanium, sodium, potassium, manganese, chromium, copper, zinc, arsenic, chlorine, and iodine are present in nearly all samples, but only in comparatively small quantities. Small percentages of vanadium are also present in many samples.

Robinson (1948) reported about 460 ppm of rare earths in a composite of three samples, and Waring and Mela (1952, p. 12, and table 3) reported 215 ppm of rare earths in a sample of Florida phosphate (table 7). Waring and Mela stated, however, that the data should not be considered as representative of all Florida phosphate rock and that the rare earths not listed were not determined.

TABLE 7.—*Rare-earth content of phosphate rock sample from Florida*

[After Waring and Mela (1952, table 3, p. 12)]

Rare earth oxide	*Percent*	*Rare earth oxide*	*Percent*
Ce	0.01	Th	------
Y	.0025	Eu	<.001
Sm	.001	Yb	.001
Gd	------	By	.001
Pr	------		
La	.005	Total	0.0215
Nd	.001		(215 ppm)

Many semiquantitative spectrographic analyses of phosphate rock from the land-pebble district were made by the Geological Survey. These analyses represent rocks from throughout the district, however, and a detailed discussion of the results would be premature. These analyses confirm the results of Jacob and others (1933), with the exception that very small amounts of the following elements are common in most samples: beryllium, boron, scandium, cobalt, nickel, gallium, strontium, yttrium, tin, lanthanum, ytterbium, and lead. Other elements in some of the samples, also in trace amounts, include niobium, molybdenum, and silver.

The mineralogical distribution of these trace elements is not definitely known. McKelvey, Cathcart, and Worthing (1951) pointed out that the rare earths, barium, and strontium may be in the apatite structure or may be absorbed on the surface of the apatite. Gallium may be associated with an aluminum phosphate mineral or with the clays. Vanadium is distributed similarly to uranium; it is apparently in larger amounts in the coarser phosphate nodules, and may be in the structure of the phosphate mineral. Zirconium and titanium may be in detrital zircon and ilmenite. Chromium and nickel may be associated with clay minerals.

ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone is not a stratigraphic unit. It may be entirely within the upper unit of the Bone Valley formation, as shown by log H, page 36, or it may also include the top part of the lower unit, as it does in sec. 6, T. 29 S., R. 21 E. (log C, p. 33). On the fringes of the land-pebble district outside the area of the Keysville quadrangle, the aluminum phosphate zone may be within the Hawthorn formation, or may even be as low stratigraphically as the Tampa limestone (Cathcart and McGreevy, 1959). The relations are shown diagrammatically on figure 4.

DISTRIBUTION AND THICKNESS

The distribution of the aluminum phosphate zone is shown on plate 10. Thickness of the zone was determined by using the top of the matrix (as determined by the phosphate companies) as the base of the zone. The top of the zone is below the loose sand of the overburden, and was picked at the sharp rise in radioactivity as shown by the gamma-ray logs. The area shown within the hachured line on plate 10 is underlain by less than 3 feet of aluminum phosphate zone. The 3-foot isopach is emphasized because 3 feet is the minimum thickness that can be mined economically with large mining equipment.

The isopach lines generally conform to the topography of the river valleys; the zone is thinnest at the rivers and thickest on the interstream divides. This distribution pattern is due in part, at least, to erosion by the rivers after the zone was formed. Channels filled with loose sand that cut through the Bone Valley formation are evidence that the zone was eroded after formation (see figs. 8 and 10). Results of equivalent uranium analyses approximately equal those of chemical uranium analyses and indicate according to Altschuler and others (1956, p. 503) that: "* * * the zone and its distribution and grade patterns originated in Pleistocene time and are probably preglacial."

The evidence indicates, therefore, that Pleistocene streams cut through the aluminum phosphate zone and probably flowed on phosphorite of the lower part of the Bone Valley or limestone of the Hawthorn formation. The relation of the zone to the present streams indicates that these streams, also, have eroded the zone. It seems likely that the modern and Pleistocene streams are occupying the same general position.

The zone underlies the entire Keysville quadrangle, except in and along the present drainage, and ranges from 0 to more than 15 feet thick, but probably averages between 6 and 7 feet in thickness.

RELATION TO CALCIUM PHOSPHATE ZONE

By definition, the aluminum phosphate zone overlies, and is in contact with, the calcium phosphate zone. The aluminum phosphate zone was derived by weathering from the calcium phosphate zone. The two zones are in contact except where the aluminum phosphate zone is absent or was formed entirely from the upper, uneconomic part of the Bone Valley formation. For example, log G of a drill hole in sec. 35, T. 30 S., R. 22 E. (p. 35), shows aluminum phosphate zone separated from the calcium phosphate zone by two beds of impermeable clay which prevented leaching of the underlying rocks.

Plates 6 and 10, the isopach maps of the calcium phosphate zone and the aluminum phosphate zone, show that both zones are correspondingly thin along the present streams. The thick aluminum phosphate zone and thin calcium phosphate zone underlying some areas on the interstream divides indicate that leaching has affected the lower phosphorite unit of the Bone Valley formation. However, equally as many areas are underlain by thick aluminum phosphate zone and correspondingly thick calcium phosphate zone and by thin aluminum phosphate zone overlying thick calcium phosphate zone. The difference in detail of the two maps makes it difficult to interpret the relations. Much more information is available for the calcium phosphate zone than for the aluminum phosphate zone.

RELATION TO OVERBURDEN

The relation of the aluminum phosphate zone to the remainder of the overburden is less complex than the relation of the aluminum phosphate zone to the calcium phosphate zone. First, the aluminum phosphate zone is included in the overburden, and where the aluminum phosphate zone is thick the overburden is thick. However, all areas of thick overburden are not underlain by thick aluminum phosphate zone, especially in the southeast quarter of the quadrangle on the ridge where the loose sand is thickest and where apparently no great thicknesses of aluminum phosphate zone formed. In addition, where the overburden is thin, the aluminum phosphate zone must also be thin.

The overburden, aluminum phosphate zone, and calcium phosphate zone all thin toward the present streams, as shown by the maps. It seems most likely that this thinning is due primarily to stream erosion that started in the Pleistocene. Certainly the present streams, at least in parts of their courses, are flowing on the limestone of the Hawthorn formation, and the blanket deposits of phosphorite, clayey sand, and sand have been removed.

ANALYTICAL VARIATIONS

Analytical data on the aluminum phosphate zone are sparse, except for data on the uranium content (including the gamma-ray logs). The distribution of uranium in the zone is shown on plate 11. Isograde contours on this map conform to the topography. The aluminum phosphate zone contains only small amounts of uranium near the modern streams, but is high in uranium under the interstream divides. In a general way, therefore, where the aluminum phosphate zone is thick it is high in uranium content, and where the zone in thin, it is low in uranium content. There are, however, areas in the interstream divides which are underlain by thin aluminum phosphate zone high in uranium content.

The uranium content and distribution of the zone are functions of weathering and erosion, and it seems likely that weathering by acid ground water is accelerated near the streams where the zone has been thinned by erosion. Thus, uranium could have been taken into solution by the acid waters, carried to the streams, and removed. This action would explain the coincidence of thin aluminum phosphate zone and low uranium content.

