Geology of Phosphate Deposits of Northern Peninsular Florida

GEOLOGICAL SURVEY BULLETIN 1118

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

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By GILBERT H. ESPENSHADE *and* CHARLES W. SPENCER

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GEOLOGY OF PHOSPHATE DEPOSITS OF NORTHERN PENINSULAR FLORIDA

By Gilbert H. Espenshade and Charles W. Spencer

ABSTRACT

Stratigraphic information, fossil collections, and phosphate samples were obtained in a reconnaissance geologic study of uraniferous phosphate deposits from exposures at numerous localities and from 30 auger-drill holes and 16 core-drill holes.

New data are presented on the lithology, stratigraphy, and paleontology of the Hawthorn formation (early and middle Miocene age) and younger beds in an area extending north from central Lake County to the Florida-Georgia line. Phosphatic dolomite is the dominant lithologic type in the Hawthorn formation and forms the lower part of the section, which is here called the phosphatic dolomite unit. Phosphorite (phosphatic clayey sand) forms the upper part of the Hawthorn, which is called the phosphorite unit. The Hawthorn is covered by nonphosphatic sand and clayey sand of Miocene(?) or younger age. Carbonate-fluorapatite, in the form of shiny pellets and grains, is the sedimentary phosphate mineral. Two varieties of dolomite occur in the Hawthorn—hard, tough, cemented dolomite and soft claylike dolomite composed of uncemented tiny dolomite rhombs. Clay beds associated with dolomite are made up of the clay minerals attapulgite and montmorillonite, with attapulgite apparently most abundant. Montmorillonite is the only clay mineral in nearly all the nondolomitic phosphorite. Both clay minerals form beds of fuller's earth. Kaolinite is the clay mineral in the clayey sands that overlie the phosphorite beds of the Hawthorn. The phosphorite unit of the Hawthorn formation in northern peninsular Florida is lithologically identical with the phosphorite of the Bone Valley formation, which overlies the Hawthorn in central Florida.

Thickness of the Hawthorn formation where intersected by the different drill holes ranges from 24 feet in one of the most southerly drill holes to 288 feet in the most northeasterly drill hole. In general, the thickness of the Hawthorn and the relative proportion of dolomite beds to phosphorite beds are greatest in the northernmost drill holes. Similar sequences of lithologic units were penetrated by most drill holes, but similar lithologic units are not everywhere of the same age. In one drill hole, both the phosphatic dolomite unit and the overlying phosphorite unit contain fossils of early Miocene age; in another drill hole, early Miocene fossils occur only in the basal beds of the phosphatic dolomite unit, and middle Miocene fossils occur in the overlying beds of the phosphatic dolomite unit.

Supergene alteration of the upper phosphorite beds of the Hawthorn formation by ground water has resulted at many places in partial leaching of apatite pellets; deposition of the secondary aluminum phosphate minerals crandallite, millisite,

and wavellite; and some enrichment in uranium, in the same manner as in the aluminum phosphate zone of weathered phosphorite in the Bone Valley formation of central Florida.

In the hard-rock phosphate district, exposures in old phosphate mines and cuttings from auger-drill holes show that there is a fairly consistent stratigraphic sequence throughout this area near the west side of the peninsula. These strata, which have been correlated with the Alachua formation, are now thoroughly weathered, much disturbed by solution slumping, and lie above irregular deposits of secondary apatite that commonly fill sinkholes and solution pits in limestone. The lower part of this sequence overlying the secondary apatite deposits is made up of thin beds of phosphatic clay and clayey sand containing sedimentary apatite pellets and grains; the upper part consists of thick beds (as much as 80 ft) of phosphatic sand. Phosphatic limestone is known at one locality, and may have once been more widespread before destruction by ground water solution. The stratigraphic sequence is somewhat similar to that of the Hawthorn formation farther east, but is in part younger, because invertebrate fossils of late Miocene age and horse teeth of early Pliocene(?) age occur in the phosphatic sands, the topmost unit.

The hard-rock phosphate deposits seem to have been formed by very thorough ground-water leaching of phosphate from marine phosphorite beds and redeposition of phosphate at depth as secondary apatite by replacement of limestone and precipitation in cavities, as proposed by some earlier investigators.

Phosphate and uranium analyses are given of samples of phosphorite, phosphatic clay, and phosphatic dolomite taken from the Hawthorn formation; some analyses of aluminum and other constituents are also given. In the phosphorite samples, between 70 and 90 percent of the total phosphate and uranium is contained in the coarse fraction ($>$ 1.19 mm size) and in the fine fraction ($<$ 0.105 mm size) combined; quartz sand is the dominant constituent in the intervening size range. Recent work by others has indicated that there are significant reserves of phosphorite in central Alachua County in addition to reserves that have been previously estimated in northern peninsular Florida.

Analyses of phosphate and uranium are given of samples of hard secondary apatite, soft apatite, and phosphatic sand from the hard-rock district and analyses for aluminum and other constituents are presented for selected samples. The uranium-P_2O_5 ratio is highest in the phosphatic sands, which are composed of about 80 to 85 percent quartz sand and 15 to 20 percent of a fine claylike mixture of kaolinite and aluminum phosphate minerals. The nonquartz part of the phosphatic sand contains about 0.010 percent uranium; in some samples the nonquartz part has more than 20 percent each of P_2O_5 and Al_2O_3.

Phosphate mining in the hard-rock district began about 1889, and was in its most productive period from 1894 to 1914; only one mine has been worked in recent years. Much more information is needed to make a reliable estimate of the reserves of hard-rock phosphate, but previous estimates of reserves are judged to be excessive because they include a considerable area that now does not appear to be geologically favorable. Total production of about 14 million long tons of hard-rock phosphate has come from only about half of the potential area of the district; certain areas are recommended for prospecting. Large tonnages of phosphatic sands that contain important aggregate amounts of uranium, phosphorus, and aluminum occur in the district; these sands form most of the overburden that is discarded in the mining operations.

INTRODUCTION

PREVIOUS INVESTIGATION

The Geological Survey engaged in a program of investigation of the occurrence and distribution of uranium in the Florida phosphate deposits on behalf of the Division of Raw Materials of the Atomic Energy Commission during the period from 1947 to 1956. Geologic studies in the land-pebble phosphate field (fig. 1) of central Florida, the principal phosphate-producing area of the State, showed that very small amounts of uranium are associated both with the primary phosphate mineral (nodules or pellets of apatite of sedimentary origin) in the lower part of the Bone Valley formation (Cathcart, 1956) and with weathered apatite and secondary phosphate minerals (mainly the aluminum phosphate minerals crandallite, millisite, and wavellite) in a zone of weathering in the upper part of the Bone Valley formation (Altschuler and others, 1956). Rock from the weathered zone (also termed the "aluminum phosphate zone" or the "leached zone") characteristically contains 8 to 12 percent P_2O_5 and about 0.012 percent uranium, in contrast to the unaltered phosphorite which commonly has 10 to 15 percent P_2O_5 and about 0.008 percent uranium (Altschuler and others, 1956, p. 500). Twofold to fourfold enrichment of uranium by weathering agencies has taken place in the aluminum phosphate zone of the land-pebble phosphate field. Material from this zone is rejected as overburden in mining operations because of its low phosphate content.

PRESENT INVESTIGATION AND SCOPE OF WORK

After several years of work in the land-pebble district, the program was extended to investigate the occurrence of uranium in the sedimentary phosphorite and secondary phosphate deposits that are widely distributed in the northern part of the State. This report deals only with those deposits (fig. 1).

In northern Florida, phosphate characteristically occurs in the Hawthorn formation and Duplin marl of Miocene age and in secondary deposits associated with the Alachua formation of Pliocene age. As will be shown (p. 37), some of the strata that have been included with the Alachua formation are Miocene in age. The main outcrop area of the Miocene phosphatic beds is in the central and eastern part of the region, where the strata dip gently to the northeast and east (pl. 1). Outliers of the Hawthorn formation occur a few miles to the west in Marion and Alachua Counties. Farther west, near the west coast of the peninsula, are the large areas of Alachua formation where the secondary phosphate deposits of the hard-rock phosphate field are found; mining was once very active here, but only one mine is now operating.

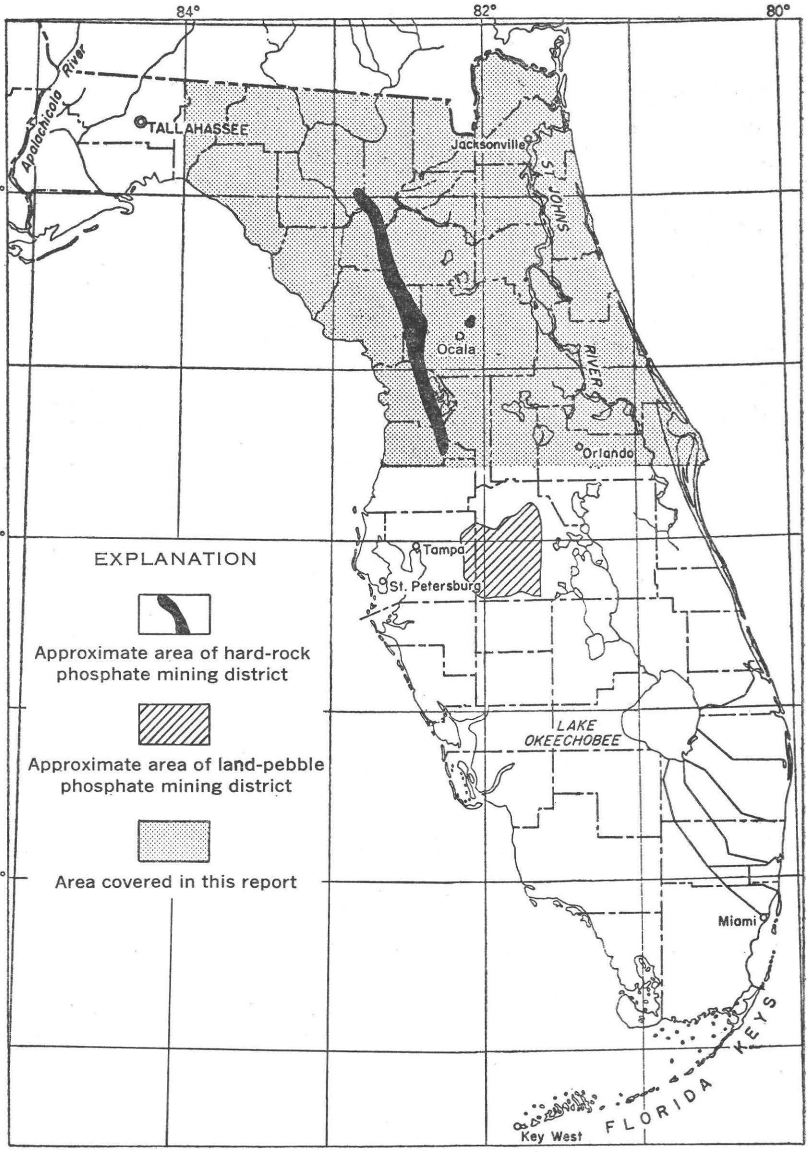

FIGURE 1.—Map showing location of area covered by report and the hard-rock and land-pebble phosphate districts.

Investigation of the association of uranium and phosphate in this large area within a limited period of time necessarily meant that the study had to be of reconnaissance nature. The procedure followed, accordingly, was to make detailed geologic studies at places that seemed to be most important and to select the points of study in such a manner that the region would be fairly well sampled.

Natural exposures that display more than a few feet of strata are very scarce in this part of Florida, because of the ever-present surficial mantle of sand, the very low topographic relief of the Florida coastal plain, and the predominance of underground drainage over stream erosion. Fortunately, quarries and pits have been excavated for limestone, phosphate, clay, and sand at many places in the region, and these provide exposures that are very informative. Drill holes were put down at places where neither natural nor artificial exposures existed; 30 holes were drilled by a jeep-mounted power auger in the hard-rock phosphate field and in the area of outliers of the Hawthorn formation in southern Marion County, and 16 holes were drilled by a rotary core drill in Miocene strata in the eastern part of the region.

A large number of samples of all varieties of primary and secondary phosphatic rocks and minerals were taken for chemical analysis, for mineralogical determinations by means of X-ray, and for petrographic study. Many samples were screened to determine the amount and relationships of phosphorus and uranium in the different size fractions. Much new information on the stratigraphy and paleontology of the post-Eocene formations was gathered from the drill holes and from the natural and artificial exposures.

Investigation of phosphate deposits in northern Florida under the current program was begun mainly by reconnaissance studies in the hard-rock phosphate field by K. B. Ketner in 1952–53, by a program of core drilling for geologic information in the area between the land-pebble phosphate and hard-rock phosphate fields in 1953 (Ketner and McGreevy, 1959), and by airborne radioactivity surveys of several areas in 1953 (Moxham, 1954). G. H. Espenshade was given the responsibility of continuing these studies in 1954. Fieldwork was carried on intermittently from October 1954 until June 1956. L. A. Brubaker was associated with the project until June 1955. C. W. Spencer took part in the field and laboratory studies from October 1955 until December 1956. Sylvio de Q. Mattoso, participant from Brazil in the Geological Survey's program under auspices of the International Cooperation Administration, worked with the field party for 7 weeks in 1956. An area of strong radioactivity anomalies south of Ocala, Marion County, which was discovered by the airborne survey (Moxham, 1954), was studied early in the program by means of 10 auger-drill holes and by surface examination. A brief report was written on the results of that phase of the study (Espenshade, 1958); information from that report is summarized in the present paper.

ACKNOWLEDGMENTS

Many colleagues in the Geological Survey have contributed to this work. Druid Wilson has devoted much time to the study of the collections of Miocene invertebrate fossils, and he is responsible for nearly all the fossil identifications and age assignments presented in this report. K. B. Ketner, Z. S. Altschuler, C. W. Cooke, and V. T. Stringfield have been particularly helpful in introducing the senior author to the geology of the phosphate deposits and northern Florida and in discussing different geologic problems in the field and office. Numerous chemical analyses and mineral determinations have been made by the various analysts named in the tables of analyses.

Herman Gunter, R. O. Vernon, and others of the Florida Geological Survey have aided the investigation in the course of several field conferences and other discussions. The staff of the Tennessee Valley Authority in Ocala, Fla., which was engaged in prospecting for phosphate deposits in the hard-rock district, has furnished data on the results of its exploration. Local residents and officials have been most cooperative; the Kibler-Camp Phosphate Enterprise gave access to its producing mine south of Dunnellon, and State and county road officials granted permission to drill holes along road right-of-ways. E. C. Pirkle, of the University of Florida, who was studying the geology of Alachua County, contributed significant information and ideas to the field studies of this project.

GENERAL GEOLOGY

STRATIGRAPHY AND GEOLOGIC HISTORY

The general features of the geology of northern peninsular Florida are well known and are outlined by Cooke (1945) in his bulletin on the geology of the State. Detailed geologic studies in the region are few, however, and cover only three counties: Citrus and Levy Counties, by Vernon (1951), and Alachua County, by Pirkle (1956a, b; 1957a, b; 1958). Much detailed stratigraphic and physiographic study remains to be done before the geology of this part of the State and the history of geologic events during the Cenozoic era are fully understood.

The oldest rocks exposed in Florida are limestones of Eocene age (mainly the Ocala limestone) that crop out along the west side of the northern part of the peninsula in an area about 140 miles long and as much as 50 miles wide (pl. 1). These Eocene limestones are exposed in a broad arch, trending northwest, that is known as the Ocala uplift, or arch. Younger sedimentary rocks surround the Ocala arch on the north, east, and south; the west side is bordered by the shallow waters of the Gulf of Mexico. Limestones of late Oligocene age (principally the Suwannee limestone) rest unconformably on the Eocene beds around the northwest and southeast ends of the arch.

Miocene sedimentary rocks of diverse character—clay, clayey sand, clayey-sandy phosphorite, and phosphatic dolomite (the Hawthorn formation)—are exposed, or have been penetrated in wells and drill holes, around the north end and east side of the arch, dipping gently northeast and east. Similar, but younger, beds (late Miocene) that are exposed farther east (pl. 1) have been correlated with the Duplin marl of North Carolina by Cooke (1945). The Miocene beds lie conformably upon the Oligocene limestone at the north end of the Ocala uplift and unconformably upon Eocene limestone at the east side of the uplift; they are also exposed in many small outliers upon the Eocene limestone near the middle of the arch and on Oligocene limestone at the south end. Phosphatic sands and clays (Alachua formation) cover the Eocene limestone in a narrow belt about 100 miles long on the axis of the Ocala arch. The age of the Alachua formation is considered to range from early Miocene to Pleistocene by Vernon (1951), and is believed to be Pliocene by Cooke (1945) and others. Pliocene and Pleistocene sediments, mostly sand and clayey sand, cover the Miocene beds along the eastern half of northern peninsular Florida.

Because the phosphate deposits are Miocene or younger in age, the pre-Miocene stratigraphy and geologic history need only a few further comments here; more complete discussions may be found in the papers by Cooke (1945) and Vernon (1951). Exploratory wells for oil in this part of Florida have shown that several thousand feet of Eocene and Cretaceous sedimentary rocks, largely of carbonate lithology, are present in depth and that beneath these strata are clastic sedimentary rocks, volcanic rocks, and granitic rocks of Paleozoic and possible Precambrian age. In the area of exposed Eocene rocks on the crest of the Ocala uplift in Citrus and Levy Counties, Vernon (1951) has distinguished three formations of Eocene age where the Ocala limestone alone is shown on plate 1. He has separated the Ocala limestone into two formations—the Ocala limestone (restricted) and the underlying Moodys Branch formation (subdivided into the Williston and Inglis members): he has also found exposures of the older Avon Park limestone at several places. Puri (1957) has recently raised the Ocala to the status of a group that is subdivided into three formations: the Crystal River (youngest), the Williston, and the Inglis.

Strata of Miocene and younger age are characterized by large amounts of clastic sediments, clay and sand, in contrast to the dominant carbonate lithology of the older Cenozoic rocks. This marked change in depositional environment was accompanied by widespread formation of sedimentary phosphate during Miocene time.

Transgressions and withdrawals of the sea have happened at different times during and since the Miocene epoch. Older clastic sediments have been reworked locally during marine invasions, and then modified further by slumping and deposition into sinkholes during periods of weathering and erosion. Similar appearing sediments in some areas contain vertebrate fossils of several ages. These events have resulted in subtle differences of lithology and stratigraphy that are easily confused or overlooked and have thereby hindered the understanding of post-Oligocene stratigraphy and geologic history.

Disagreement exists among students of Florida geology about the nature of origin and the age of the Alachua formation and the hard-rock phosphate deposits that are associated with the Alachua formation. This matter will be discussed at some length below (p. 38), but the differing points of view are here summarized. Vernon (1951) considers the Alachua formation to be a terrestrial deposit, possibly in part lacustrine and fluvatile, of sand, clay, phosphatic clay, and phosphate rock that was formed on the crest of the Ocala uplift during Miocene and later time. According to this point of view, the Ocala uplift was an island area when the marine sediments of the Hawthorn formation were deposited. Hence, the Hawthorn formation would have never extended across the crest of the Ocala arch, although Vernon (1951, p. 179) does recognize that marine clays of Hawthorn age were deposited locally in southern Citrus County (pl. 1). He regards the hard-rock phosphate deposits as ancient guano deposits. Vernon believes that the Alachua formation ranges in age from early Miocene to Pleistocene, and that it may be the terrestrial equivalent of the entire marine Miocene of Florida. Cooke (1945), on the other hand, believes that marine sediments of the Hawthorn formation were deposited in the Ocala arch area during Miocene time. Uplift followed and these beds were very deeply weathered in Pliocene time, resulting in an irregularly compacted residuum of sand, clay, and phosphatic material, which makes up the Alachua formation. Cooke agrees with Sellards (1913) that the hard-rock phosphate deposits were formed by ground-water solution of phosphate from the Miocene strata and redeposition of phosphate by replacement and cavity filling in the underlying limestone beds. We think that the theories of Cooke and Sellards are for the most part correct.

Some of the difficulty in defining the Alachua formation is due to the fact that vertebrate fossils of different ages occur in strata that have been called Alachua. Cooke (1945, p. 201) explains this situation as follows:

> The fossils commonly attributed to the Alachua formation include bones of Miocene animals, which were probably buried in sinkholes during Tampa time [pre-Hawthorn], bones of Pliocene animals, which may be regarded as the indigenous fauna, and Pleistocene bones, evidently younger than the true Alachua fauna.

There is likewise uncertainity about the age and correlation of the clayey sands that underlie the hilly "lake country" along the axis of the peninsula. These sediments are made up of white coarse sand and kaolinite, with large quartz pebbles and much mica; they commonly have crossbedding, and characteristically weather red to orange. Cooke (1945, p. 231) correlates these clayey sands with the Citronelle formation (pl. 1); its type locality is in southern Alabama, and it is presumed to be Pliocene in age. MacNeil (1950, p. 98) feels that the Citronelle formation may be Pliocene or early Pleistocene in age. These clayey sands extend southward into Highlands County, about 70 miles south of Lake Apopka, where they have also been correlated with the Citronelle by Cooke (1945, pl. 1). However, Bishop (1956, p. 24–28) concludes that the coarse clayey sands in Highlands County are deltaic deposits of Hawthorn age that grade both downward and laterally into typical marine Hawthorn strata. Near Haines City, Polk County, about midway between Lake Apopka and Highlands County, Ketner and McGreevy (1959, p. 71) have found fossils of late middle Miocene or early late Miocene age in the micaceous clayey sands that are mapped as Citronelle by Cooke (1945, pl. 1); they conclude that these clayey sands are older than the Citronelle formation in its type area.

Sands of probable Pleistocene age form a widespread mantle in northern Florida, not only in the areas shown as Pleistocene on plate 1, but also at many other places, particularly throughout the areas of clayey sand that are mapped as the Alachua or the Citronelle formation on plate 1. Slightly clayey bedded sands overlie unconformably the phosphatic sands and solution rubble of the Alachua formation in many hard-rock phosphate deposits that have surface altitudes of less than 100 feet. These bedded sands were presumably reworked from the older sands during Pleistocene marine invasions; they pass upward into loose sands, some of which appear to be windblown deposits.

STRUCTURE

The Ocala uplift, or arch, is the dominant structural feature in the exposed Cenozoic rocks of Florida. Vernon (1951, pl. 2) presents a structure contour map, based upon an horizon in the upper Eocene formations, that shows the Ocala arch and a zone of faults trending northwest along the axis of the arch. Carr and Alverson (1959, p. 59–60) describe a northwest-trending fault in northern Polk County that seems to be an extension to the southeast of the fault zone discovered by Vernon. In another map, Vernon (1951, fig. 33) shows structure contours and isopachs in Miocene strata. Another domal structure, called the Peninsular arch by Applin (1951), has been found at the unconformable contact of the Mesozoic and pre-Mesozoic rocks by exploratory drill holes for oil. The crest of this buried dome does not coincide with the Ocala uplift, for it is more than 50 miles to the northeast (Vernon, 1951, fig. 11). Cooke (1945, p. 6–7) concludes that warping of the Ocala arch began before late Eocene and continued into late Miocene. Vernon (1951, p. 62) dates this structural uplift as early Miocene in age, with possible renewed activity at later times. Ketner and McGreevy (1959, p. 75) point out that nearly horizontal beds of late Miocene age lie upon the warped beds of the Ocala uplift, and therefore the uplift must have been formed before late Miocene time.

The present study did not add much new data on the structural geology of the region. Bedding in Ocala limestone and younger strata appears horizontal, except where the younger beds have obviously slumped into sinkholes in the Ocala limestone. Several fault surfaces in Ocala limestone were seen in pits in central and western Marion County. These surfaces trend between N. 65 W. and N. 85 W. (more west than those shown by Vernon), are about vertical, and have gently plunging slickensides (10° to 20° NW. or SE.) that suggest the major component of movement was horizontal.

Miocene strata of about the same age occur over a wide range of altitudes; for example, beds with early Miocene fossils occur between 100 and 150 feet above sea level at localities 21 and 22 (pl. 1); at about 40 feet above sea level in drill hole 36; and about 270 feet below sea level in drill hole 44. These beds of early Miocene age have a northeasterly dip of about 10 feet per mile, which could represent the initial dip of the beds or could be due to differential vertical movement. However, drilling has shown that the Miocene strata have less clastic material and thicken northeastward in the direction of drill hole 44, which suggests that there was differential subsidence during Miocene sedimentation. The occurrence of fossiliferous Miocene beds of different ages at about the same altitudes (30 to 70 ft above sea level) in several drill holes—such as the lower Miocene beds in drill hole 36, middle Miocene beds in drill holes 40 to 45, and upper Miocene beds in drill holes 42 and 44—may also be the result of differential subsidence during Miocene sedimentation or may be partly the result of differential uplift since deposition.

GEOMORPHOLOGY

In northern peninsular Florida, a wide belt of flat land extends inland from each coast and merges with a higher central region whose surface ranges from nearly flat to rolling or hilly. Cooke (1939) gives the names "Coastal Lowlands" to the coastal belts and "Central Highlands" to the medial region. He states that the "Coastal Lowlands" are less than 100 feet above sea level nearly everywhere and that the

"Central Highlands" range from 40 to about 250 feet above sea level. The major topographic features of the region can be seen on the map of the high terraces and Pleistocene shorelines of Georgia and Florida by MacNeil (1950).

The geomorphology of the region is more complex than this simple classification would suggest, however. Features of topography and drainage are varied, but certain formations have characteristic surface expressions. In the region covered by plate 1, the Ocala limestone underlies most of the lowlands along the west coast and also areas of low elevation within the "Central Highlands." Sands and clayey sands of Pliocene and Pleistocene ages lie beneath the lowlands of the east coast. The highest areas (about 150 to 250 ft above sea level) largely coincide with the outliers of Hawthorn formation in southern Hernando County and northwestern Marion County; with the main outcrop area of the Hawthorn formation extending from Alachua County northwest to Hamilton County; and with the clayey sands mapped as the Citronelle formation in Bradford and Clay Counties. The north-trending axis of this last area is known as Trail Ridge.

Distinctive drainage systems have been developed in the outcrop areas of the different formations, and the nature of these drainage systems has been determined to considerable degree by the permeability of the bed rock. Surface drainage is best developed where there are thick clayey formations with poor to moderate permeability, especially in the main outcrop area of the Hawthorn formation; sinkholes and lakes are not abundant in these areas. Many sluggish streams and much swampy ground exist in the lowlands of Pliocene and Pleistocene sands and clayey sands along the east coast.

The Ocala limestone has exceptionally high permeability and a low content of insoluble matter; for these reasons, therefore, underground drainage systems dominate in areas where the Ocala limestone is exposed or is covered only by a few feet of sand. Sinkholes (commonly filled with sand and clay) and lakes and ponds abound in many parts of these areas. Surface drainage consists of a few major streams, like the Oklawaha, Withlacoochee, and Suwannee Rivers, which have practically no tributaries in the limestone areas. The subterranean drainage of many tens of square miles reaches the surface in strongly flowing springs, such as Silver Springs and Rainbow Springs, Marion County, and Homosassa Springs, Citrus County. Where the Ocala limestone is overlain by thick permeable sand of the Alachua formation in the long belt of the hard-rock phosphate field between Hernando and Gilchrist Counties (pl. 1), the topography is most irregular with many hummocks and sinks, surface drainage is also absent, and lakes are scarce. The topography is similar where less permeable clayey sands, such as those mapped as Citronelle formation, overlie the

Ocala limestone, but there are many lakes and ponds, particularly in the lake region extending southward from Lake Weir in southern Marion County.

The contrasts between drainage systems in areas of permeable Ocala limestone and areas of less permeable beds of the Hawthorn formation is well displayed on the soil map of Alachua County (Taylor and others, 1954). No surface drainage exists in the western part of the county in the area underlain by Ocala limestone (which is about coextensive with the areas of Archer, Chiefland, Hernando, and Jonesville soil series), but streams, ponds and lakes are well distributed throughout the area of Hawthorn formation to the east. Presumably the area of Ocala limestone was once covered by beds of the Hawthorn, and a stream system existed upon this surface that changed to an underground drainage system after removal of the Hawthorn formation by erosion.

A relic of former drainage systems is seen in the broad valley of the Waccasassa River, which is now occupied by swamps and a short sluggish stream. As Vernon (1951) points out, a much larger stream must have once flowed in this valley; this feature is obvious on aerial photographs of the region. Probably the Santa Fe, or the combined Santa Fe and Suwannee Rivers, flowed at one time in this valley. Also evident on the aerial photographs is what appears to be an abandoned channel of the Withlacoochee River that once extended northwest from Dunnellon along the present course of Tenmile Creek, perhaps to join the ancient Waccasassa River; abundant limestone outcrops in the Withlacoochee west of Dunnellon support the view that this stretch of the present river channel is young. White (1958, p. 19–27) has studied the drainage history of the Withlacoochee River, Lake Tsala Apopka, and the Hillsborough River, and thinks that the Withlacoochee may once have flowed southward into the Hillsborough River.

The importance of ground-water solution in lowering the surface of limestone areas in Florida was demonstrated by Sellards (1914a), who, using data on flow of large springs and the dissolved mineral content of their waters, calculated that about 400 tons of mineral solids are dissolved annually per square mile. He estimated, therefore, that the surface of central peninsular Florida is being lowered by solution at the rate of 1 foot in 5,000 or 6,000 years.

Cooke (1939) emphasizes the strong influence that fluctuations of sea level have had upon the development of landforms in Florida, not only in the deposition of Tertiary sediments of varied lithology when sea level was relatively higher than now, but also in the subsequent erosion of these formations when sea level was lower. Presumably, sea level was several hundred feet lower during the glacial stages, and under these conditions streams would have been able to deepen their channels; sinkholes may also have become deeper because of deep ground-water circulation. Deep channels in bedrock that are now filled with alluvium have been found along the Oklawaha River and at places on the Withlacoochee River by exploratory drilling along the route of the proposed trans-Florida canal. Numerous holes along the Oklawaha River in eastern Marion County were drilled through alluvium to depths of about 60 feet below sea level and stopped without reaching bedrock; several drill holes in the Withlacoochee River near Dunnellon went to comparable depths in alluvium (Corps of Engineers, U.S. Army, Jacksonville, Fla., written communication, 1943). Several filled sinkholes are described by Pirkle (1956a) in Alachua County where as much as 268 feet of sand and clay was found during drilling of water wells at places where the Ocala limestone crops out nearby.

Sea level stood higher than its present level during interglacial stages when huge volumes of melt water were returned to the oceans. Cooke (1945, p. 245–312) recognizes a series of ancient shorelines and marine terraces on the southeastern Coastal Plain, which he believes formed in the high sea-level periods between stages of continental glaciation. He has found 7 shorelines at approximate elevations of 270, 215, 170, 100, 70, 42, and 25 feet above the present sea level; the highest shoreline seems to be the oldest, and successively lower shorelines are younger. In addition to the fluctuations of sea level related to cyclic glaciation, Cooke suggests that there has also been progressive lowering of sea level because of sinking of the ocean bottom in unstable regions of the earth. Vernon (1951, p. 36–41) finds that only 4 Pleistocene terraces (each composed of a marine plain and a fluvatile equivalent) exist in Citrus and Levy Counties at altitudes of about 220, 150, 100, and 25 feet. MacNeil (1950, p. 98–99 believes that the highest terraces in Florida and Georgia are river deposits and recognizes only 4 ancient shorelines, at altitudes of about 150, 100, 25 to 35, and 8 to 10 feet above sea level.

The two lowest shorelines described by MacNeil are well preserved on the "Coastal Lowlands," but higher shorelines are by no means obvious in northern Florida. Sea level may not have remained at one elevation long enough for the development of prominent shoreline, or, possibly, ground-water solution has modified the topography in places to such an extent that the older shorelines have been obliterated. Well-bedded sands with thin clayey layers, which are probably Pleistocene marine sediments, do occur at many places at altitudes between 50 and 90 feet above sea level. These sands rest upon eroded phosphatic sands in the hard-rock phosphate field and upon clayey sands in central Clay County and in cuts of the proposed Florida ship canal in Marion County, but no associated shorelines were recognized by us. These sediments would correspond to the Pleistocene terrace sediments described by Matson and Sanford (1913), which are the Newberry terrace deposits, between 70 and 100 feet above sea level, and the Tsala Apopka terrace deposits, between 40 and 60 feet above sea level. Gravel sheets occur at several places between 115 and 150 feet above sea level in the area of outliers of the Hawthorn formation south of Ocala (Espenshade, 1958); these may be Pleistocene marine deposits.