The distribution of uranium in size products in the aluminum and calcium phosphate zones is shown in figure 16.

The average size distribution, in weight percent, is shown in the top part of the diagram. The principal difference in the size distribution in the aluminum and calcium phosphate zones is in the phosphate sand and pebble fractions. The slime fraction is in the same proportion in both zones, but the quartz sand fraction is much greater in the aluminum phosphate zone, and the phosphate sand and pebble content is much less in the aluminum phosphate zone than in the calcium phosphate zone. There is so little phosphate sand in the alumi-

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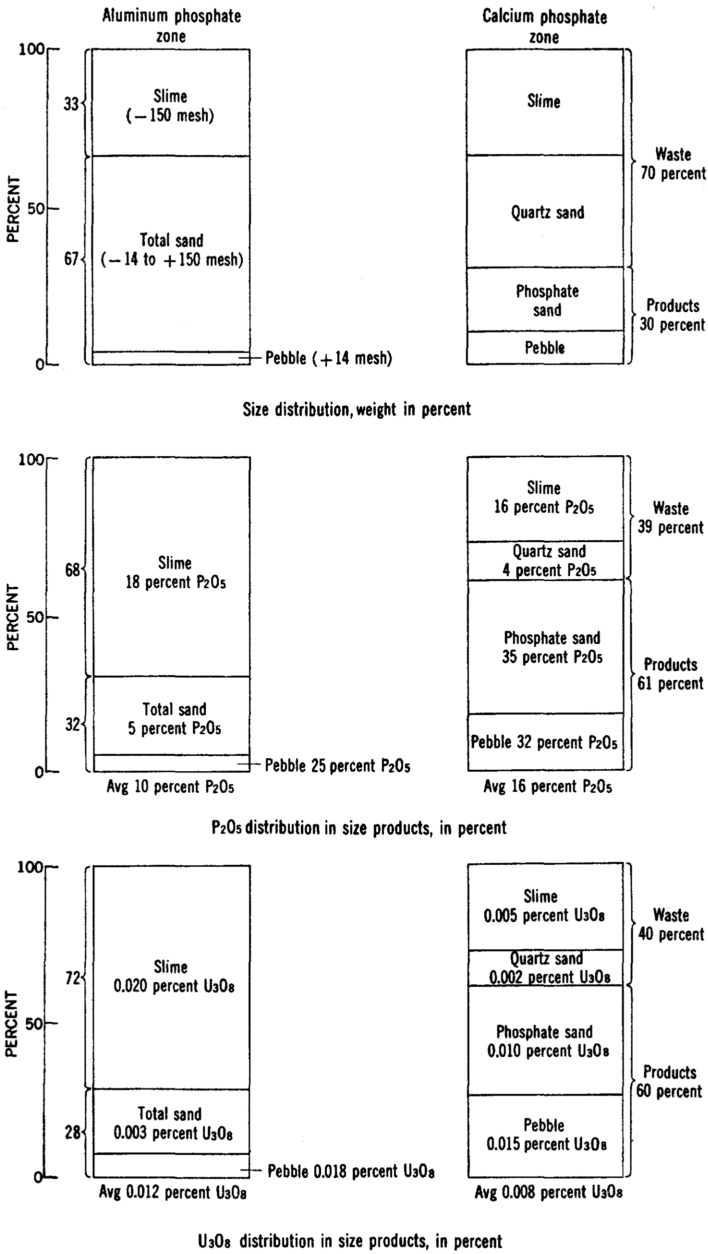

FIGURE 16.—Comparison of distribution of size products, phosphate, and uranium in the aluminum and calcium phosphate zones, land-pebble phosphate district, Florida. (Average of 565 measurements.) After Cathcart, 1955.

num phosphate zone that this fraction could not be separated. In part, the lesser phosphate content results from leaching, but it is in part due to differences in the zones prior to leaching. Much of the zone was the upper unit of the Bone Valley formation, which contains much less phosphate sand and pebble than does the lower unit.

The P_2O_5 distribution in the size products is shown in the middle part of the diagram. Sixty-one percent of the phosphate in the phosphate pebble and sand from the calcium phosphate zone is recovered, and of the 39 percent that is lost, only a small percent is in the sand fraction. Most of the P_2O_5 lost is from the slime fraction, but because the slime fraction is stockpiled, it could be recovered. By contrast, 68 percent of the P_2O_5 in the aluminum phosphate zone is in the slime fraction, and 32 percent is in the pebble and sand fractions. Thus, by screening and beneficiation, two-thirds of the phosphate from both zones can be recovered in about one-third of the volume of the rock. In one process for treating the aluminum phosphate zone, all the rock is used and about 90 percent of the phosphate and uranium is extracted by acidulation. This amount is decidedly greater than that recovered by screening and desliming.

The U_3O_8 distribution in the size products is shown on the bottom part of the diagram. In both the calcium phosphate and the aluminum phosphate zones, the uranium distribution in the size products is almost identical with the phosphate distribution; these distributions indicate that the uranium and phosphate are very closely allied.

GAMMA-RAY LOGS

Much of the information regarding the uranium content of the aluminum phosphate zone in the Keysville quadrangle has come from examination of gamma-ray logs. More than 500 gamma-ray logs were made on holes drilled in the quadrangle. Samples of the aluminum phosphate zone were taken at only 138 drill locations. The samples were analyzed for U_3O_8. In the individual drill holes, the percent equivalent U_3O_8, as estimated from the gamma-ray logs, varied by as much as 0.010 percent from the results of chemical analyses. For instance, a sample from one drill hole contained 0.004 percent U_3O_8; the equivalent uranium as estimated from the gamma-ray log was 0.014 percent, a difference of 0.010 percent. However, uranium contents from samples taken at most of the drill holes differed from the estimate from radiation measurements by about 0.001 percent. The arithmetic average for all 138 drill holes was 0.0078 percent U_3O_8, and the average estimate of equivalent uranium from radiation was 0.0083 percent U_3O_8, a difference of only 0.0005 percent. The average estimate of equivalent uranium from the gamma-ray logs is only slightly higher than the average for uranium computed from chemical analyses. The map showing the distribution of uranium in the aluminum phosphate zone can be interpreted and used with confidence, but estimates of the grade at individual drill holes may differ widely from their true values.