A brief outline of the main events of the geomorphologic history is offered here. The modern erosion cycle perhaps began in early Pliocene time following emergence of the land from the sea. Stream systems were developed on the clayey Miocene sediments, which may have extended across the full width of the peninsula at that time. Erosion of these soft sediments was doubtless rapid at the times when sea level is presumed to have been several hundred feet lower than now. As the Miocene sediments were stripped away from parts of the region, the stream systems were lowered in places onto the very permeable Ocala limestone; rivers and large streams with much sediment in their beds were able to maintain their courses on the Ocala limestone, but smaller streams disappeared because of the extensive development of underground drainage systems. These major features have been further modified by marine sedimentation and accelerated stream erosion associated with fluctuations of sea level at several times during the Pleistocene.

The geomorphologic history of northern Florida is certainly complex, and it will not be well understood until the stratigraphy of Miocene and younger formations is better known. Since many present-day landforms are so clearly the result of alternating periods of sedimentation and erosion during late Cenozoic time, stratigraphy and geomorphology must be studied together in order to work out the complete geologic history.

NOMENCLATURE OF PHOSPHATE MINERALS AND DEPOSITS

Phosphate deposits of northern Florida consist mainly of marine phosphatic sedimentary rocks, mostly clayey sand and dolomite, and a variety of alterations of these strata formed by supergene (weathering) processes. Placer deposits in streams are a relatively unimportant class of deposit in the region. The nomenclature of these phosphatic materials consists partly of local names that have long been used by the phosphate mining industry and partly of more precise mineralogic and petrographic terms.

SEDIMENTARY PHOSPHATIC MATERIALS

The Hawthorn formation in northern peninsular Florida contains small to abundant amounts of oviform phosphate particles composed of the mineral, carbonate-fluorapatite (Altschuler and others, 1958). These particles are typically structureless and are best described as "pellets"; the sand-size particles may be termed "grains." The apatite pellets are commonly between 1 and 10 mm in diameter, are white, tan, gray, dark brown, or black, and have a shiny luster. "Phosphate pellet" is used as a synonym for "apatite pellet." Phosphatized fossils, sharks' teeth, and casts and molds of small mollusks, are in places associated with the apatite pellets. In this report, a rock containing "substantial sedimentary apatite" is termed a "phosphorite," following the usage of Altschuler, Clarke, and Young (1958, p. 50).

In the Hawthorn formation in northern Florida, apatite pellets are characteristically much more abundant in clayey sand (containing montmorillonite clay), which generally forms the upper part of the formation, than in clay and sandy argillaceous dolomite, which make up the lower part of the Hawthorn. These apatite-bearing clayey sands are here called phosphorites, and the stratigraphic unit composed of these beds is called the phosphorite unit of the Hawthorn formation. Impure dolomite containing a few percent apatite pellets dominates the lower part of the Hawthorn; it is here called phosphatic dolomite and makes up the phosphatic dolomite unit of the Hawthorn formation. Beds of clay (montmorillonite and attapulgite) are common within the phosphatic dolomite unit and are called phosphatic clay where they contain several percent of fine apatite particles; beds of phosphatic clayey sand (similar to beds of the phosphorite unit) also occur in the phosphatic dolomite unit locally; beds of phosphatic limestone a few feet thick form the base of the Hawthorn at some places.

The phosphorite beds of the Hawthorn are very similar to the phosphorite that forms the lower unit of the Bone Valley formation in central Florida (Cathcart, 1956, p. 490). In the mining industry, the rich phosphorite beds of the Bone Valley are termed the "land-pebble phosphate deposits"; this term, or simply "pebble phosphate deposits," has also been applied to rich phosphorite beds of the Hawthorn in northern Florida. In streams and rivers of central and northern Florida, placer deposits of apatite pellets eroded from phosphatic sedimentary strata are termed "river-pebble deposits."

SUPERGENE PHOSPHATIC MATERIALS

Weathering has altered the phosphatic sedimentary rocks in various ways. In many places the more soluble minerals, apatite and carbonates, have been partly or completely dissolved by ground water, and some of the phosphate has commonly been redeposited in the form of secondary phosphate minerals. In the phosphatic beds of the Bone Valley formation, ground-water leaching characteristically is most thorough in the uppermost beds and gradually diminishes downward. Throughout much of the land-pebble district, apatite pellets have been dissolved in the top few feet of the phosphatic beds and secondary phosphate minerals have been formed—the calcium aluminum phosphates crandallite and millisite and the aluminum phosphate wavellite; these minerals and clay form the cementing matrix to quartz sand in moderately porous to very porous rock (Altschuler and others, 1956). This zone of strong leaching and abundant secondary phosphate minerals is known as the leached zone, or aluminum phosphate zone. Apatite pellets are generally weathered to soft white pellets in the rock just beneath this zone, but may still be fairly fresh a few feet below. This zone of abundant apatite is termed the "calcium phosphate zone" (Cathcart, 1956). Phosphorite beds of the Hawthorn formation are weathered in similar fashion with the formation of well-developed aluminum phosphate zones at many places in northern Florida.

Secondary phosphate minerals predominate in the hard-rock phosphate deposits near the west coast of northern peninsular Florida (fig. 1); these minerals have apparently been formed by very thorough weathering of sedimentary phosphate strata. Two forms of secondary apatite occur: "hard-rock phosphate," composed of cream to brown hard massive apatite that forms irregular botryoidal masses or may replace fossiliferous limestone, and "soft phosphate," composed of soft white apatite with claylike appearance and consistency (Sellards, 1913). Hard-rock phosphate is the material recovered by washing plants in the mining operations; soft phosphate is carried off as slimes in waste water and is deposited with clay and fine sand in tailing ponds from which it is generally recovered later as the product known as colloidal phosphate. A widespread thick cover of quartz sand overlies the hard-rock phosphate deposits; this is called phosphatic sand because it characteristically contains a fine matrix of kaolinite and the calcium aluminum phosphates crandallite and millisite. Mineralogically, the phosphatic sand of this district resembles the rock of the aluminum phosphate zone in the weathered phosphorites of the Hawthorn and Bone Valley formations.

HAWTHORN FORMATION AND YOUNGER BEDS

MIOCENE SERIES

HAWTHORN FORMATION

STRATIGRAPHY

The term "Hawthorne beds" was originally given to beds of phosphatic sandstones, sands, ferruginous gravels, and greenish clays exposed near Hawthorn, Alachua County, and at other places in northern peninsular Florida (Dall and Harris, 1892). Subsequent work has shown that beds of the Hawthorn formation are extensive in northern Florida (pl. 1). Recent discussions of the Hawthorn formation in this region are by Cooke (1945), Vernon (1951), and Pirkle (1956b). Because only part of the sequence is seen in most exposures, the best information on stratigraphy of the Hawthorn comes from samples from water wells and drill holes. The following discussion of the Hawthorn formation is based mainly upon the core samples of drill holes 31 to 46 (table 1), and on some additional information from the natural exposures that were examined.

TABLE 1.—*Stratigraphic section generalized from logs of core-drill holes 31 to 46*

Series	Description	Thickness (feet)
Pleistocene(?) to Recent	Sand to clayey sand, white to brown, generally fine-grained.	5– 85+
Miocene(?) or Pliocene(?)	Clayey sand to sandy clay, tan to red (weathered), medium- to coarse-grained; contains few quartz pebbles, kaolinite, and muscovite.	0– 38
Upper Miocene	Sand to limy clayey sand, gray, fine-grained; contains many fine apatite grains, shell fragments; clay minerals montmorillonite and kaolinite. These beds were found only in drill holes 42 and 44.	0– 35
Lower and middle Miocene	Hawthorn formation: Phosphorite unit: Clayey sand, white to tan, fine- to coarse-grained; contains considerable white to dark apatite pellets and grains; local thin beds of green to tan clay (montmorillonite). In samples from many holes, soft apatite pellets and aluminum phosphate minerals accompanied by uranium enrichment have resulted from weathering. Phosphatic dolomite unit: Some light-gray, hard, and dense; some cream to light gray green, soft, and unconsolidated; quartz sand and apatite grains common. Green clay (attapulgite and montmorillonite) and phosphatic clayey sand are interbedded with phosphatic sandy dolomite in strata cut by some drill holes.	0– 40 7–278
	Unconformity	
Upper Eocene	Ocala limestone: Soft, white, permeable limestone. Commonly is dolomitized, and has solution cavities near contact with the Hawthorn.	

The Hawthorn formation in this region, as defined here, consists of a sequence of beds of distinctive lithologies—limestone, dolomite, phosphatic dolomite, clay, phosphatic clayey sand, and phosphorite—that contain fossils of early and middle Miocene age. The thickness and geographic distribution of the lithologic units are variable; but in all the drill holes and in many surface exposures, beds in the lower part of the Hawthorn are dolomite, generally containing quartz sand and a small amount of apatite grains and pellets, and also interbedded clay and phosphatic clayey sand locally. These beds of sandy phosphatic dolomite and interbedded clay and phosphatic clayey sand are here grouped together as the phosphatic dolomite unit of the Hawthorn (table 1). Uppermost beds of the Hawthorn are mainly phosphorite, locally interbedded with clay, and are here called the phosphorite unit (table 1).

Dolomitic beds compose much of the Hawthorn formation, particularly where the section is thickest; in 11 of the 13 drill holes that cut the most complete sections of the Hawthorn, dolomitic beds make up 50 percent or more of the formation. Dolomite is likewise characteristic of the exposed carbonate beds of the Hawthorn formation that were examined at various places in the region, except in central Marion County where thin limestone beds occur at the base of the Hawthorn. The predominance of dolomite in the carbonate beds of the Hawthorn formation in northern Florida does not seem to have been generally recognized previously, because most writers have referred to these carbonate beds as limestone. In central peninsular Florida, carbonate beds of the Hawthorn formation are mostly dolomitic limestone, according to Carr and Alverson (1959, p. 39).

The different lithologic units of the Hawthorn formation have distinctive clay minerals. Attapulgite is the dominant mineral in the clay beds of the phosphatic dolomite unit; attapulgite and montmorillonite occur together or separately in beds of dolomite and phosphatic clayey sand in the phosphatic dolomite unit. Montmorillonite is the characteristic clay mineral in beds of the phosphorite unit. These two clay minerals are also distinctive minerals in dolomite of the Hawthorn formation and in phosphorite of the Bone Valley formation in central Florida (Petersen, 1955; Cathcart, 1956).

LITHOLOGY

DOLOMITE AND PHOSPHATIC DOLOMITE

The dolomitic beds in the lower part of the Hawthorn formation commonly contain considerable quartz sand, clay, and apatite pellets. Two varieties of phosphatic dolomite are common: soft, unconsolidated phosphatic dolomite and hard, dense phosphatic dolomite. The soft phosphatic dolomite is cream to light gray green, and largely made up of uncemented tiny dolomite rhombs. It has a claylike consistency, and may be mistaken for clay on casual examination, but the abundant little rhombic crystals are visible with the hand lens. The hard phosphatic dolomite is a cream to light gray, dense, tough rock, composed mainly of well-cemented small rhombic crystals of dolomite (generally about 0.01 to 0.04 mm in diameter, but in places as large as 0.1 mm). Dolomite pebbles and irregular tubular holes (possibly worm borings) filled with sand and phosphate are common. Quartz sand makes up 10 to 20 percent of the dolomite; the quartz grains generally are between 0.2 and 0.4 mm in diameter and have a maximum of about 1 mm. Other clastic minerals are a little feldspar, mostly microcline, and very small amounts of garnet and other heavy minerals. Apatite pellets are very common, and may form up to 5 or 10 percent of the rock; pellets are most commonly from 0.1 to 0.5 mm in diameter and have a maximum of about 3 mm.

Both the soft and hard varieties of dolomite occur together where the sequence of dolomite beds is thickest (in those drill holes that cut dolomite beds ranging in thickness from 92 to 278 feet). The hard dolomite occurs, with little or no soft dolomite, where the dolomite beds are rather thin (in those drill holes where dolomite beds range from 7 to 60 ft thick).

Considerable clay may be present, either dispersed rather uniformely throughout the dolomite or in irregular pockets in the dolomite. In a few places, as at map locality 2 (pl. 1) on the Alapaha River, Hamilton County, and in core from drill holes 43 and 45, dolomite appears to form a boxwork of stringers that cut the clay. Attapulgite and montmorillonite are the characteristic clay minerals in the dolomitic beds, with attapulgite apparently being most abundant (table 2); questionable loughlinite or sepiolite was found in a few samples.

LIMESTONE

The limestone that forms the base of the Hawthorn formation in central Marion County consists of thin beds of several varieties of white to cream dolomitic limestone: dense textured limestone with conchoidal fracture; dense limestone honeycombed with cavities about 1 to 2 inches wide and containing considerable quartz sand and small apatite grains; and very fossiliferous limestone, some of which is sandy phosphatic limestone conglomerate.

CLAY

Clay beds occur in both the phosphatic dolomite unit and the overlying phosphorite unit. The clays in both units are light gray to green, and contain variable amounts of very fine quartz and phosphate grains that are generally smaller than 0.1 mm in diameter. Attapulgite is the dominant clay mineral, associated with minor amounts of montmorillonite, in samples from clay beds in the phosphatic dolomite unit (table 2). Montmorillonite is the only clay mineral in nearly all samples from clay beds within the phosphorite unit. Both types of clay are locally known as fuller's earth. The two clays have somewhat

TABLE 2.—*Distribution of clay minerals in the major lithologic and stratigraphic units of core-drill holes 31 to 46* [1]

[The figures given are the number of samples. Except where otherwise indicated, the number of samples also indicates the number of drill holes]

Clay minerals	Clayey sand (Miocene to Pleistocene?)	Hawthorn formation (lower and middle Miocene)			
		Phosphorite unit	Phosphatic dolomite unit		
			Phosphate clayey sand	Clay	Dolomitic beds
Kaolinite	4	--------	--------	--------	--------
Kaolinite and montmorillonite	2	--------	--------	--------	--------
Montmorillonite	1	[2] 9	3	--------	[4] 2
Montmorillonite and minor sepiolitelike mineral	--------	--------	1	--------	1
Montmorillonite and attapulgite	--------	1	--------	--------	[5] 5
Montmorillonite, and attapulgite, and little sepiolitelike mineral	--------	--------	2	--------	1
Attapulgite and minor montmorillonite	--------	--------	--------	[3] 4	--------
Attapulgite	--------	--------	--------	1	4
Attapulgite and minor sepiolite(?)	--------	--------	2	--------	1

[1] The mineralogy of the drill-hole samples is given in detail on pls. 2–5 and in table 21.
[2] 7 drill holes.
[3] 3 drill holes.
[4] 1 drill hole.
[5] 4 drill holes.

different physical appearance; montmorillonite is plastic to waxy, massive, and has a conchoidal fracture, whereas attapulgite is rather crumbly, and generally has a platy or shaly parting. Some montmorillonite is hard and contains veinlets and minute aggregates of chalcedony; silicified clay of this nature lies beneath plastic clay in the old fuller's earth mine at map locality 19, Marion County (pl. 1).

Size analyses show a range in content of clay-size material from 60 to 90 percent (table 24, p. 111); grains larger than 0.1 mm are mostly apatite. A varied suite of detrital heavy minerals is found in the clay (table 24); no relationship is evident between the kinds or amounts of heavy minerals present and the kind of clay or its stratigraphic position. Samples from the same(?) bed of attapulgite clay in two drill holes (sample X445C from DH 40 and X466A from DH 41) have dissimilar size analyses and heavy-mineral suites. Apatite is in every sample and fine pyrite in all but one sample; both minerals are probably nondetrital here.

The orgin of these beds of montmorillonite and attapulgite clay that are so widespread in the Miocene strata of northern Florida is an unsolved problem. It seems quite possible that these clays were formed from volcanic ash, but no certain evidence of volcanic ash structure has been found by microscopic study. Microfossils are abundant in some clay and might be mistaken for volcanic shards. Grim (1933) found curved microstructures in clay from the old fuller's earth mine at map locality 19 (pl. 1) which he regarded as of questionable volcanic nature; microfossils are very abundant in the clay at this pit, but we have found no volcanic shards.

PHOSPHORITE

Clayey sands and sandy clays containing variable amounts of apatite are most abundant above the phosphatic dolomite unit, but are also interbedded with phosphatic dolomite. They are tan to gray where fresh, and weather white to tan. Phosphate pellets, which range in diameter from about 1 to 10 mm, are hard, shiny, and dark where fresh. In weathered material, however, the pellets are soft, dull, and light in color and may be accompanied by wavellite, crandallite, and millisite; fine-grained apatite ($<$0.1 mm) is rather abundant in some weathered phosphorite. Montmorillonite is the dominant clay mineral in beds lying above the phosphatic dolomite unit; attapulgite was also found in a few samples from phosphatic clayey sand beds within the dolomite zone (table 2). Small amounts of questionable loughlinite and sepiolite were also found.

DISTRIBUTION AND THICKNESS

Details of the stratigraphy of the Hawthorn formation are given in the logs of drill holes 31 to 46 (table 11) and in the graphic logs or sections of the holes (pls. 2–5). Thickness of the beds cut in the different drill holes that are classified as Hawthorn formation ranges from 24 feet (DH 33) to 288 feet (DH 44). Important features of the stratigraphy and lithology of the Hawthorn formation where cut by the drill holes are shown in figure 2 and in table 3. There seems to be a relationship between the depth to the Ocala limestone and the thick-

TABLE 3.—*Stratigraphic and lithologic features of Miocene phosphatic beds in core-drill holes 32, 33, 35 to 37, 39 to 46*

	Southeastern group of drill holes (32, 33, 35)	Central and northwestern group of drill holes (37, 40, 41, 46)	Central and northeastern group of drill holes (36, 39, 42–45)
Altitude of Ocala limestone.	Shallow; 8 ft below to 19 ft above sea level.	Shallow; 20 ft below to 29(?) ft above sea level.	Deep; 37–276 ft below sea level.
Thickness of dolomitic beds.	Thin; 19–35 ft	Thin to moderate; 7–60 ft.	Thick; 92–278 ft, thickening to north.
Dominant variety of dolomite.	Hard	Hard	Both soft and hard.
Percent of dolomitic beds in Hawthorn formation.	High; 70–80 percent	Low to moderate; 15–53 percent.	High; 60–85 percent.
Percent of phosphorite beds in Hawthorn formation.	Low; 20–30 percent	Moderate to high; 28–85 percent.	Low; 3–25 percent.
Percent of clay beds in Hawthorn formation.	None	Low; 0–19 percent	Low; 0–15 percent.
Thickness of Hawthorn formation.	Thin; 24–47 ft	Moderate; 55–101 ft	Moderate to thick; 95–288 ft.

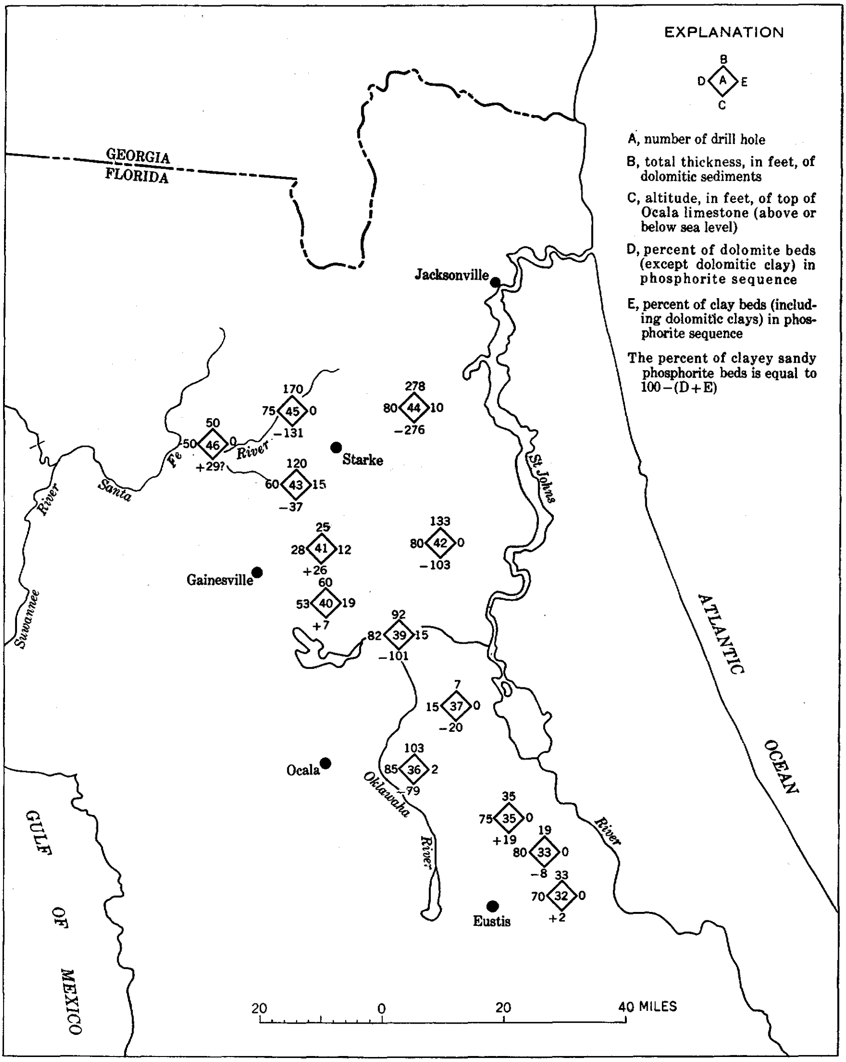

FIGURE 2.—Map showing drill holes, data on lithology of Hawthorn formation, and altitude of top of Ocala limestone.

ness and relative proportion of dolomite and phosphorite beds in the Hawthorn formation. Where the Ocala limestone is at shallow depth, the sequence of dolomite is thin and phosphorite beds make up a large proportion of the Hawthorn. Where the Ocala limestone is deeper, the dolomite sequence is thicker and makes up a large proportion of the Hawthorn formation.

The natural exposures of the Hawthorn formation in northern Florida display incomplete sections whose stratigraphy and lithology are similar to those of the beds cut by the drill holes. North of

Alachua County, the best exposures of the Hawthorn are found at map localities 2, 4, and 7 (pl. 1; table 12, p. 72). Phosphorite, clay, and phosphatic sandy dolomite comprise 63 feet of strata that are exposed on the west bluff of the Alapha River at map locality 2, Hamilton County. Eighteen feet of phosphatic clayey sand and sandy dolomite are exposed at map locality 4 on the west bank of the Suwannee River, Hamilton County. At Brooks Sink, Bradford County (map locality 7), 66 feet of dolomite, phosphatic dolomite, and clay, overlain by about 15 feet of surficial sand, are spectacularly displayed in the vertical walls of a sinkhole which is about 200 feet in diameter.

Much information about the Hawthorn formation in Alachua County has been gathered recently by Pirkle (1956b; 1957a, b) from studies of exposures and cuttings from numerous water wells and phosphate prospect holes. Pirkle (1956b) finds that the main part of the Hawthorn formation consists of beds of variable thickness of clay, sand, and limestone, which is dolomitic in places; above these beds, at many localities, is phosphorite, which may be as much as 40 feet thick. His sections (Pirkle, 1956b, figs. 10, 11) show that the phosphorite bed pinches out toward the west and northwest. The Hawthorn formation generally thickens toward the northeast, reaching a total of about 175 feet thick.

The most complete exposure of the Hawthorn formation in Alachua County is in a sinkhole called the Devil's Mill Hopper, in sec. 15, T. 9 S., R. 19 E., about 6 miles northwest of Gainesville. Pirkle (1956b, p. 215–216) has measured the following section at this locality:

Stratigraphic section at Devil's Mill Hopper

Bed	*Description*	*Thickness (feet)*
11.	Loose gray to white sand	3
	Hawthorn formation:	
10.	Abundant pebbles and grains of phosphate in a matrix of sand and clay	25
9.	Cream to yellow calcareous sandstone or sandy limestone containing in places abundant molds and casts of marine pelecypods and gastropods. Locally, phosphate pebbles and grains are common	30
8.	Whitish to gray dense dolomitic limestone	3
7.	Mainly blocky clay of fuller's earth type. Toward top of bed, in places, a grayish to blue-gray sandy clay. Microscopic crystals of pyrite are common in the blue clay	30
6.	Limestone similar to bed 4	2½
5.	Greenish-gray to gray clay of fuller's earth type; similar to bed 3	4½
4.	Sandy limestone containing many calcite fossil shells, angular blocks and rounded pebbles of fuller's earth clay, and phosphate pebbles and grains	1½
3.	Greenish-gray to gray blocky clay of fuller's earth type, with a few phosphate pebbles and rare impressions of marine fossils	18

Bed	*Description*	*Thickness (feet)*
2.	Dark colored dense dolomitic limestone (partly silicified in places) with stringers of quartz sand. Grades down into a loosely cemented calcareous sandstone. Both dense limestone and sandstone contain included blocks of fuller's earth clay	2½
1.	White to gray sand, loose to slightly cemented; contains a few brown phosphate grains and pebbles. Rare sharks' teeth	3
	Total	123

A generally similar sequence of lithologic units was found in our drill holes 40 and 41 (pl. 4; table 11, p. 60) in eastern Alachua County near the type locality of the Hawthorn formation; lithologic units in descending order in these drill holes are sand, clayey sand, phosphorite, clay and sandy clay (both montmorillonite and attapulgite), and sandy phosphatic dolomite. Total thickness of the Hawthorn sequence is 101.2 feet in drill hole 40 and 89 feet in drill hole 41.

The Hawthorn formation in Alachua County underlies a partly dissected plateau whose surface is about 150 to 200 feet above sea level. In the western and southern parts of the county the Ocala limestone is exposed at altitudes generally below 100 feet where the Hawthorn formation has been stripped away by erosion (Pirkle 1956a, b). These relations are very well seen in the soil map of Alachua County by Taylor and others (1954), which shows distinctive soils developed upon the Hawthorn formation and Ocala limestone. A belt, 5 to 6 miles wide, of loamy fine sands (called Alachua, Arredondo, and Gainesville soil series) that extends northwest from Gainesville near the west edge of the plateau, apparently overlies the beds of clay and dolomite in the lower part of the Hawthorn formation.

Miocene phosphorite occurs in the eastern part of Marion County and in a group of outliers of Hawthorn formation in the west-central part of the county (pl. 1). Between 55 and 120 feet of phosphatic beds were found in drill holes 36 and 39 in the eastern part of Marion County and in drill hole 35, Lake County (pls. 2, 3; table 11, p. 60). Incidentally, drill hole 36 is in an area that Cooke (1945, p. 1) shows as Ocala limestone; in an earlier version of the State geologic map, however, Cooke and Mosson (1929, pl. 2) show the Hawthorn formation in this area. The full Miocene sequence is nowhere exposed in the outliers farther west, but the general stratigraphy can be pieced together (tables 4, 12) from the good exposure in the old clay mine at map locality 19 and from many exposures along the roads. The Hawthorn formation in northwestern Marion County is about at the same altitude as in Alachua County, and forms the hills that are 150 to 200 feet above sea level. Clay beds, as much as 35 feet thick, are rather widespread in northwestern Marion County.

TABLE 4.—*Composite stratigraphic section of Miocene and younger beds in outliers in northwestern Marion County, Fla.*

Series	Description	Thickness (feet)
Pleistocene(?) to Recent	Loamy sand containing pebbles of phosphatic sandstone and limonite-stained sandstone.	0–4
Miocene(?) or Pliocene(?)	Sandstone, tan to gray, medium-to coarse-grained; locally with quartz pebbles as much as one-half inch in diameter; matrix of white to light-green clay, mixed with white phosphatic mineral in places.	0–10
Lower and middle Miocene	Hawthorn formation:	
	Clayey sand to sandy clay, tan to light-green; locally contains considerable apatite pellets.	0–10
	Clay, light-green, plastic to hard, compact; conchoidal fracture; contains variable amounts of apatite pellets and considerable fine quartz sand. Silicified shells of *Ostrea normalis* and manatee ribs are widespread.	5(?)–35(?)
	Limestone, cream, dense; some beds of limestone conglomerate; slightly dolomitic; contains much quartz sand and apatite pellets; very fossiliferous. Distribution is very restricted; known at map localities 14, 17 (and one-quarter mile east), 21, 22, 24, 25.	0–10
	Unconformity	
Upper Eocene	Ocala limestone: Limestone, white, soft.	

The basal beds of the Hawthorn formation in northern Marion County are thin-bedded dense sandy phosphatic slightly dolomitic limestone that has a maximum thickness of about 10 feet, and that rests upon Ocala limestone at about half a dozen localities (table 4). This basal limestone is excellently exposed in beds 7 to 8 feet thick in the quarry of the Dixie Lime Product Co., which is about one-quarter of a mile northeast of map locality 17. The limestone at map localities 21 and 22 (early Miocene age) was called Tampa limestone by Cooke (1945, p. 129–130). In addition to these localities, Puri (1957, p. 72) states that 10 feet of hard cream limestone of Hawthorn(?) age overlie Eocene limestone in the Kendrick pit of the Cummer Lime & Manufacturing Co.

In southern Marion County, interbedded phosphorite and phosphatic clay occur in outliers of the Hawthorn formation (Espenshade, 1958); thin beds of phosphatic limestone are exposed at map localities 24 and 25 (pl. 1).

The broad picture of the distribution of lithologic units within the Hawthorn formation in northern peninsular Florida seems to be that dolomite is the dominant rock type on the east, clayey-sandy phosphorite is well-developed at several places in the central part of the region, and clay and clayey sands are important lithologic types farther west and south; the basin of sedimentation was probably deepest toward the northeast, where carbonate deposition prevailed.

FAUNA AND AGE

The well-preserved fossils that were found in the phosphatic strata are of early and middle Miocene age (table 10). Although similar sequences of lithologic units were penetrated by most drill holes, similar lithologic units are not everywhere of the same age. The uppermost phosphorite beds cut in drill hole 36 have early Miocene fossils, whereas the upper phosphorite beds in drill hole 45 lie above phosphatic dolomite beds that have middle Miocene fossils. Phosphatic dolomite in drill hole 36 also has fossils of early Miocene age, but most of the phosphatic dolomite in drill hole 44 has middle Miocene fossils. In drill hole 36, the entire sequence of phosphatic beds, about 120 feet, is judged to be early Miocene. In contrast, early Miocene fossils in drill hole 44 are found only in the basal beds of the phosphatic dolomite unit; more than 200 feet of phosphatic dolomite above seem to be middle Miocene in age.

Because of these faunal and lithologic relationships, it is evident that the phosphatic sequence (phosphatic dolomite, clay, phosphorite, and other beds) must be treated as a stratigraphic unit whose age is early to middle Miocene. These strata are here assigned to the Hawthorn formation.

Close dating of the Hawthorn formation has also proved to be difficult in other parts of Florida and there is some uncertainity about its age span, although it is recognized to be younger than the Tampa limestone, which is early Miocene in age. Vernon (1951, p. 186–187) states:

> As somewhat loosely used by most students today, the formation includes all phosphorite-bearing sands, sandstones, limestones and the fuller's earth clays of peninsular Florida and as thus used is the time equivalent of all of the Miocene in parts of the State. As used in this report, the Hawthorn formation includes marine beds of Miocene age, younger than the Tampa formation, and older than marls and sands that contain a microfauna of the upper Miocene in peninsular Florida.

Puri (1953, p. 16), Cathcart (1956), and Bergendahl (1956) assign the Hawthorn to the lower and middle Miocene. Cooke (1945, p. 109) suggests that the Hawthorn is middle Miocene in age; Pirkle (1956b, p. 221), Ketner and McGreevy (1959, p. 65), and Carr and Alverson (1959, p. 33) also hold this view.

BEDS OF LATE MIOCENE AGE

Beds of fine clayey sand to limy clayey sand, tan to gray, containing abundant fine apatite pellets, overlie phosphatic dolomite in drill holes 42 and 44. Core recovery from these beds was poor in both drill holes, and the thicknesses indicated for this sequence of beds, 35 feet in drill hole 42 and 20 feet in drill hole 44 (pl. 5), are only approximate. A large suite of mollusks from these beds is judged by Wilson to be of late Miocene age (table 10). Cooke (1945, p. 187–188) states that fossiliferous sandy limestone of late Miocene age is exposed at several places in Clay County that are within a few miles of drill hole 44; he correlates these beds with the Duplin marl.

At Brooks Sink, Bradford County (table 12, loc. 7), about 26 feet of sandy dolomitic coquina with scarce phosphate pellets are exposed above typical phosphatic dolomite of the Hawthorn formation. Mollusks from these beds are middle or late Miocene in age according to Wilson (table 10). Ostracodes from the uppermost shell beds here are called lower Choctawhatchee in age by Puri (Pirkle, 1956b, p. 207–210).

MIOCENE(?) OR PLIOCENE(?) SERIES

CLAYEY SAND

The phosphatic beds are overlain in most drill holes and natural exposures by clayey sands that are composed of fine to coarse quartz grains and considerable clay. Both kaolinite and montmorillonite are present; kaolinite is more common in the uppermost beds and montmorillonite in the lower beds. Quartz pebbles and muscovite flakes occur in the clayey sand at many places. The fresh clayey sand is light to dark gray, and the weathered material is commonly mottled orange to brown. Thickness of the clayey sand where cut by the drill holes ranges from about 2 feet (DH 31) to 47.5 feet (DH 37).