Plots of three typical gamma-ray logs are shown on figure 17. In

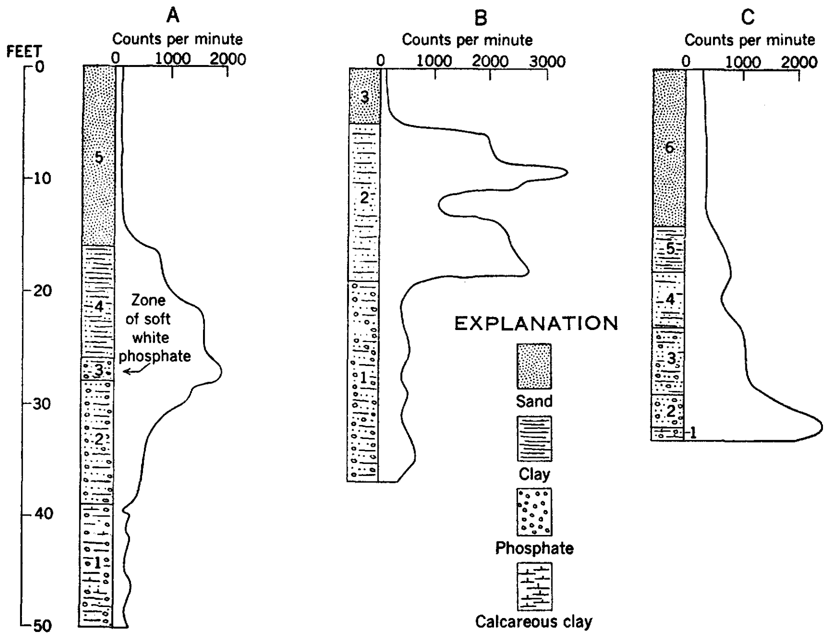

FIGURE 17.—Comparison of characteristic gamma-ray logs, Keysville quadrangle, Florida. (All drill holes were logged with identical equipment and under identical conditions, that is, time constant, range factor, and so forth, are the same for all drill holes).

log A, the highest uranium content shown is at the base of the aluminum phosphate zone (bed 3); radiation intensity drops sharply below the zone. The uranium content decreases somewhat in the bottom half of bed 4, and is low in the upper half of the zone (top half of bed 4). Uranium content decreases sharply at the top of the zone (between beds 4 and 5) at the contact with the loose sands of the overburden; this is normal profile of leaching. The highest uranium content corresponds with a thin bed (bed 3). This is a zone of which Altschuler and others (1956, p. 498) said:

Pebbles of apatite at the base of the leached zone record the onset of alteration. They are softened, highly porous, and rimmed by a bleached and whitened zone of crandallite and wavellite.

Bed 3 is commonly called the soft white phosphate zone and is characteristic of thoroughly leached sections throughout the phosphate district.

Analysis, in percent

Bed	P_2O_5	CaO	Fe_2O_3	Al_2O_3	U_3O_8 or eU_3O_8
	Drill hole A				
1, 2	13.35	----------	5.56		0.007
3, 4	5.27	1.10	0.73	5.60	.016
	Drill hole B				
2	----------	----------	----------	----------	[1] 0.012
	Drill hole C				
1, 2	15.6	----------	----------	----------	0.009
3, 4	5.26	5.83	1.59	12.38	.003

[1] eU_3O_8 computed from an average of 1,500 counts per minute.

By contrast, log C represents a hole at a location which has not been leached. The sharp increase in radioactivity is at the bottom of the calcium phosphate zone, in a sand of phosphate and quartz (beds 1 and 2); radioactivity decreases sharply in the limestone beneath. Most of the phosphate particles in the sand are black and highly polished; they show no sign of leaching. The uranium content declines abruptly at the contact of beds 2 and 3, is uniform in bed 3, which is a greenish-gray, slightly sandy clay, that contains sparse white, cream, and gray, highly polished phosphate grains. Bed 4 is a slightly clayey sand, which contains a little less uranium than bed 3. Bed 5, a clayey sand, contains a little more uranium than bed 4, and bed 6, the loose overburden sand, has near background radioactivity.

A comparison of chemical analyses of cores from drill holes A and C shows that they contained almost the same amount of phosphate. The aluminum phosphate zone at hole A (beds 3 and 4) contained 5.27 percent P_2O_5; the equivalent but unleached zone at hole C (beds 3 and 4) contained 5.26 percent. However, the CaO to P_2O_5 ratios are completely different. At hole A, the CaO to P_2O_5 ratio of 0.21 indicates that most of the phosphate is not combined as apatite, but is probably combined with alumina; at hole C, the ratio is 1.1, close to the theoretical ratio for apatite (Palache and others, 1951). Although the total Al_2O_3 content of the section at hole C is much higher than the Al_2O_3 content at hole A, the section at hole C, particularly in the bottom 6 feet, contains more clay. The high alumina content of the section at hole C probably reflects the Al_2O_3 in clay minerals. The uranium content of beds 3 and 4 at hole A is 0.016 percent, but at hole C (beds 3 and 4) it is only 0.003 percent. In addition, the slime fraction of beds 3 and 4 at hole A contained 0.028 percent U_3O_8, whereas at hole C, the slime fraction of beds 3 and 4 contained only 0.004 percent U_3O_8.

The log of hole B (fig. 17) shows a double radiation peak. Both peaks are entirely within the aluminum phosphate zone (bed 2). Radioactivity declines very sharply at the contact with bed 1 (loose sand) and with bed 3, the calcium phosphate zone below; and radioactivity also declines sharply in the middle part of the aluminum phosphate zone. The basal 2 or 3 feet of bed 2, which contain small amounts of soft white phosphate, corresponds to the bottom peak of radioactivity. The radiation gradually declines upward, and decreases sharply near the middle of bed 2. The part of the curve described thus far resembles the curve of hole A, and probably is a normal profile of leaching. The sharp second peak and its subsequent drop are harder to explain. Both peaks together may represent two beds, originally high in phosphate content, separated by a bed containing little or no phosphate. However, the entire section except for the basal part is more or less uniform in phosphate content and lithology and is very permeable. If this leaching profile resulted from a single period of weathering, the uranium probably would move downward and eventually make a profile like that at hole A. The bottom peak may represent the normal profile, and the top, the aluminum phosphate zone material that was eroded and deposited on top of the first profile. The extremely rapid decline in radioactivity at the contact with the loose sand differs from the normal profile at hole A. In the normal profile, the radiation decrease at the contact of the aluminum phosphate zone with the loose sand is much more gradual than the decrease at the same stratigraphic point at hole B.

The prevalence of double peaks in the radiation logs of the flatwoods areas suggests that the peaks may result from deposition of previously formed aluminum phosphate zone material on top of a profile of leaching. The material could have been eroded from the ridge areas and deposited on the flatwoods. Any material reaching the valleys presumably would be removed by erosion by the streams. The erosion and deposition occurred after the zone was formed and before the loose sand was deposited—sometime in the Pleistocene. The suggestion that erosion and redeposition of aluminum phosphate material is the cause of the double peaks is strengthened by the fact that the aluminum phosphate zone is often abnormally thin, and is erratic in distribution, under the ridge areas. In the valleys, the material, if deposited, presumably would be removed by erosion by the present streams.

DISTRIBUTION OF URANIUM

Uranium increases in amount downward in the aluminum phosphate zone in the normal profile of leaching (p. 62) and the highest uranium contents are associated with the zone of soft white phosphate at, or just above, the calcium phosphate zone (p. 63). Altschuler and others (1956) pointed out the increase in uranium at the base of the aluminum phosphate zone, and noted that apatite pebbles contain the most uranium and that those pebbles at the base of the zone are the most enriched. Individual pebbles may contain as much as 0.1 percent uranium. Pure wavellite contains only from 0.002 to 0.004 percent uranium, but concentrates of the calcium-aluminum phosphate minerals contain from 0.03 to 0.04 percent (Altschuler and others, 1956).