Clayey sand of this character is very widespread in the region. Its age is problematical, and is called Miocene(?) or Pliocene(?) in this report; there may be clayey sand of more than one age. The clayey sand that underlies much of eastern Alachua County is thought by Pirkle (1956b) to be of Pleistocene age or, less probably, Pliocene. Cooke (1945, pl. 1) correlates the clayey sands that occur throughout much of the middle of the peninsula with the Citronelle formation of Pliocene age. However, in Polk County (south of the area shown on pl. 1) fossils of late middle Miocene or early late Miocene age were found in similar clayey sand by Ketner and McGreevy (1959, p. 71); clayey sand in Highlands County is also called Miocene by Bishop (1956).

PLIOCENE(?) TO RECENT

SAND

Loose to loamy tan to brown sand lies upon clayey sand in many places; in general, it seems to have about the same grain size as the clayey sand, and contains quartz pebbles also where the underlying clayey sand contains quartz pebbles. Charcoal fragments are common in the loose sand. In natural exposures these sands range in thickness from a few feet to about 15 feet, but more than 30 feet of sand was penetrated in several drill holes; drill hole 38 went to a depth of 61 feet, entirely in sand. In some exposures in central Clay County and southeastern Marion County, the sands are bedded—alternating layers (1 to 3 in. thick) of clayey sand and loose sand—for several feet in the basal part. A few feet of loamy sand with pebbles of limonitic sandstone or phosphatic sandstone overlie clayey sand at places in western Marion County. These several varieties of surficial sand are probably of Pleistocene to Recent age in most places.

Post-Miocene sediments of rather different character were penetrated in 3 drill holes (31, 42, 44), 6 to 12 miles west of the St. Johns River. In drill hole 31 (pl. 2), a few feet of phosphatic gravel were found upon the Ocala limestone beneath more than 40 feet of sand. Typical phosphorite is absent here, probably because of post-Miocene erosion in the vicinity of the St. Johns River valley. In drill holes 42 and 44 (pl. 5), fine-grained tan to dark brown sand and clayey sand with considerable organic matter lie above phosphatic clayey sand of late Miocene age; its thickness is about 63 feet in drill hole 42 and 49 feet in drill hole 44. These post-Miocene sediments may be as old as Pliocene or they may be younger.

WEATHERING ALTERATIONS

SUPERGENE ALTERATION OF PHOSPHORITE

The effects and process of ground-water alteration of phosphorite in Florida are fully discussed by Altschuler, Jaffee, and Cuttitta (1956) in their study of the aluminum phosphate zone of the Bone Valley formation in the land-pebble phosphate district. The phosphorite beds (clayey sand with variable amounts of sedimentary apatite pellets) in the upper part of the Bone Valley formation have been extensively altered by ground water over large areas. In the upper part of the zone of weathering, or leached zone, apatite pellets have been completely dissolved, and the rock is now a porous sand or sandstone with a cementing matrix of clay and secondary aluminum phosphate minerals. Partly leached soft white apatite pellets still remain at the base of the leached zone. Secondary aluminum phosphate minerals consist of wavellite [$Al_3(PO_4)_2(OH)_3 \cdot 5H_2O$], crandallite [$CaAl_3(PO_4)_2(OH)_5 \cdot H_2O$], and millisite [$(NaK)CaAl_6(PO_4)_4(OH)_9 \cdot 3H_2O$]; wavellite is the dominant phosphate in the upper part of the zone, and crandallite (locally accompanied by millisite) is abundant below. Because of its mineral content, the leached zone has become known as the aluminum phosphate zone. A discontinuous hardpan of secondary apatite with subordinate limonite and chert occurs below the aluminum phosphate zone. The clay mineral is kaolinite in the aluminum phosphate zone and montmorillonite in the unaltered phosphorite.

Enrichment in uranium has taken place in the lower part of the aluminum phosphate zone; uranium occurs dominantly in the partly leached apatite pellets, and is also present in crandallite and millisite, and to a lesser extent, in wavellite. Typical rock from the aluminum phosphate zone contains about 0.012 percent uranium and 8 to 12 percent P_2O_5; unweathered phosphorite averages about 0.008 percent uranium and 10 to 15 percent P_2O_5.

In the alteration process, apatite pellets were dissolved by acid ground waters, secondary phosphate minerals were formed by precipitation and replacement, and montmorillonite was altered to kaolinite. Some solution of alumina from clay minerals took place, and crandallite and wavellite were formed by reaction of aluminum hydroxide with apatite and by reaction between phosphate-bearing ground water and clay (Altschuler and others, 1956, p. 502). The aluminum phosphate minerals were also deposited in cavities by precipitation from solution; apatite was likewise precipitated in the hardpan that was deposited at the ground-water table. Uranium dissolved from sedimentary apatite was also carried down by ground waters and was deposited mainly in the soft porous apatite pellets at the base of the aluminum phosphate zone, probably by structural replacement of the calcium; the nature of the occurrence of uranium in the aluminum phosphate minerals is not known.

Phosphorite of the Hawthorn formation of northern peninsular Florida is lithologically identical with the phosphorite of the Bone Valley formation, and it has been altered by ground waters in the same fashion. Very porous sandy rock, composed of quartz grains cemented by a mixture of kaolinite, crandallite, and wavellite that is enriched in uranium, is the characteristic final weathering product of phosphorite in the outlying areas of the Hawthorn formation near Ocala, Marion County (Espenshade, 1958). Aluminum phosphate minerals and uranium enrichment were likewise found in numerous core drill and surface samples from the upper part of the phosphorite unit in the main outcrop area of the Hawthorn formation.

The hard-rock phosphate deposits also appear to be the final weathering product of phosphatic sediments. They consist of irregular deposits of secondary apatite, in the form of hard botryoidal masses and soft claylike material, that rest upon a solution-pitted surface of limestone and are overlain by a thick cover of phosphatic sand. Minerals characteristic of the aluminum phosphate zone are in the phosphatic sand; crandallite, millisite, and kaolinite form a claylike matrix to the quartz grains.

POSSIBLE STRATIGRAPHIC IMPLICATIONS

Ketner and McGreevy (1959, p. 74–76) propose the theory that ground-water leaching in central Florida may have been so thorough that certain beds of phosphorite, clay, clayey sand, and sand are the relatively insoluble constituents that are residual from weathered limy beds rather than being the original sediments. Lithologic units of Miocene and younger age are generally in the following vertical sequence (from youngest to oldest), which is customarily regarded as being also a sequence of stratigraphic units:

Sand
Clayey sand
Phosphorite (clayey sand with apatite pellets)
Clayey-sandy phosphatic limestone

According to the theory of Ketner and McGreevy, each of the upper three lithologic units could represent a stage in the ground-water leaching of clayey-sandy phosphatic limestone. Removal first of the most soluble constituent, carbonate, could leave a residue of apatite pellets, clay, and quartz sand that has a composition equivalent to phosphorite. Solution then of apatite at a more advanced stage of leaching could leave a residue of clay and sand; extreme leaching might destroy most of the clay and leave a residue consisting largely of quartz sand.

This residual theory of the origin of certain lithologic units deserves careful study, because there is definite evidence for the operation of the process to at least a limited extent in the upper part of the deposits. In the land-pebble district the loose surficial sands are nearly identical in size, sorting, and heavy-mineral content with sand in the underlying clayey sand unit of the Bone Valley formation; the surficial sands are evidently residual from the clayey sands below (Altschuler, and others, 1956, p. 503). Similar relations are seen in some highway cuts in the area east of Ocala, Marion County, that is mapped as the Citronelle formation on plate 1; quartz pebbles occur in both the surficial sand and the underlying clayey sands.

On the other hand, there is good evidence at some localities in northern peninsular Florida that some phosphorite beds and clay beds are original sedimentary units. This is seen most convincingly at Brooks Sink, Bradford County, where soft dolomitic phosphorite is alternately interbedded with hard phosphatic dolomite in beds that range in thickness from about 1 foot to 7 feet (table 12, loc. 7). Individual beds maintain fairly constant thickness around the periphery of the cylindrical sinkhole. The vertical repetition here of phosphorite beds of consistent thickness, each between beds of phosphatic dolomite, is obviously explained as an original sedimentary feature, but cannot be explained by the residual theory. Similar relations were also found in the core samples from drill holes 43, 44, and 45 (pls. 4, 5), where clay, clayey sand, or phosphorite is interbedded with hard phosphatic dolomite at depths of 120 to 285 feet.

At the Devil's Mill Hopper, a sinkhole in central Alachua County, clay is likewise interbedded with phosphatic carbonate beds of the Hawthorn formation, but there is additional evidence that the clay is not the residual weathering product of carbonates (Pirkle, 1958). Angular and rounded blocks of clay occur in sandy phosphatic limestone and it seems to Pirkle that these clay blocks are fragments that were broken from underlying clay beds by wave action and then incorporated in the limy sediments. In some clay beds there are nodules and masses of dolomite, which seem to have replaced the clay; bedding in the clay continues through the dolomite. At places, calcite forms an intricate network of veinlets in clay and is thought by Pirkle (1958) to have been deposited by ground water within dessication cracks in the clay. Younger carbonate veins in clay also occur in beds of the Hawthorn formation where exposed at locality 2 along the Alapaha River, Hamilton County (table 12); here a few feet of clay and sandy clay are interbedded with hard dolomite, and the clay is cut by a network of dolomite veinlets that are obviously younger than the clay.

The Miocene clays in most exposures have a homogeneous appearance and greenish color, and are fairly susceptible to weathering because they are stained or weathered along cracks to reddish or brownish colors. If these clays are residual weathering products, it is very difficult to understand by what means profound ground-water leaching of impure limestone or dolomite could have produced such a homogeneous residuum that is unstable under present weathering conditions. The limonitic discoloration of the weathered clay is probably the result, at least in part, of ground-water solution of fine-grained pyrite. Pyrite was found to be a constituent in 8 out of 9 samples of clay that were taken from 5 drill holes distributed along a distance of more than 40 miles in the main belt of the Hawthorn formation (table 24) and from 3 pits located along an interval of nearly 50 miles in the hard-rock phosphate belt (table 25). Some of the clay samples are dominantly attapulgite; others are solely or mainly montmorillonite (tables 21, 22). The pyrite is most readily explained as being an original or diagenetic constituent of sedimentary clay, which has been preserved from ground-water solution because of low permeability of the clay. If the clay were residual, original pyrite in impure limy sediments surely could not have survived the thorough weathering that destroyed the carbonates. The other possible mode of origin of the pyrite is by deposition from ground waters either in sedimentary or residual clay, presumably under reducing conditions in contrast to the oxidizing conditions that now prevail. It may be questioned whether ground-water deposition of pyrite could have occurred so uniformly throughout a vertical range of at least 120 feet and over such a large area.

HARD-ROCK PHOSPHATE DEPOSITS

GEOLOGY

The hard-rock phosphate deposits are in a linear belt near the west side of the peninsula that extends northwest about 110 miles from southern Hernando to southern Suwannee County (pl. 6). The main part of the district extends a few miles farther south and northwest than the limits of the Alachua formation as shown on plate 1. Hard-rock phosphate deposits also occur in the small area of Alachua formation in central Marion County (pls. 1, 6) and at a few scattered localities northwest of the main belt.

The hard-rock phosphate deposits characteristically are a rubble of platy fragments and botryoidal masses of hard apatite with soft white claylike apatite, clay, sand, sandstone, chert, and limestone. The deposits are highly irregular in shape and size and are several feet to more than 100 feet in thickness and a few hundred square feet to more than 40 acres in area. The phosphate deposits rest upon limestone that is intricately pitted by ground-water solution; pinnacles of limestone may project 20 or 30 feet above the general surface of the limestone up into the phosphate deposit, or the phosphatic rubble may fill cylindrical well-like cavities in limestone that are a few feet in diameter and as much as 20 feet deep. Tough gray phosphatic clayey sand, as much as 80 feet thick, covers most hard-rock phosphate deposits; it is absent from some deposits, particularly between Newberry and High Springs (pl. 6) where much of the thick sand cover seems to be eroded. Good descriptions of the hard-rock phosphate deposits are given in Sellards (1913), Matson (1915), and Vernon (1951).

Most of the hard-rock phosphate deposits lie upon a surface of the Ocala limestone of late Eocene age, but some deposits rest upon older limestone and some are on younger limestone. The Avon Park limestone (middle Eocene) was found by Vernon (1951, p. 204) beneath the phosphate deposit of the Section 12 mine, a few miles southeast of Dunnellon. Blocks of silicified Suwannee limestone (late Oligocene) occur in some hard-rock phosphate deposits near the north and south ends of the district.

STRATIGRAPHY AND LITHOLOGY

Many hard-rock phosphate deposits may seem at first glance to be chaotic mixtures of hard and soft phosphate with sand, clay, and chert, yet as Vernon (1951, p. 191) points out, it is evident after further study that a definite stratigraphic order prevails throughout the district. The original relations are generally disturbed because of repeated solution slumping, and younger beds may be displaced to lower altitudes than older beds, or several beds may be mixed together.

Individual units are somewhat variable in thickness and are absent in some places; nevertheless, the same sequence of units is repeated in many deposits. This general sequence is given in the composite section of table 5, and discussed below from youngest to oldest; individual sections from several pits are described in table 13 on pages 79-80.

TABLE 5.—*Composite stratigraphic section in hard-rock phosphate district, Florida*

Series	Description	Thickness (feet)
Pleistocene(?) to Recent	Loose sand; charcoal fragments.	0-25; generally under 10.
Pleistocene	Bedded sand; alternating layers of tan sand and brown clayey sand; charcoal fragments; pebbles of phosphatic sandstone at base locally.	0-10; commonly about 5.
	Unconformity	
Miocene(?) and Pliocene(?)	Phosphatic sand or sandstone, gray; fine apatite grains nearly always at base. Mollusks of late Miocene age at map locality 11; horse teeth of early Pliocene age at map localities 8 and 20.	0-80.
	Clay, tan to green; contains fine apatite grains locally.	0-5; generally under 2.
	Sandy clay, tan, with coarse apatite pellets.	0-5.
	Phosphatic limestone; only known at 1 locality, drill hole 20.	(?).
Supergene [1]	Secondary apatite; rubble of platy fragments and botryoidal masses of hard tan apatite and soft white claylike apatite with sand, clay, and chert.	0-100; generally under 30.
Oligocene	Suwannee limestone.	0; few.
Eocene	Ocala limestone or Avon Park limestone.	

[1] Not a stratigraphic unit.

Loose surficial sands with charcoal fragments are found nearly everywhere in northern Florida; but they are thickest in the areas mapped as Alachua and Citronelle formations (pl. 1), from which they have probably been formed by weathering, and perhaps locally reworked by marine or wind action. In the northern part of the hard-rock district, cresentic and elliptical features that are probably ancient dunes are prominent on aerial photographs; they are elongated in directions between S. 60° W. and W., and the convex sides of the crescents face east, suggesting prevailing winds from that direction.

Bedded sands, at many places, have a varvelike appearance because of the alternation of layers of loose tan sand (2 to 6 in. thick) and red-brown clayey sand (¼ to 1½ in. thick); the clayey sand layers become progressively thinner and wavy upwards. These bedded sands are particularly well developed in the northern part of the district and around Dunnellon, but are scarce or absent in the southern part; they range in altitude from about 50 to 90 feet above sea level. Matson (1915, p. 22-23, 27, pl. 7) recognized these sands as being subaqueous sands occurring upon his upper Pleistocene terrace, whose altitude ranges from 70 to 100 feet above sea level; the bedded sands at lower altitudes, such as those about 50 feet above sea level near the

Sante Fe River, may be on Matson's lower Pleistocene terrace with an altitude of 40 to 60 feet. Pebble conglomerate takes the place of stratified sands at this stratigraphic horizon at a few places, as at map locality 30 (pl. 1 and fig. 3). A 4-foot bed of clay (mainly kaolinite) is interbedded with sand above the pebble zone at map locality 10 (pl. 1). Sellards (1913, p. 29) mentions the presence of pebble conglomerate in some phosphate deposits near Newberry, but he does not describe the stratigraphic relationships.

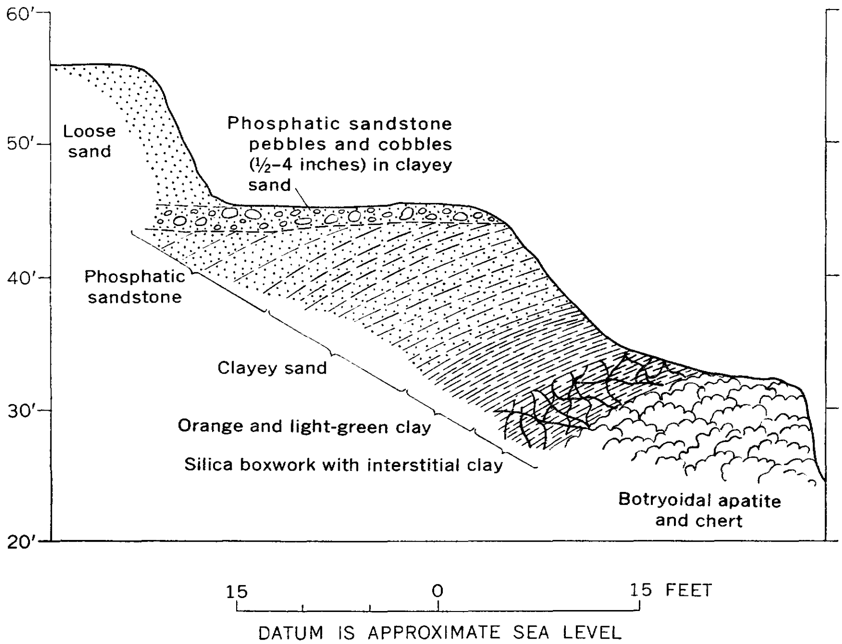

FIGURE 3.—Sketch showing the unconformity above phosphatic sandstone exposed in the northeastern part of Mutual mine, map locality 30, NW¼ sec. 28, T. 20 S., R. 20 E., Citrus County, Fla.

The light-gray clayey phosphatic sands form the thickest part of the overburden of the hard-rock phosphate deposits within the area of thick sand cover (pl. 6). The phosphatic sand unit is commonly thin, or even absent, in deposits outside the area of thick sand. Clayey sand, containing little phosphate and weathering red to orange, occurs at this stratigraphic horizon away from the belt of hard-rock deposits. The phosphatic sand is typically slightly indurated, tough, and coherent, and locally it is cemented to hard sandstone. It has an average composition of about 80 to 85 percent fine quartz sand (table 8) and about 15 to 20 percent of a fine claylike mixture of kaolinite, crandallite, and millisite. The quartz sand is well sorted and fairly uniform in grain size; median diameter of 20 samples ranged from 0.17 to 0.21 mm. Fine red to orange grains of apatite, about the same size as the quartz grains, occur nearly everywhere near the base of the phosphatic sand; fine apatite grains are locally common in some hard phosphatic sandstone.

Tan to green plastic clay, in thin beds a foot or two thick, commonly lies beneath the phosphatic sand (table 5). Fine apatite grains may be present in the clay. Samples of clay from 3 deposits were found by X-ray determination to be principally montmorillonite (table 22, p. 110), resembling the clay that is characteristic of the upper part of the Hawthorn formation; the heavy-mineral content of these clays (table 25, p. 112) is also similar to that of the clay samples from beds of the Hawthorn. In some deposits, as at locality 27 (table 13, p. 79), sandy clay containing large apatite pellets (as much as 1 cm in diameter) occurs below the clay bed. Limestone containing fine apatite grains is known to occur beneath phosphatic sandy clay at only one locality, drill hole 20 (pl. 12).

The secondary apatite zone is not an ordinary stratigraphic unit, of course, because this mixture of hard and soft secondary apatite with sand and clay slumped from above, and chert and limestone fragments relict from dissolved limestone beds has apparently been formed by ground-water activity at the contact between the phosphatic beds and the underlying limestone. In an individual deposit, the thickness of this zone may be highly variable and the upper and lower contacts very irregular. Some deposits obviously occur in solution depressions in limestone.

Secondary apatite has a wide variety of forms. Typical "hard-rock phosphate" consists of fragments or rounded masses of hard light-tan to brown dense apatite. Botryoidal structure with finely banded curved layers of apatite and irregular, discontinuous cavities is characteristic (Matson, 1915, pls. 4, 5); some botryoidal masses are 5 to 10 feet in diameter. "Plate rock" is a variety of secondary phosphate that is composed of thin platy or irregular layers (a few millimeters thick) of apatite, with wavy interstitial cavities; the layers may be broken into fragments that are cemented by dense apatite (Matson, 1915, pls. 6, 14*A*). This variety of phosphate was abundant in the mines near Anthony, which were called "plate rock" mines. Some secondary phosphate, having marked breccia structure, contains sharply angular fragments of apatite in a matrix of hard, sandy apatite. Several generations of apatite with different colors or structure are very widespread and have characteristic features, showing that phosphate deposition was discontinuous. Breccia structure is evidently formed by collapse and breakage of a mass of secondary phosphate into a solution cavity, followed by cementation of the fragments by a younger generation of apatite. Delicate incrustations of tiny wavellite needles may line cavities in the apatite.

Phosphatized casts of fossils from the Eocene limestones are not uncommon (Matson, 1915, pl. 14*B*). Druid Wilson identified the following genera of mollusks in samples from the stockpile of the Kibler-Camp phosphate mine (sec. 17, T. 17 S., R. 19 E.):

Pelecypoda:
- *Barbatia* sp.
- *Glycymeris* sp.
- "*Venericardia*" n. sp.
- *Fimbria* sp. (genus confined to Eocene in North America)

Gastropoda:
- *Xenophora* sp.

Porous silicified limestone is commonly partly replaced by finely banded apatite, but we have not seen replacements of this nature in pure limestone. For this reason, it may be that phosphatized fossil casts represent replacement of silicified fossiliferous limestone rather than direct replacement of the pure limestone. Phosphatized manatee ribs and shark, mastodon, and horse teeth are also found in the deposits (Sellards, 1913, pls. 4–7).

Soft white claylike phosphate mixed with sand and clay forms the matrix of the hard-rock phosphate. This material is washed away from the hard-rock phosphate in the milling process and deposited in waste ponds. These slimes are composed largely of apatite, crandallite, quartz, and possibly kaolin and montmorillonite minerals according to X-ray determinations [1] of five samples of slimes.

Many characteristics of the hard-rock phosphate deposits are displayed in the small deposit on the Ross property, Marion County (pl. 7). Stratigraphic relations are not disturbed much by solution slumping here; phosphatic sand lies nearly horizontally upon a few feet of sand and sandy clay containing large phosphate pellets, which in turn, lies above typical secondary phosphate rubble (map loc. 18, pl. 1 and table 13). This deposit is several miles east of the area of thick sand cover and is evidently a small outlier of the phosphatic beds that is preserved in a shallow sink in Ocala limestone in an area where most of the phosphatic strata has been stripped by erosion.

Twenty auger-drill holes were put down in the southern half of the hard-rock district to get stratigraphic information and to obtain samples of the phosphatic sands (pls. 8–12). Correlation between the strata penetrated in the different holes proved difficult, but it appears that the sands are most phosphatic in the low areas within the belt of hard-rock deposits. The highest areas have less secondary phosphate and better preserved remnants of the original sediments, such as the phosphatic limestone found in drill hole 20 (pl. 12) on a hill of 150 feet altitude and the thick clay in drill hole 8 (pl. 9) on a hill of

[1] F. A. Hildebrand and D. D. Riska, analysts.

195 feet altitude; thick beds of clay underlie the highest hills at the southern end of the district.

AGE OF THE PHOSPHATIC SANDS AND CLAYS

These phosphatic sands and clays, as well as the underlying secondary apatite deposits, were originally named the "Dunnellon formation" by Sellards (1910, p. 32), but he later concluded that they were equivalent to the Alachua formation and dropped his earlier name (Sellards, 1914b).

Invertebrate fossils have been found in these sands at only one place, the old phosphate mine of locality 11 (pl. 1; table 10) where they occur in large loose blocks of phosphatic sandstone within the pit; Druid Wilson assigns late Miocene age to these mollusks. Horse teeth found in place in phosphatic sand at map localities 8 and 20 are called early Pliocene(?) by G. E. Lewis (written communication, 1956), who identified these teeth as follows:

Map locality 8:

Hard-rock phosphate mine in SW¼NW¼ sec. 21, T. 9 S., R. 17 E., Alachua County. Sample 277 from phosphatic clayey sand.

Undetermined bone fragments
3 fragments of upper cheek teeth
2 ?very much worn cheek teeth of ?*Nannippus* aff. *N. minor*
1 fragment of carapace of ?*Gopherus* sp.

Map locality 20:

Hard-rock phosphate mine in SW¼SW¼ sec 4, T. 14 S., R. 19 E., Levy County. Sample 181 from phosphatic sand, 8 feet below top of bed.

Much-worn upper cheek tooth of *Nannippus* cf. *N. minor*.

Lewis states:

> If these horse teeth do in fact represent much-worn *Nannippus* teeth, I would judge their age to be early Pliocene. However, the upper cheek teeth of *Nannippus* are very highcrowned when little worn (35 to 75 mm high), and have a discrete protocone almost to the base of the crown, whereas these Alachua and Levy County specimens are 19 (No. 181), 15 and 13 (No. 277) mm high at the paracone, and in the Alachua County specimens (No. 277) the protocone is connected to the protoconule as in the genus and subgenus *Merychippus* (*Protohippus*). Therefore, the remote possibility exists that No. 277 *might* be secondarily derived *Merychippus* aff. *M. gunteri* from the early Middle Miocene Hawthorn formation. The discrete protocone and very complicated enamel patterns of the fossettes of No. 181 make its reference to *Nannippus* much more probable.

According to Simpson (1929), vertebrate fossils of Miocene age have been found in one phosphate deposit near Newberry, vertebrate fossils of early Pliocene age have been found at 6 localities in the hard-rock district, and Pleistocene vertebrates have also been found at various places in the district. He rejects the custom of assigning all these fossils to the Alachua formation, because he believes that Pliocene and Pleistocene fossils have not only been mixed together naturally, but that fossils from several localities that are some miles apart have been erroneously reported as coming from a single locality. Simpson (1929, p. 260) concludes that "the fauna of the Alachua formation, when purged of mixture, is probably not later than the close of the lower Pliocene."

No general agreement on the nature and age of the Alachua formation has yet been reached. Pirkle (1956b) gives a recent review of the problems and points out that strata of the Hawthorn formation and also Pleistocene sediments have been included with the Alachua formation. Vernon (1951, p. 189–195) regards the Alachua as a terrestrial deposit of early Miocene to Pleistocene age. Cooke (1945, p. 200) states:

> The Alachua is unique among geologic formations in Florida in that most of it was not deposited in water, either salt, or brackish, or fresh. The bulk of the Alachua is merely the collapsed and compacted residue of the Hawthorn formation *in situ* together with accumulations in sinkholes and ponds. These later accumulations contain the bones of Pliocene animals.

He comments that it was a considerable expansion of the original meaning of the Alachua formation for Sellards to include the phosphatic sand of the hard-rock district in the Alachua.

Ketner and McGreevy (1959, p. 59–70), from studies in several phosphate mines at the south end of the hard-rock phosphate district, conclude that the term "Alachua formation" should be restricted to clay deposits of late Miocene or early Pliocene age and should not include the phosphatic sands and underlying units. They assign the phosphatic sands to the Hawthorn formation (middle Miocene according to their view) and the clay and phosphorite below to the Tampa limestone (early Miocene). We, too, believe that the phosphatic sands and underlying units should not be placed in the Alachua formation; we feel, however, from the evidence of fossils from the northern part of the district, that the age of these beds falls somewhere in the range between middle Miocene and early Pliocene.

ORIGIN

Most investigators of the hard-rock phosphate deposits have agreed that the phosphate was deposited from ground waters by replacement of limestone and by precipitation in cavities, but they have not agreed upon the nature of the original phosphatic material from which the ground waters dissolved phosphate in the first place. The original phosphatic source material has obviously been greatly modified by ground-water leaching. The principal theories that have been offered about the nature of this original phosphatic material are given below.

1. Marine phosphorite of Miocene or younger age once covered the area of the hard-rock phosphate district; phosphate was dissolved by ground water and reprecipitated at depth.

2. Sedimentary phosphate originally occurred in Eocene limestone or other pre-Miocene strata; phosphate was dissolved by ground water and reprecipitated at depth.

3. Guano deposits accumulated on island bird rookeries during Miocene and younger time; these have been modified by ground water during and since guano deposition.

The first theory, that the hard-rock deposits are the end product of long periods of weathering of Miocene or younger phosphorites which once covered the district, was originally proposed by Sellards (1913) and was also supported by Matson (1915) and Cooke (1945); Sellards reviewed all the theories of origin suggested by earlier workers. This mode of origin seems to us to be most probable, for reasons that will be discussed below.

The second theory has no evidence in its support, because sedimentary phosphorite of pre-Miocene age is unknown in formations that crop out in Florida.

The guano theory was favored by several of the early students of the hard-rock phosphate deposits, and it has recently been strongly endorsed by Vernon (1951); he concludes that the hard-rock phosphate district was an island area during much of Miocene and younger time, and that enormous amounts of guano accumulated in large bird colonies. The phosphate deposits would thus be guano deposits that have been modified by ground-water action.

The choice between the weathered phosphorite and the guano theories of origin of the hard-rock phosphate deposits depends mainly upon the true nature of the phosphatic sand, clay, and phosphorite of the hard-rock phosphate district. Is it the residuum of marine phosphorite from which nearly all soluble material has been leached, or is it made up of terrestrial sediments accumulated on guano islands? Present evidence clearly indicates, we believe, that the phosphatic sands, sandy clays, and clays that overlie the secondary phosphate deposits represent a marine stratigraphic sequence that is similar in several respects to, and different in some ways from, the Hawthorn formation of known Miocene age which is exposed farther east. Remnants of beds of early and middle Miocene age in the southern part of the Ocala uplift, just south of the hard-rock phosphate district, are described by Carr and Alverson (1959, p. 59–60); they conclude, "the evidence indicates that there was extensive, if not complete, inundation of the uplift by lower and middle Miocene seas." There is a possibility that the hard-rock district was a land area early in the Miocene as suggested by Cooke (1945, p. 119–120), rather than during all the Miocene as Vernon (1951) suggests, before it was submerged and covered by sediments of younger Miocene and Pliocene age. Guano deposits could, therefore, have been formed in the area during early Miocene time; these conjectural guano deposits might have been later changed by phosphatic ground waters descending through overlying marine phosphorite strata. Although the possiblity of initial guano deposits must be admitted, we find no evidence to support the guano theory and think that the phosphate deposits of the hard-rock district were most probably formed by the profound weathering of marine phosphorite beds in the manner outlined below.

The evidence for the existence of a uniform stratigraphic sequence, above the hard-rock phosphate deposits has already been given (p. 33–35). This sequence is broadly similar to that of the known Miocene phosphatic beds in northern Florida (table 6). Corresponding units have similar lithologic characteristics. The apatite grains and pellets that are found nearly everywhere in the clays and sands above the secondary apatite deposits are identical in appearance, except for generally being lighter in color due to weathering, with apatite pellets and grains in phosphorite beds of the Hawthorn. Kaolinite is the characteristic clay mineral of the upper sandy unit in the hard-rock district and also above the known Miocene beds; montmorillonite is the clay mineral in the more clayey unit beneath in both sequences. Montmorillonite must certainly be the primary clay mineral in these sequences, as it is in the Bone Valley formation of the land-pebble district in central Florida (Altschuler and others, 1956). We do not have good evidence for the origin of kaolinite in the phosphatic sand, however; it might have been formed by the weathering of montmorillonite, as Altschuler, Jaffe, and Cuttitta (1956) have shown is the case in the land-pebble district, or possibly from the weathering of feldspar, or it might be the original sedimentary clay mineral.

Phosphatic carbonate rock (limestone) has been found only at one locality in the hard-rock district, a poor sample from auger-drill hole 20; the insoluble residue of this limestone consists of nearly equal parts of attapulgite and quartz.[2] This occurrence may be an unleached remnant of phosphatic carbonate strata that were once widespread in the area.

Silicified wood is mentioned by both Sellards (1913, p. 28–29) and Vernon (1951) as occurring in the hard-rock phosphate deposits. However, Sellards notes that it is very rare, to which we would agree, because we found none in the many pits that we examined. The presence of silicified wood in the deposits can have little significance in relation to the origin of the deposits, until something is known about the stratigraphic position and distribution of the silicified wood.

Although there seems to be good evidence for the widespread deposition of marine phosphorite in the hard-rock district, various im-

[2] X-ray determination by H. C. Starkey, P. D. Blackmon, J. C. Hathaway, and Gillison Chloe.

portant stratigraphic and geomorphologic problems remain to be solved, among which are the following:

1. Were there originally extensive beds of phosphatic carbonate in the lower part of the sequence? Core drilling at the site of auger-drill hole 20 (pl. 1) and on other hills in the region with altitudes of about 150 feet might yield significant information on this matter.