Thus, uranium in the aluminum phosphate zone, as in the calcium phosphate zone, is associated with the more calcic minerals and most closely with the mineral apatite. In the aluminum phosphate zone uranium shows a direct relation to phosphate, fluorine, and calcium, and an inverse relation to silica (Cathcart, 1956). The correspondence indicates that uranium may substitute for calcium in the apatite structure as suggested by McKelvey and Nelson (1950) and by Goldschmidt (1954). The fact that the ionic radii of bivalent calcium (1.06A) and quadrivalent uranium (1.05A) are almost identical (Goldschmidt, 1954) indicates that substitution of uranium for calcium is plausible; furthermore, Altschuler and others (1954) demonstrated that much of the uranium in apatite is quadrivalent.

DISTRIBUTION OF PHOSPHATE

The phosphate content of the aluminum phosphate zone parallels closely the uranium content. Phosphate distribution for the aluminum phosphate zone has not been mapped because the analytical data are too sparse.

ECONOMIC FACTORS

Economic factors of the aluminum phosphate zone were discussed by Cathcart and McGreevy (1959). The assumption was made that uranium and phosphate will be recovered as coproducts and that alumina will not be recovered.

The Tennessee Valley Authority has developed a process to make fertilizer from the aluminum phosphate zone, and was scheduled to begin operation of a 40,000-ton-per-year pilot plant sometime in 1958. The ore (raw aluminum phosphate zone material) is calcined, then uranium and P_2O_5 are extracted with a mixture of nitric and sulfuric acid. After filtration, the extract is concentrated by evaporation and is made into fertilizer by continuous ammoniation and granulation. Potassium chloride is added to make a three-component fertilizer. Uranium can be recovered from the extract prior to the ammoniation step (Hignett and others, 1957). Table 8 gives the composition of the raw material and of the fertilizer made from it.

TABLE 8.—*Composition of raw ore and of the fertilizer produced from the aluminum phosphate zone*

[Analyses in percent. Adapted from Hignett and others (tables I and X, 1957)]

Constituent	V-20		V-10	
	Raw ore	Fertilizer	Raw ore	Fertilizer
P_2O_5	9.9	[1] 15.0	15.3	[1] 22.5
Al_2O_3	8.3	8.3	10.6	9.8
Fe_2O_3	1.3		3.4	
CaO	7.7	3.2	11.3	4.9
SiO_2	65.6		51.1	
F	0.8		1.2	
Ign. loss	5.9		6.8	
SO_3		1.6		0.8
H_2O		3.5		2.8
K_2O		14.2		12.1
N [1]		14.3		11.6

Total.

The phosphate content of the fertilizer made in this process is higher by about half than the phosphate content of the raw ore, the alumina content of the fertilizer is about the same as in the raw ore, and the calcium content of the fertilizer is less than half of the calcium content of the raw ore.

The most desirable raw material should be high in phosphate and uranium and low in calcium and alumina. A high calcium content requires more acid for treatment than a low calcium content; calcium is therefore an undesirable constituent. Alumina is present in about the same amounts in the fertilizer and in the raw material; alumina is an undesirable diluent in fertilizer, and therefore should be as low as possible in the raw material. Absolute maximum limits for these materials have not yet been determined. Lower limits have been arbitrarily set on phosphate and uranium contents. Material containing less than 5 percent P_2O_5 probably could not be economically treated; hence the P_2O_5 cutoff is set at 5 percent. Aluminum phosphate zone containing more than 5 percent P_2O_5 almost always contains more than 0.005 percent uranium, whereas material containing less than 5 percent P_2O_5 very frequently has less than 0.005 percent uranium. In addition, unleached clayey sand of the upper part of the Bone Valley almost always contains less than 0.005 percent uranium; this material is generally low in phosphate and relatively high in calcium and is not economically minable. Very often the only data available are on uranium content, and if 0.005 percent uranium content is set as the lower limit for economic ore, most of this unleached material will be eliminated.

Other factors must be considered in determining whether the aluminum phosphate zone is minable. These are:

1. Thickness of the zone. Three feet is the minimum thickness that can be economically mined with present equipment.

2. Thickness of waste over the zone. If this thickness is too great, it would be uneconomical to mine the zone. No absolute limit for this thickness can be given at this time. The amount of waste is computed in cubic yards moved to recover 1 ton of product, and the ratio of tons of product per cubic yard of aluminum phosphate zone is not known. This factor is not of immediate concern, however, because mining of aluminum phosphate zone will be done in conjunction with mining of the matrix.

3. Distribution of the matrix. The aluminum phosphate zone will be mined only in conjunction with the mining of the matrix, at least in the foreseeable future. Therefore, plans for mining the zone will have to be made in consultation with the phosphate-mining companies.

TONNAGE CALCULATIONS

CALCIUM PHOSPHATE ZONE

Reserves of phosphate in the Keysville quadrangle were compiled from mining company data. Tonnages were compiled on the basis of 40-acre blocks; tonnages of some unprospected blocks adjacent to or surrounded by prospected blocks were included in the totals as inferred reserves. No distinction is made in the total tonnage figures for grade variations; some grades are unminable under present conditions. In addition, about 22 percent of the land in the Keysville quadrangle has not been prospected; tonnage estimates for this land have not been made.

Measured, indicated, and inferred reserves of phosphate in the quadrangle are 219,675,000 long tons of pebble and 173,886,000 long tons of concentrate.

The average uranium content of the pebble fraction is slightly more than 0.016 percent; the pebble fraction contains about 35,000 long tons of uranium. The concentrate fraction contains an average of slightly more than 0.013 percent uranium, or about 22,600 long tons of uranium. The average uranium contents are based on more than 2,300 analyses and are probably representative.

ALUMINUM PHOSPHATE ZONE

Adequate data with which to compute tonnage and grade for the aluminum phosphate zone are available for only about 100 drill-hole locations. The total thickness of the aluminum phosphate zone was sampled at each of these locations, and was analyzed chemically for phosphorus, alumina, calcium oxide, iron, and uranium. Table 9 gives the average chemical analysis and the total tonnage for 3,140 acres.

TABLE 9.—*Tonnage and analytical data, aluminum phosphate zone*

Fraction	Thickness (feet)	Long tons	Constituent, in percent				
			P_2O_5	CaO	Al_2O_3	Fe_2O_3	U_3O_8
Total, aluminum phosphate zone	6.8	33,800,000	6.75	4.07	5.81	1.12	0.009
−150 mesh		14,200,200	9.62	5.39	11.59	1.83	0.017

Computation from data given in table 9 shows that 79.5 percent of the uranium and 60 percent of the phosphate is in the slime fraction (−150 mesh), and that the aluminum phosphate zone contains in all 2,280,000 tons of P_2O_5 and 3,040 tons of U_3O_8, an average of a little less than 1 ton of uranium per acre and somewhat more than 700 tons of phosphate per acre.

Tonnage and grade were computed for an additional three hundred fifty 40-acre tracts in each of which one or more drill holes were logged with a gamma-ray unit. The 14,000 acres in these 40-acre tracts contains 102 million long tons of aluminum phosphate zone rock in beds that average slightly less than 8 feet thick and have an average content of about 0.009 percent equivalent U_3O_8.

The total inferred and indicated tonnage of the aluminum phosphate zone rock in the Keysville quadrangle is 136.4 million long tons of material in beds with an average thickness of 7.6 feet and with an average grade of 0.009 percent U_3O_8. The average P_2O_5 content is known only for the 33 million tons of material for which chemical analyses are available, but is probably about 6 percent for all the rock.

Drilling data are available for only 17,000 of the 165,000 acres in the Keysville quadrangle. About 8,000 acres have been mined, and about 54,000 acres of the quadrangle are underlain by aluminum phosphate zone that is less than 3 feet thick (pl. 10). Thus, an area of 103,000 acres is underlain by potentially minable aluminum phosphate zone; only 16.6 percent of this area has been prospected. Half of the area unprospected for aluminum phosphate zone may be underlain by minable material; hence, an additional 43,000 acres of land is a potential resource. It is assumed that this land is underlain by the same average thickness as the prospected land and that it represents an additional 341 million long tons of material, making a total for the quadrangle of 477 million long tons of aluminum phosphate zone. If this material contains an average of 6 percent P_2O_5 and

0.009 percent U_3O_8, the aluminum phosphate zone contains 28 million long tons of phosphate and almost 43,000 tons of U_3O_8, in the quadrangle.

PHOSPHATE RESOURCES OF THE HAWTHORN FORMATION

The Hawthorn formation underlies the entire Keysville quadrangle and averages about 60 feet in thickness. Although the formation is not uniformly phosphatic at all drill hole locations, phosphate nodules are abundant in some beds of the formation. Not many samples of the formation were analyzed, but the average content of phosphate of the analyzed samples is about 10 percent BPL. If all, or most of, the BPL content is in the phosphate particles, which average about 60 percent BPL, then about 15 percent by weight of the rock or about 200 tons per acre-foot is phosphate nodules. If then, half of the total thickness, or 30 feet of the Hawthorn is phosphatic, the formation contains about 6,000 tons of phosphate nodules per acre in the 165,000 acres in the Keysville quadrangle; therefore, the Hawthorn formation in the Keysville quadrangle is estimated to contain about 1 billion long tons of phosphate.

MINE AND TRACT DESCRIPTIONS

SYDNEY MINE

The Sydney mine of the American Cyanamid Co. is in T. 29 S., R. 21 E., Hillsborough County, and includes about 2,500 acres (Crago, 1950). In December 1949, a plant with a nominal capacity of 500,000 tons of phosphate rock per year began operation at the Sydney mine.

The phosphate deposits of the land-pebble district are basically similar, but each has certain peculiarities that require some modification of the standard ore-dressing practice. Prospecting at the Sydney tract showed that the matrix consists of a succession of lenticular beds of unconsolidated sandy clay, clayey sand, and clay containing varying amounts of phosphate pellets, pebbles, and clay-sized particles. The phosphate particles are softer at the Sydney mine than in most places in the phosphate district. Both the matrix and the aluminum phosphate zone in the Sydney mine are characterized by numerous beds of relatively pure clay ranging in thickness from less than 1 foot to about 4 feet.

The abundance of the clay, together with the softness of the phosphate, made it necessary to reduce the size of the clay balls that form in mining and pumping, without scrubbing and thereby breaking up (sliming) the phosphate particles. The problem was solved by changes in the milling procedure (Crago, 1950).

The matrix ranges in thickness from 0 along Turkey Creek to more than 40 feet in the SW¼ sec. 28, T. 29 S., R. 21 E., and probably averages between 10 and 15 feet (pl. 6).

The overburden (pl. 7) ranges from less than 4 feet to more than 60 feet in thickness, and averages about 30 feet.

An examination of figures 17 and 18 shows that the matrix and overburden are not related; thick overburden may overlie thick or thin matrix; thin overburden may overlie thick or thin matrix.

The topographic map of the upper surface of the Hawthorn formation (pl. 2) shows a karst topography with a more or less random distribution of the sink holes. The drainage of ancestral Turkey Creek is slightly east of the mining area.

Comparison of the matrix isopach map (pl. 6) with the map of the Hawthorn topography (pl. 2) shows that in a general way thick matrix overlies depressions on the Hawthorn surface.

A detailed cross section of the Sydney mine shows some of these relations (fig. 18). At the south end of the section the matrix is 5½ feet thick, and here the Hawthorn reaches its maximum elevation (40 feet above sea level). By contrast, at the point of lowest elevation of the Hawthorn (about 31 feet, marked "contact in drainage ditch" on fig. 18) the matrix is 11½ feet thick. The matrix reaches a maximum thickness of almost 13 feet slightly north of the contact in the drainage ditch, and at this point the elevation of the Hawthorn is still low. The slight thinning of the matrix to the north corresponds to the postulated rise in elevation of the surface of the Hawthorn.

The leached or aluminum phosphate zone, including the clayey sand of the upper unit of the Bone Valley and the upper part of the lower unit of the Bone Valley, is thin (14½ feet thick) at the south edge of the diagram, thickens to a maximum of about 19 feet in the center of the diagram, and then thins to a minimum of 11½ feet at the north end of the section. Most of the thinning and thickening of the leached zone is in the upper light-gray clayey sand bed of the upper unit of the Bone Valley. The very irregular contact of the upper bed of the upper unit of the Bone Valley with the sands of Pleistocene age suggests pre-Pleistocene erosion.

The terrace sands of Pleistocene age are complementary in thickness with the upper unit of the Bone Valley formation.

The thickest matrix consists of alternating clay and sand beds. To the south, the clay beds pinch out, and on the Hawthorn high at the south edge of the section the matrix is sandy, except for the thin clay bed at the top. The increase in thickness of the matrix in the Hawthorn low is due to the three lenses of clay matrix. The three sand beds at the south edge of the section can be distinguished in the field