2. Are two different lithologic facies that were deposited contemporaneously represented in the hard-rock district and the area farther south? Thick beds of montmorillonite clay (25 to 30 ft thick) overlain by thin beds of phosphatic sand occur at altitudes between 150 and 200 feet in Citrus and Hernando Counties adjacent to the southern part of the hard-rock district,[3] as at map locality 29 (pl. 1; table 13). Within the main hard-rock district beds of montmorillonite clay are thin (less than 5 ft thick) and occur at altitudes below 100 feet; these beds may contain apatite grains and pellets, and are commonly overlain by a thick cover of phosphatic sand (50 to 75 ft thick).

3. What is the reason for the general difference in altitude of 50 to 100 feet between the 2 areas just discussed? The most likely reasons for this difference in altitude are (1) differential uplift between these areas since deposition, such as Altschuler and Young (oral communication, 1958) believe has occurred between northward-trending ridges and valleys in the land-pebble district, or (2) much more active groundwater solution in the area of thin clay and thick phosphatic sand beds (hard-rock district) than in the area of thick clay beds (Citrus and Hernando Counties). It is easily possible that several hundred feet of limestone has been dissolved by ground water beneath the phosphatic sand cover of the hard-rock district, if limestone solution in Florida proceeds at the rate estimated by Sellards (1914a), that is, 1 foot in 5,000 or 6,000 years.

4. Could the phosphatic sand have originally been deposited in a very long sand bar, now much changed by erosion, in which phosphate deposition was restricted to a narrow part of the sand bar? The area of thick sand cover is more than 100 miles long in a northwest trend, and the hard-rock phosphate deposits occur mostly in a rather narrow belt along the east side of this area (pl. 6). The present linear distribution of the hard-rock phosphate deposits could perhaps be more readily explained as the result of weathering of a sedimentary phosphorite deposit of linear rather than broad extent.

5. Since the phosphatic beds of the hard-rock district may be in part younger than the Hawthorn formation, is it possible that erosion

[3] The areas of Miocene clay mapped in Citrus County by Vernon (1951) are shown on plate 1, but there are some unmapped areas of clay in Hernando County, such as the clay found in drill hole 8 (pl. 9), that are not shown on plate 1.

TABLE 6.—*Comparison of stratigraphy of hard-rock phosphate*

Hard-rock phosphate district		Area to east of hard-rock phosphate district, outliers of Miocene and younger beds in northern Marion County	
Series	Description	Series	Description
Pleistocene(?) to Recent.	Loose sand; charcoal fragments	Pleistocene(?) to Recent.	Loamy sand with pebbles of phosphatic sandstone.
Pleistocene	Sand and clayey sand tan, interbedded; charcoal fragments; pebbles of phosphatic sandstone at base locally.		
Middle Miocene(?) to lower Pliocene(?).	Phosphatic sand and sandstone, gray; 15–20 percent kaolinite and aluminum phosphate minerals; fine apatite grains in lower part. Fossils at map localities 8, 11, and 20. Clay, tan to green; contains fine apatite grains locally. Sandy clay, tan, with coarse apatite pellets. Phosphatic limestone; known only in drill hole 20.	Miocene or Pliocene(?).	Sandstone, tan to gray, medium- to coarse-grained; contains quartz pebbles; cementing matrix of clay and fine phosphate mineral.
	Hard-rock phosphate deposits; rubble of secondary apatite, sand, clay and chert (not a stratigraphic unit).	Lower and middle Miocene.	Hawthorn formation: Clayey sand to sandy clay, tan to light-gray; contains apatite pellets locally. Clay, light-green, plastic to hard; contains apatite pellets and quartz sand. Manatee ribs and silicified shells of *Ostrea normalis* are common. Limestone, cream, dense; some beds of limestone conglomerate; slightly dolomitic; much quartz sand and apatite pellets; very fossiliferous.
Eocene and Oligocene.	Limestone (Suwanee limestone, Ocala limestone, or Avon Park limestone).	Upper Eocene	Ocala limestone: Limestone, white, soft.

of the Hawthorn formation during late Miocene and early Pliocene time could have supplied some of the phosphate pellets and grains, quartz sand, and clay deposited in the strata of the hard-rock district?

Uplift of the marine phosphorite strata of the hard-rock district probably took place early in Pliocene time. A surface drainage system was developed at first, but this was eventually succeeded by the underground drainage system which now predominates. Remnants of the ancient stream system can be traced between present-day valleys, depressions, and sinkholes on the topographic maps at a scale of 1:24,000. The stream drainage system may have had only a brief existence because of the high permeability of the phosphatic sands and *district with stratigraphy of areas to the east and south*

Area to east of hard-rock phosphate district, generalized from logs of core drill holes 31 to 46		Area to south of hard-rock phosphate district, between Hernando and Hardee Counties (after Ketner and McGreevy, 1959)	
Series	Description	Series	Description
Pleistocene(?) to Recent.	Sand to clayey sand, white to brown, generally fine-grained.	Miocene to Recent.	Sand, quartz, loose, massive.
Miocene or Pliocene(?).	Clayey sand to sandy clay, tan, medium- to coarse-grained; contains few quartz pebbles, kaolinite, and muscovite.	Upper middle to lower upper Miocene.	Sand, quartz, micaceous, very fine-grained to medium-grained, brown to white.
Upper Miocene.	Sand to limy clayey sand, gray, fine-grained; contains many fine apatite grains, montmorillonite, and kaolinite. These strata found only in drill holes 42 and 44.		
Lower and middle Miocene.	Hawthorn formation: Phosphorite, white to tan, fine- to coarse-grained; considerable apatite pellets and grains; thin clay beds locally (montmorillonite). Phosphatic dolomite, soft to hard, cream to gray; contains quartz sand and apatite grains; interbedded green clay (attapulgite and montmorillonite) and phosphatic sandy clay.	Middle Miocene.	Hawthorn formation: Sand unit: Sand, quartz, clayey, fine-grained, brown to gray; interstitial secondary phosphates. Phosphorite unit: Sand and apatite pellets, clayey, gray to brown; fine-grained quartz sand; apatite pellets up to pebble sizes. Limestone unit: Limestone, clayey, sandy; apatite pellets up to pebble sizes.
		Lower Miocene.	Tampa limestone: Clay unit: Clay, sandy, very fine-grained, greenish to brown. Limestone unit: Limestone, clayey, sandy, yellowish; apatite pellets of sand size. Phosphorite unit: Clay size and concretionary apatite, clay, and sand.
Upper Eocene	Ocala limestone: White, soft; dolomitized in a few drill holes; solution cavities generally present near contact with Miocene beds.	Upper Oligocene.	Suwannee limestone: Limestone, sandy, very fine-grained.
		Upper Eocene	Ocala limestone: Limestone, pure.

the solubility of the underlying rocks. Once the underground drainage system was established, leaching of carbonate and phosphate was accelerated. D. E. White (oral communication, January 1960) points out that these chemical reactions could take place readily because soil moisture may acquire considerable acidity by dissolving CO_2 derived from vegetation and micro-organisms in the soil zone. Any calcium carbonate would first be leached by the descending acidic waters; after its removal, phosphate would be gradually dissolved and carried downward, and perhaps laterally, to be deposited as secondary apatite in the zone where limestone is being actively dissolved and the acidic waters are being neutralized. Solution slumping took place repeat-

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edly, causing brecciation of secondary apatite or mixing it with other materials. Phosphate deposition was discontinuous, and several generations of secondary apatite are commonly evident, such as successive botryoidal layers, phosphate breccia recemented by apatite, and cavities in hard tan apatite partly filled by chalklike apatite. The origin of the abundant soft claylike apatite is not clear; it may have been deposited from solution in ground water, or possibly it was transported as a suspension of very fine particles in the ground water. However, Ketner and McGreevy (1959, p. 76–77) suggest that the soft apatite is a primary mineral deposited in early Miocene time in phosphatic beds in the Tampa limestone, whereas the hard botryoidal apatite was formed much later by ground-water action. The aluminum phosphate minerals crandallite and millisite were formed in the phosphatic sands, and wavellite was formed as incrustations of delicate crystals in fractures in clay and cavities in hard apatite. The kaolinite that is associated with the aluminum phosphate minerals in the phosphatic sands may also have been formed in the weathering process.

Original sedimentary apatite pellets and grains are still present at many places. Apatite pellets (as large as 1 cm) in clay or very clayey sands have commonly escaped complete solution, although they may be weathered to a soft chalklike state. Small red or brown apatite grains (less than 0.5 mm) are very widespread in the lower part of the phosphatic sands. Some of this phosphatic sand has been cemented to a hard sandstone. A few thin patches of phosphatic sand and sandstone with grains and pellets of apatite occur about 5 miles east of Inverness at map locality 28 (pl. 1) in secs. 7 and 18, T. 19 S., R. 21 E.; these probably are small outliers of Miocene phosphorite.

Considerable erosion has taken place since the formation of the hard-rock phosphate deposits. The elongate belt of thick sand cover (pl. 6) seems to have undergone marine erosion nearly everywhere along its west side. The phosphatic sands have been partly or completely stripped from many deposits between Newberry and High Springs (pl. 6) at altitudes less than 100 feet above sea level; masses of secondary apatite probably were originally exposed at the surface here, and they are known to crop out at various places farther south. Loose sands or bedded sands commonly rest unconformably upon secondary phosphate rubble in the Newberry-High Springs region. A probable earlier erosional break, represented by conglomerate beds which are a foot or two thick and are composed of rounded pebbles of chert and phosphatic sandstone within clayey sand or reworked phosphatic sand, occurs at map locality 10 (pl. 1) and several nearby pits. Two erosional breaks were also recognized in deposits of this region by Matson (1915, p. 29, 53), who also points out that the deposits near Newberry generally are thinner and have less barren overburden than deposits south of Dunnellon. In all probability, this situation is the result of greater erosion in the area near Newberry where much of the thick sand cover is absent (pl. 6).

ECONOMIC GEOLOGY

HISTORY OF PHOSPHATE MINING

The first phosphate mining in Florida was in phosphorite beds near Hawthorn, Alachua County, in 1883 and 1884 (Sellards, 1913, p. 41), after the discovery that the sandstone being quarried here for construction stone by C. A. Simmons contained considerable phosphate (Hawes, 1883). River pebble deposits were mined in northern Florida to a limited extent in Black Creek, Clay County.

Phosphate was discovered in the hard-rock phosphate district in a well dug near Dunnellon by Albertus Vogt in May 1888 (Sellards, 1913). Prospecting and mining developed rapidly, and by 1909 there were 20 companies that were operating 75 plants. Only 3 companies were operating in 1941; the Kibler-Camp Phosphate Enterprise has been the only company active in the district since 1949. The Tennessee Valley Authority began prospecting for hard-rock phosphate deposits in 1950; most of their work before 1956 was in the area south of Dunnellon. About 500 pits have been worked in the district by about 75 companies according to Kibler (1941).

Total production of hard-rock phosphate was about 14,293,000 long tons to the end of 1960. The largest quantity sold in 1 year was 646,156 long tons in 1907 (fig. 4). The tonnage sold annually exceeded 300,000 long tons each year from 1894 to 1914, but it has been less than 200,000 long tons during every year since 1914, except for 1919 and 1920; the amount sold annually since 1950 has ranged between 70,000 and 96,000 long tons, equal to about 1 percent of the annual production from the land-pebble field. Most of the hard-rock phosphate has been exported. In recent years, the slimes from old tailings ponds have been dug up, dried, and the "soft" or "colloidal" phosphate sold for use as a soil conditioner or for mixing with cattle feed.

The hard-rock phosphate industry during its most productive period is well described by Matson (1915); Kibler (1941) gives a good account of the modern period. In the early days of mining, the overburden sand was removed by horse scraper, and the phosphate ore mined by pick and shovel. Now the overburden is removed by washing it hydraulically into a sump and then pumping it to a waste pond. The phosphate ore is mined by dragline to depths of about 50 feet below water level; mining below water level was formerly

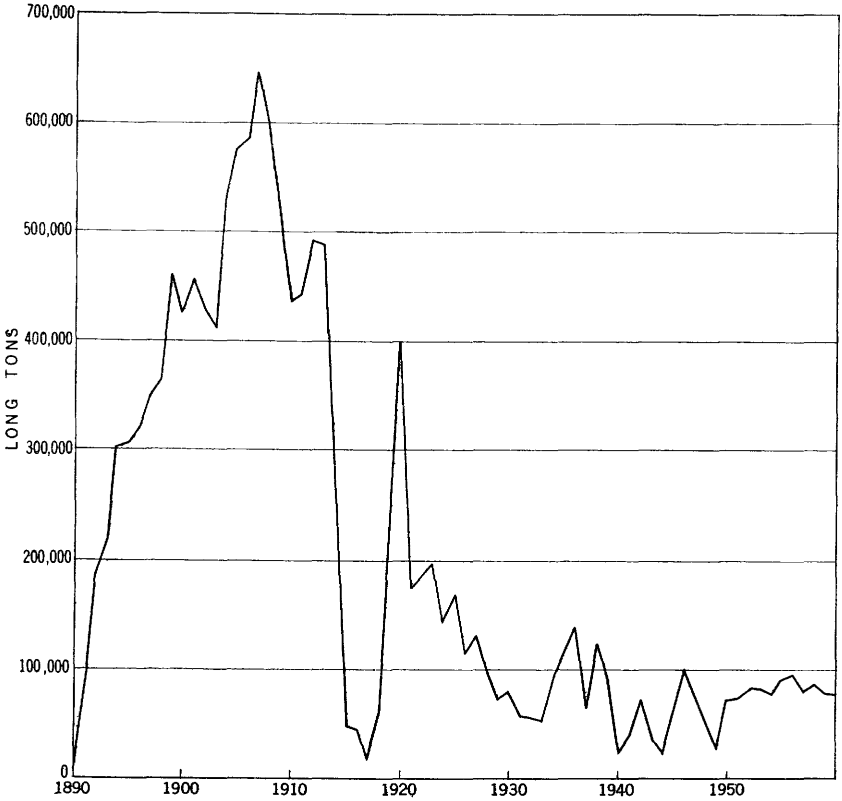

FIGURE 4.—Florida hard-rock phosphate marketed from 1890 to 1960.

done by dredges. As much as 70 feet or so of overburden can be removed economically if 1 long ton of phosphate can be recovered for 6 to 10 cubic yards of overburden moved. The ore is hauled in cable-drawn cars up a trestle to a preliminary washing plant, and then goes by rail to a central plant several miles away for final treatment. The final product ranges from +48 mesh (about 0.01 in.) to 2½ inches in diameter; much of the slime that goes to waste-settling ponds is eventually recoveıed as soft phosphate.

Much systematic drilling by means of jet drills is necessary to discover and outline minable phosphate deposits, because of the thick sand cover and the lack of reliable geologic guides to the deposits; generally at least 16 holes per acre (holes spaced 50 ft. apart) are required to prove an orebody. An average of about 6,200 tons of phosphate was recovered per acre during the first 50 years of mining, and about 14,000 tons has been recovered per acre in recent years (Mansfield, 1942).

PHOSPHORUS AND URANIUM IN THE HAWTHORN FORMATION

The new data gathered about the occurrence of phosphorus and uranium in the Hawthorn formation come from drill hole and channel samples from 35 localities that are rather widely distributed in northern Florida. Much of this information is summarized in table 7; more detailed data, including analyses of different size fractions, are given in tables 14–16 and 21 and in the report on the area south of Ocala (Espenshade, 1958).

TABLE 7.—*Summary of analyses of samples of phosphatic beds of the Hawthorn formation for* P_2O_5 *and uranium*

A. SAMPLES OF PHOSPHORITE WITH SIGNIFICANT CONTENT OF P_2O_5 AND URANIUM

Drill-hole samples

Locality	Depth (feet)	Percentage		Phosphate minerals [1]
		P_2O_5	Uranium	
Drill hole				
25 [2]	1 -3	17.1	0.015	----------
25 [2]	[3] 17 -21	8.4	.020	----------
26 [2]	4.5- 7.5	8.0	.004	----------
26 [2]	[3] 12 -16	10.3	.005	----------
27 [2]	[3] 17.5-21	5.6	.022	----------
27 [2]	30 -41.5	20.7	.005	----------
28 [2]	40 -43.5	9.1	.005	----------
29 [2]	[3] 4.5- 9.0	15.0	.014	----------
32	28 -32	10.8	.015	Apm.
32	33 -39.5	12.9	.017	Ap.
37	61.5-65.5	16.7	.010	Ap.
40	37 -40	6.2	.013	Ap, W.
40	40 -46	10.0	.004	Apm, Wm.
41	17 -22	8.6	.019	Ap, W.
41	22 -24	15.9	.009	Ap.
45	30.5-34	14.6	.008	Apm.
46	29.5-32.8	10.1	.003	Ap.

Surface samples

Locality	Sample length (feet)	Percentage		Phosphate minerals [1]
		P_2O_5	Uranium	
Map locality				
5	4.5	14.3	0.003	Ap, W, C.
6	1.5	10.1	.001	
7; 3 samples: Range	1.8-2.2	10.2-11.8	0.002- .008	Ap.
9	6	16.5	.012	Ap, W.
12	1	16.0	.016	Ap, W.

[1] Phosphate minerals were determined by X-ray only for the samples listed here: Ap, apatite; W, wavellite; C, crandallite. Minerals identified microscopically: Apm, apatite; Wm, wavellite.
[2] Detailed analyses of samples from drill holes 21–30 are given in Espenshade (1958); detailed analyses of other samples are given in tables 14–16 and 21.
[3] Samples of what is probably the same bed; the 4 drill holes are spaced about 200 ft apart along a road.

B. SAMPLES OF PHOSPHATIC CLAYEY SAND WITH LOW TO MODERATE CONTENT OF P_2O_5 AND URANIUM

Locality	Sample length (feet)	Percentage	
		P_2O_5	Uranium
Drill hole			
32 to 46; 22 samples:			
Range	1–10	1.8–7.9	0.001–0.006
Average	4.1	4.9	.003
Map locality			
2	19	4.8	.002
3	4	6.1	.003
4	18	4.5	.001
7; 4 samples: Range	3.6–4.5	4.5–5.1	.001–.004

C. SAMPLES OF PHOSPHATIC CLAY FROM SOUTH OF OCALA

Locality	Sample length (feet)	Percentage	
		P_2O_5	Uranium
Drill hole			
21 to 30; 16 samples:			
Range	1–9	3.5–9.8	0.001–0.006
Average	4.0	5.8	.002

Significant amounts of phosphorus and (or) uranium were found in phosphorite at the 15 localities listed in table 7*A*. Five of these localities (DH 25–29, pl. 1) are close together in the outlier of the Hawthorn formation west of Belleview, Marion County (Espenshade, 1958), and 4 other localities (DH 40, 41 and map localities 9, 12, pl. 1) are in an extensive are of phosphorite in eastern Alachua County (Pirkle, 1957b); the other localities are scattered from Lake County to Columbia County. Content of P_2O_5 in these higher grade samples ranges from 5.6 to 20.7 percent, with most of the samples having more than 10 percent; uranium ranges from 0.001 to 0.022 percent; thickness of samples is from 1 to 11.5 feet. The composition of the phosphorite beds may vary markedly within short distances, as suggested by the 4 analyses of samples from what is apparently the same bed (table 7*A*, DH 25–27 and 29); percent P_2O_5 ranges from 5.6 to 15.0 and percent uranium from 0.005 to 0.022. Phosphatic clayey sands of lower grade at other localities commonly contain about 5 percent P_2O_5 and 0.003 percent uranium (table 7*B*); some of this material contains soft claylike dolomite. Samples of hard phosphatic dolomite were not analyzed, but the most phosphatic dolomite is judged to contain about 5 percent P_2O_5. Beds of plastic green montmorillonite clay in the Hawthorn formation south of Ocala contain abundant small white phosphate particles; 16 samples of this phosphatic clay have an average content of 5.8 percent P_2O_5 and 0.002 percent uranium (table 7*C*).

No consistent relationship is evident between the uranium and phosphorous content of the phosphorite samples. However, the analyses of the different size fraction show that in most of the higher grade samples, between 70 and 90 percent of the total P_2O_5 and uranium is contained in the coarse fraction (+14-mesh, or >1.19 mm) and fine fraction —150-mesh, or <0.105 mm) combined; either the coarse fraction or the fine fraction may contain most of the phosphorous and uranium. Quartz sand is the dominant constituent in the intervening size range (—14- and +150-mesh). Distribution of phosphorus and uranium seems to be rather erratic in the lower grade material. In only 3 out of 12 samples of the lower grade material do the combined +14-mesh and —150-mesh fractions have more than 50 percent of the total P_2O_5; 6 of the 12 samples have more than 50 percent of the total uranium in the combined coarse and fine fractions.

In the apatite pellets themselves (as distinguished from the samples of the phosphorite just described) the content of P_2O_5 and uranium is related to the sizes of the apatite particles. The small apatite pellets, such as the —35+150-mesh flotation contentrates (tables 14, 15), nearly always have higher P_2O_5 and lower SiO_2 content than the large pellets (+14-mesh), because inclusions of quartz sand are more common in the larger pellets; uranium content is commonly lower in the small pellets than in the large pellets. The uranium-phosphorus ratio generally is highest in the —150-mesh size, about half as large in the +14-mesh size and still less in the flotation concentrates of —35+150-mesh size. Similar patterns of uranium and phosphorus relationships were found by Cathcart (1956, p. 493) in a study of hundreds of samples from the land-pebble phosphate district; he states: "the phosphate content increases and uranium content decreases as the size of the nodules decrease." Cathcart's figure 170*B* indicates that the uranium-phosphate ratio in the phosphorites of the landpebble district is also highest in the —150-mesh fraction (slimes).

Phosphorite of the Hawthorn formation at many of the sample localities in northern Florida has been altered by ground-water redistribution of phosphorus and uranium. These alterations are rather well-developed in phosphorite cut by drill holes 32, 37, 40, 41, 45, and 46 (tables 14, 16) and at several surface exposures. The upper part of the phosphorite beds has soft chalklike apatite pellets at all these places; kaolinite, claylike apatite, wavellite, crandallite, phosphate-cemented sandstone, and angular fragments of secondary apatite are also present at some places (table 7*A*). Radioactivity logs of some drill holes indicate high uranium content in the weathered upper beds of the clayey-sandy phosphorite (pls. 2–4). Uraniferous beds were also detected by the radioactivity logs in the lower part of the phosphatic dolomite sequence at depths of 80 to 335 feet in drill holes 35, 41, 42, 44, and 45 (pls. 2, 4, 5). Core recovery from these beds was poor, and it is not known whether the high uranium content is associated with secondary phosphate minerals. It may be that poorly consolidated phosphorite, which did not yield good core samples, is interbedded with the phosphatic dolomite here. Uranium enrichment of these beds might be the result of a hypothetical period of terrestrial weathering which interrupted phosphatic sedimentation during Miocene time, or it might be due to deep ground-water circulation in post-Miocene time.

Highly leached phosphorite, consisting of soft vesicular sandstone cemented by a white mixture of wavellite, crandallite, and kaolinite, is abundant in the outlying areas of the Hawthorn formation south of Ocala (Espenshade, 1958) and also at several places north of Ocala, particularly in secs. 18 and 36, T. 13 S., R. 21 E., and sec. 1, T. 14 S., R. 21 E. Apatite pellets have for the most part been completely leached, and the rock now has numerous ovoid cavities; partly decomposed apatite pellets are in places relict in the cavities. The leached phosphorite is very similar to the aluminum phosphate, or leached zone, rock of the upper part of the Bone Valley formation of the land-pebble district (Altschuler and others 1956). Samples of this porous, leached phosphorite from the area south of Ocala are rather uniform in composition: P_2O_5 ranges from 12.7 to 16.8 percent, uranium from 0.019 to 0.023 percent, Al_2O_3 from 14.7 to 20.0 percent, and quartz from 40.1 to 54.1 percent; specific gravity of the rock is about 1. Phosphatic sandstone from the old C. A. Simmons' quarry a few miles west of Hawthorn, Alachua County, is similar in composition; the analyses of 2 samples contain 13.05 and 16.07 percent P_2O_5, 12.85 and 19.57 percent Al_2O_3, and 12.02 and 2.83 percent CaO (Hawes, 1883). The first sample probably contains apatite as well as aluminum phosphate minerals, as indicated by its high CaO content.

PHOSPHOROUS AND URANIUM IN THE HARD-ROCK PHOSPHATE DEPOSITS

According to Mansfield (1942, p. 45), the grade of +48-mesh hard-rock phosphate produced through the years has been 29.8 percent P_2O_5 (65 percent BPL, bone phosphate of lime) or better; much of the material shipped has contained a minimum of 35.3 percent P_2O_5 (77 percent BPL). Four samples of secondary phosphate from hard-rock mines have a P_2O_5 content ranging from 21.2 to 30.0 percent (table 19, p. 102); uranium content of these 4 samples ranges from

0.003 to 0.011 percent. The best phosphate and uranium values are in the +20-mesh and −150-mesh size fractions; the uranium-P_2O_5 ratio is highest in the −150-mesh fraction.

Six samples of soft phosphate or slimes from tailing ponds at different mines in the district ranged in content from 18 to 23.1 percent P_2O_5, 0.004 to 0.008 percent uranium, and 11.1 to 15.9 percent Al_2O_3 (table 20, p. 102). This size material (−48-mesh) makes up at least 35 percent of the ore, according to information from W. L. Akin, phosphate prospector, as quoted by Mansfield (1942, p. 45); the −48-mesh fraction in the 4 samples of table 19 (p. 102) makes up from 45.8 to 63.6 percent of the total sample.

The phosphatic sand overburden of the hard-rock phosphate deposits has only a low content of both phosphate and uranium, but this is nearly all contained in the claylike nonquartz fraction that makes up from 15 to 20 percent of the sands (table 8). A considerable number of samples gives an indication of the uranium, P_2O_5, and Al_2O_3 content of the phosphatic sands; this information is summarized in table 8, and some of it is given in more detail in tables 17 and 18 (p. 99–101). The present study supports the conclusion reached by K. B. Ketner (written communication, 1953) from his sampling program that the uranium content of the −200-mesh fraction (mostly nonquartz material) is about 0.010 percent. The calculated P_2O_5 content of the nonquartz material ranges from 8.9 to 25.3 percent and the calculated Al_2O_3 content from 22.7 to 29.9 percent. The ratio of uranium to P_2O_5 generally is several times larger in the phosphatic sands then it is in the hard-rock phosphate. Uranium is presumably associated with aluminum phosphate minerals in these sands, as it is in the aluminum phosphate rock of weathered phosphorite; this was recognized earlier by Ketner (written communication, 1953).

TABLE 8.—*Content of quartz, uranium, P_2O_5, and Al_2O_3, in percent, in phosphatic sand of hard-rock phosphate district, Florida*

Quartz		
Average of samples from—	*Quartz*	
14 phosphate mines	86.3	
4 auger-drill holes	84.0	
Estimate of K. B. Ketner [1]	80.0	
Uranium		
Average of samples from—	*Uranium*	*Uranium in nonquartz material (calculated)*
4 mines, northern part of district	0.002	0.014
5 mines, central part of district	.004	.017
4 mines, southern part of district	.002	.014
14 auger-drill holes [2]	.002 eU	.011 eU
	Uranium in −200-mesh fraction	
14, from northern part of district [1]	0.007	
29, from southern part of district [1]	.011	

See footnotes at end of table.

TABLE 8.—*Content of quartz, uranium,* P_2O_5*, and* Al_2O_3*, in percent, in phosphatic sand of hard-rock phosphate district, Florida*—Continued

P_2O_5

Average of samples from—	P_2O_5	P_2O_5 *in nonquartz material (calculated)*
4 mines, northern part of district	1.8	8.9
5 mines, central part of district	5.5	25.3
4 mines, southern part of district	3.1	17.6
14 auger-drill holes	3.2	18.1

Al_2O_3

Average of samples from—	Al_2O_3 *Total*	Al_2O_3 *Soluble*	Al_2O_3 *Total in nonquartz material (calculated)*	Al_2O_3 *Soluble in nonquartz material (calculated)*
4 mines, southern part of district	5.3	3.9	29.9	22.0
6 auger-drill holes	4.0	3.1	22.7	17.6

[1] Samples of phosphatic sand from hard-rock phosphate mines taken by K. B. Ketner (written communication, 1953).

[2] The equivalent uranium (eU) analyses used in calculating this figure are those of samples for which percent P_2O_5 was also determined (table 18). The numerous other uranium analyses (table 18), many of which have <0.001 percent eU, are not included in this average.

RESOURCES

HAWTHORN FORMATION

Mansfield (1942, p. 31–34) has estimated the reserves of recoverable phosphate from land-pebble deposits (phosphorite beds) in northern Florida to be as follows:

County	*Reserves (millions of long tons)* *Known*	*Probable*	*Possible*
Hamilton	1	24	25
Clay	------	------	90
Bradford	------	------	55
Lake and Orange	------	------	100

The prospecting data available to Mansfield were limited, and for this reason he classified more than 90 percent of the reserves in the category of "possible" ore. His information on the grade of the pebble phosphate is likewise meager, but it does indicate that the SiO_2 content is high, especially in pebble phosphate from Hamilton and Clay Counties. SiO_2 occurs as inclusions of quartz sand in the pebbles and grains of phosphate; Mansfield points out that the phosphate could be beneficiated readily by grinding and flotation to remove much of the SiO_2.

Pirkle (1957b) has presented information about important occurrences of pebble phosphate in the upper part of the Hawthorn formation in eastern Alachua County. He found phosphorite beds, ranging in thickness from a few feet to 30 or 40 feet, that were covered by sand and clayey sands as much as 45 feet thick, in 2 areas: just north and northeast of Gainesville, an area of nearly 50 square miles; and about 10 to 15 miles southeast of Gainesville. In the area southeast of Gainesville, samples from 5 drill holes (0.5 to 1 mile southwest of DH 40) indicated the amount of washed pebble phosphate and flotation concentrate recoverable per acre to range from about 4,000 to 10,000 long tons. The grade of the recovered phosphate ranged from 62.5 to 65.4 percent BPL (28.8 to 30 percent P_2O_5) and from 8.72 to 11.51 percent insoluble.

Included quartz sand is more abundant in the coarse pebble (+14-mesh) than in the fine flotation concentrates (−20+150-mesh); the +14-mesh size ranges from 26.7 to 28.1 percent P_2O_5 compared to 31.6 to 32.2 percent for the flotation concentrates. Pirkle estimates that phosphate reserves of Alachua County are a minimum of between 30 to 50 million long tons of recoverable phosphate whose grade will exceed 50 percent BPL (22.9 percent P_2O_5).

The localities sampled during the present study are too widely separated for the results to be used for estimates of tonnage and grade. This formation is also insufficient to evaluate critically the reserve estimates made by Mansfield, but it does add a little support to Pirkle's conclusion that pebble phosphate underlies extensive areas in Alachua County. Furthermore, core from drill hole 41 (table 7) suggests that comparable beds of phosphorite may be present in the vicinity of Orange Heights, about 6 miles east of the main area described by Pirkle.

HARD-ROCK PHOSPHATE DISTRICT

Mansfield (1942, p. 46–48) estimated the reserves of phosphate in the hard-rock district, using information based upon prospecting and mining experience within the district. His reserves estimate is given in table 9, arranged a little differently from its original form in order to present the estimate more fully.

TABLE 9.—*Estimate by Mansfield (1942) of phosphate reserves in main hard-rock district, Florida*

Reserves	Acres	+48-mesh size 65 percent BPL, or 29.8 percent P_2O_5		−48-mesh size 40–65 percent BPL, or 18.3–29.8 percent P_2O_5	
		Long tons per acre	Long tons	Long tons per acre	Long tons
Known	4,932	8,370	41,280,840	2,170	10,702,440
Probable	69,308	8,370	580,107,960	2,170	150,398,360
Total known and probable	74,240	8,370	621,388,800	2,170	161,100,800
Possible:					
Additional ore in area of known and probable reserves		5,630	417,971,200	1,447	107,400,500
Ore beyond above area, that is, west to Jefferson County and south to Pasco County	46,000			5,000	230,000,000
Grand total	120,240		1,039,360,000		498,501,300

Mansfield's estimate is based upon expected recovery per acre (as determined by past experience) and the acreage of areas believed to contain phosphate deposits. His tonnage estimate for the area of

4,932 acres is entirely reasonable, but all this tonnage can hardly be regarded as known or measured ore. The area that Mansfield regards as having probable reserves of phosphate is clearly excessive, because he includes considerable ground in which the phosphatic sands are absent or have been widely eroded, and in which there is little likelihood that minable hard-rock phosphate deposits exist; the largest such area is in western Marion County where the Ocala limestone is at the surface. Furthermore, the figures for recovery per acre derived from the productive area should not be applied to such a large surrounding area, in which the phosphatic strata have been eroded in many places. Mansfield's estimate of possible ore seems overliberal for the same reasons, that is, excessive area and too large a factor for recovery per acre.