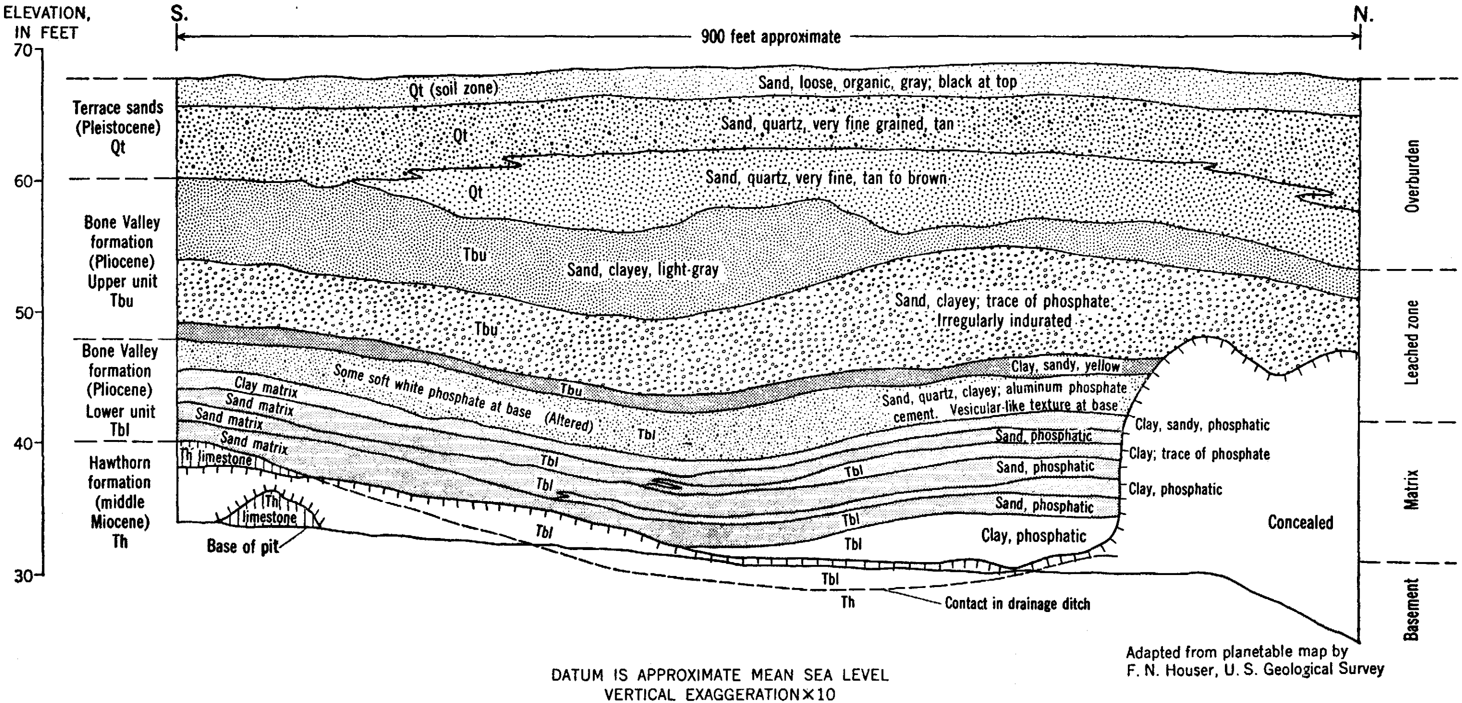

Figure 18.—Stratigraphic section, Sydney mine, SW¼SW¼ sec. 27, T. 29 S., R. 21 E.

by slight variations in color and in phosphate content, and can be correlated, on this basis, with the sand beds at the north end of the section. The contact of the aluminum phosphate zone with the matrix is at the top of the upper clay unit of the matrix. Alteration stopped at the impermeable clay bed.

The Bone Valley formation is draped into the low area; it forms a very gentle syncline. This structural feature may be due to initial dip, rather than to later structural movements.

Drilling data show that the lower part of the Bone Valley matrix in the Sydney area is characterized by white sandy phosphatic clay, which increases in amount downward and reaches a maximum at the base of the matrix. The clay becomes less abundant in the underlying residual bedclay of the Hawthorn. Black phosphate nodules are characteristically more abundant in the lower parts of the Bone Valley matrix than in the upper parts or in the bedclay.

Bedclay is sporadically present in the Sydney area, although none is in the face shown in figure 18. The bedclay can be distinguished from the overlying Bone Valley matrix by its content of dark-blue to olive-drab to dark-brown plastic, water-filled clay. White sandy calcareous clay is also characteristic of the bedclay. In addition, pronounced color banding of the clay is much more conspicuous in the bedclay than in the overlying matrix of the Bone Valley.

A contact thought to be that of the Bone Valley and Hawthorn formations in the Sydney area can be delineated from drill holes on the basis of these characteristics.

ELEANOR MINE

The Eleanor mine of the Coronet Phosphate Co. is in secs. 8, 9, and 16, T. 30 S., R. 22 E. Mining, which was carried on both north and south of the Alafia River, started about 1945 and continued to 1951.

Prospecting shows that this mine is underlain by typical matrix and overburden, except that both are thinner than average because the mine is close to the Alafia River. The overburden ranges in thickness from 0 to about 30 feet, and averages 15 feet; the matrix ranges in thickness from 0 to more than 20 feet, and averages about 8 feet.

Both the matrix and overburden thin markedly and regularly toward the river, except in the NW¼ sec. 16, where the loose sand of the overburden thickens to fill a pre-Pleistocene channel cut into the Hawthorn formation. Figure 9 shows the course of the channel, and section *B–B′* on plate 4 is a diagram of the channel as exposed in the mining pit. Gray loose sand of Pleistocene age overlies the upper clayey sand of the Bone Valley on both sides of the channel, and can be traced across the channel, where it overlies a brown iron-stained loose, but uniformly thick, sand. The sand was deposited after the channel was filled, and may be a deposit of late Pleistocene age. The channel, at its north end, at or close to the Alafia River was cut down to hard limestone or dolomite of the Hawthorn formation. Headward, to the southeast, the channel sand rests on phosphorite of the lower unit of the Bone Valley or on the clayey sand of the upper unit of the Bone Valley. Where the channel sand overlies the phosphorite of the lower unit of the Bone Valley, as at M–7½ on the isometric fence diagram (pl. 4), the position of the channel can be determined easily, but where the sand rests on clayey sand of the upper unit of the Bone Valley, it is difficult to determine the position of the channel. The following criteria have been used to map the position of the channel:

1. Abrupt thickening of the loose sands. At 8 locations in the channel, the loose sands ranges in thickness from 16 to 23 feet and averages 20 feet, whereas at 36 locations on the sides of the channel, the loose sands ranges from 3 to 13 feet and averages 7 feet. This criterion was used when only drill data were available, for example, at location M–8.
2. Torrential crossbedding of the loose sand, for example, location K–9.
3. Lenses of reworked fragmental phosphate in the loose sand, for example, location L–10.
4. Removal of all or most of the upper clayey sand unit of the Bone Valley, as at location M–8.

The following three stratigraphic sections show the lithology within the channel:

Log K.—Mine-face section, location K–9, sec. 16, T. 30 S., R. 22 E.

	Feet
Pleistocene:	
Terrace sands:	
Sand, loose, gray; some carbonaceous material	2
Sand, loose, gray; 0.001 percent U	6
Channel fill: Sand, loose, white and gray; torrentially crossbedded; trace of broken phosphate nodules in middle of unit; 0.002 percent U	15
Total, terrace sands	23
Pliocene:	
Bone Valley formation (upper unit): Sand, clayey, gray-green; some secondary cement of aluminum phosphate minerals; 0.016 percent U	1
Bone Valley formation (lower unit): Sand and gravel of phosphate; trace of quartz and clay	4
Total, exposed Bone Valley	5
Base not exposed.	

Log L.—Mine-face section, location L–10, sec. 16, T. 30 S., R. 22 E.

	Feet
Pleistocene:	
Terrace sands: Sand, loose, gray	6
Channel fill:	
Sand, loose, quartz, brown and white. Abundant broken and partly subrounded fragments of phosphate nodules; 0.017 percent U; 2.9 percent P_2O_5	3
Sand, loose, quartz, white	11
Total, terrace sands	20
Pliocene:	
Bone Valley formation (upper unit):	
Clay, sandy, blue-green; secondary cement of aluminum phosphate; 0.019 percent U; 13.5 percent P_2O_5; 11.5 percent I and A; 18.0 percent CaO	2
Sand, clayey; contains abundant coarse phosphate nodules; 0.010 percent U; 22.1 percent P_2O_5; 7.6 percent I and A; 32.5 percent CaO	6
Total, Bone Valley	8
Miocene:	
Hawthorn formation: Dolomite, sandy and clayey, with phosphate nodules. Cavities and borings at the top of the dolomite are filled with sandy clay with phosphate nodules; 0.001 percent U; 6.8 percent P_2O_5; 28.6 percent CaO; 12.7 percent MgO; 3.4 percent I and A	4
Total, exposed Hawthorn	4
Base of exposure.	

The reworked phosphate in the top bed of the channel-fill is of considerable interest. The broken edges of the fragmental material are slightly worn; the material is fresh and apparently not leached.

Log M.—Mine-face section, location M–8, sec. 16, T. 30 S., R. 22 E.

	Feet
Pleistocene and Recent:	
Terrace sand and channel fill: Sand, loose, white, quartz	17.0
Pliocene:	
Bone Valley formation (lower unit):	
Sand and gravel of quartz and phosphate. Trace of light-green clay	2.3
Sand, clayey, interbedded with sandy clay. Both beds contain phosphate nodules and granules	3.1
Base of exposure.	

The sand section is thick, and the entire upper unit of the Bone Valley is missing.

The normal or average section at the Eleanor mine consists of about 8 feet of loose sand, about 6 feet of clayey sand of the upper unit of the Bone Valley formation and about 8 feet of calcium phosphate zone. The calcium phosphate zone is mostly in the lower unit of the

Bone Valley; a small part at the base is residuum derived from the Hawthorn formation.

This buried channel shows that, prior to the deposition of sediments probably of latest Pleistocene age, a period of erosion followed the deposition of the Bone Valley formation.

To the north of the Alafia River, in sec. 8, T. 30 S., R. 22 E., a black carbonaceous sand lens cuts out the matrix (see section *A–A′*, pl. 4). This depression filling differs from the channel fill in several respects. The depression fill is much smaller—only 50 feet wide at the top and 14 feet wide at the base of the exposure. No lateral extensions of the fill could be found, hence it apparently is not a channel but possibly a filled sink hole. The sediment filling the depression is very similar to present-day swamp deposits.

This section also shows a thickening of the loose sand to the west and a consequent thinning of the lower unit of the Bone Valley formation. The zone of soft white phosphate is missing on the west side of the filled area.

In the eastern part of the mine, in secs. 9 and 16 (pl. 4), the matrix includes both the lower unit of the Bone Valley formation and residual, calcareous clay of the Hawthorn formation. In this part of the mine, the contact between the Bone Valley and Hawthorn formations was placed at the base of the coarse bedded sand of phosphate and quartz overlying the massive calcareous clay of the Hawthorn (fig. 8). The lower unit of the Bone Valley formation is normally a coarse sand or gravel, but at some places, as at F½–7½ on the fence diagram, the lower unit of the Bone Valley consists of a basal gravel overlain by a fine-grained sandy clay with phosphate nodules.

In the western part of the mine, in sec. 8, the matrix is uniform and is not divisible into definite lithologic units; it is shown on the fence diagram (pl. 4) as undifferentiated calcium phosphate zone. At K–8, sec. 8, a barren sand lens and a barren clay lens are within the calcium phosphate zone.

BOYETTE MINE

The Boyette mine of the American Agricultural Chemical Co. is in T. 31 S., R. 21 E., Hillsborough County. Mining began in 1945 and the mine was in operation in 1962.

The basement—the surface on which the Bone Valley formation was deposited—is limestone or dolomite of the Hawthorn formation, calcareous clay (residual from the carbonate rock), or green laminated clay (fig. 5). The surface of the basement at the Boyette mine (pl. 2) is a westward-trending ridge modified by small circular depressions and hills; it is a karst topography.

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The calcium phosphate zone includes both the lower unit of the Bone Valley formation and the residual, calcareous clay of the Hawthorn formation. The zone clearly transgresses stratigraphy. For example, at locations O–2, M–2, and K–2, sec. 36 (pl. 5), the zone is entirely within the residual clays of the Hawthorn formation, at location I–2 the zone consists of about equal parts of Hawthorn and Bone Valley, and at locations G–2, E–2, and C–2, the zone is entirely within the Bone Valley formation.

The contact between the Bone Valley and Hawthorn formations is shown on figure 5; it is placed at the break between sands of phosphate and quartz with minor clay, and the underlying calcareous sandy clay of limestone.

The isopach map of the calcium phosphate zone (pl. 6) shows a series of small, closed contours with a more or less random orientation. The zone ranges in thickness from 0 along Pringle Branch to a maximum of about 15 feet, and averages somewhat less than 10 feet.

The isopach map of the overburden (pl. 7) is similar to the isopach map of the calcium phosphate zone; it shows a series of small, randomly oriented, closed contours. The overburden, which includes loose sand of Pleistocene age, clayey sand assigned to the upper unit of the Bone Valley formation, and the hardpan, ranges in thickness from less than 10 to more than 40 feet and averages about 25 feet.

The relations of the sand, clayey sand, and hardpan in the area of the Boyette mine are shown in plate 5. This diagram clearly shows the secondary nature of the hardpan. At location K–16, sec. 36, the hardpan is entirely within the loose sand of the Pleistocene. At location O–8, sec. 36, the hardpan is in contact with the lower phosphorite unit of the Bone Valley formation; here the secondary iron cement possibly has altered the loose sand, the clayey sand of the upper unit of the Bone Valley, and a part of the lower unit of the Bone Valley. The hardpan at location E–10, sec. 3, is entirely within the clayey sand of the upper unit of the Bone Valley; at location O–2, sec. 36, the hardpan is in contact with residual clay of the Hawthorn, and the lower part of the Bone Valley formation, if present, is obscured by the hardpan.

Clayey sand of the upper part of the Bone Valley, including the aluminum phosphate zone, is thickest in a zone that trends west from the east end of sec. 1 to the west end of sec. 2. The clayey sand thins both to the north and to the south. The calcium phosphate zone, particularly that part of the zone that is assigned to the lower unit of the Bone Valley, tends to be thin where the clayey sand is the thickest. This thinning may indicate that the leaching which formed the aluminum phosphate zone has altered a part of the phosphorite of the lower unit of the Bone Valley.

Hardpan is absent from the area where the aluminum phosphate zone is thickest. Acid ground waters that formed the hardpan layers may have contained little or no iron in the area shown in the central part of the diagram, and, may therefore have continued to leach the phosphate from the Bone Valley formation; this action would have caused the aluminum phosphate zone (the lower part of the clayey sand unit) to be thicker.

At the surface, loose quartz sand assigned to the Pleistocene ranges from about 2 feet to more than 20 feet in thickness. The loose sand is underlain by clayey sand of the upper unit of the Bone Valley, except at the streams where it may overlie phosphorite of the lower unit of the Bone Valley (as at location J ½–2½, sec. 13), calcareous clay of the Hawthorn formation (as at location D ½–2½, sec. 12), or hard bedrock (as at location P ½–15, sec. 15).

FISHHAWK TRACT

The Fishhawk tract, in parts of secs. 33 and 34, T. 30 S., R. 21 E., has not been mined. Drilling by Wayne Thomas, owner of the tract, provided information for the fence diagram (pl. 3). The drill holes were logged by D. C. Alverson of the U.S. Geological Survey.

The isometric fence diagram (pl. 3) clearly shows the lenticular lithologic units in both the Bone Valley and Hawthorn formations. No fossils were found in the cuttings from any of the drill holes; all correlations are lithologic. All drill holes bottomed in material too hard for the hand-auger drill to penetrate. This hard material probably is limestone or dolomite of the Hawthorn formation.