In summary, present geologic information, which was not available to Mansfield, indicates that a significant part of the areas included in his estimate should be excluded because of unfavorable geologic conditions. Much more information is needed about the hard-rock phosphate deposits and the geology of the region before a satisfactory estimate of the hard-rock phosphate reserves can be made.

The phosphatic sands of the hard-rock district may be regarded as a potential resource of phosphate and also uranium and aluminum, because of the enormous tonnages of phosphatic sand that exist in the district. Here again, information is too poor to permit estimation of the tonnages of phosphatic sand because the size of the area and the thickness of sand are known only in a very general way. If the average thickness is about 15 feet, there would be about 15 million long tons per square mile where the sands have not been eroded; the content of mixed clay and aluminum phosphate minerals would be between 2 and 3 million tons per square mile. Thus, the total tonnage of aluminum phosphate minerals and clay contained in the phosphatic sands of the district may be much larger than the reserves of recoverable hard-rock phosphate.

RECOMMENDATIONS FOR PROSPECTING

HAWTHORN FORMATION

More exploration of phosphorite beds of the Hawthorn formation is desirable in the vicinities of drill holes 37, 41, and 46 and map locality 5 (pl. 1), in addition to the areas discussed by Mansfield (1942) and Pirkle (1957b). There may be significant amounts of phosphate pellets, eroded from the phosphorite beds of eastern Alachua County, in the bottoms of the large lakes of the region—Newman, Lochloosa, and Orange. The outliers of the Hawthorn formation in southern Marion County may have phosphorite beds of potential economic importance. However, much of this material has been strongly weathered and altered to aluminum phosphate rock, and considerable exploration would be needed to determine the extent and grade of unaltered pebble phosphate.

HARD-ROCK PHOSPHATE DISTRICT

Reliable guides to secondary phosphate deposits in the hard-rock district have not been discovered, and the exploration practice has been to search for outcrops of phosphate (which have long since been found), and to drill systematically in the vicinity of, or in the ground between, old mines. The location and distribution of these deposits must be mainly dependent upon two factors: the original sedimentary distribution, which may have been largely restricted to the eastern part of the sand-covered area; and the redistribution of phosphate by ground waters, which may have involved considerable lateral transport of phosphate in places. Old stream channels and sinkholes must have been the sites of most active ground-water movement, and these are especially recommended for prospecting. They are well shown on the Geological Survey's new 7½-minute topographic sheets (1:24,000 scale) that cover much of the district, and can be readily found by tracing out the 50-foot and 100-foot contour lines. The possibility of partial erosion of deposits must be kept in mind in prospecting areas where thick sand cover is lacking (pl. 6).

Research to improve the technique of prospecting for hard-rock phosphate deposits deserves careful investigation. For many years the customary practice has been to drill at closely spaced intervals through the phosphatic sand, and then to take samples by chopping bit or core bit from any hard-rock deposit lying below. It is possible that the phosphatic sand lying above a hard-rock deposit has a higher phosphate content than does sand lying above barren ground. If so, widely spaced drilling and sampling of phosphatic sand at shallow depths might suffice to outline areas of abnormally high phosphate content that overlie unsuspected hard-rock deposits. This matter could be readily tested by shallow drilling and sampling in phosphatic sand above some explored but unmined hard-rock phosphate ore bodies.

Much of the mining and prospecting has been concentrated in two parts of the hard-rock district—in a belt between Newberry and High Springs at the northern end of the district and in another belt between Dunnellon and a few miles north of Hernando near the center of the district (pl. 6). The parts of the hard-rock district where mining has been moderate to heavy make up a total length of about 55 miles, and the parts where there has been little or no mining have about the same total length. It is probable that undiscovered deposits still exist in both of these parts. Several extensive areas that have not been prospected much are regarded as favorable for exploration:

1. Between Newberry and High Springs, in the area of thick sand cover just west of the main group of mines.

2. The sand-covered area from Florida State Route 24 between Archer and Bronson for about 25 miles south to near Dunnellon has scarcely been prospected; there are a few old mines farther east where the sand cover is thin and discontinuous. See the Bronson NE, Bronson SE, Tidewater, and Romeo 7½-minute topographic quadrangles.

3. In the vicinity of Dunnellon, in the sinkhole country just west of the heavily mined area. See the Dunnellon and Holder 7½-minute quadrangles.

4. The large valley that trends northwest from sec. 12, T. 20 S., R. 19 E. (Inverness quadrangle) to sec. 11, T. 19 S., R. 19 E. (Lecanto quadrangle); the old Hamburg and Holder mines are in this valley.

5. The sinkhole country extending about 7 miles south of Inverness has been little prospected. See Inverness and Nobleton 7½-minute quadrangles.

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TABLES 11–25

TABLE 11.—*Logs of core from drill holes 31 to 46*

[Sample number in "Description" column followed by F indicates that fossils are described in table 10; C indicates that chemical analyses are given in table 14; M indicates that mineralogy as determined by X-ray is given in table 21. Depth interval of sample is given in parentheses]

DH 31, NE¼SW¼ SEC. 19, T. 18 S., R. 29 E.

Lake County, Fla., beside Florida State Route 44, 1.75 miles northeast of Cassia Post Office. Approximate collar altitude, 53 ft

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
Pleistocene(?) to Recent	42	42	Sand, white, fine-grained (fishtail bit cuttings; not cored).
Miocene or later	44	2	Phosphate; contains fine to coarse black pellets with sand, yellow-brown clay balls, and shell fragments (fishtail bit cuttings; not cored). Sample X312 (42–44 ft) F.
Upper Eocene: Ocala limestone	46	2	Limestone, white, soft, granular. Sample X314 (44.5–46 ft) F.
	48.5	2.5	No core recovered.
	50	1.5	Limestone, white, soft, granular. Sample X315 (48.5–50 ft) F. Bottom of hole.

DH 32, SW¼ SEC. 34, T. 18 S., R. 28 E.

Lake County, Fla., beside Florida State Route 44, 1.05 miles west of Blackwater Creek. Approximate collar altitude, 76 ft

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
Pleistocene(?) to Recent	18	18	Sand, white, fine to coarse, slightly clayey (fishtail bit cuttings; not cored).
Miocene(?) or Pliocene(?)	20	2	Sand, white, medium-grained, clayey.
	27	7	Sand? No core recovered.
	28	1	Sand, white, medium- to coarse-grained, very clayey.
Lower and middle Miocene: Hawthorn formation	30.5	2.5	Phosphatic sand, white, medium- to coarse-grained; poorly sorted with soft secondary(?) phosphate; moderate radioactivity. Sample X31920 (28–32 ft) C.
	36	5.5	Phosphorite; contains fine to coarse tan phosphate pellets (soft near top of unit) in cream to light-green clayey sand; few shells and sharks' teeth; moderate radioactivity. Sample X321 (33–36 ft) C, M.
	40.5	4.5	Phosphorite; contains fine tan to orange phosphate grains in tan to light gray-green clayey sand; fossiliferous in lower 1.5 ft. Samples X322 (36–38.2 ft) C; X323 (38.2–38.7 ft) C; X324 (38.7–39.5 ft) C, M; X325 (39.5–40.5 ft) F.
	54.5	14	Dolomite, phosphatic, sandy, tan to gray, hard; many brown to black phosphate pellets (as large as 1 cm); bone and teeth fragments; core recovery <20 percent. Sample X327 (45.5–54.5 ft) F.
	63.2	8.7	Dolomite, phosphatic, sandy, gray, dense; contains abundant fine phosphate grains (1–2 mm in diameter); fossiliferous. Sample X328 (54.5–63.2 ft) F.
	74	10.8	Cuttings like above interval; hard drilling; no core recovered.
Upper Eocene: Ocala limestone	76	2	Cavity; top of Ocala limestone?
	83	7	Soft rock; no core recovered. Bottom of hole.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

DH 33, CENTER OF LINE BETWEEN SECS. 29 AND 30, T. 17 S., R. 28 E.

Lake County, Fla., beside State Route 42, 0.22 mile south of Paisley Post Office. Approximate collar altitude, 55 ft

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
Pleistocene(?) to Recent	1	1	Brown sand.
Miocene(?) or Pliocene(?)	9.7	8.7	Clayey sand, orange to yellow-brown, fine- to medium-grained; few limonite nodules in lower part.
	20	10.3	Sand?; cuttings, no core recovered.
	34	14	Clayey sand, white to yellow-brown, fine- to medium-grained (with few quartz pebbles as large as 1 cm); some fine muscovite and heavy black grains of unknown mineral.
	37	3	Sand?; no core recovered.
	39	2	Clayey sand, tan, fine.
Lower and middle Miocene: Hawthorn formation	44	5	No core recovered; moderate radioactivity.
	47	3	Dolomite, phosphatic, sandy; contains tan to light-gray soft to hard fine to coarse (1 cm) phosphate pellets; fossiliferous. Sample X335 (45.5–47 ft) F.
	58.2	11.2	Dolomite, phosphatic, sandy; contains tan soft to hard fine to coarse phosphate pellets; fossiliferous; core recovery about 30 percent. Sample X336 (47–58.2 ft) F.
	60.3	2.1	Dolomite(?), very hard; no core recovered.
	63	2.7	Cavity.
Upper Eocene: Ocala limestone	78	15	Dolomite, tan, granular, and soft white limestone; core recovery about 15 percent. Samples X337 (63–68 ft) F; X338 (68–78 ft) F, M.
	80	2	No core recovered. Bottom of hole.

DH 34, NW¼ SEC. 17, T. 16 S., R. 27 E.

Lake County, Fla. beside Florida State Route 19, 10.3 miles north of intersection with State Route 42. Approximate collar altitude 53 ft

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
Pleistocene to Recent	35	35	Sand, tan, medium- to coarse-grained (cuttings; no core recovered). Bottom of hole.

DH 35, SE¼NW¼ SEC. 31, T. 16 S., R. 27 E.

Lake County, Fla., beside State Route 19, about 6.85 miles north of intersection with State Route 42. Approximate collar altitude, 109 ft

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
Pleistocene(?) to Recent	32.5	32.5	Sand, white to tan, fine to coarse, somewhat clayey; scattered heavy black grains of unknown mineral.
Miocene(?) or Pliocene(?)	42.2	9.7	Clayey sand, yellow to brown, fine- to medium-grained; contains some muscovite and considerable heavy black grains of unknown mineral.
	43.2	1	Clay, mottled gray and red-brown, plastic (kaolinite). Sample X348 (42.2–43.2 ft) M.
Lower and middle Miocene: Hawthorn formation	59.5	16.3	Phosphorite, tan to light-gray, clayey (montmorillonite and attapulgite), sandy; contains fine to coarse red-brown to black phosphate pellets and muscovite; dolomitic near base; sharks teeth. Samples X349B (47–48.3 ft) C, M; X349CD (48.3–51 ft) C; X350 (51–55 ft) C; X351 (55–59.5 ft) C, M.
	64	4.5	Dolomite, phosphatic, sandy, gray and tan, slightly fossiliferous; core recovery about 20 percent; fairly high radioactivity.
	66	2	No core recovered.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
DH 35, SE¼NW¼ SEC. 31, T. 16 S., R. 27 E.—Continued			
Lower and middle Miocene—Continued			
Hawthorn formation—Continued	73	7	Dolomite, phosphatic, sandy, cream, granular, slightly fossiliferous. Sample X353A (66–67.5 ft) F.
	74	1	No core recovered.
	75.5	1.5	Dolomite, phosphatic, sandy, cream, claylike.
	82	6.5	Dolomite, light-tan, dense to granular, hard; contains little quartz and phosphate pellets; fossil fragments; high radioactivity.
	83	1	No core recovered; moderate radioactivity.
	88	5	Dolomite, phosphatic, sandy, tan, dense to porous; contain abundant phosphate; fossiliferous. Sample X356 (83–88) ft) F.
	90	2	Dolomite?, hard; no core recovered.
Upper Eocene:			
Ocala limestone	104	14	Cavity. Top of Ocala limestone?
	113	9	Sand and clayey sand, red-brown to gray-green cavity filling.
	114	1	Limestone, soft, white. Sample X357 (104–114 ft) F. Bottom of hole.
DH 36, SE¼SE¼ SEC. 15, T. 15 S., R. 24 E.			
Marion County, Fla., beside State Route 40, 0.2 mile southeast of State Route S314. Approximate collar altitude, 77 ft			
Pleistocene(?) to Recent	7	7	Sand, tan, medium- to coarse-grained.
Miocene(?) or Pliocene(?)	26.5	19.5	Clayey sand, white, gray, to red-brown, fine to coarse; contains muscovite and heavy black grains of unknown mineral near base; few silicified fossil fragments at base.
	27.5	1	Clay, olive, plastic, (montmorillonite); contains muscovite and some coarse quartz in upper part. Sample X362 (26.5–27.5 ft) M.
	28.5	1	No core recovered.
	31	2.5	Sand, white, very fine.
	32.5	1.5	No core recovered.
Lower Miocene:			
Hawthorn formation	34	1.5	Clayey sand, tan to light-gray, fine- to medium-grained; silicified fossils. Sample X364 (33.5–34 ft) F.
	36.3	2.3	Sandy clay, tan to greenish; contains few fine phosphate pellets; abundant silicified fossils. Sample X365 (34–36.3 ft) F.
	39	2.7	Clay, olive-green, waxy (montmorillonite); contains tiny white phosphate grains. Sample X366 (36.3–39 ft) M.
	46	7	No core recovered.
	49.5	3.5	Sandy clay, tan to olive, plastic; contains little fine phosphate.
	53.0	3.5	Clayey sand, phosphatic, tan, medium-grained (dolomite and attapulgite). Sample X369 (49.5–53 ft) C, M.
	55.5	2.5	Clay with little quartz and phosphate.
	57.5	2	Dolomite, tan, porous; contains little quartz and phosphate; few fossils.
	63	5.5	No core recovered; hard drilling; high radioactivity.
	66	3	Cavity.
	73	7	Dolomite, tan, soft to hard; contains little quartz and phosphate; fossiliferous; core recovery about 15 percent. Sample X372(66–73 ft) F.
	82	9	No core recovered.
	85	3	Dolomite, tan, hard; contains little quartz and phosphate; fossiliferous; core recovery about 10 percent; fairly high radioactivity. Sample X373 (82–85 ft) F.
	87	2	No core recovered.
	97	10	Clayey sand and dolomite; contains some tan clay (montmorillonite) and much fine phosphate; fossiliferous; core recovery about 30 percent. Samples X374A (87–92 ft) M; X374B (92–97 ft) F, M.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
DH 36, SE¼SE¼ SEC. 15, T. 15 S., R. 24 E.—Continued			
Lower Miocene—Continued Hawthorn formation—Continued	109	12	No core recovered; fairly high radioactivity.
	114	5	Dolomite, sandy, phosphatic, gray to tan; contains brown phosphate pellets as large as 5 cm; fossil fragments; core recovery about 15 percent.
	116	2	No core recovered.
	120	4	Dolomite, phosphatic, sandy, tan; contains abundant phosphate; fossil fragments; core recovery about 20 percent.
	135	15	Dolomite, sandy, phosphatic, light-gray, soft to hard; contains fine quartz and phosphate.
	137	2	Dolomite, phosphatic, sandy, light-gray, soft; contains considerable quartz and some phosphate; scattered shark teeth. Sample X380 (135–137 ft) C, M.
	152	15	Dolomite, phosphatic, sandy tan to gray, soft to hard; contains considerable quartz and phosphate pellets (as large as 1 cm); poorly preserved fossils.
	156	4	Cavity.
Upper Eocene: Ocala limestone	170	14	Sand and clay; cavity filling?
	178	8	Limestone, soft, white; core recovery about 10 percent. Sample X385 (156–178 ft) F. Bottom of hole.
DH 37, SE¼SE¼ SEC. 27, T. 13 S., R. 25 E.			
Marion County, Fla., at intersection of State Route 314 and 18. Approximate collar altitude, 90 ft			
Pleistocene(?) to Recent	7.3	7.3	Sand, tan, fine, and little red clay.
Miocene(?) or Pliocene(?)	15	7.7	Clayey sand, yellowish, fine to coarse, poorly sorted
	32	17	No core recovered.
	34	2	Clayey sand, tan, fine to coarse.
	40	6	No core recovered.
	42	2	Clayey sand, tan, medium- to coarse-grained; contains muscovite.
	45.5	3.5	No core recovered.
	50.5	5	Clayey sand, tan, fine; heavy black grains of unknown mineral.
	53.5	3	No core recovered.
	54.8	1.3	Clayey sand, tan to dark orange, fine; contains muscovite.
Lower and middle Miocene: Hawthorn formation	60.5	5.7	Clayey sand, orange to red; contains little phosphate; moderate radioactivity.
	61.5	1	No core recovered.
	65.5	4	Phosphorite, light-gray, very clayey (montmorillonite), sandy; contains brown phosphate pellets as large as 8 mm. Sample X394 (61.5–65.5 ft) C, M.
	66.5	1	No core recovered; high radioactivity.
	70.5	4	Phosphorite, tan to light-green, sandy, very clayey; contains phosphate pellets and white sandy secondary phosphate. Sample X395 (66.5–67.5 ft) C.
	75	4.5	No core recovered.
	78	3	Clayey sand, phosphatic tan to light-green; contains abundant fine phosphate and some dolomite fragments. Sample X397 (75–78 ft) C.
	80	2	No core recovered.
	89	9	Clayey sand, phosphatic, tan to light-green; contains brown phosphate pellets; sharks' teeth; silicified shells in upper part. Samples X398A (80–82 ft) F; X398AB (80–85 ft) C; X398C (85–89 ft) C.
	100	11	Clayey sand white; contains some fine phosphate grains and muscovite.
Lower and middle Miocene	106	6	No core recovered.
	110	4	Dolomite; contains some fine quartz and phosphat; poorly preserved fossils.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
DH 37, SE¼SE¼ SEC. 27, T. 13 S., R. 25 E.—Continued			
Upper Eocene: Ocala limestone	130	20	No core recovered.
	131	1	Limestone, white; fossiliferous. Sample X403 (130–131 ft) F. Bottom of hole.
DH 38, SE¼NW¼ SEC. 30, T. 11 S., R. 24 E.			
Marion County, Fla., half-mile northeast of Orange Springs. Approximate collar altitude 65 ft			
Pleistocene(?) to Recent	24	24	Clayey sand; white to pink, fine- to medium-grained; about 25 percent clay (kaolinite); contains some heavy black grains of unknown mineral. Sample X406 (7–11 ft) M.
	85	61	Sand, fine to coarse; contains some heavy black grains of unknown mineral (cuttings; not cored). Bottom of hole.
DH 39, NW¼SW¼ SEC. 30, T. 11 S., R. 24 E.			
Marion County, Fla., beside road to Oklawaha River, 0.2 mile east of Orange Springs. Approximate collar altitude, 66 ft			
Pleistocene(?) to Recent	4	4	Sand, light-gray, fine.
	9.2	5.2	Clayey sand, gray to red-brown, fine- to medium-grained, very clayey (kaolinite). Sample X410 (4–9.2 ft) M.
	10.5	1.3	Sand, tan, fine- to medium-grained; contains scattered muscovite.
	46	35.5	Sand, yellow to tan, fine (cuttings; not cored).
Miocene(?) or Pliocene(?)	48	2	Clayey sand, fine; contains few quartz pebbles and some muscovite.
	51.5	3.5	No core recovered.
	52	.5	Clayey sand, medium- to coarse-grained; contains some muscovite.
	56	4	No core recovered.
	58	2	Sand, tan, fine to coarse, slightly clayey; contains scattered muscovite.
	63	5	No core recovered.
	72	9	Very clayey sand, fine; contains abundant muscovite.
Lower and middle Miocene: Hawthorn formation	74	2	Clayey sand, fine to coarse; contains abundant muscovite and fine secondary phosphate?
	80.8	6.8	Phosphorite, tan to gray, sandy, clayey (montmorillonite); contains fine to coarse dark phosphate pellets and dolomite fragments; phosphatized fossil fragments, moderate radioactivity. Samples X418 (74.8–76 ft) F, C, M; X419 (76–78.5 ft) C; X420 (78.5–80.8 ft) C.
	87.2	6.4	Dolomite, sandy, white to gray, hard; phosphatic, clayey, poorly preserved fossils; core recovery about 50 percent.
	100.5	13.3	Dolomite, white to light-gray, soft; contains fine quartz and phosphate; fossiliferous. Samples X423B (90–93 ft) F.
	112	11.5	Dolomitic clay; olive shaly clay (attapulgite) with much silt-size dolomite crystals, fine quartz, and phosphate. Sample X425A (100.5–103 ft) M.
	113	1	Dolomitic phosphorite, light-gray; contains much sand and clay (montmorillonite and attapulgite). Sample X426 (112–113 ft) C, M.
	133	20	Dolomite, phosphatic, sandy, light-green, soft, claylike; most phosphatic near top.
	134.5	1.5	No core recovered.
	136	1.5	Dolomite, sandy, phosphatic, light-green, hard; core recovery about 10 percent.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
DH 39, NW¼SW¼ SEC. 30, T. 11 S., R. 24 E.—Continued			
Lower and middle Miocene—Continued			
Hawthorn formation—Continued	138	2	Dolomitic clay; contains tan scattered phosphate grains.
	142	4	Dolomite, sandy, phosphatic, tan; contains much fine phosphate; core recovery about 30 percent.
	148	6	No core recovered.
	152	4	Dolomite, sandy, phosphatic, and clay, tan; core recovery about 25 percent.
	155	3	Dolomite, tan, porous; contains little quartz and phosphate; poorly preserved fossils; core recovery about 10 percent.
	159	4	No core recovered.
	162	3	Dolomite, tan, hard; contains scattered quartz and phosphate; core recovery about 30 percent.
	167	5	Clay and dolomite, tan to green; lower few inches hard fossiliferous dolomite; core recovery about 30 percent.
Upper Eocene:			
Ocala limestone	168	1	Dolomite, tan; fossiliferous; no sand or phosphate. Sample X437 (167–168 ft) F. Bottom of hole.
DH 40, SW¼SW¼ SEC. 29, T. 10 S., R. 22 E.			
Alachua County, Fla., beside dirt road, 0.5 mile west of Atlantic Coast Line RR. crossing. Approximate collar altitude, 136 ft			
Pleistocene(?) to Recent	4.8	4.8	Sand, gray, fine- to medium-grained.
Miocene(?) or Pliocene(?)	6	1.2	Clayey sand, light-gray to pink, medium-grained.
	9.5	3.5	Sandy clay (kaolinite), white to pink. Sample X440 (6–8.5ft) M.
	16	6.5	Clayey sand, yellow to red, fine to coarse.
	18	2	No core recovered.
	27.8	9.8	Clayey sand, yellow to red, medium- to coarse-grained; core recovery about 20 percent.
Lower and middle Miocene:			
Hawthorn formation	37	9.2	Clayey sand, phosphatic, white to tan clayey sand; sandstone fragments cemented by wavellite(?); high radioactivity. Sample X442E (27.8–37 ft) C.
	46	9	Phosphorite, tan to brown, with quartz, fine to coarse phosphate pellets, and sand grains cemented by wavellite; very clayey (montmorillonite). Sample X443A (37–40 ft) C, M; X443BC (40–46 ft) C.
	53	7	Phosphorite, brown to light-gray, with fine quartz and phosphate; clayey (montmorillonite); fairly high radioactivity. Sample X443DE (46–51 ft) C, M.
	56	3	Clay, light-gray; contains considerable fine quartz and some phosphate.
	68	12	Clay, light-gray, waxy (mainly attapulgite, with minor montmorillonite and very fine apatite). Sample X445C (58.5–67.5 ft) M.
	75.5	7.5	Dolomitic clay, light-green; contains dolomite fragments and little quartz.
	77.5	2	Dolomite, sandy, phosphatic, light-gray.
	79	1.5	Sandy clay, light-gray; crumbly clay with scattered phosphate pellets.
	82	3	No core recovered.
	89	7	Limestone, light-gray, with some quartz and phosphate; clay in lower one-half foot; fossiliferous; core recovery <40 percent.
	98	9	No core recovered.
	99	1	Dolomite, sandy, cream; contains little phosphate.
	105	6	No core recovered.
	108	3	Dolomite, clayey, sandy, tan; contains considerable fine phosphate; fossiliferous. Sample X452 (107.5–107.7 ft) F.
	115	7	No core recovered.
	126	11	Dolomite, sandy, tan to gray, soft to hard; contains tiny phosphate pellets; fossiliferous; core recovery about 30 percent.
	129	3	Dolomite, gray, friable; contains little quartz and phosphate.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series andf ormation	Depth to base of unit (feet)	Thick-ness (feet)	Description
DH 40, SW¼SW¼ SEC. 29, T. 10 S., R. 24 E.—Continued.			
Upper Eocene: Ocala limestone	136	7	Cavity partly filled with phosphatic clayey sand; top of Ocala limestone?
	146	10	Limestone, white, soft to hard; fossiliferous. Sample X456 (129-146 ft) F. Bottom of hole.
DH 41, NE¼NW¼ SEC. 18, T. 9 S., R. 22 E.			
Alachua County, Fla., beside State Route 26, about 0.45 mile west of U.S. Highway 301 at Orange Heights. Approximate collar altitude, 128 ft			
Pleistocene(?) to Recent	5	5	Sand, brown, fine.
Miocene(?) or Pliocene(?)	12.5	7.5	Clayey sand, tan to gray; contains considerable moscovite.
	13	.5	Clay (kaolinite and montmorillonite about equal), brown-gray, with some fine sand. Sample X459 (12.5-13 ft) M.
Lower and middle Miocene: Hawthorn formation	14	1	Clayey sand, yellow and gray, medium-grained; contains some claylike secondary phosphate(?). Sample X460 (13-14 ft) C.
	17	3	No core recovered; very high radioactivity; probable uraniferous alminum phosphate zone.
	20.5	3.5	Clayey sand, white to tan, fine to coarse; contains some wavellite(?) and soft fine phosphate pellets. Sample X461AB (17-20.5 ft) C.
	24	3.5	Phosphorite, light-gray, clayey, sandy; contains much soft to hard white to tan phosphate pellets; some wavellite. Samples X461C (20.5-22 ft) C, M; X461D (22-24 ft) F, C, M.
	32.5	8.5	Clayey sand, tan to light-gray; contains fine to coarse quartz and little phosphate.
	35.5	3.	No core recovered.
	37.4	1.9	Clayey sand, fine, white; contains scattered phosphate.
	46	8.6	Clay (montmorillonite), light-green to tan, waxy; contains some fine quartz and considerable fine phosphate. Sample X464A (37.4-44 ft) M.
	52.4	6.4	Sandy clay, white, with some fine phosphate.
	63	10.6	Clay (attapulgite), white to light-green, waxy, flaky; contains little quartz and phosphate. Sample X466A (52.4-59 ft) M.
	72.4	9.4	Clayey sand; light-gray, with fine phosphate; moderate radioactivity; core recovery about 30 percent. Sample X467 (72-72.4 ft) C.
	77.5	5.1	Phosphorite, tan to gray, clayey (attapulgite), sandy; contains abundant fine phosphate; fairly high radioactivity. Samples X468A (72.4-75.5 ft) C, M; X468B (75.5-77.5 ft) C.
	88	10.5	Dolomite, phosphatic, sandy, gray, hard; contains abundant quartz and phosphate; few poorly preserved fossils; very high radioactivity at base.
	94	6	Dolomite, phosphatic, sandy, white, hard; core recovery about 30 percent.
	95.5	1.5	Cavity.
	98	2.5	Dolomite, tan to light-gray; contains some fine sand and phosphate.
	100	2	Cavity.
	102	2	Dolomite, tan to light-gray; contains some fine sand and phosphate.
Upper Eocene: Ocala limestone	120	18	Limestone, white, soft, fossiliferous; core recovery about 10 percent. Sample X473 (102-120 ft) F. Bottom of hole.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
DH 42, NE¼NE¼ SEC. 17, T. 9 S., R. 25 E.			
Putnam County, Fla., beside Florida State Route 100, about 0.04 mile southeast of road intersection at Baywood. Approximate collar altitude, 128 ft			
Pliocene(?) to Recent	10	10	Sand, fine, brown.
	25	15	No core recovered.
	26	1	Sand, fine, brown.
	30	4	No core recovered.
	36	6	Sand, fine, dark-brown; contains much organic material; clayey near base.
	43	7	No core recovered.
	47	4	Sand, light-tan, somewhat clayey; core recovery about 10 percent.
	63	16	No core recovered.
Upper Miocene	64	1	Clayey sand with much fine phosphate.
	68	4	No core recovered.
	74.5	6.5	Clay, tan to gray (montmorillonite and kaolinite), with much quartz and fine phosphate; fossil fragments. Samples X480A (68–73 ft) M; X480B (73–74 ft) F; X481 (74–74.5 ft) F.
	88	13.5	No core recovered.
	98	10	Clayey sand, light-gray, limy; contains much fine phosphate; fossil fragments. Samples X482A (88–89 ft) F; X482B (89–90 ft) F; X482C (90–90.8 ft) F; X482D (90.8–91.5 ft) F.
Lower and middle Miocene: Hawthorn formation	109	11	Dolomitic phosphorite, light-tan to gray, clayey (attapulgite and montmorillonite), sandy; contains much fine phosphate and some soft dolomite; moderate radioactivity. Samples X490 (98–100.5 ft) C, M; X492 (100.5–104 ft) C; X495 (104–106 ft) C; X497 (106–109 ft) C, M.
	110	1	Dolomite, sandy, phosphatic, light-gray, hard.
	124	14	Dolomite, tan, soft, clayey; contains fine phosphate and quartz; few sharks' teeth.
	129.5	5.5	Dolomitic sand, tan to light-green, coarse; contains some phosphate and soft dolomite.
	135.5	6	Dolomite, tan, soft, clayey (montmorillonite and attapulgite); contains considerable phosphate and quartz. Sample X520 (130.5–132 ft) M.
	138.5	3	Dolomite, light-gray, hard, dense; contains much quartz and some phosphate.
	159	20.5	Dolomite, olive to light-gray, soft to medium-hard, clayey; contains much quartz and little phosphate.
	168	9	Dolomite, sandy, phosphatic, medium-gray, hard.
	172.5	4.5	Dolomite, clayey, green-gray, soft; contains quartz and phosphate.
	176	3.5	Dolomite, light-gray, medium-hard; contains clay (montmorillonite), quartz, and phosphate. Sample X533A (172.5–174 ft) M.
	181	5	Dolomite, medium-gray, soft; contains quartz and phosphate.
	183.5	2.5	Dolomite, sandy, phosphatic, green-gray, hard.
	187	3.5	No core recovered.
	193	6	Dolomite, very sandy and phosphatic, gray, soft to hard; core recovery about 20 percent.
	196	3	Dolomite, cream, soft; contains abundant fine quartz and phosphate.
	201	5	Dolomite, light gray-greeen, dense; contains little fine quartz and phosphate in lower 2 ft.
	208	7	Dolomite, sandy, phosphatic, tan to light-greenish, soft, granular, fossiliferous; very high radioactivity. Samples X542 (201–203 ft) M; X54344 (203–208 ft) C.
	212	4	Dolomite, sandy, phosphatic, soft to hard, light gray-green; high radioactivity. Samples X54546 (208–212 ft) C.
	219.5	7.5	Dolomite, sandy, phosphatic, medium-hard, light-gray; high radioactivity.
	231	11.5	Dolomite, sandy, gray, hard, dense, phosphatic, fossiliferous; core recovery about 30 percent.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
DH 42, NE¼NE¼ SEC. 17, T. 9 S., R. 25 E.—Continued			
Upper Eocene:			
Ocala limestone	256	25	No core recovered.
	266	10	Limestone, white, porous, very fossiliferous. Sample X552 (256-266 ft) F. Bottom of hole.
DH 43, NW¼NE¼ SEC. 32, T. 7 S., R. 21 E.			
Bradford County, Fla., beside Florida State Route S225, about 1,100 ft north of Santa Fe River. Approximate collar altitude, 138 ft.			
Pleistocene(?) to Recent	4.5	4.5	Sand, tan to gray, fine, loose.
Miocene(?) or Pliocene(?)	14.2	9.7	Clayey sand, tan to reddish, fine to coarse.
Lower and middle Miocene:			
Hawthorn formation	15.7	1.5	Clay, light-green, waxy (mixed layer mica— montmorillonite); contains some fine sand and phosphate; fairly high radioactivity. Sample X558 (14.2-15.7 ft) M.
	17	1.3	Clayey sand, white fine.
	19.5	2.5	No core recovered.
	22	2.5	Clayey sand, white to pink.
	25	3	No core recovered.
	27	2	Clayey sand, white, fine- to medium- grained.
	31	4	Clayey sand, phosphatic, white to light-tan; contains some wavellite, soft claylike apatite, and phosphate pellets.
	34	3	No core recovered.
	36	2	Phosphorite; tan clayey sand with much fine phosphate.
	39.8	3.8	Sandy clay, light-tan (montmorillonite), with some fine quartz and phosphate. Sample X569 (36-37.5 ft) M.
	54.5	14.7	Dolomite, sandy, clayey, phosphatic, tan to light green-gray, soft, sharks teeth. Sample X572 (39.8-41.3 ft) M; X581 (53-54.5 ft) M.
	56	1.5	Dolomite, sandy, phosphatic, gray to tan, dense.
	59	3	No core recovered.
	72	13	Dolomite, white to light-gray, hard; contains little quartz and phosphate; moderate radioactivity; core recovery about 20 percent.
	74	2	No core recovered.
	75	1	Very dolomitic sandstone, light-brown; hard, contains little phosphate.
	80	5	No core recovered.
	83	3	Dolomite clayey, gray to greenish, soft.
	90	7	Dolomite, sandy, light-gray, soft to hard; contains much fine quartz and little phosphate; core recovery about 25 percent.
	94	4	No core recovered.
	99	5	Dolomite, sandy, light-gray, hard, core recovery about 20 percent.
	117	18	Clay, light-green to gray, shaly (mainly attapulgite and little montmorillonite); contains dolomite and sand locally; core recovery about 20 percent. Sample X592 (110-117 ft) M.
	120	3	No core recovered.
	122	2	Silicified clay, medium-gray, dense; core recovery about 20 percent.
	129	7	No core recovered.
	138	9	Dolomite, sandy, phosphatic, cream to tan; contains considerable phosphate; fossiliferous; core recovery about 20 percent.
	143	5	No core recovered.
	153	10	Phosphorite; contains dark-gray clayey (attapulgite) sand with abundant fine phosphate; core recovery about 10 percent. Sample X595 (143-153 ft) C, M.
	158	5	Phosphorite; contains green-gray clayey sand with much fine phosphate. Sample X595 (153-158 ft) C.
	163.4	5.4	Dolomite, sandy, cream to gray, dense; contains little phosphate; core recovery about 25 percent.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
DH 43, NW¼ NE¼ SEC. 32, T. 7 S., R. 21 E.—Continued			
Upper Eocene:			
Ocala limestone	165.5	2.1	Cavity.
	175	9.5	No core recovered.
	179	4	Limestone, light-gray, granular; core recovery about 20 percent. Sample X599 (175–179 ft) F Bottom of hole.
DH 44, NW¼NW¼ SEC. 27, T. 5 S., R. 24 E.			
Clay County, Fla., beside Florida State Route 21 about 0.2 mile south of junction with Florida State Route 215. Approximate collar altitude, 81 ft			
Pliocene(?) to Recent	8	8	Sand, tan to gray, fine.
	16	8	Sand, pink, fine; contains little clay.
	18	2	No core recovered.
	22	4	Sand, light-gray, fine.
	25	3	No core recovered.
	27	2	Clayey sand, light-gray, fine.
	28.5	1.5	No core recovered.
	31	2.5	Sand, white to tan, fine; core recovery about 20 percent.
	47	16	No core recovered.
	49.3	2.3	Clayey sand, dark-brown to gray, fine.
Upper Miocene	53	3.7	Limy sand to hard marl, phosphatic, tan to gray, very fossiliferous. Samples X610 (49.3–51.4 ft) F; X611 (51.4–52 ft) F; X612 (52.5–53 ft) F.
	69	16	No core recovered.
Lower and middle Miocene:			
Hawthorn formation	105	36	Dolomite, light-cream to gray, mostly soft; contains abundant fine quartz and phosphate; clayey (montmorillonite and attapulgite); fossiliferous; moderate radioactivity. Samples X613 (69–72 ft) M; X614 (72–75 ft) C; X620 (91–97 ft) C, M; X623 (100–105 ft) C.
	105.5	.5	Dolomite, sandy, phosphatic, gray, hard, fossiliferous. Sample X625 (105–105.5 ft) F.
	109	3.5	No core recovered.
	143	34	Dolomite, sandy, clayey, phosphatic, light-gray to green, soft, slightly fossiliferous.
	149	6	Dolomite, sandy, phosphatic, olive-green, porous, very fossiliferous. Sample X637 (143–149 ft) F.
	152	3	No core recovered.
	158.5	6.5	Dolomite, sandy, phosphatic, light-gray, soft.
	174	15.5	Clayey sand, dolomitic, gray, fine, soft, contains much fine muscovite and phosphate. Sample X642 (169–174 ft) C, M.
	178	4	Dolomite, sandy, phosphatic, gray, soft to hard.
	181	3	Dolomite, sandy, phosphatic, greenish, soft, clayey.
	195	14	Dolomite, sandy, phosphatic, gray, hard, fossiliferous. Sample X645 (181–189 ft) F.
	200	5	No core recovered.
	200.5	.5	Dolomite, light-gray, with scarce quartz and phosphate.
	217	16.5	No core recovered.
	225	8	Dolomite, sandy, phosphatic, light-gray, soft. Sample X648 (217–220 ft) C, M.
	227	2	Dolomite, light-gray, hard; contains fine quartz and phosphate.
	235	8	Dolomite, gray to green, soft, clayey; contains fine muscovite, fine quartz, and phosphate.
	265	30	Sandy clay, greenish, with fine quartz and muscovite.
	275	10	Dolomite, clayey, greenish; contains little phosphate; core recovery about 10 percent.
	285	10	Sandy clay (montmorillonite and attapulgite), green-gray, fine; contains muscovite and phosphate. Sample X660 (280–285 ft) M.
	288	3	No core recovered.
	295	7	Clayey sand, light-green; contains phosphate, muscovite, and little dolomite.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
DH 44, NW¼NW¼ SEC. 27, T. 5 S., R. 24 E.—Continued			
Lower and middle miocene—Con. Hawthorn formation—Con.	304	9	Dolomite, sandy, and clay, light-gray, soft to hard; contains little phosphate; very high radioactivity; core recovery 50 percent.
	307	3	Dolomite, sandy, phosphatic, tan, hard, fossiliferous; high radioactivity. Sample X663 (304–307 ft) F.
	310	3	No core recovered.
	317	7	Dolomite, sandy, phosphatic, gray, hard.
	327	10	Dolomite, sandy, phosphatic, light-gray, hard; core recovery about 30 percent.
	337	10	Dolomite, tan to greenish, hard; locally sandy and phosphatic; very high radioactivity; core recovery about 40 percent. Sample X666 (327–337 ft) F.
	349	12	Dolomite, gray to tan, dense; contains little quartz and phosphate; core recovery about 15 percent.
	357	8	Dolomite, sandy, phosphatic, light-gray; core recovery about 30 percent. Sample X668 (349–357 ft) F.
Upper Eocene: Ocala limestone	379	22	Limestone, white, porous, very fossiliferous; core recovery <5 percent. Sample X669 (357–379 ft) F. Bottom of hole.
DH 45, SW¼NE¼ SEC. 29, T. 5 S., R. 21 E.			
Bradford County, Fla., beside Florida State Route 229, about 0.2 mile southeast of New River. Approximate collar altitude, 114 ft			
Pleistocene(?) to Recent	4	4	Sand, tan, fine.
Miocene(?) or Pliocene(?)	15.8	11.8	Clayey sand, gray to reddish, fine- to medium-grained; more clay (kaolinite) near base. Sample X703 (14.2–15.8 ft) M.
	17.7	1.9	Clay, green, brown to reddish, plastic.
	19	1.3	Sandy clay, tan to greenish, fine- to medium-grained.
	22	3	No core recovered.
Lower and middle Miocene: Hawthorn formation	23.5	1.5	Clayey sand, phosphatic; white to tan soft claylike phosphate; contains some white phosphate pellets. Sample X705 (22–23.5 ft) C.
	34	10.5	Phosphorite; tan, clayey (montmorillonite and attapulgite?) sand with considerable phosphate pellets; fossiliferous in upper part; moderate radioactivity. Samples X706 (23.5–28 ft) C, M; X707 (28–30.5 ft) C; X708 (30.5–34 ft) C, M.
	37	3	Dolomite, phosphatic, sandy, white, soft.
	46	9	Dolomite, phosphatic, sandy, light-yellow to tan, soft, clayey (montmorillonite and attapulgite); contains abundant fine phosphate; fossiliferous. Samples X710 (37–39 ft) F, M; X711 (39–43 ft) F; X712 (43–46 ft) F.
	53	7	Dolomite, sandy, phosphatic, cream to gray, soft; contains much fine phosphate.
	55	2	No core recovered.
	76.8	21.8	Dolomite, sandy, phosphatic, cream to light-gray, soft, clayey (montmorillonite and attapulgite). Samples X716 (55–58 ft) C; X717 (58–61 ft) C, M.
	85	8.2	Dolomite, sandy, phosphatic, light-gray, hard, clayey (attapulgite), fossiliferous; core recovery about 40 percent. Sample X722 (78–85 ft) F, M.
	88	3	No core recovered.
	103	15	Dolomite, sandy, phosphatic, cream to green, soft; contains abundant quartz and phosphate; core recovery about 40 percent.
	111	8	Dolomite, gray, dense, hard; contains little quartz and phosphate; core recovery about 25 percent.
	120	9	Dolomite, clayey, gray, soft; contains little sand, phosphate, and clay (attapulgite) with boxwork structure of dolomite; core recovery about 50 percent. Sample X725 (113–120 ft) M.