Bedclay is present in much of the area, but not where laminated clay beds of the Hawthorn formation are present. This clay apparently was relatively impermeable and prevented the leaching of carbonate from the limestones. The clay is lenticular. The basal part of the clay contains flint nodules at locality G–9. This clay is thought to be a part of the Hawthorn formation because it is lithologically similar to clay in the Hawthorn in other areas, and because similar clay has not been found in the Bone Valley formation. A lens of loose quartz sand is interbedded with the clay at locality I–1. This sand is also assigned to the Hawthorn formation.

The lower phosphorite unit of the Bone Valley formation rests on the laminated clay or on the residual bedclay of the Hawthorn formation. The phosphorite unit of the Bone Valley ranges in thickness from 0 to about 19 feet. This unit pinches and swells and is absent over a rather large area in sec. 33. The lower unit of the Bone Valley is overlain by clayey sand, sand, or clay of the upper unit of the Bone Valley, or by loose sand of Pleistocene age. All the beds of the upper unit of the Bone Valley are lenticular. The most persistent bed of the upper unit of the Bone Valley is the clayey sand that covers most of the area. Where both clayey sand and clay of the upper unit of the Bone Valley are present, the more clayey bed always underlies the clayey sand. The clay bed does contain lenses of more or less pure sand at several places. The clayey sand bed contains some grains of soft white phosphate, but the clay bed is usually nonphosphatic.

The lithologic correlations are probably correct, inasmuch as the differences in lithologies are striking; the stratigraphic correlations as shown on the diagram, however, may not be correct. It is possible, that the clay, clayey sand, and sand beds, assigned to the upper part of the Bone Valley formation, may represent flood-plain deposits of Pleistocene age along Fishhawk Creek and its tributaries. For example, at locality K–9, a trace of phosphate nodules occurs in the loose sand; the loose sand is underlain by clayey sand, and the clayey sand rests on hard bedrock. This point is close to Fishhawk Creek, and all this material could be flood-plain deposits of the creek. However, the stratigraphic correlations, as shown, seem to be the best interpretation possible.

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, p. 1230–1231.

Altschuler, Z. S., Clarke, R. S., and Young, E. J., 1954, Uranium in apatite [abs.]: Geol. Soc. America Bull., v. 65, p. 1225–1226.

——— 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 Cuttita, 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.

Applin, P. L., and Applin, E. R., 1944, Regional subsurface stratigraphy and structure of Florida and southern Georgia: Am. Assoc. Petroleum Geologists Bull., v. 28, p. 1673–1753.

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

Berman, Robert, 1953, A mineralogic study of churn drill cuttings from a well through the Bone Valley formation, Hillsborough County, Florida [abs.]: Nuclear Sci. Abs., v. 7, no. 18A, abs. 5060, p. 616.

Brodkorb, Pierce, 1955, The avifauna of the Bone Valley formation: Florida Geol. Survey Rept. Inv. 14, 57 p.

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., 1955, Economic geology of the land-pebble phosphate district, *in* Geologic investigations of radioactive deposits, semiannual progress report, June 1–Nov. 30, 1955: U.S. Geol. Survey Trace Elements Inv. Rept. 590, issued by U.S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, Tenn., p. 281–282, fig. 60.

——— 1956, Distribution and occurrence of uranium in the calcium phosphate zone of the land-pebble phosphate district of Florida, *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. 489–494.

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.

——— 1959, Cenozoic echinoids of eastern United States: U.S. Geol. Survey Prof. Paper 321.

Cooke, C. W., and Mansfield, W. C., 1936, Suwannee limestone of Florida [abs.]: Geol. Soc. America Proc., 1935, p. 71–72.

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

Crago, Arthur, 1950, Three new steps in treating Florida phosphate rock: Eng. Mining Jour., v. 151, no. 11, p. 78–83.

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

Davidson, D. F., 1952, Relation of the "topography" of the Hawthorn formation to size of phosphate particles in the deposits, and to topography, in the northern part of the land-pebble phosphate field, Florida: U.S. Geol. Survey Trace Elements Inv. Rept. 337, issued by U.S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, Tenn., 17 p.

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

Goldschmidt, V. M., (by Alex Muir, ed.), 1954, Geochemistry: Oxford Clarendon Press, 730 p.

Hignett, T. P., Siegel, M. R., Kelso, T. M., and Meline, R. S., 1957, Utilization of high-aluminum phosphate ore from the Florida leached-zone ore deposits: Tennessee Valley Authority Chem. Eng. Bull. 3, 32 p.

Hunt, C. B., and Hunt, A. P., 1957, Stratigraphy and archeology of some Florida soils: Geol. Soc. America Bull., v. 68, p. 797–806.

Jacob, K. D., and others, 1933, The composition and distribution of phosphate rock with special reference to the United States: U.S. Dept. Agriculture, Tech. Bull. 364, 90 p.

Johnson, L. C., 1888, The structure of Florida: Am. Jour. Sci., ser. 3, v. 36, p. 230–236.

Kerr, P. F., and others, 1950, X-ray diffraction measurements and chemical analyses, *in* Analytical data on reference clay minerals: Clay minerals standards, Am. Petroleum Inst. Project 49. Prelim. Rept. 7, p. 1–58.

King, P. B., 1951, The tectonics of middle North America: Princeton, N.J., Princeton Univ. Press, 203 p.

McKelvey, V. E., Cathcart, J. B., and Worthing, H. W., 1951, Preliminary note on the minor metal content of Florida phosphate rock: U.S. Geol. Survey Trace Elements Inv. Rept. 236, issued by U.S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, Tenn., 6 p.

McKelvey, V. E., and Nelson, J. M., 1950, Characteristics of marine uranium-bearing sedimentary rocks: Econ. Geology, v. 45, p. 35–53.

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 shore lines in Florida and Georgia: U.S. Geol. Survey Prof. Paper 221–F, p. 95–107.

Mansfield, G. R., 1942, Phosphate resources of Florida: U.S. Geol. Survey Bull. 934, 82 p.

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.

Mossom, D. S., 1925, A preliminary report on the limestones and marls of Florida: Florida Geol. Survey 16th Ann. Rept., p. 27–203.

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

Palache, Charles, Berman, Harry, and Frondel, Clifford, 1951, Dana's system of mineralogy: 7th ed., rev., New York, John Wiley & Sons, Inc., v. 2, 1124 p.

Robinson, W. O., 1948, The presence and determination of molybdenum and rare earths in phosphate rock: Soil Science, v. 66, p. 317–322.

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

Siems, H. B., 1951, Fertilizers, *in* Kirk, R. E., and Othmer, D. F., eds., Encyclopedia of chemical technology: New York, The Interscience Encyclopedia, Inc., v. 6, p. 376–452.

Simpson, G. G., 1929, The extinct land mammals of Florida: Florida Geol. Survey 20th Ann. Rept., p. 229–279.

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

Waring, C. L., and Mela, Henry, Jr., 1952, The determination of small amounts of rare earths in phosphate rocks: U.S. Geol. Survey Trace Elements Inv. Rept. 239, issued by U.S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, Tenn., 20 p.

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