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thick-ness (feet)	Description
DH 45, SW¼NE¼ SEC. 29, T. 5 S., R. 21 E.—Continued			
Lower and middle Miocene—Continued			
Hawthorn formation—Continued	130.8	10.8	Dolomite, light-gray, soft; locally sandy, phosphatic, or clayey; core recovery about 20 percent.
	136	5.2	Dolomite, sandy, phosphatic, light-gray; some opalescent silica in upper part; core recovery about 10 percent.
	150	14	No core recovered.
	158	8	Dolomite, light-gray; contains little sand and phosphate; core recovery about 25 percent.
	161	3	No core recovered.
	162.5	1.5	Dolomite, light-gray; contains little sand and phosphate.
	173	10.5	Sandy clay (montmorillonite); contains gray-green fine sand and phosphate. Sample X731 (168–173 ft) M.
	188	15	Sandy clay, light-greenish; some fine phosphate.
	193	5	Sandy clay (mainly attapulgite and minor montmorillonite), olive to gray; contains considerable fine phosphate grains. Sample X734 (188–193 ft) M.
	197	4	No core recovered.
	204	7	Clayey sand, gray to tan; contains fine phosphate.
	215	11	Sand, dolomitic, phosphatic; tan to gray, clayey; fossil fragments; core recovery about 30 percent.
	217	2	No core recovered.
	220.5	3.5	Dolomite, sandy, phosphatic, gray, medium to hard, fossiliferous; high radioactivity; core recovery about 30 percent. Sample X738 (217–220.5 ft) F.
	228.5	8	No core recovered; high radioactivity.
	229	.5	Dolomite, sandy, phosphatic, gray, hard.
	244	15	No core recoved.
Upper Eocene:			
Ocala limestone	257	13	Limestone, tan, porous, very fossiliferous; core recovery about 30 percent. Sample X740 (244–257 ft) F. Bottom of hole.
DH 46, NE¼NE¼ SEC. 30, T. 6 S., R. 19 E.			
Union County, Fla., beside State Route 18, about 0.75 mile west of intersection with State Route 23. Determination of collar elevation not reliable; probably between 125 and 150 ft.			
Pleistocene(?) to Recent	6.5	6.5	Sand, yellow to gray, fine.
Miocene(?) or Pliocene(?)	8.5	2	Clayey sand; white to tan, fine.
Lower and middle Miocene:			
Hawthorn formation	13.2	4.7	Clayey sand, phosphatic, with white to tan fine tiny wavellite crystals locally and soft phosphate pellets; high radioactivity. Sample X74445 (8.5–13.2 ft) C.
	29.5	16.3	Clayey sand, phosphatic, with white to pale-green soft phosphate pellets.
	38.5	9	Clayey sand, phosphatic, with white to tan clay (montmorillonite) and abundant fine dolomitic phosphate. Sample X749 (29.5–32.8 ft) C, M.
	41	2.5	Clay (montmorillonite), light-green, waxy; contains some fine quartz and phosphate. Sample X752 (38.5–41 ft) M.
	44	3	Sandy clay, phosphatic and dolomite; light-green.
	49	5	Clayey sand, phosphatic, light-gray; contains much fine phosphate and clay (montmorillonite and loughlinite) (?). Sample X755 (47–49 ft) M.
	53	4	No core recovered.
	67	14	Clayey sand, phosphatic, olive to gray; thin clay layers; contains considerable fine phosphate.
	70	3	No core recovered.
	72	2	Dolomite, sandy tan, dense, hard; contains little phosphate; few fossils.
	79	7	No core recovered.
	82	3	Dolomite, sandy tan, hard; contains little phosphate

TABLE 11.—*Logs of core from drill holes 31 to 46*—Continued

Series and formation	Depth to base of unit (feet)	Thickness (feet)	Description
DH 46, NE¼NE¼ SEC. 30, T. 6 S., R. 19 E.—Continued			
Lower and middle Miocene—Continued			
Hawthorn formation—Continued	83	1	No core recovered.
	83.8	.8	Dolomite, sandy, cream to tan, hard; contains some phosphate; fossiliferous. Sample X761 (83–83.8 ft) F.
	92	8.2	No core recovered.
	93	1	Limestone, sandy, phosphatic, cream, very fossiliferous. Sample X762 (92–93 ft) F.
	109	16	No core recovered.
Upper Eocene: Ocala limestone	115	6	Limestone, white, soft, fossiliferous. Sample X763 (109–115 ft) F, M. Bottom of hole.

TABLE 12.—*Stratigraphic sections of Miocene phosphatic beds in northern peninsular Florida*

MAP LOCALITY 1

West bank of Apalahoochee River at bridge about 1½ miles northeast of Jennings, NE¼ lot 224, Hamilton County

Lower and Middle Miocene:
  Hawthorn formation:
    Sandy clay, phosphatic; medium gray on fresh surface, weathers to light tan; well bedded with thin shaly partings; contains considerable muscovite; some sandy layers (as much as 1 in. thick) with abundant fine phosphate grains. About 7½ ft exposed above water level and at least 1½ ft below water level.*

MAP LOCALITY 2

West bluff of Alapaha River, NE¼NE¼ sec. 20, T. 2 N., R. 13 E., Hamilton County

	Thickness (feet)
Pleistocene(?) to Recent:	
Loose loamy sand, brown; scattered quartz pebbles	15
Lower and middle Miocene:	
Hawthorn formation:	
Clayey sand, tan to gray; some coarse quartz grains as large as 2 mm; also contains crandallite(?), kaolinite, montmorillonite, and dolomite.[1] Sample 303 [2]	6
Clayey sand, phosphatic, tan; contains abundant white phosphate pellets from 0.5 to 2 mm in diameter. Sample 302	3
Clayey dolomite, phosphatic, cream, soft; fine brown to gray phosphate grains, abundant fine quartz; poorly preserved fossils. Also contains attapulgite and minor sepiolite?[1] Sample 301	6.5

*** Mineralogy of clay sample 294, as determined by X-ray methods:**

[Analysts: P. D. Blackmon, G. W. Chloe, J. C. Hathaway, H. C. Starkey]

Size (millimeters)		*Estimated amount (parts in ten)*
0.002–0.050	Dolomite	8
	Quartz	2
<0.002	Montmorillonite	4
	Quartz	1
	Dolomite	Trace

See numbered footnotes at end of table, p. 78.

TABLE 12.—*Stratigraphic sections of Miocene phosphatic beds in northern peninsular Florida*—Continued

MAP LOCALITY 2—Continued

	Thickness (feet)
Lower and middle Miocene—Continued	
Hawthorn formation—Continued	
Clayey sand phosphatic, cream; fine, white to brown phosphate grains. Sample 299	1
Clayey dolomite, phosphatic, cream; contains abundant very fine quartz and scattered fine brown phosphate grains. Sample 298	2. 5
Dolomite, phosphatic, sandy, cream, soft; much fine quartz and dark-brown phosphate; also contains considerable attapulgite and little montmorillonite;[1] abundant mollusks (sample 298) of early or middle Miocene age [3]	2
Sandy clay, light-green	2
Dolomite, cream, with irregular clay-filled pockets	5
Clay, light-green, platy parting	5
Sandy clay, light-green, with shaly parting; contains scattered tiny phosphate pellets. Abundant dolomite forms irregular masses and lenses up to several feet thick and networks of veinlets in clay. Clay is predominantly attapulgite with minor montmorillonite [1]	15
Water level, Alapaha River, about 60 ft above sea level.	
Total	63

MAP LOCALITY 3

East bank of Suwannee River, 100 yd north of bridge, Florida State Route 6, NW¼ sec. 10, T. 1 N., R. 16 E., Columbia County

	Thickness (feet)
Pleistocene(?) to Recent:	
Sand, loose tan	15
Lower and middle Miocene:	
Hawthorn formation:	
Clayey sand, phosphatic, mottled yellow and gray; contains abundant fine dark phosphate grains and considerable dolomite fragments. Fine fraction (<0.105 mm) consists of quartz, dolomite, and attapulgite.[4] Sample 304 [2]	4
Water level, Suwannee River.	
Total	19

See footnotes at end of table.

TABLE 12.—*Stratigraphic sections of Miocene phosphatic beds in northern peninsular Florida*—Continued

MAP LOCALITY 4

West bank of Suwannee River, SE¼SE¼ sec. 36, T. 1 N., R. 16 E., Hamilton County

	Thickness (feet)
Lower and middle Miocene:	
Hawthorn formation:	
Clayey sand, phosphatic, buff, fine-grained, with thin layers of light-green clay; abundant black phosphate grains as large as 2 mm in diameter. Sample 308 [2]	12
Clayey sand, phosphatic, cream; contains abundant fine quartz and phosphate grains. Sample 307	2.5
Clayey sand, phosphatic, cream; contains much fine sand and abundant phosphate grains (0.1–10 mm in diameter). Sample 306	1
Dolomite, phosphatic, sandy, white to tan; contains considerable dark phosphate grains and scattered poorly preserved pelecypods and sharks' teeth. Sample 305	2.5
Water level, Suwannee River.	
Total	18

MAP LOCALITY 5

Pit beside road just north of Falling Creek bridge, NW¼SE¼ sec. 15, T. 2 S., R. 16 E., Columbia County

	Thickness (feet)
Pleistocene(?) to Recent:	
Sand, loose tan	2+
Lower and middle Miocene:	
Hawthorn formation:	
Sandy clay, phosphatic, gray; contains abundant fine dark phosphate grains. Fine fraction (<0.105 mm) consists of wavellite, kaolinite, apatite, crandallite, and quartz.[4] Sample 310 [2]	2
Sandy clay, phosphatic, gray to brown; contains abundant white to brown phosphate pellets. Sample 309	2.5
Sandy clay, light-green, sticky	4.5
Base of pit.	
Total	11+

MAP LOCALITY 6

East bank of the South Fork of Black Creek, SW¼NE¼ sec. 13, T. 5 S., R. 24 E., Clay County

	Thickness (feet)
Lower and middle Miocene(?):	
Hawthorn(?) formation:	
Clayey sand, phosphatic, tan; contains poorly sorted fine to coarse (2 mm in diameter) quartz grains and scattered brown phosphate pellets (0.2–1 mm in diameter). Sample 293 [2]	2
Covered	2
Dolomite, phosphatic, sandy, cream; contains abundant fine quartz and scattered dark-brown phosphate pellets (mostly <0.5 mm in diameter). Sample 292	5

See footnote at end of table.

TABLE 12.—*Stratigraphic sections of Miocene phosphatic beds in northern peninsular Florida*—Continued

MAP LOCALITY 6—Continued

	Thickness (feet)
Lower and middle Miocene(?)—Continued	
Hawthorn(?) formation—Continued	
Covered	5.5
Clayey sand, phosphatic, yellow; contains abundant brown phosphate pellets (1–10 mm in diameter). Sample 291	1.5
Water level of South Fork of Black Creek (<10 ft above sea level).	
Total	16

MAP LOCALITY 7

Brooks Sink, SW¼ sec. 12, or NW¼ sec. 13, T. 7 S., R. 20 E., Bradford County

	Thickness (ft	*in)*	*Probable equivalent units of Pirkle (1956, p. 207–210)*
Pleistocene(?) to Recent:			
Sands and clayey sands	15±		
Middle or upper Miocene:			
Dolomitic coquina, cream to tan, sandy; abundant mollusks (samples 321, 322) of middle or late Miocene age [3]	25	0	19, 18
Dolomitic coquina, cream; contains considerable clay and fine quartz and little black phosphate pellets; abundant mollusks (sample 320) of middle or late Miocene age [3]	1	0	17
Lower and middle Miocene:			
Hawthorn formation:			
Dolomite, phosphatic, sandy, cream; contains abundant dark brown phosphate pellets (0.5–5 mm in diameter) and much quartz (0.1–0.2 mm). Sample 319 [2]	1	11	16, 15
Dolomite, phosphatic, cream, soft; contains abundant quartz (0.1–0.2 mm in diameter), scattered brown to black phosphate pellets (1–15 mm in diameter), irregular pockets of brown clay, and some large pelecypods. Sample 318	1	8	14, 13
Sandy clay, phosphatic, and dolomite, tan to gray; contains abundant brown to gray phosphate pellets and some sharks' teeth. Clay is attapulgite.[4] Sample 317	2	0	12
Sandy clay, phosphatic, and dolomite, tan to brown; contains abundant gray to brown phosphate pellets. Sample 316	4	6	11
Dolomite, phosphatic, sandy, tan hard; contains scattered phosphate pellets and abundant large pelecypods	1	0	10
Clayey sand, phosphatic, and dolomite, medium-gray; contains abundant brown to black phosphate pellets and scattered fossils. Sample 315	4	6	9

See footnotes at end of table.

TABLE 12.—*Stratigraphic sections of Miocene phosphatic beds in northern peninsular Florida*—Continued

MAP LOCALITY 7—Continued

Lower and middle Miocene—Continued Hawthorn formation—Continued	Thickness (ft	in)	Probable equivalent units of Pirkle (1956, p. 207–210)
Dolomite, phosphatic, sandy, gray, buff-weathering, hard; contains scattered fine black phosphate pellets		10	8
Dolomite, phosphatic, sandy, gray, buff-weathering, soft; contains abundant fine quartz and phosphate grains. Sample 314	3	8	7
Clayey dolomite, phosphatic, sandy, light-gray, buff-weathering, dense, hard; contains abundant quartz and phosphate grains (mostly <0.5 mm in diameter), irregular dolomite fragments (pebbles?), wormborings(?), and scattered fossils; considerable attapulgite clay.[2] Sample 313	7	0	6
Dolomitic clay, phosphatic, sandy, green-gray, brown-weathering, tough; contains abundant tan to gray phosphate grains and some sharks' teeth. Sample 312 (of lower 1 ft 9 in)	2	6	5
Dolomite, light-gray, buff-weathering, hard; irregular connecting tubular cavities; makes conspicuous ledge around sink	1	6	4, 3, 2(?)
Phosphatic clay, tan, tough; irregular connecting pockets with abundant phosphate pellets	1	11	
Clayey dolomite, phosphatic, sandy, blue-gray; irregular concentrations of flat brown phosphate pellets. Sample 311	2	2	
Dolomitic(?) clay, blue, tan-weathering, tough, massive	2	2	
Sandy clay, blue, tan-weathering, tough; contains scattered dark phosphate pellets		8	1(?)
Clay breccia or conglomerate, composed of angular fragments of light green-gray clay (as large as 1 in. in diameter) in matrix of bluish-gray sandy clay	2	7	
Water level, February 14, 1956.			
Total exposed thickness of Hawthorn formation	40	7	

See footnotes at end of table.

TABLE 12.—*Stratigraphic sections of Miocene phosphatic beds in northern peninsular Florida*—Continued

MAP LOCALITY 9

Diversion ditch just north of Gainesville airport, NW¼NW¼ sec. 24, T. 9 S., R. 20 E., Alachua County

	Thickness (feet)
Miocene(?) or Pliocene(?):	
Clayey sand, grayish-tan, iron-stained	2
Slightly clayey sand, brown to gray, medium- to coarse-grained; contains few large quartz pebbles (>5 mm in diameter); locally iron stained [3]	11. 6
Slightly clayey sand, brown, with stringers (a few inches thick) of green plastic clay	3
Covered	2
Lower and middle Miocene:	
Hawthorn formation:	
Clayey sand, phosphatic. Fine fraction (<0.105 mm) of sample 323 contains apatite, a montmorillonite mineral, quartz, probable wavellite, plus small amount unidentified; sample 324 contains kaolinite, apatite, quartz plus slight trace unidentified.[4] Samples 26, 323, and 324.[2]	6
Water level.	
Total	24. 6

MAP LOCALITY 16

Along road about 0.5 mile south of Fairfield, NE¼ sec. 13, T. 13 S., R. 20 E., Marion County. Surface altitude about 160 ft

	Thickness (feet)
Pleistocene(?) to Recent:	
Clayey sand, coarse with pebbles of ferruginous sandstone	6
Lower and middle Miocene:	
Hawthorn formation:	
Clay, plastic, green	6–8
Clay, green, hard and flintlike, breccia structure; contains abundant phosphate pellets	10
Possible range of thickness	22–24

Along road about 1 mile south of Fairfield, SE¼ sec. 13, T. 13 S., R. 20 E., Marion County. Surface altitude about 180 ft

	Thickness (feet)
Pleistocene(?) to Recent:	
Gravel of phosphatic sandstone pebbles and phosphate pellets	1–2
Lower and middle Miocene:	
Hawthorn formation:	
Clayey sand to sandy clay, light-green; contains abundant phosphate pellets in lower part; siliceous boxwork throughout; limonite staining at top	10
Clay and sandy clay, interbedded, with scattered tiny white phosphate pellets	7–8
Possible range of thickness	18–20

See footnotes at end of table.

TABLE 12.—*Stratigraphic sections of Miocene phosphatic beds in northern peninsular Florida*—Continued

MAP LOCALITY 17

Exposure on U.S. Highway 441, 1.5 mile north of Lowell, NW¼ sec. 22, T. 12 S., R. 21 E., Marion County

	Thickness (feet)
Pleistocene(?) to Recent:	
Loamy sand, with abundant pebbles of phosphatic sandstone	3–4
Lower and middle Miocene:	
Hawthorn formation:	
Limy bed, with phosphate and clay pellets; contains abundant fossils. Sample 221 of early or middle Miocene age [3]	1–2
Clay, hard, flintlike; contains phosphate pellets	10
Limestone, cream, dense, very fossiliferous. Sample 220 of early or middle Miocene age [3]	2
Possible range of thickness	16–18

MAP LOCALITY 19

Abandoned fuller's earth pit of Superior Earth Co., NW¼NE¼, sec. 34, T. 13 S., R. 20 E., Marion County

	Thickness (feet)
Pleistocene(?) to Recent:	
Sandy clay, dark-brown, with abundant pebbles of limonitic sandstone (1 quartz pebble, 2 in. in diameter); worn fragments of silicified shells of *Ostrea normalis* [3]	2–4
Lower and middle Miocene:	
Hawthorn formation:	
Clayey sandstone, phosphatic, white to gray; quartz grains (0.1–1 mm in diameter) in cement of clay and very fine phosphate mineral; numerous thin siliceous(?) stringers form boxwork. Worn fragments of silicified shells of *Ostrea normalis* [3] occur near base of sandstone near west end of pit. See partial chemical analysis of sample 23 of lower 3 ft at east end of pit [2]	4–6
Clay, light gray-green; weathers chalky; stiff shaly parting. A layer about 10 in. thick of abundant silicified shells of *Ostrea normalis* [3] occurs about 5 ft below the top of the clay beds near the west end of the pit; manatee ribs also occur in clay near center of pit	18
Covered	3
Clay, gray-green, hard; conchoidal fracture; brecciated structure; seems to be silicified to chert locally and is cut by thin chalcedony stringers; white phosphate pellets in upper part	11
Possible range of thickness	38–42

[1] X-ray determination of mineralogy by P. D. Blackmon, G. W. Chloe, J. C. Hathaway, and H. C. Starkey.

[2] Partial chemical analyses given in table 16.

[3] Fossil identifications and age designation by Druid Wilson, table 10.

[4] X-ray determination by Betsy Levin.

TABLE 13.—*Stratigraphic sections in hard-rock phosphate district, Florida*

MAP LOCALITY 10

Old phosphate mine in SW¼ sec. 6., T. 10 S., R. 17 E., Alachua County. Surface altitude between 75 and 100 ft

	Feet
Pleistocene(?) to Recent:	
Sand, yellow-tan, fine clayey	5
Clay, medium-gray, waxy; contains some very fine quartz; mostly kaolinite, some montmorillonite, crandallite(?) (sample 256, table 22)	4
Sand, tan, tough; contains few clay beds several inches thick	5
Sand, white to tan, with scattered phosphate pellets and phosphatic sandstone pebbles	6
Smooth rounded pebbles of light-gray chert (as much as 3 in. in diameter) in sand	0–1
Upper Miocene(?):	
Phosphatic sand, white, with few apatite grains near base	13
Thickness	33–34

MAP LOCALITY 18

Old phosphate mine on Ross property in SW¼SE¼ sec. 22, T. 13 S., R. 19 E., Marion County (pl. 7). Surface altitude about 75 ft

	Feet
Upper Miocene(?):	
Phosphatic sand with tiny phosphate grains	16
Phosphatic sand with abundant phosphate pellets as large as 1 in	2
Sand with very few phosphate pellets	1. 5
Sandy clay, green to tan; contains scattered orange phosphate pellets	2. 5
Supergene: [1]	
Rubble of hard and soft secondary phosphate	5–15(?)
Upper Eocene:	
Ocala limestone:	
Limestone and silicified limestone.	

MAP LOCALITY 23

Old phosphate mine northeast of Anthony in SE¼ sec. 3, T. 14 S., R. 22 E., Marion County. Surface altitude about 75 ft

	Feet
Pleistocene(?) to Recent:	
Sand, loose brown	2
Miocene(?) or Pliocene(?):	
Clayey sand, mottled orange and brown, medium- to coarse-grained	2–4
Upper Miocene(?):	
Clayey sand, phosphatic, white to gray	4–10(?)
Supergene: [1]	
Phosphate ore consisting of a rubble of phosphate pellets, vesicular phosphatic sandstone, and angular fragments of hard secondary apatite in matrix of sand, clay, and claylike apatite	0–15(?)
Upper Eocene:	
Ocala limestone:	
Extremely irregular surface of pinnacles and large cylindrical cavities formed by solution at contact with phosphate deposit.	

[1] Not a stratigraphic unit.

TABLE 13.—*Stratigraphic sections in hard-rock phosphate district, Florida*—Con.

MAP LOCALITY 26

Section 12 phosphate mine, N½ sec. 12, T. 17 S., R. 18 E., Citrus County. Surface altitude 80 to 110 ft

	Feet
Pleistocene(?) to Recent:	
Sand, loose tan, with charcoal fragments	4–12
Bedded sand, white to tan, alternating thin layers of sand and clayey sand	0–10
Miocene(?) or Pliocene(?):	
Sand and clayey sand, tan	0–6
Miocene:	
Phosphatic sand, tough, white to light-gray	10–30+
Clay, olive-green to brown, with considerable phosphate pellets locally; silicic boxwork	0–5
Possible range of thickness above secondary phosphate	14–63
Supergene:[1]	
Secondary phosphate; rubble of hard and soft phosphate, sand, clay, and chert. Thickness after Vernon (1951, p. 204)	11–27
Miocene:	
Organic material, black to brown (after Vernon, 1951, p. 204)	0–0.6
Clay, red, waxy, dense (after Vernon, 1951, p. 204)	0.5–1.6
Upper Eocene:	
Avon Park limestone:	
Limestone, gray to tan, hard, dense (Vernon, 1951, p. 204).	

MAP LOCALITY 27

New sump pit in NW¼NE¼ sec. 5, T. 18 S., R. 19 E., Citrus County. Surface altitude about 90 ft

	Ft	*in*
Pleistocene(?) to Recent:		
Sand, loose brown	10–15	-----
Miocene:		
Phosphatic sand, white to tan	18	-----
Clayey sand, light-brown	1	9
Clay, green-tan, montmorillonite (sample 163, table 22), sandy; stringers of secondary silica	1	8
Phosphorite, greenish-tan, sandy-clayey; contains much white phosphate pellets	1	4
Supergene:[1]		
Secondary phosphate, white to gray; rubble of hard apatite fragments in soft phosphate	>3	6

MAP LOCALITY 29

Old clay mine in SE¼NW¼ sec. 25, T. 20 S., R. 19 E., Citrus County. Surface altitude about 150 ft

Pliocene or Pleistocene(?):	
Sand, gray, with pebbles of limonitic sandstone	2–3
Clay sand, limonitic	3–4
Miocene:	
Phosphatic sand, light-gray	3–4
Clay, light green-gray	20–25
Possible range of thickness	28–36

[1] Not a stratigraphic unit.

TABLE 14.—*Partial chemical analyses, in percent, of samples from core-drill holes 32, 35 to 37, 39 to 46*

[Uranium analyses are chemical unless followed by "e," which indicates radiometric determination of equivalent uranium. <0.001 is considered to be 0 percent eU in calculating total eU content of samples. Analysts: S. M. Berthold, J. W. Budinsky, B. L. Ingram, B. A. McCall, Roosevelt Moore, W. P. Tucker, Jr.]

Drill hole	Sample	Depth (feet)	Size fraction [1] (mesh)	Percentage of total sample	P_2O_5	U	Insoluble	SiO_2	Al_2O_3
32	X31920	28– 32	------	100. 0	10. 8	0. 015	------	------	------
	X321	33– 36	[2]+14	7. 5	31. 60	. 040	------	8. 98	1. 98
			−14+35	4. 4	27. 4	. 028	22. 07	------	------
			[2]−35+150(c)	5. 1	30. 53	. 024	------	10. 36	2. 11
			−35+150(t)	37. 5	4. 4	. 005	------	------	------
			−150	45. 5	12. 0	. 021	48. 38	------	17. 3
				100. 0	12. 2	0. 017			
	X322	36– 38. 2	+14	1. 1	23. 2	0. 008	33. 42	------	------
			−14+35	5. 9	13. 3	. 007	61. 70	------	------
			−35+150(c)	0	------	------	------	------	------
			−35+150(t)	25. 5	1. 7	. 003e	------	------	------
			−150	67. 5	11. 8	. 017	47. 69	------	14. 9
				100. 0	9. 4	0. 013			
	X323, X324	38. 2– 39. 5	+14	31. 5	28. 7	0. 025	15. 92	------	------
			−14+35	18. 5	19. 9	. 017	27. 95	------	------
			−35+150(c)	3. 2	25. 3	. 021	24. 51	------	------
			−35+150(t)	21. 5	1. 3	. 003e	------	------	------
			−150	25. 3	26. 4	. 067	12. 65	------	7. 3
				100. 0	20. 5	0. 029			

See footnotes at end of table.

TABLE 14.—*Partial chemical analyses, in percent, of samples from core-drill holes 32, 35 to 37, 39 to 46*—Continued

Drill hole	Sample	Depth (feet)	Size fraction [1] (mesh)	Percentage of total sample	P_2O_5	U	Insoluble	SiO_2	Al_2O_3
35	X349B	47- 48.3	+14	2.8	25.5	0.018	42.50	----	----
			−14+35	11.3	2.6	.003	90.89	----	----
			−35+150(c)	0	----	----	----	----	----
			−35+150(t)	34.7	2.0	.002	----	----	----
			−150	51.2	2.0	.029	72.95	----	14.8
				100.0	2.7	0.016			
	X349CD	48.3- 51	+14	5.0	24.5	0.015	20.18	----	----
			−14+35	27.1	4.6	.003	83.72	----	----
			−35+150(c)	2.8	29.8	.009	8.57	----	----
			−35+150(t)	42.6	0.8	<.001e	----	----	----
			−150	22.5	2.6	.003	63.45	----	10.6
				100.0	4.2	0.002			
	X350	51- 55	[2]+14	5.0	24.0	0.013	----	17.42	1.65
			−14+35	37.1	4.1	.003	85.14	----	----
			[2]−35+150(c)	2.4	28.46	.008	----	7.18	1.18
			−35+150(t)	23.0	1.2	.002e	----	----	----
			−150	32.5	3.1	.003	45.02	----	8.2
				100.0	4.7	.003			
	X351	55- 59.5	+14	6.7	21.4	0.007	12.50	----	----
			−14+35	17.3	5.7	.002	81.85	----	----
			−35+150(c)	2.2	28.6	.007	8.79	----	----
			−35+150(t)	18.3	1.8	.002e	----	----	----
			−150	55.5	1.2	.007	40.58	----	7.4
				100.0	4.0	0.005			

36	X369	49.5–53	+14	3.3	27.0	0.010	8.26	--------	--------
			−14+35	19.3	7.6	.003	74.97	--------	--------
			−35+150(c)	2.4	31.2	.008	5.63	--------	--------
			−35+150(t)	35.8	1.7	<.001e	--------	--------	--------
			−150	39.2	2.6	.008	35.09	--------	4.1
				100.0	4.7	0.004			
	X380	135–137	+14	23.8	9.6	0.004	37.69	--------	--------
			−14+35	15.7	11.7	.004	55.60	--------	--------
			−35+150(c)	0	--------	--------	--------	--------	--------
			−35+150(t)	16.3	3.1	.002e	--------	--------	--------
			−150	44.2	1.6	.001	66.58	--------	14.0
				100.0	5.3	0.002			
37	X394	61.5–65.5	+14	45.8	28.8	0.016	23.51	--------	--------
			−14+35	10.3	11.4	.007	66.12	--------	--------
			−35+150(c)	1.8	32.2	.014	15.20	--------	--------
			−35+150(t)	20.4	1.1	.001	--------	--------	--------
			−150	21.7	7.0	.006	57.50	--------	14.0
				100.0	16.7	0.010			
	X395	66.5–67.5	+14	3.0	18.8	0.008	36.88	--------	2.5
			−14+35	23.5	5.2	.002	82.99	--------	.9
			−35+150(c)	3.3	29.0	.006	12.50	--------	--------
			−35+150(t)	47.3	1.9	<.001e	--------	--------	--------
			−150	22.9	7.4	.002	51.10	--------	11.4
				100.0	5.3	<0.001			

See footnotes at end of table.

TABLE 14.—*Partial chemical analyses, in percent, of samples from core-drill holes 32, 35 to 37, 39 to 46*—Continued

Drill hole	Sample	Depth (feet)	Size fraction [1] (mesh)	Percentage of total sample	P_2O_5	U	Insoluble	SiO_2	Al_2O_3
37	X397	75- 78	+14	2. 5	3. 8	<0. 001	45. 13	--------	--------
			−14+35	21. 7	6. 7	. 001	81. 20	--------	--------
			−35+150(c)	1. 3	30. 7	. 004	5. 93	--------	--------
			−35+150(t)	59. 7	2. 5	. 001e	--------	--------	--------
			−150	14. 8	1. 8	. 001	57. 33	--------	12. 8
				100. 0	3. 7	0. 001			
	X398AB	80- 85	+14	2. 1	25. 8	0. 003	25. 72	--------	--------
			−14+35	14. 7	4. 1	. 001	80. 68	--------	--------
			−35+150(c)	2. 6	34. 2	. 006	3. 87	--------	--------
			−35+150(t)	38. 5	4. 3	. 001e	--------	--------	--------
			−150	42. 1	3. 9	. 002	60. 65	--------	11. 2
				100. 0	5. 3	0. 002			
	X398C	85- 89	+14	3. 1	17. 0	0. 004	41. 27	--------	--------
			−14+35	27. 5	3. 8	. 002	87. 86	--------	--------
			−35+150(c)	0	--------	--------	--------	--------	--------
			−35+150(t)	33. 3	5. 1	. 001e	--------	--------	--------
			−150	36. 1	2. 7	. 001	61. 52	--------	10. 6
				100. 0	4. 2	0. 001			
39	X418, X419, X420	74. 8- 80. 8	+14	9. 4	23. 3	0. 014	22. 73	--------	--------
			−14+35	9. 3	10. 0	. 004	57. 83	--------	--------
			−35+150(c)	0	--------	--------	--------	--------	--------
			−35+150(t)	43. 2	2. 4	. 002e	--------	--------	--------
			−150	38. 1	3. 5	. 004	41. 05	--------	7. 9
				100. 0	5. 5	0. 004			

	X426	112–113	+14	10. 2	18. 3	0. 006	22. 73		
			−14+35	34. 7	4. 1	. 001	85. 91		
			−35+150(c)	0					
			−35+150(t)	39. 8	2. 8	. 002e			
			−150	15. 3	4. 7	. 008	42. 20		7. 1
				100. 0	5. 1	0. 003			
40	X442E	27. 8– 37		100. 0	3. 0	0. 009e			
	X443A	37– 40	+14	4. 8	13. 8	. 006	74. 00		10. 7
			−14+35	14. 0	4. 3	. 004	87. 48		. 4
			−35+150(c)	0					
			−35+150(t)	53. 2	1. 4	. 002e			
			−150	28. 0	14. 8	. 041	45. 30		14. 8
				100. 0	6. 2	0. 013			
	X443BC	40– 46	+14	7. 0	26. 1	0. 008	27. 60		2. 7
			−14+35	22. 5	16. 5	. 004	53. 23		
			−35+150(c)	7. 6	30. 8	. 008	11. 96		
			−35+150(t)	33. 1	1. 4	. 002e			
			−150	29. 8	5. 4	. 003	62. 91		14. 9
				100. 0	10. 0	0. 004			
	X443DE	46– 51	+14	2. 6	22. 5	0. 012	42. 71		
			−14+35	5. 9	19. 6	. 004	45. 37		
			−35+150(c)	6. 5	28. 0	. 009	20. 97		
			−35+150(t)	51. 7	1. 8	. 003e			
			−150	33. 3	2. 6	. 003	71. 01		16. 6
				100. 0	5. 4	0. 004			

See footnotes at end of table.

TABLE 14.—*Partial chemical analyses, in percent, of samples from core-drill holes 32, 35 to 37, 39 to 46*—Continued

Drill hole	Sample	Depth (feet)	Size fraction [1] (mesh)	Percentage of total sample	P_2O_5	U	Insoluble	SiO_2	Al_2O_3
41	X460	13– 14	------	100. 0	1. 5	0. 001e	------	------	------
	X461AB	17– 20. 5	------	100. 0	6. 1	. 016	------	------	------
	X461C	20. 5– 22	+14	8. 1	22. 7	. 025	39. 90	------	8. 1
			−14+35	30. 0	12. 2	. 012	66. 31	------	3. 6
			−35+150(c)	1. 4	29. 8	. 024	11. 47	------	6. 6
			−35+150(t)	25. 5	2. 3	. 002	------	------	------
			−150	35. 0	22. 2	. 059	31. 55	------	11. 3
				100. 0	14. 3	0. 027			
	X461D	22– 24	+14	19. 8	26. 5	0. 012	23. 21	------	4. 1
			−14+35	15. 5	13. 3	. 006	61. 03	------	4. 0
			−35+150(c)	4. 1	29. 4	. 012	12. 80	------	3. 9
			−35+150(t)	32. 1	1. 4	<. 001e	------	------	------
			−150	28. 5	24. 3	. 019	23. 78	------	9. 5
				100. 0	15. 9	0. 009			
	X467	72– 72. 4	------	100	5. 5	0. 006e	------	------	------
	X468AB	72. 4– 77. 5	+14	0. 4	10. 1	. 008	------	------	------
			−14+35	27. 0	2. 9	. 003	89. 61	------	------
			−35+150(c)	4. 4	28. 7	. 029	8. 22	------	------
			−35+150(t)	35. 0	0. 9	. 002e	------	------	------
			−150	33. 2	4. 8	. 009	60. 56	------	9. 2
				100. 0	4. 0	0. 006			

42	X490	98–100. 5	+14	3. 2	11. 2	0. 004	50. 56	---	---
			−14+35	30. 9	5. 2	. 002	81. 26	---	---
			[2]−35+150(c)	1. 8	28. 54	. 006	---	6. 54	1. 22
			−35+150(t)	18. 9	2. 4	. 002e	---	---	---
			−150	45. 2	0. 8	. 002	33. 51	---	6. 8
				100. 0	3. 3	0. 002			
	X492	100. 5–104	+14	1. 1	6. 8	0. 001	64. 42	---	---
			−14+35	35. 4	3. 1	. 003	85. 93	---	---
			−35+150(c)	1. 2	29. 0	. 004	10. 10	---	---
			−35+150(t)	34. 7	2. 1	. 002e	---	---	---
			−150	27. 6	1. 1	. 002	38. 68	---	7. 3
				100. 0	2. 6	0. 002			
	X495, X497	104–109	+14	1. 6	5. 9	0. 009	35. 78	---	---
			−14+35	9. 9	4. 1	. 003	82. 67	---	---
			−35+150(c)	0	---	---	---	---	---
			−35+150(t)	46. 4	2. 0	. 001e	---	---	---
			−150	42. 1	1. 0	. 005	55. 24	---	9. 6
				100. 0	1. 8	0. 003			
	X54344	203–208		100. 0	1. 0	0. 002e	---	---	---
	X54546	208–212		100. 0	4. 0	. 008e	---	---	---
43	X595	143–153	+14	4. 1	23. 0	0. 020	16. 22	---	---
			−14+35	19. 0	3. 8	. 003	83. 85	---	---
			−35+150(c)	0	---	---	---	---	---
			−35+150(t)	38. 9	3. 0	. 004e	---	---	---
			−150	38. 0	4. 6	. 008	60. 98	---	9. 5
				100. 0	4. 6	0. 006			

See footnotes at end of table.

TABLE 14.—*Partial chemical analyses, in percent, of samples from core-drill holes 32, 35 to 37, 39 to 46*—Continued

Drill hole	Sample	Depth (feet)	Size fraction [1] (mesh)	Percentage of total sample	P_2O_5	U	Insoluble	SiO_2	Al_2O_3
43	X596	153–158	+14	7.7	4.0	0.004	33.67		
			−14+35	12.0	4.8	.005	78.48		
			−35+150(c)	0					
			−35+150(t)	46.6	3.3	.003e			
			−150	33.7	3.0	.002	62.43		10.3
				100.0	3.4	0.003			
44	X614	72–75		100.0	9.8	0.004e			
	X620	91–97	+14	5.0	15.8	<0.001	20.71		
			−14+35	18.5	10.0	.001	62.09		
			−35+150(c)	0					
			−35+150(t)	38.7	3.0	.002e			
			−150	37.8	10.8	.004	50.89		10.3
				100.0	7.9	0.002			
	X623	100–105	+14	8.8	23.9	0.005	18.93		
			−14+35	24.1	13.7	.003	52.90		
			−35+150(c)	0					
			−35+150(t)	29.0	3.0	.001e			
			−150	38.1	0.8	.001	53.36		10.6
				100.0	6.5	0.002			
	X642	169–174		100.0	3.4	0.001e			

	X648	217–220	+14	0. 7	14. 4	0. 003	--------	--------	--------
			−14+35	17. 1	9. 6	. 010	85. 67	--------	--------
			−35+150(c)	3. 9	30. 3	. 004	8. 56	--------	--------
			−35+150(t)	51. 7	0. 9	. 001	--------	--------	--------
			−150	26. 6	1. 3	. 002	35. 20	--------	6. 3
				100. 0	3. 7	0. 003			
45	X705	22–23. 5		100. 0	5. 4	0. 002e	--------	--------	--------
	X706	23. 5–28	+14	8. 9	28. 2	0. 015	18. 83	--------	--------
			−14+35	7. 3	22. 7	. 008	35. 42	--------	--------
			−35+150(c)	6. 9	31. 0	. 012	9. 57	--------	--------
			−35+150(t)	49. 9	1. 0	. 002e	--------	--------	--------
			−150	27. 0	1. 8	. 008	52. 63	--------	14. 0
				100. 0	7. 3	0. 006			
	X707	28–30. 5	+14	2. 5	27. 9	0. 014	17. 35	--------	--------
			−14+35	8. 8	17. 6	. 008	49. 18	--------	--------
			−35+150(c)	10. 6	30. 3	. 010	8. 76	--------	--------
			−35+150(t)	54. 9	0. 9	. 001e	--------	--------	--------
			−150	23. 1	2. 6	. 003	65. 42	--------	16. 7
				100. 0	6. 6	0. 003			
	X708	30. 5–34	[2]+14	25. 3	26. 23	0. 013	--------	20. 14	1. 40
			−14+35	11. 4	22. 6	. 006	26. 32	--------	--------
			[2]−35+150(c)	8. 2	30. 62	. 011	--------	8. 24	1. 43
			−35+150(t)	31. 0	1. 7	. 002e	--------	--------	--------
			−150	24. 1	9. 8	. 010	47. 09	--------	12. 3
				100. 0	14. 6	0. 008			

See footnotes at end of table.

TABLE 14.—*Partial chemical analyses, in percent, of samples from core-drill holes 32, 35 to 37, 39 to 46*—Continued

Drill hole	Sample	Depth (feet)	Size fraction [1] (mesh)	Percentage of total sample	P_2O_5	U	Insoluble	SiO_2	Al_2O_3
45	X716	55–58	+14	3. 5	22. 8	0. 005	19. 35		
			−14+35	10. 4	14. 5	. 003	48. 64		
			−35+150(c)	0					
			−35+150(t)	47. 4	3. 4	. 002e			
			−150	38. 7	5. 2	. 002	38. 93		7. 4
				100. 0	5. 9	0. 002			
	X717	58–61	[2]+14	6. 1	21. 05	0. 008		25. 60	1. 27
			−14+35	16. 3	13. 7	. 003	51. 07		
			−35+150(c)	0					
			−35+150(t)	48. 9	3. 8	. 002			
			−150	28. 7	7. 5	. 002	32. 35		6. 8
				100. 0	7. 5	0. 003			

46	X74445	8.5–13.2	----------	100.0	5.3	0.009e	----------	----------	----------
	X749	29.5–32.8	+14	6.3	24.7	.004	31.76	----------	----------
			−14+35	24.3	7.9	.001	77.13	----------	----------
			−35+150(c)	0	----------	----------	----------	----------	----------
			−35+150(t)	18.0	4.6	.002e	----------	----------	----------
			−150	51.4	11.3	.005	48.99	----------	12.2
				100.0	10.1	0.003			

[1] Mesh size, in millimeters:

+14 .... >1.19
−14+35 .... 1.19–0.42
−35+150(c) .... 0.42–.105, flotation concentrates.
−35+150(t) .... 0.42–.105, flotation tailings.
−150 .... <0.105.

[2] For other constituents, see table 15.

634777—63——7

TABLE 15.—*Chemical analyses, in percent, of*

[Analysts: B. L. Ingram

Drill hole	Sample	Depth (feet)	Size fraction [1]	P_2O_5	U	CaO	F
32	X321	33–36	+14(mesh)	31.60	0.040	45.04	3.70
32	X321	33–36	−35+150(c)	30.53	.024	43.00	3.50
35	X350	51–55	+14	24.00	.013	40.10	2.74
35	X350	51–55	−35+150(c)	28.46	.008	45.06	2.96
42	X490	98–100.5	−35+150(c)	28.54	.006	45.38	3.04
45	X708	30.5–34	+14	26.23	.013	40.14	3.26
45	X708	30.5–34	−35+150(c)	30.62	.011	46.18	3.64
45	X717	58–61	+14	21.05	.008	34.98	2.66

[1] +14-mesh fraction, >1.19 mm; −35+150-mesh fraction (c); 0.42 to 0.105 mm, flotation concentrates.

selected samples, of apatite pellets from core-drill holes

and Roosevelt Moore]

Combustion CO_2	Acid evolution	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	H_2O
3. 78	3. 50	8. 98	1. 93	0. 73	0. 19	0. 58	0. 17	3. 94
5. 96	3. 21	10. 36	2. 11	1. 23	. 29	. 67	. 09	4. 53
6. 81	5. 53	17. 42	1. 65	1. 21	. 84	. 92	. 52	3. 84
7. 24	4. 81	7. 18	1. 18	2. 41	. 65	. 92	. 32	4. 30
7. 14	5. 39	6. 54	1. 22	1. 92	1. 05	. 92	. 27	4. 61
3. 48	3. 47	20. 14	1. 40	2. 00	. 43	. 74	. 39	3. 18
4. 54	3. 59	8. 24	1. 43	1. 59	. 53	. 66	. 34	3. 36
6. 59	5. 62	25. 60	1. 27	1. 56	1. 44	. 86	. 51	3. 51

TABLE 16.—*Partial chemical analyses, in percent, of samples of phosphatic beds of the Hawthorn formation from exposures in northern peninsular Florida*

[<0.001 is considered to be 0 percent eU in calculating total eU content of samples. Analysts: S. M. Berthold, J. W. Budinsky, G. J. Daniels, Glen Edgington, B. A. McCall, Roosevelt Moore, T. D. Murphy, Jr., R. E. Smith, Ann Sweeney, W. P. Tucker, Jr., J. L. Waring]

A. SAMPLES FROM HAMILTON COUNTY

Sample	Location of sample	Distance above river level (feet)	Thickness (feet)	Size fraction [1] (mesh)	Percentage of total sample	P_2O_5	U	eU	Insoluble	Al_2O_3
303	Map locality 2: West bank of Alapaha River, NE¼NE¼ sec. 20, T. 2 N., R. 13 E.	42–48	6		100.0	3.7		0.004		
302	do	39–42	3		100.0	3.9		.001		
301	do	32.5–39	6.5		100.0	3.5		<.001		
299	do	31.5–32.5	1		100.0	15.1		.005		
298	do	29–31.5	2.5		100.0	7.8		<.001		
298–303 combined	do	29–48	19		100.0	4.8		.002		
308	Map locality 4: West bank of Suwannee River, 100 yd below Benton Bridge, SW¼SW¼ sec. 31, T. 1 N., R. 17 E.	6–18	12		100.0	4.8		.001		
307	do	3.5–6	2.5		100.0	2.7		<.001		
306	do	2.5–3.5	1		100.0	5.8		.002		
305	do	0–2.5	2.5	+14	45.6	5.3	0.005	.003	22.4	
				−14+35	11.1	9.8	.003	.002		
				−35+150(c)	0					
				−35+150(t)	14.4	5.3	.001	<.001		
				−150	28.9	.6	.002	<.001	18.4	6.8
					100.0	4.4	0.003	0.002		
305–308 combined	do	0–18			100.0	4.5		0.001		

B. SAMPLES FROM COLUMBIA COUNTY

Sample No.	Location of sample	Thickness (feet)	Size fraction [1] (mesh)	Percentage of total sample	P_2O_5	U	eU	Insoluble	Al_2O_3
304	Map locality 3: East bank of Suwannee River, 100 yd north of bridge, Florida State Route 6, NW¼ sec. 10, T. 1 N., R. 16 E.	4	+14	8.2	19.3	0.007	0.006	----------	----------
			−14+35	21.3	11.7	.001	<.001	----------	----------
			−35+150(c)	0	----------	----------	----------	----------	----------
			−35+150(t)	32.8	4.6	.004	.003	82.51	----------
			−150	37.7	1.3	.002	<.001	29.88	7.2
				100.0	6.1	0.003	0.001		
310	Map locality 5: Pit beside road just north of Falling Creek bridge, NW¼SE¼ sec. 15, T. 2 S., R. 16 E.	2	+14	3.6	21.5	0.003	0.003	35.14	----------
			−14+35	13.3	13.0	.001	<.001	59.26	----------
			−35+150(c)	16.2	33.9	.003	.003	2.36	----------
			−35+150(t)	41.4	4.9	----------	<.001	----------	----------
			−150	25.5	1.9	.004	.003	52.46	4.1
				100.0	10.5	----------	0.001		
309	Same as sample 310, and just below it	2.5	----------	100.0	17.4	----------	0.004	----------	----------

C. SAMPLES FROM CLAY COUNTY

Sample	Location of sample	Distance above river level (feet)	Thickness (feet)	P_2O_5	eU
293	Map locality 6: East bank of the South Fork of Black Creek, SW¼NE¼ sec. 13, T. 5 S., R. 24 E.	14–16	2	8.4	0.003
292	do	7–12	5	.5	<.001
291	do	0– 1.5	1.5	10.1	.001

See footnote at end of table.

TABLE 16.—*Partial chemical analyses, in percent, of samples of phosphatic beds of the Hawthorn formation from exposures in northern peninsular Florida*—Continued

D. SAMPLES FROM BROOKS SINK, BRADFORD COUNTY

Map locality 7, SW¼ sec. 12, or NW¼ sec. 13, T. 7 S., R. 20 E.

Sample	Vertical distance below base of coquina bed exposed in upper part of sink: From— (ft)	From— (in)	To— (ft)	To— (in)	Thickness (ft)	Thickness (in)	Size fraction[1] (mesh)	Percentage of total sample	P_2O_5	U	eU	Insoluble	Al_2O_3
318, 319	0	0	3	7	3	7		100.0	4.9	----------	0.004	----------	----------
317	3	7	5	7	2	0	+14	31.4	20.6	0.014	.012	16.14	----------
							−14+35	9.7	18.5	.010	.008	26.63	----------
							−35+150 (c)	0	----------	----------	----------	----------	----------
							−35+150 (t)	21.0	4.2	.002	.003	----------	----------
							−150	37.9	2.7	.007	.004	17.23	14.3
								100.0	10.2	0.008	0.007		
316	5	7	10	1	4	6	+14	13.0	10.9	0.005	0.005	15.84	----------
							−14+35	10.2	11.4	.004	.004	----------	----------
							−35+150 (c)	0	----------	----------	----------	----------	----------
							−35+150 (t)	26.1	3.6	----------	<.001	----------	----------
							−150	50.7	2.0	.002	.002	15.38	5.0
								100.0	4.5	----------	0.002		
315	11	1	15	7	4	6	+14	7.1	10.0	0.004	0.003	----------	----------
							−14+35	5.0	13.2	.004	.002	----------	----------
							−35+150 (c)	0	----------	----------	----------	----------	----------
							−35+150 (t)	48.5	6.3	.001	<.001	75.99	----------
							−150	39.4	1.6	.001	.001	15.42	4.5
								100.0	5.1	0.001	0.001		
314	16	5	20	1	3	8		100	4.7	----------	0.001	----------	----------
312	27	10	29	7	1	9	+14	31.5	19.2	0.007	0.005	12.35	----------
							−14+35	20.2	12.0	.003	.002	54.96	----------
							−35+150 (c)	0	----------	----------	----------	----------	----------
							−35+150 (t)	14.6	10.2	.003	.002	----------	----------
							−150	33.7	5.4	.002	.002	38.53	6.0
								100.0	11.8	0.004	0.003		

311	33	0	35	2	2	2	+14	13.2	14.1	0.005	0.004	----------	----------
							−14+35	2.6	20.5	.008	.007	9.03	----------
							−35+150(c)	0	----------	----------	----------	----------	----------
							−35+150(t)	6.6	6.0	----------	.003	----------	----------
							−150	77.6	9.6	.002	.002	59.60	9.9
								100.0	10.2	----------	0.002		

E. SAMPLES FROM ALACHUA COUNTY

Sample	Location of sample	Thickness (feet)	Size fraction (mesh)	Percentage of total samples	P_2O_5	U	eU	Insol-uble	Al_2O_3
26	Map locality 9: Westernmost exposure of phosphorite in diversion ditch just north of Gainesville airport, NW¼NW¼ sec. 24, T. 9 S., R. 20 E.	3	+3	4.2	23.8	0.024	----------	----------	----------
			−3+20	13.4	23.3	.027	----------	----------	----------
			−20+48	9.0	16.7	.022	----------	----------	----------
			−48+150	55.4	4.5	.006	----------	----------	----------
			−150	18.0	12.6	.036	----------	----------	----------
				100.0	10.4	0.016			
323	325 ft east of sample 26	6	+14	30.7	26.5	0.019	.020	18.87	1.9
			−14+35	27.0	18.8	.007	.009	43.69	1.4
			−35+150(c)	0	----------	----------	----------	----------	----------
			−35+150(t)	20.9	4.2	.003	.004	----------	----------
			−150	21.4	11.4	.019	.016	51.34	5.5
				100.0	16.5	0.012	0.013		
324	225 ft east of sample 26	6	+14	40.6	27.0	0.018	0.019	15.83	1.8
			−14+35	10.3	26.2	.013	.012	21.12	----------
			−35+150(c)	1.4	31.0	.014	.015	6.41	1.9
			−35+150(t)	19.2	2.8	.001	.001	----------	----------
			−150	28.5	6.3	.015	.012	63.65	15.0
				100.0	16.4	0.013	0.013		
45	Map locality 12: Roadside, about 200 yd. west of west branch of Lochloosa Creek, SE¼SE¼ sec. 25, T. 10 S., R. 21 E.	1	+20	36.6	22.9	0.020	----------	----------	----------
			−20+48	18.5	12.3	.011	----------	----------	----------
			−48+150	17.7	5.5	.004	----------	----------	----------
			−150	27.2	16.1	.023	----------	----------	----------
				100.0	16.0	0.016			

See footnote at end of table.

TABLE 16.—*Partial chemical analyses, in percent, of samples of phosphatic beds of the Hawthorn formation from exposures in northern peninsular Florida*—Continued

F. PHOSPHATIC SANDSTONE FROM MARION COUNTY

Sample	Location of sample	P_2O_5	U	Quartz	P_2O_5 in nonquartz material (calculated)	U in nonquartz material (calculated)
23	Map locality 19: Abandoned fuller's earth pit, NW¼NE¼ sec. 34, T. 13 S., R. 20 E. Sample from lower 3 ft of phosphatic sandstone at east end of pit.	6.6	0.005	63.1	17.8	0.014

[1] Mesh size, in millimeters:

+3	>6.35.
−3+20	6.35–0.84
−20+48	0.84–.297.
−48+150	0.297–.105.
−150	<.105.
+14	>1.19.
−14+35	1.19–0.42.
−35+150(c)	0.42–0.105, flotation concentrates.
−35+150(t)	0.42–0.105, flotation tailings.
−150	<0.105.

TABLE 17.—*Partial chemical analyses, in percent, of samples of phosphatic sands from some hard-rock phosphate mines, Florida*

[Analysts: E. Y. Campbell, G. J. Daniels, M. H. Delevaux, B. A. McCall, Roosevelt Moore, T. D. Murphy, Jr., Marian Schnepfe, R. E. Smith, W. P. Tucker, Jr., J. L. Waring]

Location of sample	Thickness (feet)	P_2O_5	U	Quartz	P_2O_5 in nonquartz material (calculated)	U in nonquartz material (calculated)
Suwannee County:						
Sec. 2, T. 6 S., R. 15 E	10	0.5	0.003	77	2.2	0.013
Gilchrist County:						
Sec. 12, T. 9 S., R. 16 E	16	4.5	.003	68.5	3.5	.010
Alachua County:						
Sec. 21, T. 10 S., R. 17 E	25	.6	.002	90.4	6.3	.021
Levy County:						
Sec. 17, T. 11 S., R. 17 E	12	6.1	.003	77.5	27.1	.013
Marion County:						
Sec. 13, T. 15 S., R. 18 E	15	1.3	.001	88.1	9.0	.012
Sec. 23, T. 16 S., R. 19 E	8	4.4	.002	80.9	22.8	.012
Citrus County:						
Sec. 3, T. 18 S., R. 19 E	11	5.0	.003	78.6	23.7	.014
Sec. 22, T. 18 S., R. 19 E	15	6.6	.004	[1] 79.7	[1] 27.8	[1] .020
Sec. 23, T. 18 S., R. 19 E	10	4.4	.004	[2] 81.2	[2] 24.0	[2] .021
Sec. 26, T. 18 S., R. 19 E	10	6.6	.004	75.8	27.0	.022
Sec. 35, T. 18 S., R. 19 E	24	2.9	.002	79.1	13.9	.010
Sec. 1, T. 19 S., R. 19 E	7	4.1	.003	83.0	24.1	.018
Sec. 26, T. 19 S., R. 19 E	12.5	2.7	.002	85.4	18.5	.014
Sec. 12, T. 20 S., R. 19 E	17	3.3	.003	83.2	19.6	.018

[1] Content of top 10 ft.
[2] Content of top 5 ft.

TABLE 18.—*Partial chemical analyses, in percent, of samples from auger-drill holes 1 to 20*

[Analysts: J. W. Budinsky, G. J. Daniels, M. H. Delevaux, C. R. Johnson, B. A. McCall, P. R. Moore, T. D. Murphy, Jr., R. E. Smith, Ann Sweeney, W. P. Tucker, Jr., J. L. Waring]

Drill hole	Sample	Depth (feet)	P_2O_5	U	eU	Quartz	Al_2O_3		CaO
							Total	Soluble	
1	X11	7.5–12.5	------	------	<0.001	------	------	------	------
	X13–14	17.5–27.5	------	------	<.001	------	------	------	------
	X15	27.5–31	------	------	<.001	------	------	------	------
	X16–17	31–43.5	0.27	0.0002	<.001	78.5	------	------	------
	X18	43.5–48.5	------	------	<.001	------	------	------	------
	X19	48.5–53.5	------	------	<.001	------	------	------	------
	X20	53.5–58.5	------	------	<.001	------	------	------	------
	X21	58.5–63.5	------	------	<.001	------	------	------	------
	X22	63.5–68.5	------	------	<.001	------	------	------	------
	X23	68.5–78.5	------	------	<.001	------	------	------	------
2	X25–26	3.5–13.5	------	------	<.001	------	------	------	------
	X29–30 [1]	23.5–33.5	.3	<.001	------	------	1.9	1.7	0.11
	X31	33.5–38.5	------	------	<.001	------	------	------	------
	X32	38.5–43.5	------	------	<.001	------	------	------	------
	X33	43.5–48.5	------	------	<.001	------	------	------	------
	X34	48.5–53.5	------	------	<.001	------	------	------	------
	X35	53.5–58.5	------	------	<.001	------	------	------	------
	X36	58.5–63.5	------	------	<.001	------	------	------	------
	X37	63.5–68.5	------	------	<.001	------	------	------	------
	X38	68.5–73.5	------	------	<.001	------	------	------	------
	X39	73.5–76.5	------	------	<.001	------	------	------	------
	X40	76.5–78.5	1.6	------	.002	------	------	------	------
	X41	78.5–83.5	5.8	.005	------	61.9	------	------	------
	X42	83.5–88.5	1.9	------	.003	------	------	------	------

See footnote at end of table.

TABLE 18.—*Partial chemical analyses, in percent, of samples from auger-drill holes 1 to 20*—Continued

Drill hole	Sample	Depth (feet)	P_2O_5	U	eU	Quartz	Al_2O_3		CaO
							Total	Soluble	
3	X45	8.5–13.5	0.9		.002				
	X46	13.5–18.5			.002				
	X47	18.5–23.5			.002				
	X48	23.5–28.5	1.2		.001				
	X49	28.5–33.5			.002				
	X50	33.5–38.5			.002				
	X51	38.5–43.5	1.1		.003				
	X52	43.5–48.5			.002				
	X53	48.5–53.5			.003				
	X54	53.5–58.5	1.2	0.008	.006	89.9			
	X55	58.5–63.5	1.2	.006	.006	90.8			
	X56	63.5–68.5	2.1	.003		90.0			
4	X62–63	23.5–33.5			<.001				
	X66[1]	43.5–48.5	.4	.001			7.5	4.2	0.34
	X67	48.5–53.5			<.001				
	X68	53.5–58.5			<.001				
	X69	58.5–63.5			<.001				
	X70	63.5–68.5			<.001				
	X71	68.5–73.5			<.001				
	X72	73.5–78.5			<.001				
5	X76	8.5–15.5			<.001				
	X81	38.5–48.5			.001				
	X82–83	48.5–58.5			.001				
	X84	58.5–68.5			.001				
	X85	68.5–73.5			.002				
	X86	73.5–78.5	1.6		.002				
	X87	78.5–83.5			.002				
	X88	83.5–88.5	1.0		.002				
6	X90	5 – 8.5			<.001				
	X91	8.5–18.5			<.001				
	X96	33.5–43.5			<.001				
	X97	43.5–48.5			<.001				
	X98	48.5–53.5			<.001				
	X99	53.5–58.5			<.001				
	X100	58.5–63.5			<.001				
	X101	63.5–73.5			<.001				
	X102	73.5–83.5			<.001				
7	X104	8.5–13.5			.001				
	X106[1]	17.0–20.5	.8	.001			13.7	11.2	1.64
	X109	25.5–28.5			.001				
8	X112	1 – 3			.002				
	X113	3 – 8.5			.001				
	X114	9 –11.5			.001				
	X115	12.5–13.5			.001				
9	X119	4.5–10			<.001				
	X122	18.5–23.5			<.001				
	X124	28.5–33.5			<.001				
	X126	38.5–44.5			<.001				
	X127	44.5–51			<.001				
	X128	51 –53.5			<.001				
	X129	53.5–58			<.001				
	X130	58 –62			<.001				
	X131	62 –63.5			<.001				
10	X132	1 – 5.5			.002				
	X133	5.5– 8.5			.001				
	X136	23.5–33.5			.001				
	X137	33.5–43.5			.002				
	X138	43.5–53.5			.002				
	X139	53.5–63.5	2.2	.001	.003	87.6			
	X140	63.5–73.5			<.001				
	X141	73.5–79.5			.002				
	X142	79.5–83.5			.001				
11	X145	8.5–18.5			<.001				
	X147	23.5–33.5			.001				
	X149	43.5–53.5	7.8		.001				
	X151	58.5–61.5	19.8	.002	.003	25.0			

See footnote at end of table.

TABLE 18.—*Partial chemical analyses, in percent, of samples from auger-drill holes 1 to 20*—Continued

Drill hole	Sample	Depth (feet)	P_2O_5	U	eU	Quartz	Al_2O_3		CaO
							Total	Soluble	
12	X154	4.5-13.5	--	--	<.001	--	--	--	--
	X156	22.0-33.5	--	--	<.001	--	--	--	--
	X157	33.5-38.5	--	--	<.001	--	--	--	--
	X158	38.5-48.5	--	--	<.001	--	--	--	--
	X159	48.5-58.5	--	--	<.001	--	--	--	--
	X160	58.5-68.5	--	--	<.001	--	--	--	--
	X161	68.5-78.5	3.6	--	<.001	--	--	--	--
13	X163	8.5-19	--	--	<.001	--	--	--	--
	X164	19 -26	--	--	<.001	--	--	--	--
	X168 [1]	43.5-53	2.9	0.001	--	--	4.1	3.6	1.02
	X169	53 -57.5	--	--	.001	--	--	--	--
14	X172	14 -23.5	--	--	<.001	--	--	--	--
	X173	23.5-25	--	--	<.001	--	--	--	--
	X174	25 -33.5	--	--	<.001	--	--	--	--
	X175	33.5-39.5	--	--	.001	--	--	--	--
	X176	39.5-43.5	--	--	<.001	--	--	--	--
	X177	43.5-52.5	--	--	<.001	--	--	--	--
15	X178 [1]	1 - 8.5	9.1	.004	--	--	7.3	6.5	7.16
	X179	8.5-18.5	6.2	.002	.002	77.7	--	--	--
	X181	23.5-33.5	8.5	--	.002	--	--	--	--
	X183	43.5-53.5	5.3	--	.002	--	--	--	--
	X184	53.5-63.5	--	--	.001	--	--	--	--
	X185	63.5-73.5	--	--	<.001	--	--	--	--
	X186	73.5-83.5	4.6	--	.002	--	--	--	--
16	X189	13.5-23	--	--	<.001	--	--	--	--
	X190	23 -28.5	--	--	<.001	--	--	--	--
	X193	43.5-53.5	--	--	<.001	--	--	--	--
	X196	73.5-83.5	--	--	<.001	--	--	--	--
17	X199	13.5-20	--	--	<.001	--	--	--	--
	X200	20 -23.5	4.8	--	.003	--	--	--	--
	X201 [1]	23.5-26	1.9	.001	--	--	9.6	5.5	.56
	X202	26 -28.5	.8	--	.004	--	--	--	--
	X203	28.5-32.5	--	--	.001	--	--	--	--
	X204	32.5-33.5	--	--	.002	--	--	--	--
	X205	33.5-38	--	--	.002	--	--	--	--
	X206	38 -42.5	6.9	--	.003	--	--	--	--
	X207	42.5-43.5	--	--	.002	--	--	--	--
	X208	43.5-50	8.6	--	.002	--	--	--	--
18	X211	3.5-13.5	--	--	<.001	--	--	--	--
	X213	23.5-33.5	--	--	.001	--	--	--	--
	X215	37 44	--	--	.001	--	--	--	--
	X216	44 -46.5	--	--	.002	--	--	--	--
	X217	46.5-53.5	3.1	--	.003	--	--	--	--
	X220	67 -71	8.3	--	.002	--	--	--	--
	X221	71 -73	25.6	.005	.005	11.9	--	--	--
	X222 [1]	73 -79	30.4	.008	--	--	2.9	2.9	40.3
	X223	79 -83.5	32.8	.006	.005	6.45	--	--	--
19	X226	12.5-13.5	--	--	<.001	--	--	--	--
	X227	13.5-18.5	1.8	--	.002	--	--	--	--
	X228	18.5-23.5	--	--	.002	--	--	--	--
	X229	23.5-29.5	2.1	--	.002	--	--	--	--
	X230	29.5-31	--	--	.001	--	--	--	--
20	X232	5 - 8.5	--	--	.002	--	--	--	--
	X233	8.5-13	--	--	.002	--	--	--	--
	X234 [1]	13 -16.5	6.2	.006	--	--	8.7	7.0	1.12
	X235	16.5-18.5	--	--	.003	--	--	--	--
	X236	18.5-26	--	--	.002	--	--	--	--
	X237	26 -35	1.7	--	.003	--	--	--	--
	X238	35 -43.5	--	--	.002	--	--	--	--
	X239	45 -48	1.4	--	.002	--	--	--	--
	X240	48 -57	2.4	--	.001	--	--	--	--
	X241	57 -62	2.6	--	.002	--	--	--	--

[1] Mineralogy of −200-mesh (<0.074 mm) is given in table 21.

TABLE 19.—*Uranium and P_2O_5 content, in percent, of different size fractions of samples of secondary phosphate from hard-rock phosphate mines, Citrus and Marion Counties, Fla.*

[Analysts: G. J. Daniels, Glen Edgington, T. D. Murphy, Jr., R. E. Smith, Ann Sweeney, J. L. Waring]

Location of sample	Size fraction[1] (mesh)	Uranium	P_2O_5	Percentage of total		
				Sample	Uranium	P_2O_5
Marion County:						
Sec. 3, T. 14 S., R. 22 E	+20	0.005	32.8	45.2	47.4	58.0
	−20+48	.002	20.9	8.6	3.6	7.0
	−48+150	.002	9.2	10.7	4.5	3.8
	−150	.006	22.5	35.5	44.5	31.2
Entire sample		0.005	25.6	100.0	100.0	100.0
Sec. 33, T. 15 S., R. 19 E	+20	0.011	33.0	43.4	44.8	47.7
	−20+48	.009	26.0	10.8	9.1	9.4
	−48+150	<.005	14.3	16.5	7.7	7.8
	−150	.014	36.0	29.3	38.4	35.1
Entire sample		0.011	30.0	100.0	100.0	100.0
Sec. 23, T. 16 S., R. 18 E	+20	0.003	35.5	48.5	54.8	66.3
	−20+48	.002	14.5	5.0	3.7	2.8
	−48+150	.001	3.7	14.9	5.7	2.1
	−150	.003	23.6	31.6	35.8	28.8
Entire sample		0.003	25.9	100.0	100.0	100.0
Citrus County:						
Sec. 3, T. 18 S., R. 19 E	+20	0.007	32.6	20.6	20.3	30.4
	−20+48	.005	17.1	15.8	11.1	12.2
	−48+150	.001	5.0	28.1	3.9	6.4
	−150	.013	31.7	35.5	64.7	51.0
Entire sample		0.007	21.2	100.0	100.0	100.0

[1] Mesh size, in millimeters:

+20	>0.84
−20+48	0.84–0.297
−48+150	0.297–.105
−150	<0.105

TABLE 20.—*Partial chemical analyses, in percent, of samples of "soft phosphate" from tailing ponds of some hard-rock phosphate mines, Florida*

[Analysts: E.Y. Campbell, G. J. Daniels, M. H. Delevaux, Roosevelt Moore, T. D. Murphy, Jr., R. A. Powell, R. E. Smith, Ann Sweeney, W. P. Tucker, Jr., J. L. Waring.]

Location of sample	P_2O_5	U	CaO	Al_2O_3	
				Total	Soluble
Columbia County:					
Sec. 19, T. 6 S., R. 16 E	23.1	0.006	25.4	12.6	
Gilchrist County:					
Sec. 21, T. 8 S., R. 16 E	19.2	.006	21.1	11.1	
Citrus County:					
Sec. 3, T. 18 S., R. 19 E	23.0	.008	22.6	15.9	13.8
Sec. 23, T. 18 S., R. 19 E	20.6	.004	18.5	13.8	12.6
Sec. 26, T. 19 S., R. 19 E	18.0	.007	23.9	15.4	12.6
Sec. 28, T. 20 S., R. 20 E	21.7	.005			

TABLE 21.—*Mineral constituents of samples from core-drill holes 32, 33, and 35 to 46*

[Analysts: PB, P. D. Blackmon; DC, Dorothy Carroll; GC, G. W. Chloe; JH, J. C. Hathaway; BL, Betsy Levin; HS, H. C. Starkey]

Drill hole	Sample	Depth (feet)	Size fraction (millimeter)	Percentage of total sample	Mineral constituents [1]	Quantitative estimates (parts in 10)	Analysts
32	X321	33 - 36	<0.1	[2] 45.5	Apatite, trace quartz, plus unidentified material. The pattern of the unidentified material is very diffuse, and may represent one or possibly two clays.		BL.
	X324	38.7- 39.5	< .1	19.4	Apatite plus a small amount of quartz		BL.
33	X338	68 - 78		100.0	Dolomite	9	HS, PB, GC.
					Calcite	1	
35	X348	42.2- 43.2	< .002	77.4	Kaolinite	7	JH, HS, GC.
					Montmorillonite	1	
					Mica	Trace	
					Quartz	Trace	
			0.002- .062	13.0	Quartz	8	
					Kaolinite	1	
					Mica	Trace	
	X349B	47 - 48.3	< .1	51.2	Quartz, a montmorillonite mineral, probably apatite, plus a small amount unidentified.		BL.
	X351	55 - 59.5	< .1	55.5	Dolomite, a montmorillonite mineral, attapulgite, quartz, plus slight amount unidentified.		BL.
36	X362	26.5- 27.5	< .002	62.4	Montmorillonite	9	JH, HS, GC.
					Mica	Trace	
					Kaolinite	Trace	
					Attapulgite(?)	Trace	
			.002- .062	20.4	Quartz	9	
					Montmorillonite		
	X366	36.3- 39	< .002	61.2	Montmorillonite	2	JH, HS, DC, GC.
					Mixed-layered mica:		
					Montmorillonite	3	
					Apatite	4	
			.002- .050	13.6	Quartz		
					Apatite		

See footnotes at end of table.

TABLE 21.—*Mineral constituents of samples from core-drill holes, 32, 33, and 35 to 46*—Continued

Drill hole	Sample	Depth (feet)	Size fraction (millimeter)	Percentage of total sample	Mineral constituents [1]	Quantitative estimates (parts in 10)	Analysts
36	X369	49.5– 53	< .1	39.2	Dolomite, quartz, attapulgite, possible apatite, plus an unidentified phase which has a strong peak at 11.9±0.2 A.[3]		BL.
	X374AB	87 – 97		100.0	Quartz	4	HS, PB, GC.
					Apatite	4	
					Dolomite	1	
			< .002		Montmorillonite	9	
					Attapulgite	Trace	
	X380	135 –137	< .1	44.2	Montmorillonite, dolomite, quartz, and a small amount of apatite.		BL.
37	X394	61.5–65.5	< .1	21.7	A montmorillonite mineral, apatite, plus quartz		BL.
38	X406	7 – 11	< .002	27.0	Kaolinite	9	JH, HS, GC.
					Mixed-layer mica-montmorillonite	Trace	
					Quartz	Trace	
			.002– .062	3.4	Quartz	9	
39	X410	4 – 9.2	< .002	58.0	Kaolinite	9	JH, HS, GC.
					Mixed-layer mica-montmorillonite	Trace	
					Quartz	Trace	
			.002– .062	10.8	Quartz	9	
					Kaolinite	Trace	
	X418	74.8– 76	< .002		Montmorillonite (dioctahedral)	8	JH, HS, DC, GC.
					Apatite	1	
					Attapulgite(?)	Trace	
			.002– .050		Pyrite		
					Apatite		
					Quartz		
					Montmorillonite		
	X425A	100.5–103	< .002	61.8	Attapulgite	8	JH, HS, GC.
					Montmorillonite	1	
					Quartz	Trace	
					Dolomite	Trace	

			.002– .062	17.7	Quartz Dolomite Feldspar	5 4 Trace	
	X426	112 –113	< .1	15.3	Dolomite, apatite, a montmorillonite mineral, attapulgite, quartz, possible calcite, plus small amount unidentified.		BL.
40	X440	6 – 8.5	.002	72.4	Kaolinite	10	JH, HS, GC.
			.002– .062	2.4	Quartz Kaolinite	8 1	
	X443A	37 – 40	< .1	28.0	Apatite, wavellite, a montmorillonite mineral, plus quartz.		BL.
	X443DE	46 – 51	< .1	33.3	Apatite, a montmorillonite mineral, plus quartz		BL.
	X445C	58.5– 67.5	.002	89.1	Attapulgite Montmorillonite Apatite	7 1 2	JH, HS, DC, GC.
			.002– .050	6.3	Quartz	9	
41	X459	12.5– 13	< .002	70.4	Montmorillonite Kaolinite Quartz	4 4 Trace	JH, HS, GC.
			.002– .062	19.0	Quartz Montomorillonite(?)	9 Trace	
	X461C	20.5– 22	< .1	35.0	Apatite, quartz, plus wavellite		BL.
	X461D	22 – 24	< .1	28.5	Apatite, trace quartz, and slight trace unidentified		BL.
	X464A	37.4– 44	< .002	81.5	Montmorillonite Apatite Mica Quartz	6 3 Trace Trace	JH, HS, CG.
			.002– .062	8.3	Quartz Apatite Feldspar(?)	7 2 Trace	
	X466A	52.4– 59	< .002	71.0	Attapulgite Apatite Montmorillonite	7 2 Trace	JH, HS, DC, GC.
			.002– .050	6.7	Quartz Feldspar Apatite	7 2 Trace	

See footnotes at end of table.

TABLE 21.—*Mineral constituents of samples from core-drill holes, 32, 33, and 35 to 46*—Continued

Drill hole	Sample	Depth (feet)	Size fraction (millimeter)	Percentage of total sample	Mineral constituents [1]	Quantitative estimates (parts in 10)	Analysts
41	X463A	72.4– 75.5	< .1	35.8	Apatite, attapulgite, quartz, an unidentified phase which has a strong peak at 11.9±0.2 A,[3] plus a small amount unidentified.		BL.
42	X480A	68 – 73	< .002	43.9	Montmorillonite	6	JH, HS, CC.
					Kaolinite	3	
					Quartz	Trace	
			.002– .062	30.8	Quartz	7	
					Feldspar	1	
					Calcite	Trace	
					Pyrite	Trace	
	X490	98 –100.5	< .1	45.2	Dolomite, attapulgite, plus quartz		BL.
	X497	106 –109	< .1	52.1	Dolomite, quartz, a montmorillonite mineral, attapulgite, plus possible feldspar.		BL.
	X520	129.5–132		100.0	Dolomite	7	HS, PB, GC.
					Quartz	1	
			< .002		Montmorillonite	4	
					Attapulgite	4	
					Sepiolitelike mineral(?)	1	
	X533A	172.5–174		100.0	Dolomite	7	HS, PB, GC.
					Quartz	1	
			< .002		Montmorillonite	7	
					Sepiolitelike mineral(?)	2	
					Attapulgite(?)	Trace	
	X542	201 –203		100.0	Quartz	4	HS, PB, GC.
					Dolomite	4	
					Calcite	Trace	
					Attapulgite	Trace	
43	X558	14.2 –15.7	< .002	80.0	Mixed-layer mica-montmorillonite	8	JH, HS, GC.
					Kaolinite	Trace	

			.002– .062	10.0	Quartz	7	
					Mixed layer mica-montmorillonite	2	
					Kaolinite	Trace	
	X569	36 –37.5	< .002	64.5	Montmorillonite	9	JH, HS, GC.
					Attapulgite	Trace	
					Quartz	Trace	
			.002– .062	18.2	Quartz	7	
					Feldspar	1	
					Apatite	1	
	X572	39.8– 41.3		100.0	Dolomite	6	HS, PB, GC.
					Quartz	2	
					Attapulgite	Trace	
	X581	53 – 54.5		100.0	Dolomite	7	HS, PB, GC.
					Quartz	1	
					Attapulgite	Trace	
	X592	110 –117	< .002	42.4	Attapulgite	8	JH, HS. DC, GC.
					Montmorillonite	1	
			.002– .050	17.8	Attapulgite		
					Quar z		
	X595	143 –153	< .1	38.0	Apatite, attapulgite, quartz, plus an unidentified phase which has a strong peak at 11.9 ±0.2 A.[3]		BL.
44	X613	69 – 72		100.0	Dolomite	5	HS, PB, GC.
					Quartz	3	
					Calcite	1	
					Apatite	1	
			< .002		Montmorillonite	4	
					Attapulgite	4	
	X620	91 – 97	< .1	37.8	Dolomite, quartz, apatite, attapulgite, plus possibly a montmorillonite mineral.		BL.
	X642	169 –174		100.0	Quartz	4	HS, PB, GC.
					Dolomite	3	
					Feldspar	2	
					Attapulgite	Trace	
	X648	217 –220	< .1	26.6	Dolomite (with slightly larger spacings), quartz, trace unidentified.		BL.
	X660	280 –285	< .002	23.5	Montmorillonite	6	JH, HS, GC.
					Attapulgite	2	
					Sepiolitelike mineral(?)	1(?)	
			.002– .062	5.7	Quartz	8	
					Feldspar	1	
					Apatite	Trace	

See footnotes at end of table.

TABLE 21.—*Mineral constituents of samples from core-drill holes, 32, 33, and 35 to 46*—Continued

Drill hole	Sample	Depth (feet)	Size fraction (millimeter)	Percentage of total sample	Mineral constituents [1]	Quantitative estimates (parts in 10)	Analysts
44	X662	295 -304		100.0	Dolomite	4	HS, PB, GC.
					Quartz	4	
					Attapulgite	Trace	
45	X703	14.2- 15.8	< .002	54.3	Kaolinite	8	JH, HS, GC.
					Mica	Trace	
					Quartz	1	
					Pyrite(?)	Trace	
			0.002- .062	9.1	Quartz	9	
	X706	23.5- 28	< .1	27.0	Apatite, quartz, and probably a montmorillonite mineral.		BL.
	X708	30.5- 34	< .1	24.1	Apatite, quartz, a montmorillonite mineral, probable attapulgite, plus possibly a small amount of dolomite.		BL.
	X710	37 - 39		100.0	Dolomite	7	HS, PB, GC.
					Quartz	2	
					Apatite	1	
			< .002		Montmorillonite	4	
					Attapulgite	4	
	X717	58 - 61	< .1	28.7	Dolomite, a montmorillonite mineral, attapulgite, quartz, plus slight amount unidentified.		BL.
	X722	78 - 85		100.0	Dolomite	6	HS, PB, GC.
					Quartz	3	
					Apatite	1	
			< .002		Attapulgite	10	
	X725	113 -120		100.0	Dolomite	6	HS, PB, GC.
					Apatite	2	
					Calcite	½	
					Quartz	½	
					Attapulgite	Trace	
					Boxwork:		
					Dolomite	9	
					Quartz	Trace	
					Attapulgite	Trace	
					Calcite	Trace	

					Filling:		
					Attapulgite	5	
					Apatite	2	
					Dolomite	2	
					Quartz	1	
	X731	168 –173	< .002	66.4	Montmorillonite	4	JH, HS, GC.
					Apatite	4	
					Quartz	Trace	
					Mica	Trace	
			.002– .062	5.6	Quartz	5	
					Pyrite	2	
					Apatite	1	
					Feldspar	1	
	X734	188 –193	< .002	53.5	Attapulgite	6	JH, HS, GC.
					Apatite	2	
					Montmorillonite	1	
					Sepiolitelike mineral(?)	Trace (?)	
			.002– .062	5.6	Quartz	4	
					Apatite	5	
					Feldspar(?)	Trace	
46	X749	29.5–32.8	< .1	51.4	A montmorillonite mineral, apatite, quartz, plus possible dolomite.		BL.
	X752	38.5–41	< .002	72.7	Montmorillonite	8	JH, HS, DC, GC.
					Mica	Trace	
					Apatite	1	
			.002– .050	3.1	Quartz		
					Pyrite		
					Apatite		
	X755	47 –49	< .002	49.1	Montmorillonite	4	JH, HS, GC
					Sepiolitelike mineral(?)	3 (?)	
					Apatite	2	
					Quartz	Trace	
			.002– .062	5.6	Quartz	5	
					Apatite	4	
	X763	109 –115		100.0	Calcite	10	HS, PB, GC.

[1] Mineral constituents determined by X-ray methods.
[2] Percent by weight of total sample.
[3] Betsy Levin states: "This is the position of the strongest reflection of sepiolite. The electron micrographs of these samples [<0.053 mm size] show long narrow fibers which are diagnostic of attapulgite and (or) sepiolite. Samples containing this unidentified phase were treated to determine whether or not this phase is montmorillonite, but no characteristic effects were observed."

TABLE 22.—*Mineral constituents of clay samples from the hard-rock phosphate district, Florida*

[X-ray determinations of minerals by P. D. Blackmon, Dorothy Carroll, G. W. Chloe, J. C. Hathaway, H. C. Starkey]

Size fraction (millimeter)	Mineral constituents	Quantative estimates (parts in 10)
MAP LOCALITY 10		
Old phosphate mine in SW¼ sec. 6, T. 10 S., R. 17 E., Alachua County. Sample 256 from sandy clay bed (4 ft thick) whose base is about 12 ft above phosphatic sand (table 13)		
Total sample	Quartz	5
	Kaolinite	3
	Crandallite(?)	2
0.002–0.062	Quartz	10
<0.002	Kaolinite	5
	Montmorillonite	1
	Quartz	2
	Crandallite(?)	1
	Dolomite	Trace
MAP LOCALITY 11		
Old phosphate mine in NE¼ sec. 21, T. 10 S., R. 17 E., Alachua County. Sample 244 [1] from green plastic clay bed (2 ft thick) beneath hard phosphate sand		
0.002–0.062	Quartz	9
<0.002	Montmorillonite (dioctahedral)	8
	Kaolinite	1
	Quartz	Trace
Old phosphate pit in NW¼NW¼ sec. 26, T. 11 S., R. 17 E., Levy County. Sample 198 [1] from irregular bed of clay (about 2 ft thick) near base of typical phosphatic sand		
0.002–0.062	Quartz	9
<0.002	Montmorillonite (dioctahedral)	9
MAP LOCALITY 27		
New sump pit in NW¼NE¼ sec. 5, T. 18 S., R. 19 E., Citrus County. Sample 163 [1] from green-tan clay bed (1 ft 8 in. thick) beneath phosphatic sand (table 13)		
0.002–0.062	Quartz	9
<0.002	Montmorillonite (dioctahedral)	9
	Mica	Trace
	Kaolinite	Trace
	Quartz	Trace

[1] Size analyses and heavy-mineral content given in table 25.

TABLE 23.—*Mineral constituents of −200-mesh material in samples from auger-drill holes 1 to 20 in the hard-rock phosphate district, Florida*

Drill hole	Sample	Depth (feet)	Mineral constituents [1]
2	X29–30	23.5–33.5	Quartz and a possible trace of kaolinite and (or) an unidentified clay mineral.
4	X66	43.5–48–5	Quartz, kaolinite, and a possible trace of crandallite.
7	X106	17–20.5	Quartz and a montmorillonite mineral.
13	X168	43.5–53	Quartz, millisite, and possibly crandallite and kaolinite.
15	X178	1–8.5	Millisite, kaolinite, apatite, possible crandallite, and quartz.
17	X201	23.5–26	Kaolinite, quartz, and a possible trace of millisite and (or) crandallite.
18	X222	73–79	Apatite and a slight trace of quartz.
20	X234	13–16.5	Crandallite, wavellite, kaolinite, and a trace of millisite.

[1] Mineral constituents determined by X-ray methods by D. D. Riska.

TABLE 24.—*Size analyses and heavy-mineral content of clay samples from core-drill holes 36, 39 to 41, and 43 and 46*

SIZE ANALYSES

Size fraction (millimeter)	Percentage of size fraction of sample [1]			
	X366	X445C	X466A	X752
>2	0.6	------	------	------
1–2	1.2	------	0.1	0.1
0.5–1	2.7	0.2	1.3	1.5
0.25–0.5	3.4	.8	2.9	7.3
0.10–0.25	7.4	1.1	4.5	3.2
0.05–0.10	9.7	2.7	13.6	11.8
0.002–0.05	13.6	6.3	6.7	3.1
<0.002	61.2	89.1	71.0	72.7

HEAVY MINERAL CONTENT

[Abundance is based on visual estimates. A, 75–90 percent; F, 10–25 percent; S, <5 percent. Analysts: Dorothy Carroll, G. W. Chloe, J. C. Hathaway, H. C. Starkey]

Mineral	Relative mineral content of size fraction [2] of sample [1]											
	X366		X418		X445C		X466A		X592		X752	
	+120[2]	+230[3]	+120	+230	+120	+230	+120	+230	+120	+230	+120	+230
Apatite	A	A	A	F	A	F	A	A	F	F	A	A
Opaques [3]	------	------	F	S	S	S	------	S	S	S	S	S
Pyrite	------	------	F	F	S	S	S	F	F	A	F	F
Zircon	------	S	S	S	------	S	------	S	S	S	S	S
Sillimanite	------	------	F	F	S	S	------	S	S	------	------	------
Tourmaline	------	S	S	------	------	S	------	S	------	S	------	------
Garnet	S	S	S	------	S	------	S	F	S	S	S	------
Kyanite	------	S	------	S	S	------	------	S	------	------	------	------
Staurolite	------	------	S	------	S	S	------	S	------	------	------	------
Rutile	------	------	------	S	------	S	------	F	S	S	------	------
Epidote	------	------	F	A	------	------	------	------	------	S	------	------
Amphibole	------	------	------	------	------	S	------	------	------	------	------	------
Monazite	------	------	------	------	------	------	------	------	------	S	------	------
Sphene	------	S	------	S	------	------	------	------	------	------	------	------
Hypersthene	------	------	------	------	------	S	------	------	------	------	------	------
Anatase	------	------	------	------	------	------	------	------	------	S	------	------

[1] Location of sample:
X366—DH 36, 36.3–39 ft.
X418—DH 39, 74.8–76 ft; mechanical analysis is omitted because sample was of −150=mesh fraction.
X445C—DH 40, 58.5–67.5 ft.
X466A—DH 41, 52.4–59 ft.
X592—DH 43, 110–120 ft; mechanical anaylsis is omitted because the sample apparently was not disaggregated completely.
X752—DH 46, 38.5–41 ft.

[2] +120-mesh fraction=0.25 to 0.12 mm range; +230-mesh fraction=0.12 to 0.06 mm range.

[3] Opaques include ilmenite, oxidized pyrite, and several contain a little magnetite.

TABLE 25.—*Size analyses and heavy-mineral content of clay samples from the hard-rock phosphate district, Florida*

SIZE ANALYSES

Size fraction (millimeter)	Percentage of size fraction of sample [1]		
	163	198	244
>2	8.5	----	0.2
1–2	1.4	0.1	4.3
0.5–1	3.0	1.1	5.9
0.25–0.5	14.2	3.7	3.8
0.10–0.25	8.0	5.3	2.2
0.05–0.10	4.5	2.8	.9
0.002–0.05	10.7	12.4	11.5
<0.002	49.3	74.5	71.0

HEAVY-MINERAL CONTENT

[Abundance is based on visual estimates. A, 75–90 percent; FA, 25–75 percent; F, 10–25 percent; S, <5 percent. Analysts: Dorothy Carroll, G. W. Chloe, J. C. Hathaway, H. C. Starkey]

Mineral	Relative mineral content of size fraction [2] of sample [1]					
	163		198		244	
	+120	+230	+120	+230	+120	+230
Apatite	----	----	----	----	F	F
Opaques [3]	F	FA	A	S	A	A
Pyrite	----	S	S	F	----	S
Zircon	A	FA	----	S	S	S
Sillimanite	F	FA	----	----	F	F
Tourmaline	S	F	----	S	----	S
Garnet	F	F	----	----	S	----
Kyanite	S	F	----	S	S	S
Staurolite	----	S	----	S	----	S
Rutile	S	S	----	S	----	S
Spinel	S	----	----	----	----	----
Epidote	S	----	----	S	----	S
Amphibole	----	----	----	S	----	----
Monazite	----	----	----	----	S	S
Sphene	----	----	----	----	----	S

[1] Location of sample:
163. Greenish-tan clay, 1 ft thick; map locality 27, new pit, NW¼NE¼ sec. 5, T. 18 S., R. 19 E., Citrus County.
164. Clay, about 2 ft thick; old pit, NW¼NW¼ sec. 26, T. 11 S., R. 17 E., Levy County.
244. Light-green clay, 2 ft thick; map locality 11, old pit, NE¼ sec. 21, T. 10 S., R. 17 E., Alachua County.

[2] +120-mesh fraction =0.25 to 0.12 mm range; +230-mesh fraction=0.12 to 0.06 mm range.

[3] Opaques include ilmenite, oxidized pyrite, and several samples containing a little magnetite.

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